BUILDING CONSTRUCTION

(IN M.K.S. Units)

A Practical Guide in the technique of building construction for students preparing for A.M.I.E., U,P.S.C., Degree, Diploma, and other examinations conducted by Indian Universities

By

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STANDARD PUBLISHERS DISTRIBUTORS

1705/B, Nai Sarak, DELHI-6.

BOX : 1066 PHONE : 26270

Published by :

N.C. Jain (Prop.),
Standard Publishers Distributors,
1705-B, Nai Sarak, Delhi-6.

1st Edition *1959*

Price : Rs. 25·00

Printed at :

P.B.H. Press,
Bara Hindu Rao,
Delhi-110006.

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NOTATIONS USED IN THIS BOOK

Symbol	*Stands for*
A	Area of the concrete in compression
A_c	Area of steel in compression
A_e	Equivalent area of spiral reinforcements
A_k	Area of concrete in column core
A_t	Area of the steel in tension
a	Lever arm
a_1	Lever arm factor *i.e.*, ratio of lever arm of resisting couple to the depth 'd' or $a_1 = \frac{a}{d}$
B.M.	Bending Moment
br	Breadth of the rib of a T-beam
C	Total compression
c	Stress in concrete in compression
c'	Stress in concrete surrounding steel
d	Effective depth
d_e	Inset of compression steel
d_s	Total depth of slab in T-beam
m	Modular ratio
n	Depth of neutral axis below compression edge
n_1	Neutral axis factor $= \frac{n}{d}$
S.F.	Shear force
s	Shear stress
S_b	Bond stress
T	Total tension
t	Tensile stress in reinforcements

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NOTATIONS USED IN THIS BOOK

Symbol	*Stands for*
A	Area of the concrete in compression
A_c	Area of steel in compression
A_e	Equivalent area of spiral reinforcements
A_k	Area of concrete in column core
A_t	Area of the steel in tension
a	Lever arm
a_1	Lever arm factor *i.e.*, ratio of lever arm of resisting couple to the depth 'd' or $a_1 = \frac{a}{d}$
B.M.	Bending Moment
br	Breadth of the rib of a T-beam
C	Total compression
c	Stress in concrete in compression
c'	Stress in concrete surrounding steel
d	Effective depth
d_e	Inset of compression steel
d_s	Total depth of slab in T-beam
m	Modular ratio
n	Depth of neutral axis below compression edge
n_1	Neutral axis factor $= \frac{n}{d}$
S.F.	Shear force
s	Shear stress
S_b	Bond stress
T	Total tension
t	Tensile stress in reinforcements

1

Foundations

1·1 Definition. Foundation is the lowest part of a structure which provides a base for the super-structure proper. This term includes the portion of the structure below the ground level as well as the artificial arrangement of concrete block, piles, raft, grillage etc. provided to transmit the loads on the structure including the dead weight of the structure itself to the soil below.

If a steel girder provided in a structure is found to be weak and flexible, it can usually be strengthened by suitable means ; if a column acting as a load bearing member in a building is found to be inadequate, it can be made safe by providing reinforcements or by introducing intermediate columns, but if the foundation of a building yields and raptures the structure, then little can be done to improve the situation.

1·2 Purpose of Foundation. It is often misunderstood that the foundation is provided to support the load of the structure but in fact it is a device to transmit the load of the structure to the soil below. Foundation is provided for the following four main purposes :

(*i*) To distribute the weight of the structure over large area so as to avoid over-loading of the soil beneath.

(*ii*) To load the sub stratum evenly and thus prevent unequal settlement.

(*iii*) To provide a level surface for building operations.

(*iv*) To take the structure deep into the ground and thus increase its stability, preventing overturning.

1·3 Site Exploration. Before the foundation plans are prepared, an investigation of the sub-soil should be made to determine the character of the underlying material at site. The aim of the site exploration is to acquire a general picture of the geology of the area.

1·4 Purpose of Site Exploration. The informations obtained from site exploration are essentially needed for taking the following decisions :

(*i*) To fix the value of the safe bearing capacity of the soil.

(*ii*) To select an economical yet safe type of foundation.

(*iii*) To fix the depth upto which the foundation must be taken inside the ground.

(*iv*) To predict the likely settlement of the selected foundation and to make allowance for the same in the design.

(*v*) To know the underground water level and if needed, to decide upon the method to be adopted to solve the ground water problem.

(*vi*) To forecast the difficulties which are likely to be encountered due to the nature of the sub-soil, during construction and to take advance action in that regard.

1·5 Methods of Site Exploration. The methods commonly adopted for site exploration are :

(*i*) Inspection

(*ii*) Test pits

(*iii*) Probing

(*iv*) Boring

(*i*) *Inspection* : Inspection of the site is the first step which should be taken prior to the design and construction of a structure. This includes the study of all neighbouring quarries or cuts made in the nearby areas for construction purposes ; the study of existing structures and, if possible, of their foundations. Information gathered in respect of other's experience in making excavation in that locality may prove to be of great help. The study of the strata exposed to view in the old pits, unlined wells or banks of nallahas in the near vicinity may reveal the nature of the soil at different depths.

The other important informations which can be gathered during site inspection are summarised below.

(*i*) Whether the ground is soft, hard, marshy, water logged or made-up type.

(*ii*) Classification of soil by visual examination.

(*iii*) Behaviour of the ground during changes in ground water-level. Whether the rain water gets drained off or causes flooding of site.

(*iv*) Whether, there is likelyhood of excessive movement of ground (This may be due to unstable site slopes, subsidence due to mining or the site being very near, some old drain, pits, well, underground working etc).

(*v*) Whether the sub-soil water contains sulphates or other chemicals in quantities sufficient to cause damage to foundations.

(*ii*) *Test pit* : The best way to ascertain the nature of the sub-soil strata is to dig a hole and see. The holes which are large

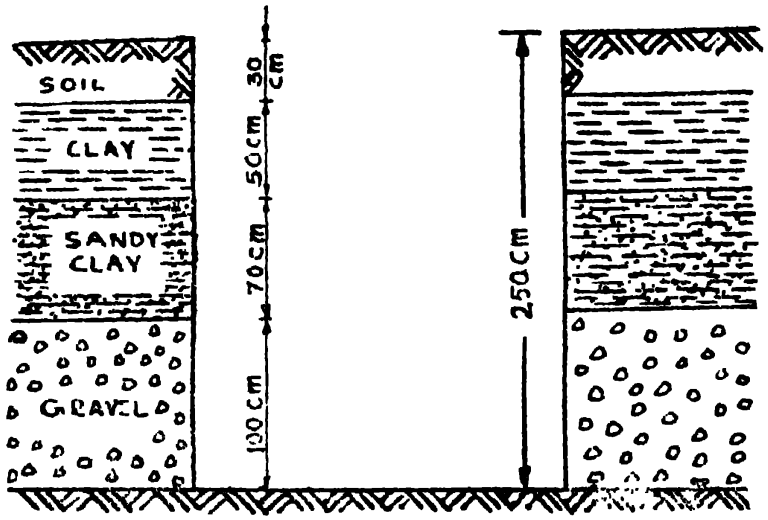


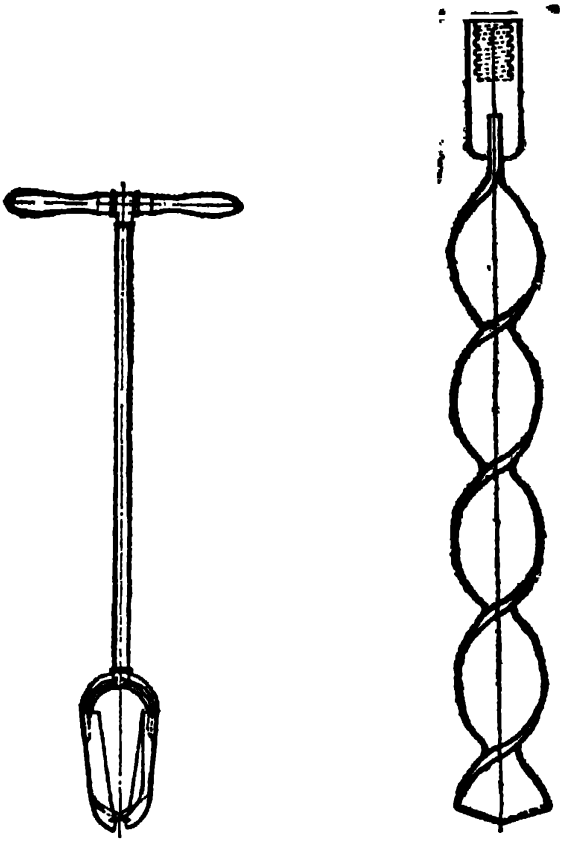
Fig. 1·1

Test pit

enough to permit the entry of persons for inspection are called 'Test pits'. They may be dug by hand or by excavating equipment. The dimensions of its sides largely depend upon the depth upto which the excavation is to be made. In cohesionless soils, the sides of the test pit are sharply sloped. In cohesive soils, at depth below 3 m, bracing is required to keep the sides of the pits vertical. They are comparatively expensive and hence they are only used for structure having shallow foundations (upto 3 metres).

(*iii*) *Probing* : In this method of exploration, a steel bar of 25 mm. to 40 mm. in diameter with a pointed end is driven in the ground until a hard sub-stratum is met with. The bar is driven by allowing it to fall vertically under its own weight or by drop hammer. At intervals the bar is drawn out and some idea of the nature of the soil is obtained by examining the soil sticking to the sides of the bar. The method is suitable to be performed in the places where the soil is soft like clay, gravel or sand. A rough idea of the nature of strata is obtained from the number of blows required to drive the rod inside the ground. Experienced workmen engaged in the execution of the driving operation may be able to judge the soil at various depths by reading the way the rod penetrates into the ground. This method is not always to be relied upon completely. More definite measures should be taken to ascertain the results arrived at by this method.

(*iv*) (*a*) *Auger boring* : The examination of the sub-soil conditions for ordinary buildings to be erected in clayey or sandy soil can be best performed by a post hole auger. The auger is held vertically and is driven into the ground by rotating its handle by applying leverage. The auger is pressed down during the process of rotation. At every 30 cm. of depth penetrated, the auger is taken out and the samples of the soils are collected separately for examination. This method can be conveniently used for soil penetration upto 15 m. depth. The types of augers commonly used are shown in Figs. (1·2-1·3). For deeper holes or in grounds where gravel, boulders, or compact material is present this method is not adopted.



Figs. 1·2-1·3
Different types of augers

(*iv*) (*b*) *Wash boring*. For test boring over 3 m. in depth, this method can be conveniently used. In this method a hollow steel pipe known as casting-pipe or drive pipe is driven into the ground for a certain depth. Then a gas pipe usually known as water jet pipe, which is shorter in diameter, is lowered into the casing pipe. At its upper end, the jet pipe is connected to a water supply system while the lower end of the pipe is contracted so as to produce jet action. Water under considerable pressure is forced down the gas pipe. The hydraulic pressure displaces the material immediately below the pipe and the slurry thus formed is forced up through the annular space between the two pipes. The slurry is collected and samples of material encountered are obtained by settlement. In this process the particles of finer material like clay, loam etc. do not settle easily and the larger and heavy particles of the soil may not be brought up at all. Moreover, the exact position of a material in the formation cannot be easily located. However the change of stratification can be guessed from the rate of progress as well as the colour of slurry flowing out. Yet the results obtained by wash boring process give fairly good information about the nature of the sub-soil strata. This method can be adopted in soft to stiff, cohesive soils and fine sand.

(*iv*) (*c*) *Percussion boring.* This method consists of breaking up of the sub-strata by repeated blows from a bit or chisel. The material thus pulverised is converted into slurry by pouring water in the bore. At intervals the slurry is bailed out of the hole and dried for examination. This method can be adopted in rocks and soils having boulders. However this method is not recommended for loose sand or clayey soils.

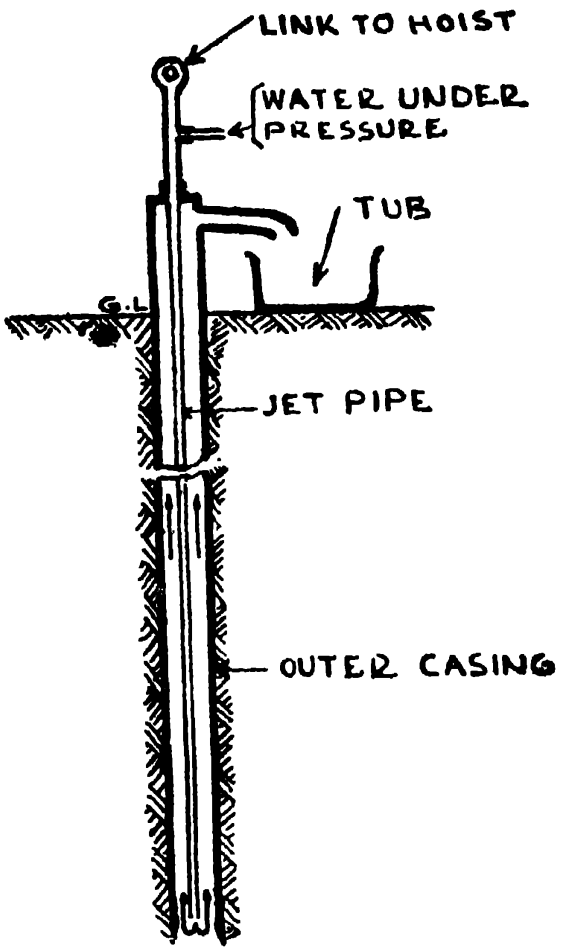


Fig .1·4
Wash boring equipment

(*iv*) (*d*) *Core drilling.* When rocks or hard pans are to be penetrated for examination, core drilling is done to get undisturbed sample of the formation. In this process a hole is made by rotating a hollow-steel tube having a cutting bit at its base. The cutting bit makes an annular cut in the strata and leaves a cylinderical core of the material in the hollow tube. Two types of cutting bits are generally used, namely, diamond bit and shot bit. Diamond bit consists of industrial diamonds set in the face of the bit and in shot bit, chilled shot is used as an abrasive to cut the hard pan. When core samples of small diameter are needed, diamond bit is preferred.

1·6 Location of trial pits or bore holes. The location and the spacing of trial pits or bone holes for a particular site require special consideration. The pits or the bore holes should be so located as to give adequate information in respect of changes in properties of the underlying strata with depth. The number and spacing of the trial pits or bore holes to be adopted for a site will depend upon the areas of the plot as well as the type of structure to be built. For a plot of 0·4 hectare we may have one trial pit or bore hole near each corner and one in the middle. For smaller size of plot and ordinary structure, one trial pit or bore hole near the centre should be sufficient. The depth of the pit or bore hole will depend upon the characteristics of the soil as well as the type of structure, its shape, size and loading conditions etc. As a thumb

rule, its depth should be one and a half times the probable width of the footing or 1·5 m whichever is more. In case of weak soils however, the pits or the bore holes should be taken to a depth at which the loads can be carried by the soil without undesirable settlement.

1·7 Bearing Capacity. The terms bearing value, bearing power and bearing capacity are used to designate the ability of sub-soil to support the load of the structure including other live or dead loads on it without yielding. The bearing capacity of a soil

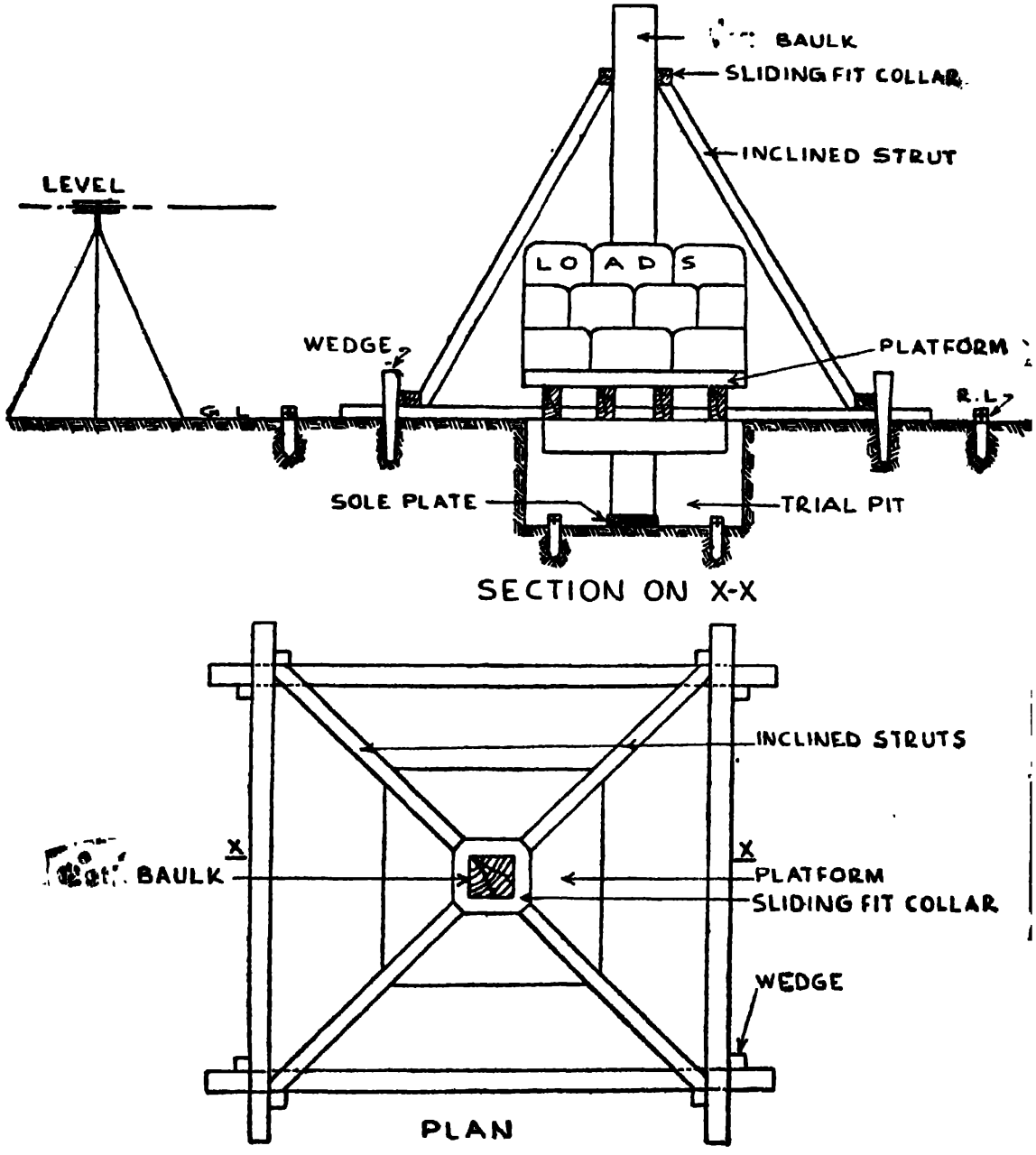


Fig. 1·5
Testing bearing capacity of soil

depends upon the characteristics of its particles. The finer the particle, the more variable are cohesive and frictional properties of the soil and the heavier the unit weight of the soil or lesser the voids, greater is its strength to carry loads. The minimum load which will cause failure of a foundation is called the ultimate bearing power of the soil. The ultimate bearing power of soil as obtained from the field test is divided by a factor of safety to get the safe bearing capacity of the soil. The factor of safety usually varies from 2 to 3 depending upon the nature of soil. Thus, in order to ensure the stability of a structure, the soil below the foundation should not be loaded so as to exceed the limits of its safe bearing capacity.

1·8 Method of Testing the Bearing Capacity of Soils. There are different methods employed for testing the bearing capacity of soils. One of the methods in its simplest form consists of a timber baulk about 30 cm. square and 1·25 m. to 2·5 m. long. A flat iron plate of 30 cm. × 30 cm. in area and 25 mm. in thickness is fixed to the bottom of the baulk with the help of counter-sunk screws. The size of the plate for lose and medium compact sandy and silty soils should be 60 cm. square. For gravelly and dense sandy soils, size of plate may vary from 35 cm. sq. to 75 cm. sq. The thickness of plate should in no case be less than 25 mm. A trench of suitable size is excavated at the site to a depth at which the structure is to rest. The timber baulk is held vertical in the trench. A loading platform is constructed on the top of the baulk. In order to keep the baulk vertical during the process of loading, four inclined struts are employed. The inclined struts are connected to a 'sliding fit' iron collar provided near the top of the baulk and are prevented from sliding by a system of horizontal struts provided at their bases. Two wooden pegs are driven at the bed of the trench a little away from the baulk and the exact level difference between the top of the pegs and the top of the loading platform is recorded. Test load, which usually consists of sand bags, iron bars, rolled steel sections etc. is then placed gently on the loading platform. The load is allowed to stand until settlement is recorded and the test load is then increased, usually by 500 kg. Again the increased load is allowed to stand till there is no settlement and the settlement is recorded. This process is repeated till the load on the platform just makes the ground yield and there is a sudden sinking of the baulk. The settlement can be recorded by use of dial gauges or deflectometers or any other suitable instruments. The load and the corresponding settlements are plotted graphically in the form of a curve. The value of load say W, which causes the curve to bend suddenly is noted.

Then the ultimate bearing capacity of soil

$$= \frac{W}{\text{Area of the sole plate}}$$

and the safe bearing capacity of soil

$$\frac{W}{\text{Area of the sole plate} \times \text{Factor of safety}}$$

TABLE 1·1

SAFE BEARING CAPACITY OF DIFFERENT SOILS AS RECOMMENDED BY I.S. CODE

S. No.	*Description of Soils*	*Safe Bearing capacity in kg/cm²*
	(*a*) Rocks	
(*i*)	Rocks without laminations and defect such as granite, trap etc.	33
(*ii*)	Laminated rocks without defects such as sand stone, limestone etc.	16·5
(*iii*)	Shattered and broken bed rock and hard shale cemented materials etc.	9·0
(*iv*)	Soft rock	4·5
	(*b*) Non-Cohesive Soils	
(*v*)	Compact gravel or sand and gravel	4·5
(*vi*)	Compact and dry coarse sand	4·5
(*vii*)	Compact and dry medium sand	2·5
(*viii*)	Fine dry sand, silt,	1·5
(*ix*)	Dry and loose gravel, coarse to medium sand or mixture of sand and gravel	2·5
(*x*)	Loose and dry fine sand.	1·0
	(*c*) Cohesive Soils	
(*xi*)	Dry soft shale, hard or stiff clay in deep bed	4·5
(*xii*)	Medium clay which can be readily indented with a thumb nail	2·5
(*xiii*)	Medium clay and sand clay mixture which can be indented with strong thumb pressure	1·5
(*xiv*)	Soft clay which can be indented with moderate thumb pressure.	1·0
(*xv*)	Very soft clay which can be penetrated by several centimetres with the thumb.	0·5

The above values of safe bearing capacities of soils can be increased by an amount equal to the weight of virgin soil removed from the ground above the base of foundation. In case of non-cohesive soils, the tabulated values of safe bearing capacities should be reduced by 50% if the ground water table is above or very near the foundation bed. However, if the ground water table is below the foundation bed by a distance equal to the width of foundation, no reduction will be made in the tabulated figures.

The bearing capacities of black cotton soil, shrinkable soils, made up ground etc. differ from site to site. Detailed site exploration should be carried out to decide the allowable bearing capacity of soil for a particular site. In the absence of such investigations it is safe to assume the value of safe bearing capacity of such soils as 0·5 kg/cm^2.

1·9 Methods of Improving the Bearing Capacity of Soils. The following methods are generally adopted to improve the bearing capacity of soils :

(1) Increasing the depth of the footing is the simplest method of increasing the bearing capacity. The method is restricted in sites where the sub-soil water level is much below and deep excavations do not increase the cost of the structure disproportionately.

TABLE 1·2

SAFE PERMISSIBLE LOAD ON MASONRY

S. No.	*Description of Masonry*	*Tonne/m^2*
1	Brick masonry in 1 : 3 cement mortar	100
2	Brick masonry in 1 : 4 cement mortar	88
3	Brick masonry in 1 : 6 cement mortar	50
4	Brick masonry in lime motar	44
5	Ashlar stone masonry in 1 : 3 cement motar ...	170
6	Rubble masonry in 1 : 3 cement mortar	90 to 110
7	Rubble masonry in lime mortar	30 to 50
8	Cement concrete *M*200 (1 : 1½ : 3)	510
9	Cement concrete *M*150 (1 : 2 · 4)	440
10	Cement concrete *M*100 (1 : 3 : 6)	280
11	Cement concrete (1 : 4 : 8)	110
12	Lime concrete	50 to 75

(2) Drainage is a well-known method to improve the bearing capacity of certain soils. The drain with open joints are laid in trenches just above the footing base. The sub-soil water is drained through the tile drains outside the bearing strata.

(3) Granular materials, like sand, gravel or crushed stone is blended into the natural soil by ramming. The layer of soil thus formed is much stronger and is of improved bearing capacity.

(4) By confining the soil in an enclosed area with the help of sheet piles. This method is used with advantage in shallow foundations in sandy soils.

(5) By driving sand piles. This method is based on the principle of reducing the void volume of the natural soil. Holes are made in the soft soil with the help of wooden piles or other means and then sand is filled in the holes and rammed. These are called sand piles. Bearing capacity of soft soil can be appreciably improved by driving sand piles at close spacing.

1·10 Types of Foundations. Foundations can be broadly classified into two types, *i.e. deep foundations* and *shallow foundations.* Pile, cofferdams and caisson fall under the category of deep foundations. Deep foundations are separately described in chapter 2.

1·11 Shallow Foundations. When the foundation is placed immediately beneath the lowest part of the super structure, it is termed as shallow foundation. The object of this type of foundtion is to distribute the structural loads over a considerable horizontal area near the surface. The various types of foundations which can be included under shallow foundation are :

1. *Spread footings*
2. *Grillage foundation*
3 *Eccentrically loaded footings*
4. *Combined footings*
5. *Mat or raft foundation.*

1 12 Spread Footings. As the name suggests, in case of spread footings, the base of the member transmitting load to the soil is made wider so as to distribute the load over wider area. Broadly speaking all the type of foundation mentioned above can be covered under the term spread. However, from design and construction point of view they have been treated separately. The various footings described under this classification are :

(*a*) *Wall footings*

(*b*) *Reinforced concrete footings*

(*c*) *Inverted arch footings*

(*d*) *Column footings.*

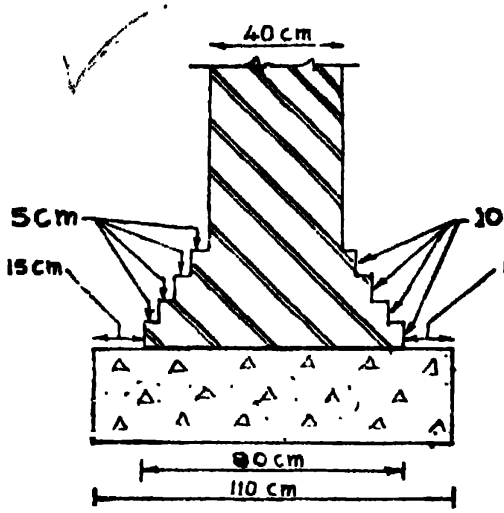


Fig. 1·6

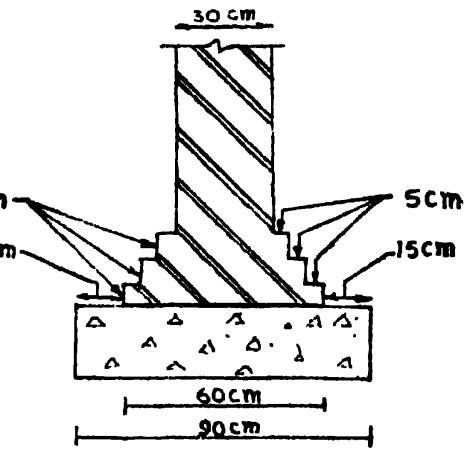


Fig. 1·7

Two and 1½ brick thick (modular bricks) wall footing using standard bricks in metric units

(*a*) **Wall footings.** It consists of several courses of bricks, the lowest course being usually twice the breadth of the wall above. The increased base width of the wall is achieved by providing 5 cm. (¼th brick length) offset on either side of the wall. The depth of each courseis usually 10cm (depth of one brick). In some cases however the bottom courses are made 20 cm. (depth of two bricks) deep. The footings of various wall thicknesses have been shown in Figs. (1·6-1·7). In case of footings for *stone walls* the size of offset is slightly more than that of the brick wall footing. A bed of lean concrete of uniform thickness is first spread over the entire length of the wall. For foundations over

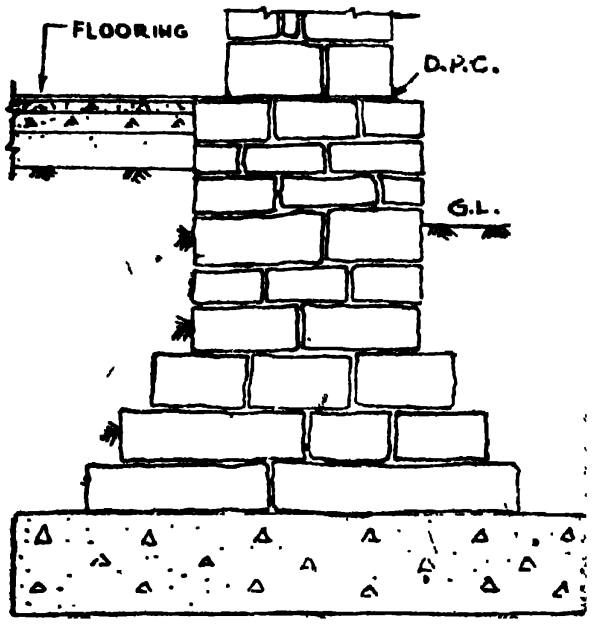


Fig. 1·8
Stone-wall footing

firm soil or compact ground, the concrete bed below the brick wall footing may be dispensed with. The depth of lean concrete bed is seldom less than 15 cm. and its projection on either side of the wall base usually varies between 10 cm. t› 15 cm. In any case, the depth of the concrete bed should never be less than its projection beyond the wall base. The concrete bed provides a plain surface upon which the wall footing can be started directly. It not only rectifies the inequalities of excavation but also bridges over soft patches in the soil below. The design of the brick wall footings and the concrete bed block is fully described in Chapter 3.

(*b*) **Reinforced concrete footings**. In places where the walls are subjected to relatively heavy loading and the bearing capacity of the soil on which the wall footing is to rest is very low, the type of footing described above will work out to a massive structure. In such cases it is desirable to provide reinforced concrete footing below the wall. This appreciably reduces the volume of concrete in the bed

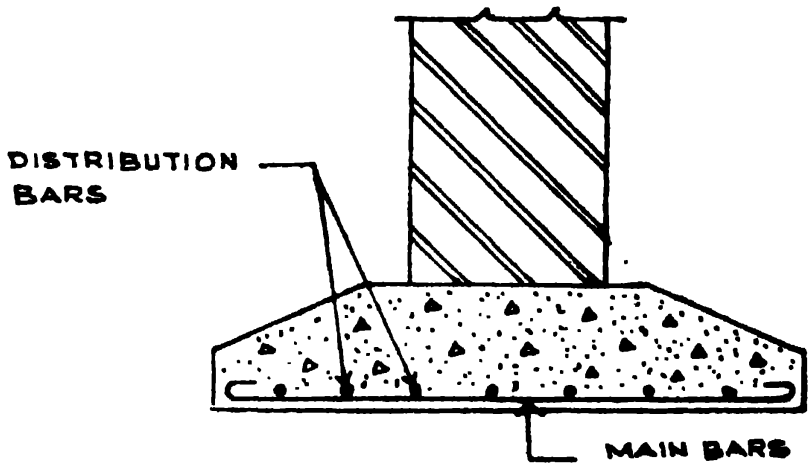


Fig. 1·9
Reinforced concrete footing for a wall

block and as such proves to be economical. A 8 cm. bed of lean concrete is usually provided below the reinforced concrete footing to perform the function of concrete bed block. The reinforced concrete footing for a wall is shown in Fig. 1·9.

(*c*) **Inverted arch footings**. With the advancement in engineering technique, inverted arch construction is rarely done these days. One of the drawbacks in this type of construction is that the end piers have to be specially strengthened by buttresses to avoid the arch thrust rapturing the pier junction. There is no check to the load applied. The advantage of inverted arch construction is that in soft soils the depth of foundation is greatly reduced. Inverted arch footing has been shown in Fig. 1·10.

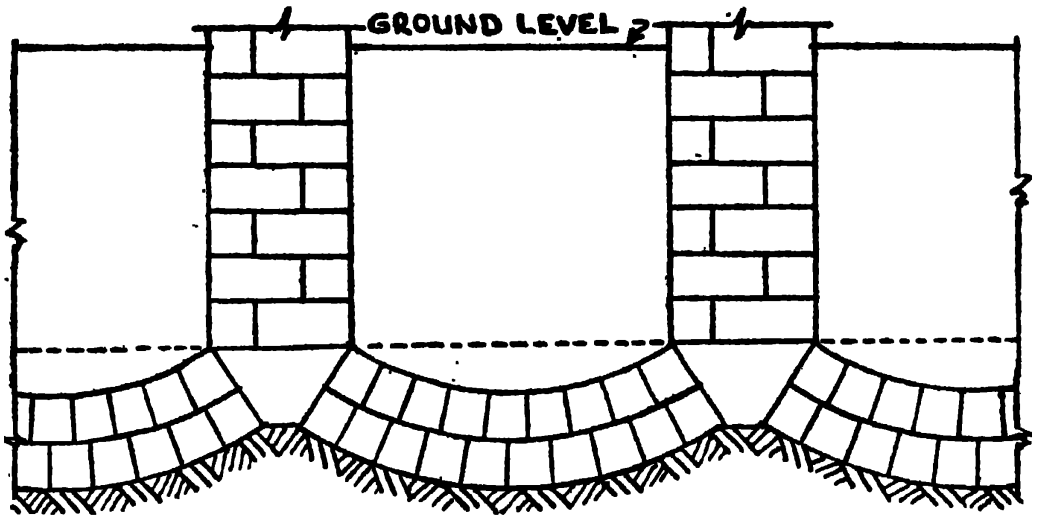


Fig. 1·10 ·

Inverted arch foundation

(*d*) **Column footings** (*Independent footings*). An independent footing is one which is provided under a column or other similiar member for distributing the concentrated loads in the form of uniformly distributed load on the soil below. The footing may be square, rectangular or circular in plan. Depending upon the load to be carried, and the bearing capacity of the soil, independent footing may be of brick masonry, stone masonry, R.C.C., steel grillage etc.

(*i*) *Footing for brick pillars.* Square footing is the simplest and most economical to be provided under pillars, columns or stanchions.

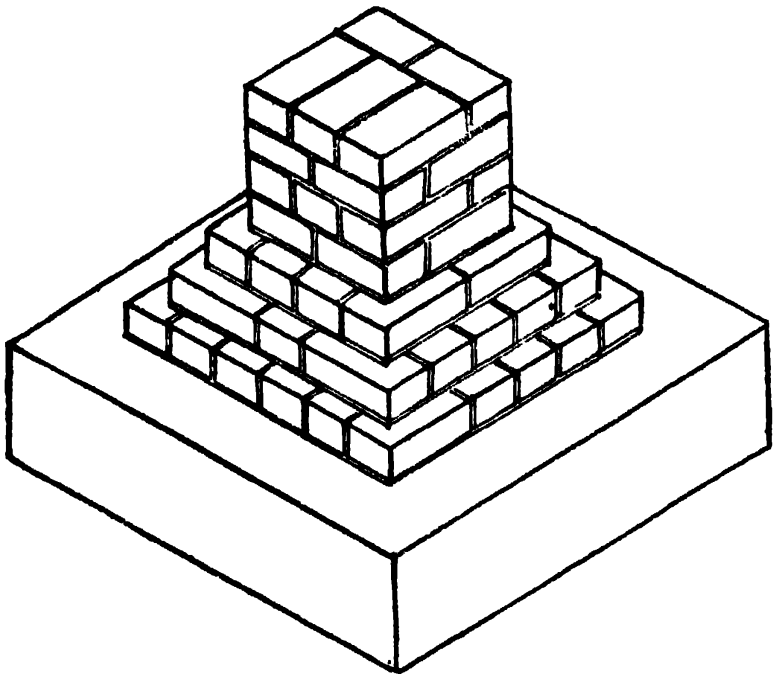


Fig. 1·11

Brick pillar footing

The area of the base is calculated by dividing the total load to which the pillar is subjected to, by the safe bearing capacity of the soil. The desired base width is obtained by means of offsets, which run symmetrical alround the pillar.

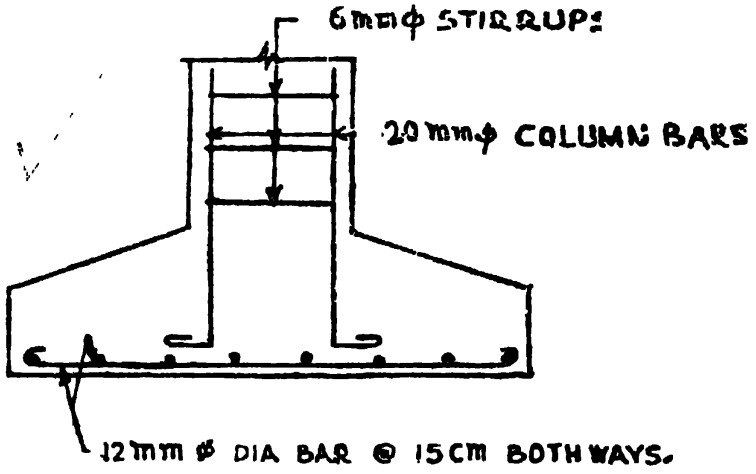
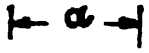


Fig. 1·12
R.C.C. column footing

(*ii*) *R.C C. column footings.* On account of their low bending strength, the footings constructed with brick, stone or plain concrete require considerable depth to be safe to carry heavy loads. The depth of plain concrete footing can be appreciably reduced by providing reinforcements at its base to take up tensile stresses. R.C.C.



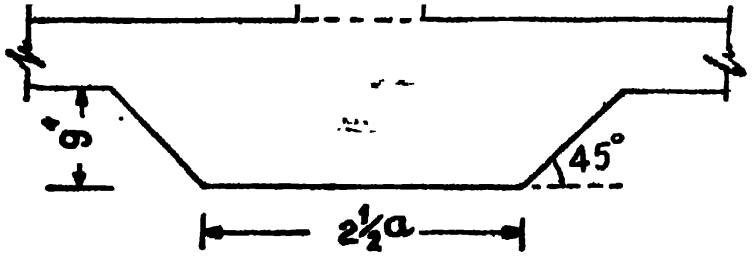


Fig. 1·13
Shape and proportion of a column foundation monolithic with floor slab

column footings may be circular, rectangular or square in plan. The footing is reinforced both ways by means of mild steel bars placed at right angles to one another at equal distances apart.

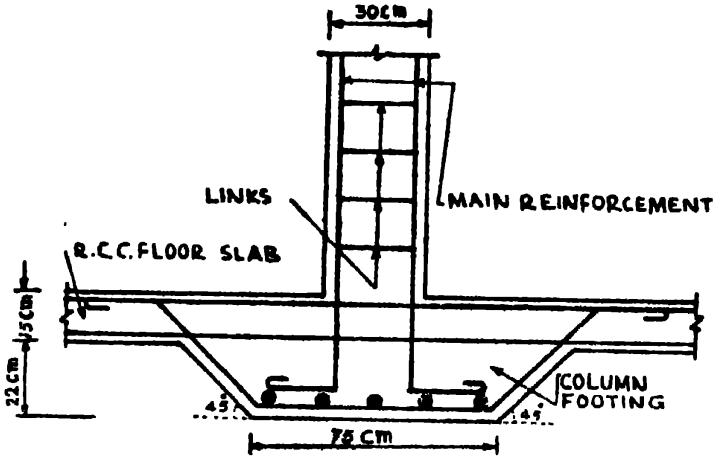


Fig. 1·14

Position of reinforcements in column in Fig. 1·13

(*iii*) *Stone pillar footings.* This type of footing is similiar in construction to the footing for brick pillar. In this construction the regular offsets on all the four sides of pillar are of slightly bigger in width and depth.

1·13 Grillage Foundations. When heavy structural loads from columns, piers or stanchions are required to be transferred to a soil of low bearing capacity, grillage foundation is often found to be lighter and more economical. This avoids deep excavation and provides the necessary area at the base to reduce the intensity of pressure. Depending upon the material used in construction grillage foundation can be broadly divided in the following two categories.

(*a*) *Steel grillage*

(*b*) *Timber grillage*

(*a*) *Steel grillage.* Steel grillage foundation consists of steel beam (R S.J.'s) also known as grillage beams which are provided in single or double tiers. In case of double tier grillage, the top tier is laid at right angles to the bottom one. The grillage beams of each tier are held in position by 20 mm. ϕ spacer bars with 25 mm. ϕ pipe separators. The beams are suitably spaced so as to provide facility for the placing and rodding of concrete between them. A minimum clearance of 8 cm. is considered most suitable. In any case, the distance between the flanges of the beams should not be more than one and a half to two times the flange width with a maximum of 30 cm. If the beams are spaced more distance apart, there is a danger of the concrete filling not acting monolithically with the beam, and as such, may result in the failure of the foundation. In order to protect the beams against corrosion, a minimum

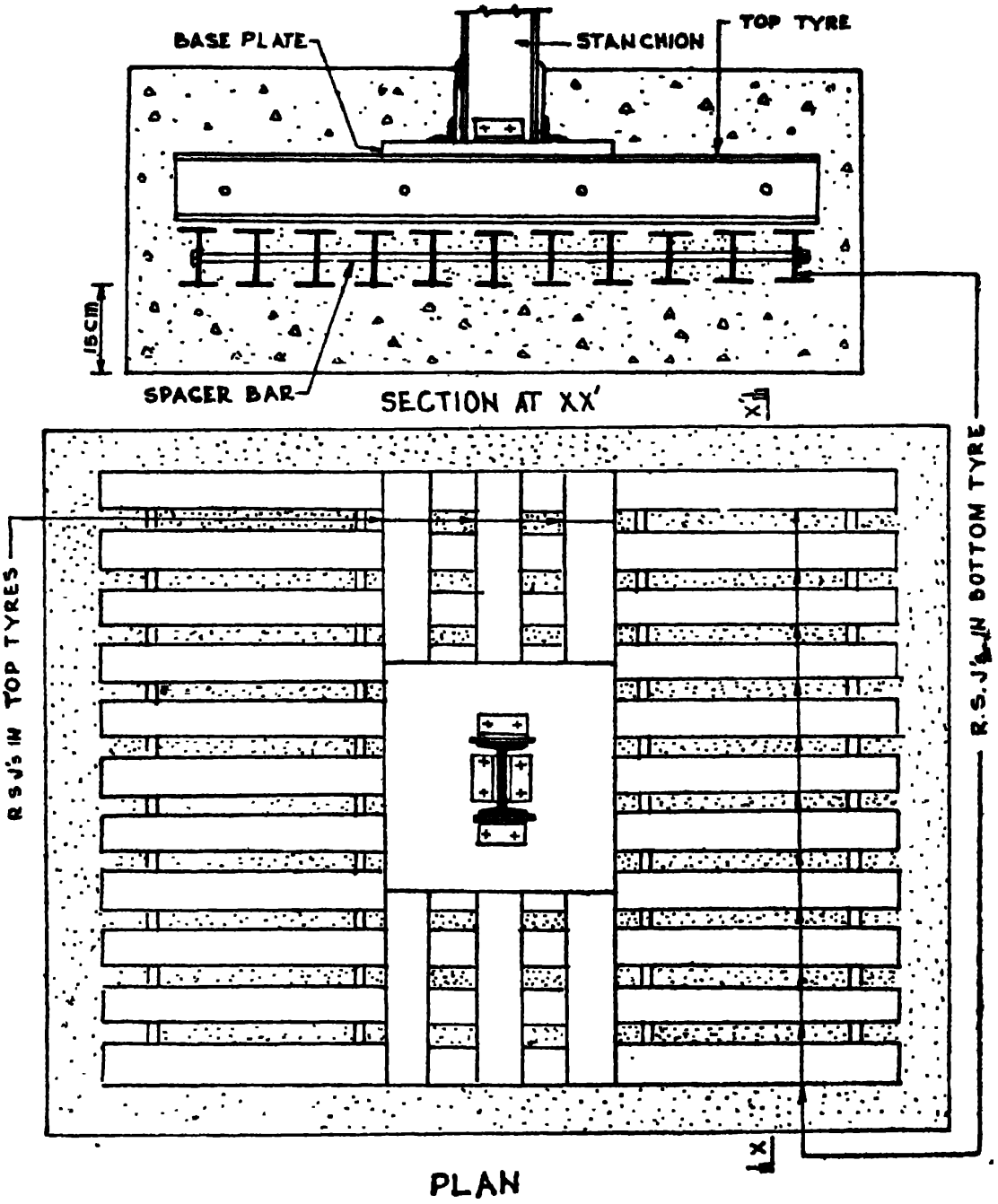


Fig. 1·15

Steel grillage foundation

cover of 10 cm. is kept on the outer sides of the external beams as well as above the upper flange of the top tier. Cover of concrete under the lower beam should not be less than 15 cm.

Method of construction. Excavations are carried to the designed depth and the bed is well levelled. This foundation bed is covered with a layer of rich mixture of concrete not less than 15 cm. in thick-

ness. This is well compacted so as to make the layer of concrete an impervious bed. Grillage beams of the designed dimensions are then placed on this bed of concrete at specified distance apart using separators. The upper surface of the grillage beam flanges is brought in a horizontal plane and rich cement grout is then poured all round the lower flanges of the beams so as to secure the beams to the concrete bed. The concrete is then placed between and around the beams. If another tier is required to be provided, it is kept at right angles to the already laid tier and the entire space is filled with concrete.

(*b*) *Timber grillage.* Where the soil encountered is soft and is permanently water-logged building walls can be most economically supported by carefully designed timber grillage foundations. This

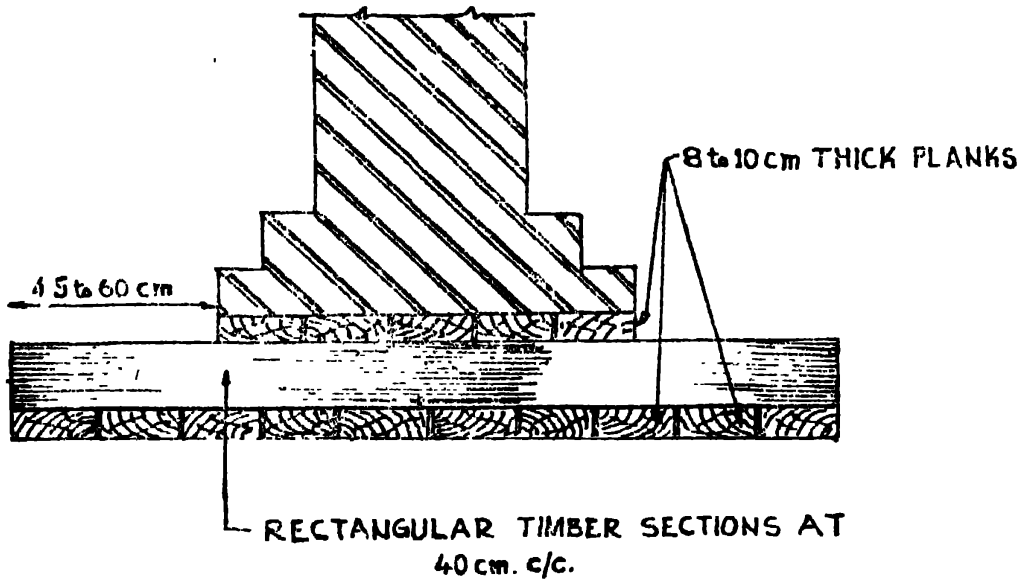


Fig. 1·16

Timber grillage foundation for a wall

type of foundation can be safely used for light buildings by limiting the loading on the soil to 5·5 tonne/m^2. In this type of construction the concrete block usually provided below the wall footing is replaced by timber platform.

The timber platform consists of planks usually 8 cm. to 10 cm. in thickness, arranged in two layers, one longitudinal and the other across the wall extending beyond the footing base by about 45 cm. to 60 cm. on either side. In the lowermost layers, the planks are 5 cm. to 8 cm. in thickness while in the upper layer they are usually 8 cm. to 10 cm. thick depending upon the loading and site conditions. The two layers of planks are separated by rectangular sections of

timber spaced at not more than 38 cm. centre to centre, the depth of the sections being 0·75 times the width.

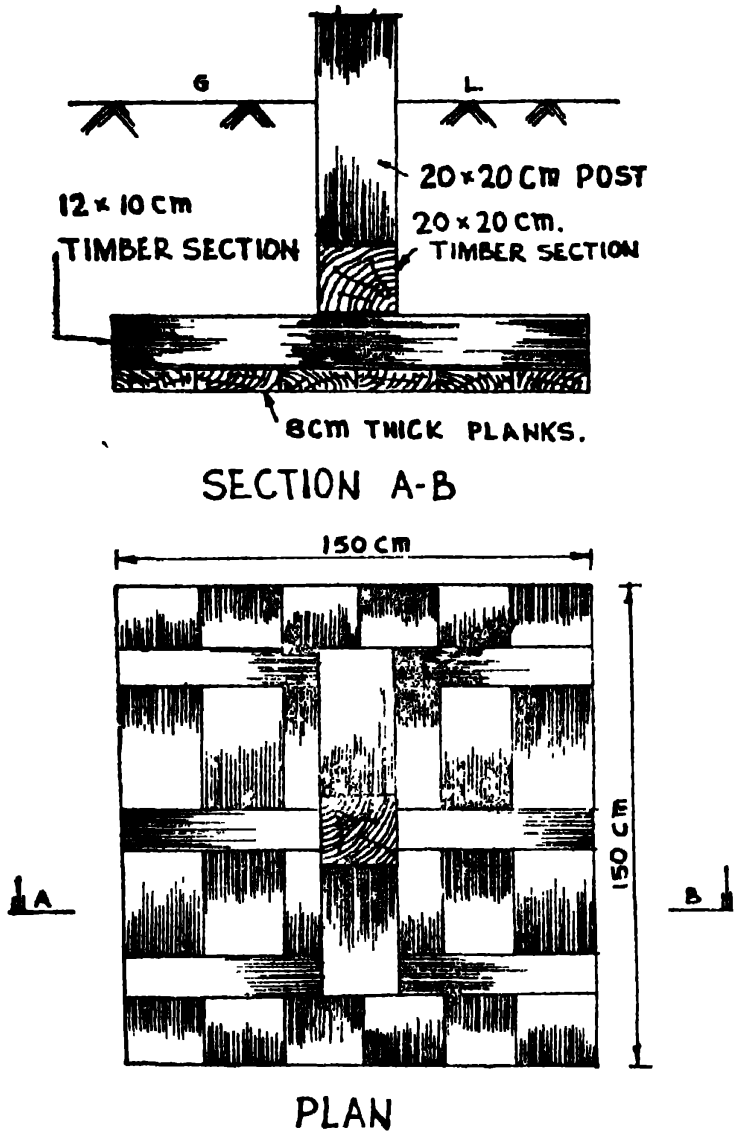


Fig. 1·17
Grillage foundation for a timber post

The arrangement of scantlings in case of grillage foundations for a column on a timber post is shown in Fig . 1·17

1·14 Eccentrically Loaded Footings. As far as practicable, the foundation, it may be for a wall or column, is so shaped and proportioned that the centre of gravity of the imposed loads coincide with the *c g.* of the supporting area of base. However, when walls or columns are to be placed close to property lines, the required supporting areas of the base cannot be placed concentrically with the imposed loads without overlapping the property lines. Hence, different methods are adopted to ensure the stability of the wall or column

without encroaching the area outside the boundary line of the building. Some of the methods are given below :

(*i*) *Offsetting the footings.* The footing of a boundary load bearing wall is so shaped as to have a considerable wider footing with regular offsets on the inside while the wall face is kept flush with the boundary line. As is obvious, the imposed load acting on one side of the centre of the footing, loads the supporting area unequally. The pressure at the edge of wall nearest to the point of application of imposed load will be found to be

$$= p_1 = \frac{W_1}{b}\left(1 + \frac{6e}{b}\right) \qquad \ldots(i)$$

where

W_1 = total load per unit length coming on the supporting area.

b = width of the supporting area.

e = eccentricity of load or the distance between the *c g.* of the load and the *c.g.* of supporting area of base.

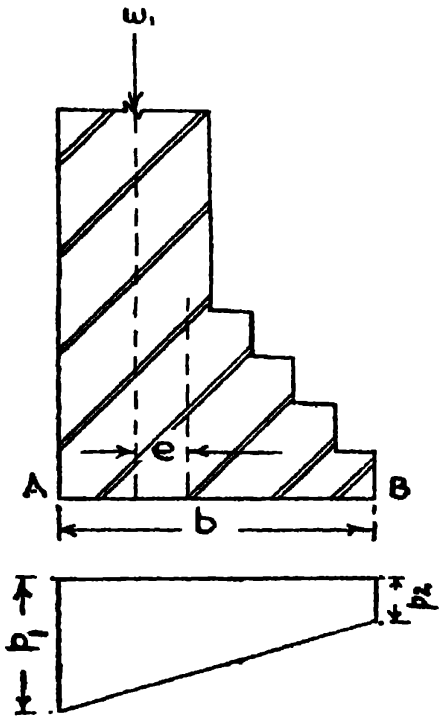


Fig. 1·18

The pressure at the edge of footing farthest from the point of application of imposed load will be found to be

$$= p_2 = \frac{W_1}{b}\left(1 - \frac{6e}{b}\right) \qquad \ldots(ii)$$

Referring equation (*ii*), we find that if the eccentricity is $\frac{b}{6}$, p_2 becomes zero and if e is greater than $\frac{b}{6}$, the value of p_2 will be negative and as such the footing will have tension at B. In masonry construction excessive tension is not permissible and hence in order that the supporting area is fully in compression, the width of footing is so adapted that the c.g. of the load falls within the middle third of the base.

(*ii*) *By providing strap footing.* Offsetting of the footing is desirable in firm soil, while in soft soil and under heavy loading conditions, there is danger of the maximum pressure on the outer edge of the footing exceeding the bearing capacity of soil. In such circumstances, the load from the outer column is balanced by the

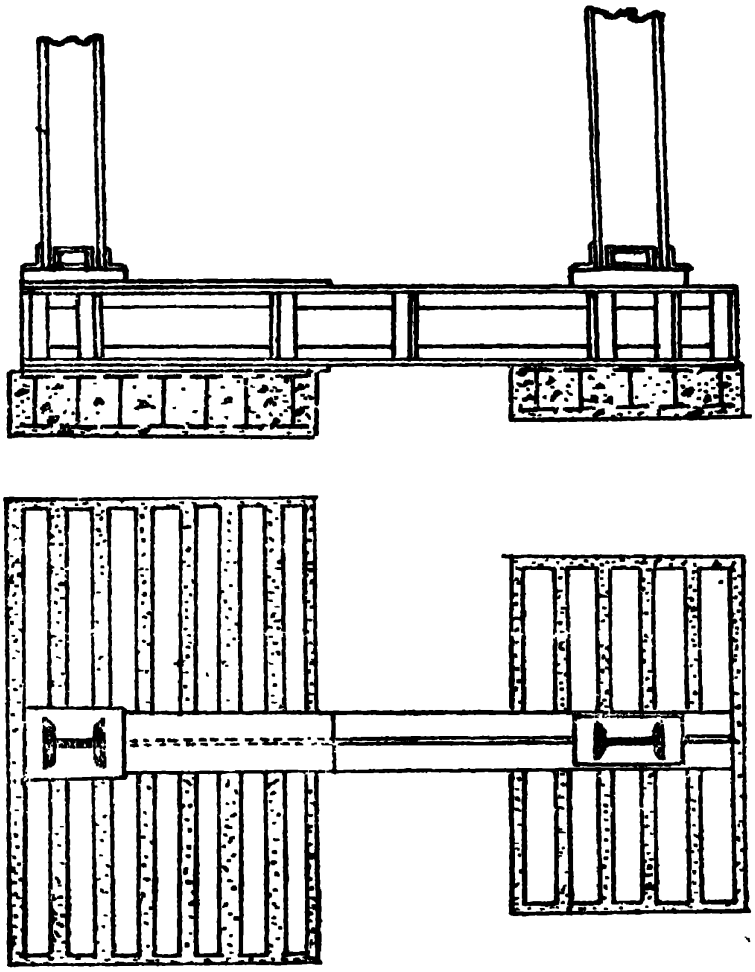


Fig. 1·19
Sectional elevation and plan of steel grillage strap footing

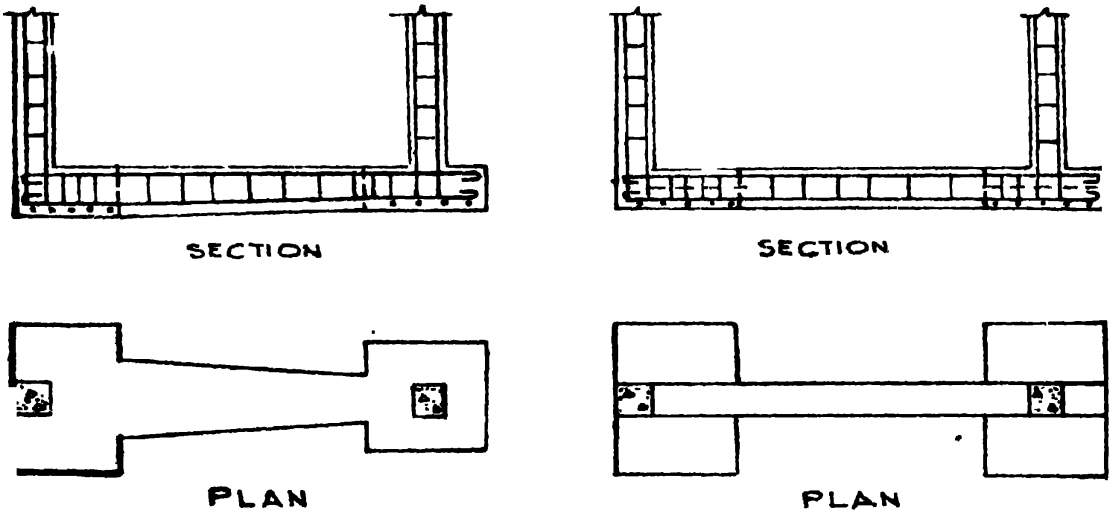


Fig. 1·20
R.C.C. Strap footing

load from the inner column through a cantilever beam acting about a fulcrum. Cantilever or strap footing may be constructed in reinforced concrete, or steel grillage. In case, the interior column cannot be provided, a suitable concrete block may be built to provide the necessary anchorage. The value of the weight of concrete block can be obtained by simple principle of lever. Referring to Fig. 1·21, we find that :

$$W_1 \times l_1 = W_2 l_2$$

or

$$W_2 = \frac{W_1 l_1}{l_2}$$

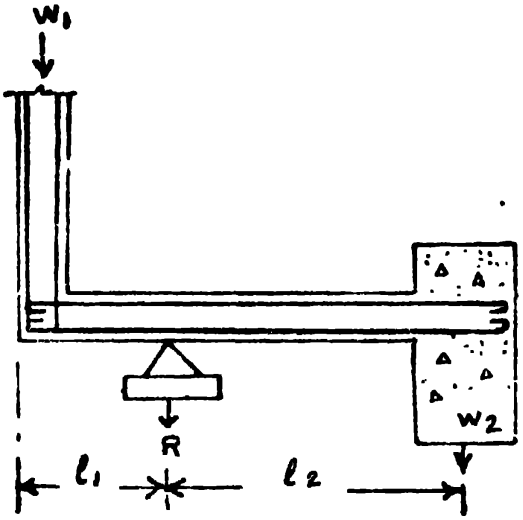


Fig. 1·21

and the reaction at the fulcrum is given by :

$$R = W_1\left(\frac{l_1}{l_2} + 1\right).$$

1·15 Combined Footings. A combined footing is so proportioned that the centre of gravity of the supporting area is in line with the *c.g.* of the two column loads. A combined footing may be rectangular or trapezoidal in shape. Rectangular shape is only

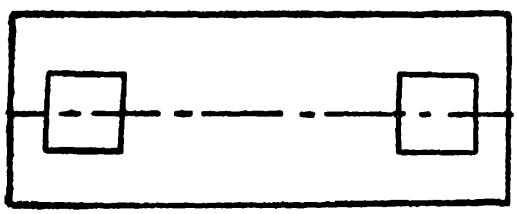


Fig. 1·22
Combined rectangular footing

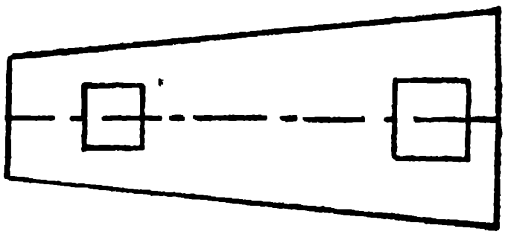


Fig. 1·23
Combined trapezoidal footing

possible where loading condition is such that either the two columns are equally loaded or the interior column carries greater load. Trapezoidal shaped footing can be possible under any condition of loading.

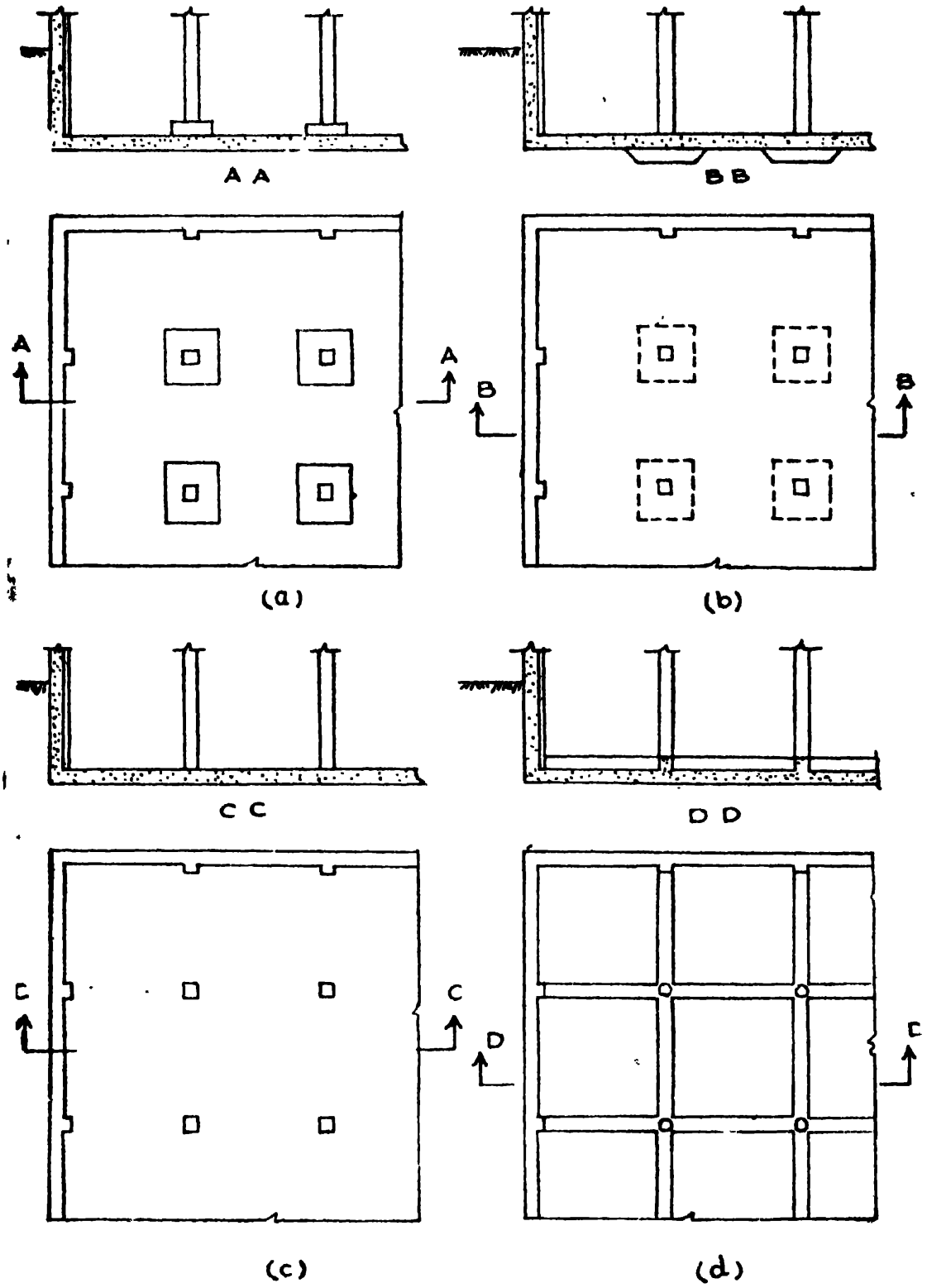


Fig. 1·24
Different types of raft foundations

1·16 Raft foundation. In made-up ground, soft clay or marshy site having a low value of its bearing power, heavy concen-

trated structural loads are generally supported by providing raft foundation. Also if the structure is liable to subsidence on account

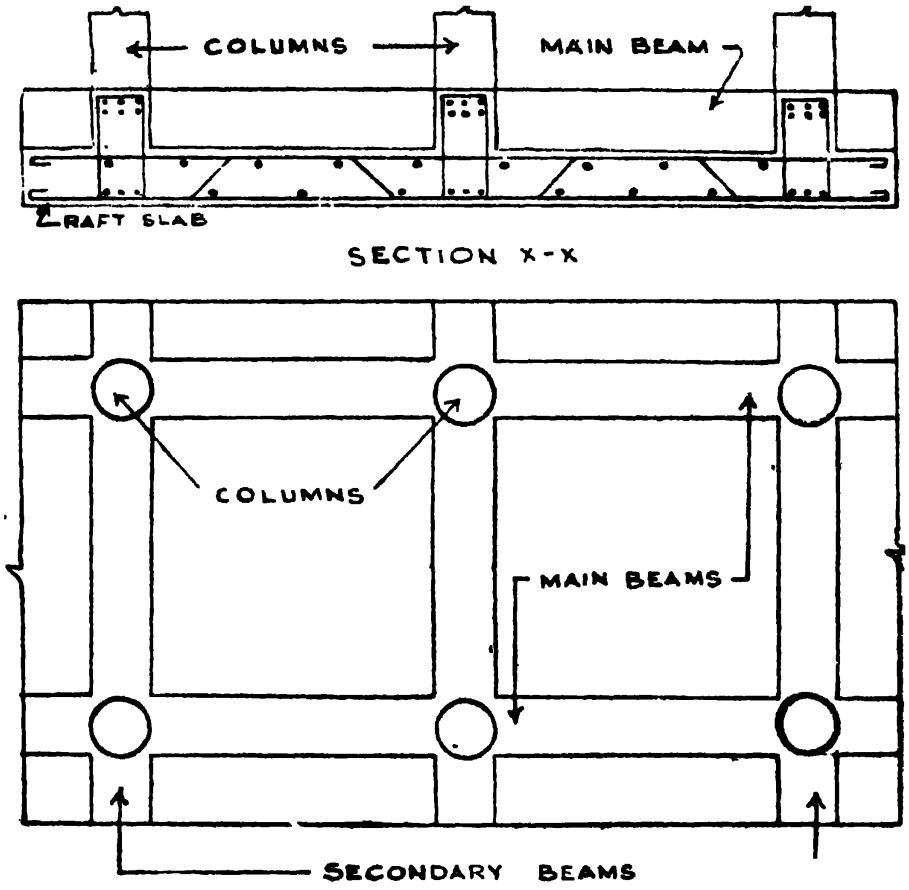


Fig. 1·25
Raft foundation

of its being located in mining area or due to uncertain behaviour of its sub-soil water condition, raft foundation should be preferred. It provides an economical solution to difficult site conditions, where pile foundation cannot be used advantageously and independent column footing becomes impracticable.

Raft foundation consists of thick reinforced concrete slab covering the entire area of the bottom of the structure like a floor. The slab is reinforced with bars running at right angles to each other both near bottom and top face of the slab. Sometimes it is necessary to carry the excessive column load by an arrangement of inverted main beams and secondary beams, cast monolithically with the raft slab.

Method of construction. The raft slab generally projects for a distance of 30 cm. to 45 cm. on all the sides of the outer walls of the

structure and as such the area of excavation is slightly more than the area of the structure itself. The excavation is made to the required depth and the entire excavated area is well consolidated, water being liberally used during the process of consolidation. This surface when dry, provides the base upon which the raft slab is laid. All the precautions that are necessary to be observed during the reinforced concrete construction are strictly adhered to and further construction is started only after the curing of the raft has been fully done.

1·17 Foundations in Black Cotton Soil. Construction on black cotton soil, commonly known as a shrinkable soil has always been a difficult problem for the engineers. Inspite of many precautions, the structure built on black cotton soil cracks terribly without any warning. In India, about 16% of the land comprises black cotton soil and this type of soil is found in many other countries of the world.

Black cotton soil is dangerous for the buildings on account of its volumetric changes with the change of atmospheric conditions. It swells excessively when wet and shrinks excessively when dry. Black cotton soil has thus a great affinity for water. This tendency of soils is on account of the presence of fine clay particles which swell when they come in contact with water. The differential settlement of the structure, caused by the movement of the ground on account of alternate swelling and shrinkage, results in formation of cracks. The cracks thus formed are sometimes 15 to 20 cm. wide and 2·5 to 4 m. deep.

1·18 Precautions for the Safety of Foundations in Black Cotton Soil. The following precautions are generally adopted while building structures on black cotton soil :

(1) To limit the loads on the soil to 5·5 Tonne/m^2. If water is liable to find an access to the foundations, the limit of loading should then be restricted to 4900 kg./m^2

(2) To take the foundation to such depths where the cracks cease to extend. The minimum depth of foundation should be at least 1·5 m.

(3) To provide reinforced concrete ties or bands alround the main walls of the building. The R.C.C. ties or band which may be 10 cm. to 15 cm. deep should be placed at plinth level, lintel level and eaves level. In case of flat roof, the R.C.C. slab itself acts as a tie and as such no extra band need be provided near the roof in such cases.

(4) If the depth of black cotton strip above given ground is only 1 to 2 m., the entire soil above the hard bed may be completely removed and the foundation laid on the hard bed below.

(5) If the depth of cracks is great, say 3 to 4 m., R.C.C. piles may be provided below the concrete bed block.

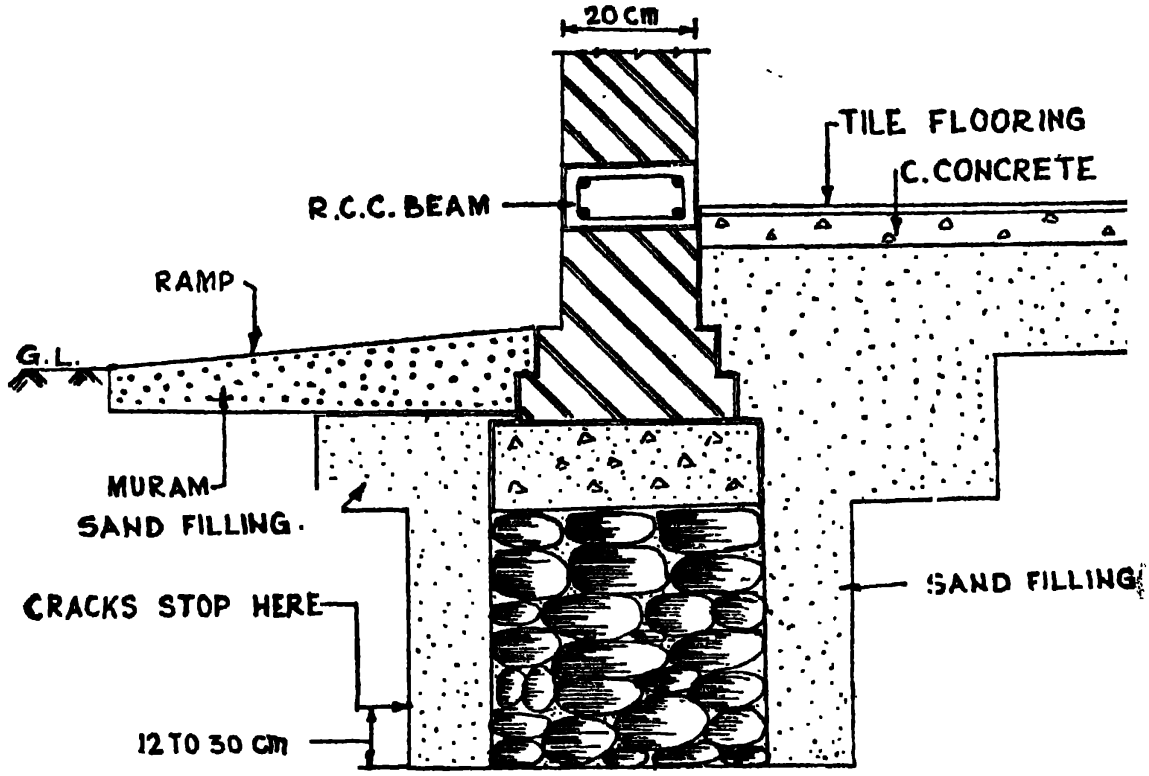


Fig. 1·26

Foundation in black cotton soil showing R.C.C. band at plinth-level

(6) In important structures, raft foundation should be provided so as to float the building on the bed below, quite independent of the surrounding soil.

(7) To prevent the intimate contact of black cotton soil with the parts of the structure by digging trenches on either side of the foundation and filling them with granular material like sand or moorum.

(8) For less important structures like compound walls etc., the foundations should preferably be taken at least 15 cm. below the depth at which cracks disappear.

(9) In case of ordinary buildings, the foundation should be taken at least 30 cm. deeper than the depth where the cracks stop.

(10) The bed of foundation trench should be made firm or hard by ramming it well. On the rammed bed a 30 cm. layer of good hard moorum should be spread in layers of 15 cm. each layer being well watered and rammed before laying the next layer. On this layer either a stone or sand bed should be raised to the desired height to rest the foundation concrete bed block upon it.

(11) The masonry for the walls should start at least 15 cm. below the general ground level.

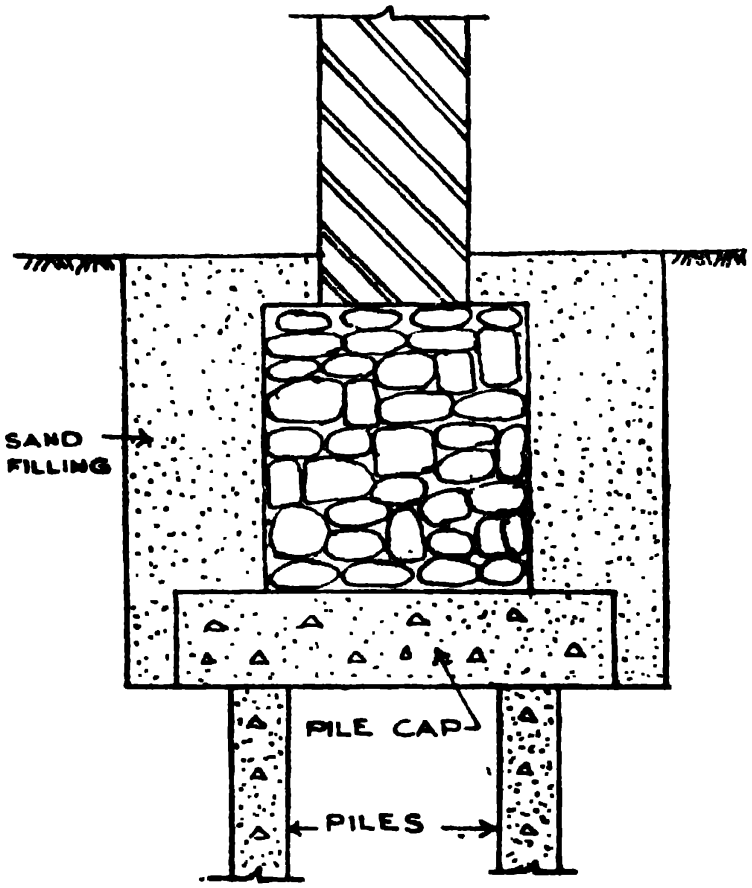


Fig. 1·27
Wall footing resting on piles in black cotton soil

(12) In case of compound walls or structures of less importance, the width of trench should be atleast 130 cm. ; the width of foundation bed being 100 cm. with 15 cm. wide strip of sand filling on either side of foundation bed. Refer Figs. 1·28 and 1·29.

(13) In case of main walls or load bearing walls, the trench width should preferably be 90 to 120 cm. greater than the width of foundation bed block.

(14) CBRI has developed a new method of providing foundation in black cotton soil by using under-reamed piles. The construction of under-reamed piles is briefly discussed below.

Under reamed piles. Under-reamed pile is a form of short pile which is commonly recommended for providing safe and economical foundations in black cotton soil and in other soils having low value of bearing capacity. In this type of foundation ; the structure is anchored to the ground at a depth where ground movement due to changes in moisture content are negligible. The method of construction of under-reamed pile is very simple.

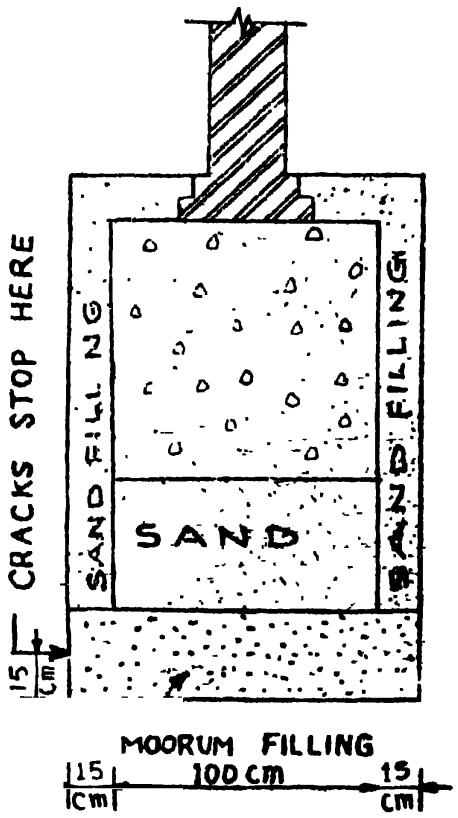


Fig. 1·28. Foundation in black cotton soil with concrete bed block resting on sand bed

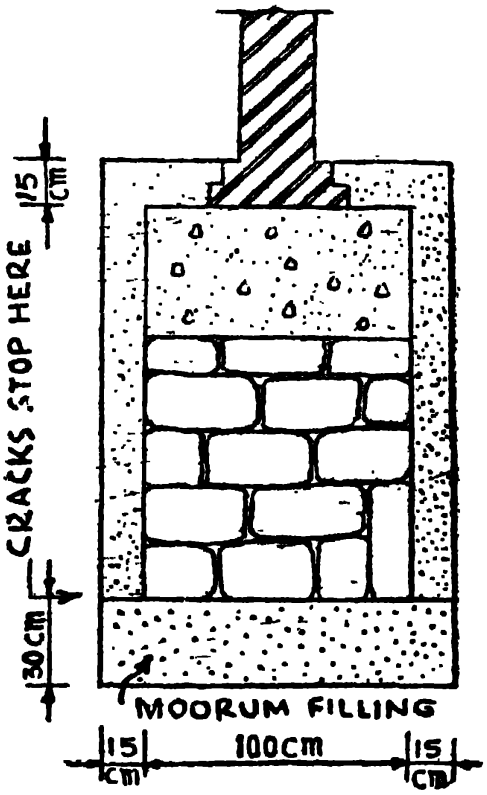


Fig. 1·29. Foundation in black cotton soil with concerete bed block resting on stone bed

The holes, for casting the piles in the ground, may be bored by using hand augers. The diameter of the pile may vary between 200 to 380 mm and the depth should not normally exceed 3·7 metre. In order to increase the bearing capacity and the anchorage of the pile, one or more bulbs are formed at it base by enlarging the bore hole by a special tool known as under-reaming tool. In normal practice the diameter of the bulb is kept $2\frac{1}{2}$ times the diameter of the pile and the piles are spaced not closer than 2 times the diameter of the pile bulb (under-ream).

After the pile holes are ready for concreting, reinforcement cages are lowered in the holes and concrete is poured by use of a funnel. In black cotton soil, the capping beams are cast about 75 mm above the ground so that structure remains independent of the ground movement.

1·19 Pier Foundation. When a heavy building is to be situated in sandy soil or soft soil, overlying hard bed at reasonable depth, pier foundations are sometimes used to transfer the load of the building to the hard bed below. This method consists in sinking vertical shafts up to hard bed and filling them with concrete.

The diameter of the shaft and their centre to centre spacing depend upon the loading condition, nature of soil and depth at

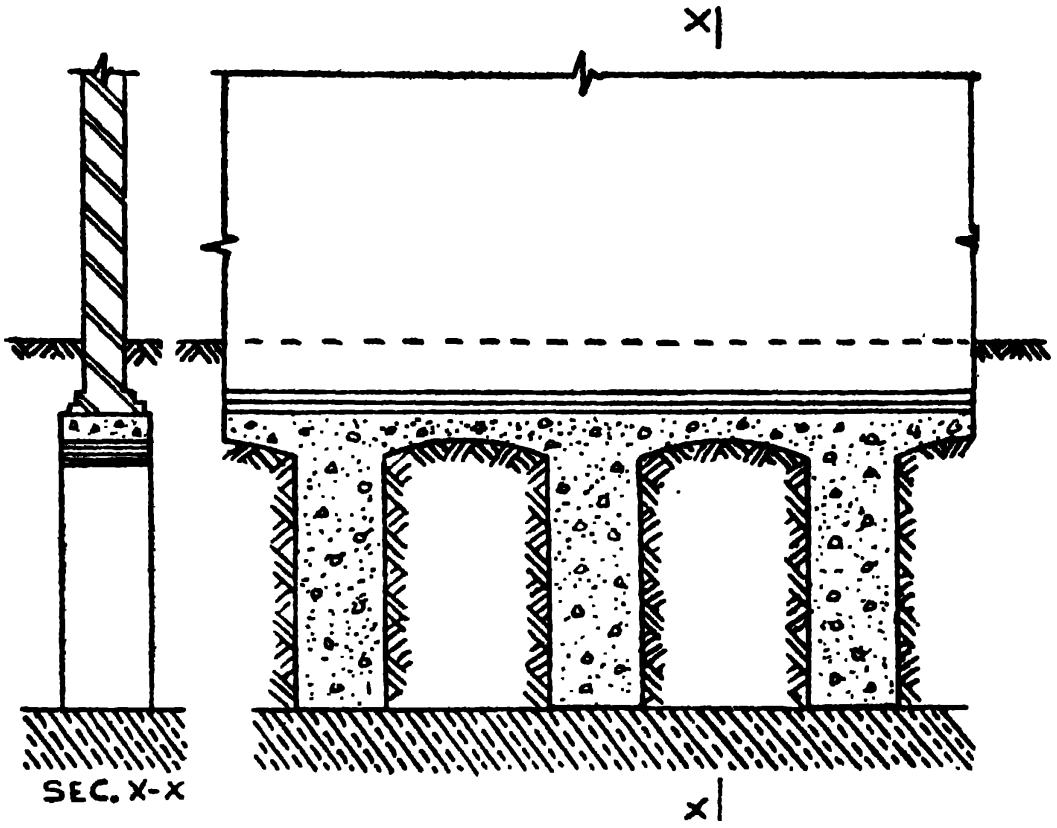


Fig. 1·30

Wall footing resting on pier foundation.

which the hard bed is situated. However, in no case the diameter or the least horizontal dimension (in case of square or rectangular pier) of plain concrete pier should be less than 1/12th its height. To prevent the side earth from falling in, the inside of the shaft is sometimes lined with timber. The timber lining in removed during the filling up of the shaft with concrete. The shafts are connected to each other by a reinforced cement concrete or steel grillage cap. The concrete cap is sometimes built in the form of arch.

1 20 Foundations on Sloping Ground. To avoid sloping foundation bed or excessive depth of excavation at the top end, stepped foundation is necessary to be provided in a considerably sloping ground. This is achieved by cutting the portion of the foundation trench in steps. The steps should not preferably be more than the depth of the concrete bed and each step should be a multiple of the depth of one brick so as to fit in with the brick courses. The lap of concrete at each step should never be less than the vertical thickness of the concrete.

In some cases the bottom of the footings of different walls of the same structure may be at different levels. The following limitations (as given by I.S.I.) are necessary to be observed in deciding the depth of footings in such circumstances.

(1) The distance between the lower edge of the footing to the sloping surface should not be less than 1 m for soils and 60 cm for rocks.

(2) In clayey soils, the line drawn between the lower adjacent edge of the upper footing and the upper adjacent edge of the lower footing should not have a steeper slope than 2 : 1 (*i.e.* two horizontal : one vertical).

(3) In granular soils, the line drawn between the lower adjacent edges of adjacent footings should not have a slope steeper than 2 : 1 (*i.e.* one horizontal : one vertical).

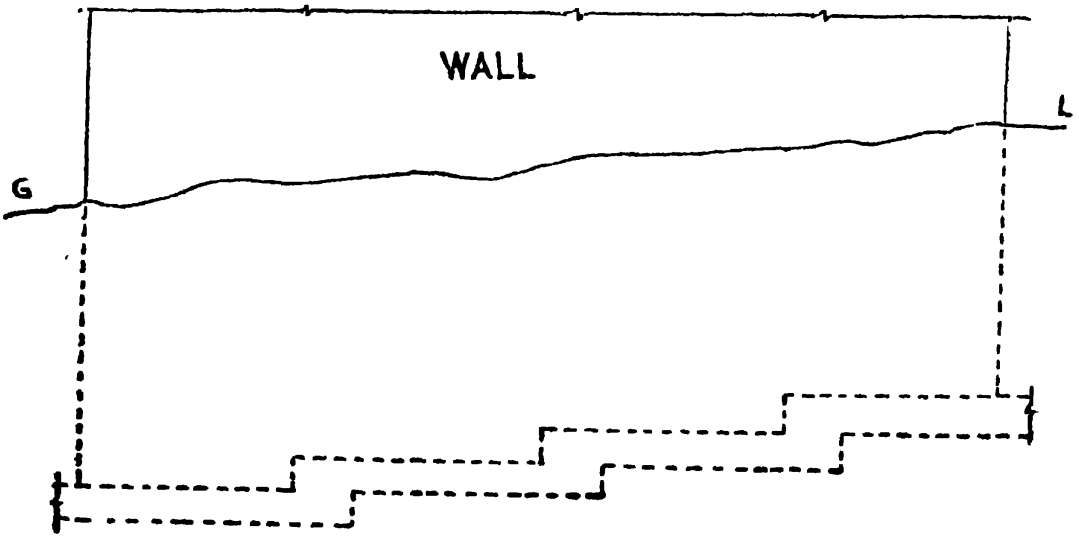


Fig. 1·31. Elevation of stepped foundation.

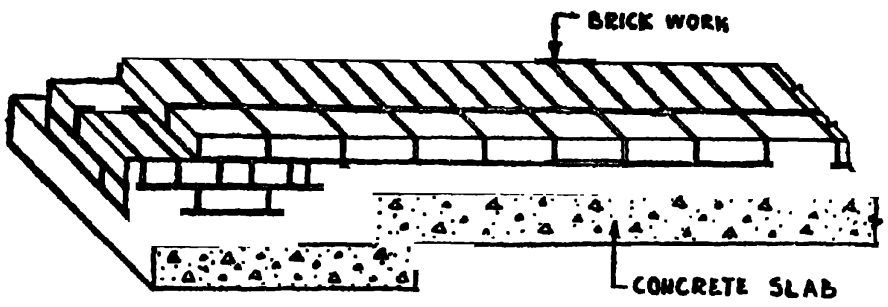


Fig. 1·32. Isometric view of stopped foundation.

1·21 Machine foundation. The design of machine foundation involves careful study of the vibration characteristics of the

foundation system. Ralevent data required for the design and construction of the foundation of machine should be obtained from the manufacturer of the machine, prior to the start of design unit. All parts of machine foundation should be designed for maximum stresses due to the worst combination of vertical loads, torque, longitudinal and transverse forces, stresses due to temperature variation and the foundation dead load. In case, the foundation layout is partly built up of beam and column construction, straight bars should be provided both at top and bottom of the beams and the spacing of the stirrups should be close. The main foundation block should have the designed thickness and should be reinforced both at top and bottom ; even if the reinforcements are not required from design considerations.

The general principles of machine foundation design are given below :

(1) The mass of the foundation block should be adequate to absorb vibrations and also to prevent resonance between the machine and the adjacent soil. This can be guarded against by increasing the weight of foundation block in proportion to the power of the engines. Some authors suggest that for each break horse power of multi-cylinder engines, a minimum of 725 kg weight of foundation should be provided for gas engines, 565 kg for diesel engines and 225 kg for steam engines. For single cylinder engines, the above value should be increased by 40 to 60%. As a thumb rule, the weight of the foundation should be at least $2\frac{1}{2}$ times the weight of the whole machine.

(2) To avoid the possibility of differential settlement, the foundation should be so dimensioned that the resultant force due to the weight of the machine and the weight of the foundation passes through the centre of gravity of the base contact area.

(3) The foundation should be stiff enough to have necessary rigidity, since the slightest deflection of foundation can cause considerable bearing troubles.

(4) To avoid transmission of vibration from the machine to the adjoining parts of the building, a gap should be left alround the machine foundation to isolate it from the adjoining parts of the building.

(5) As far as possible, overhanging cantilevers should be avoided. However in situation, when it is not possible to avoid them, they should be designed for strength and rigidity against vibrations.

(6) All units of machine foundation should be provided with reinforcement running both ways along the surface of the concrete block. The concrete cover to the reinforcement should not be less than 75 mm at the bottom, 50 mm on sides and 40 mm at the top.

In case of foundation for steam turbo-generators, cover for the reinforcements at bottom, side and top of base slab should not be less than 100 mm.

(7) The amount of reinforcement in foundation units should not be less than 25 kg/m^3 of concrete for impact type or reciprocating type of machines ; 50 kg/m^3 of concrete for rotary type of machines and 100 kg/m^3 of concrete for steam turbo generators.

(8) M 150 to M 200 grade of concrete can be used in the foundations and as far as possible the entire block should be concreted in one operation without construction joints.

1·22 Causes of Failure of Foundations. The causes of failure of foundations may be summarised under the following heads :

(1) Unequal settlement of the sub-soil.

(2) Unequal settlement of masonry.

(3) Horizontal movement of the soil adjoining the structure.

(4) Shrinkage due to withdrawal of moisture from the soil below the foundation.

(5) Lateral pressure tending to over-turn the structure.

(6) Action of atmosphere.

(7) Lateral escape of the soil below the foundation.

(1) *Unequal settlement of the sub-soil.* Unequal settlement of foundation results in dangerous cracks which ultimately lead to the destruction of the structure. If the nature of soil and the loading conditions are uniform over the entire site of the building, the distribution of pressure can be safely assumed to be uniform and the danger of unequal settlement is minimised. In practice, however, it is frequently found that different conditions exist under different parts of the building. If some portion of a building is higher, the soil below the higher portion will be subjected to greater pressure than the soil below the lower portion of the building. Or one section of a building may rest on rock and the adjacent section on a compressible clayey soil. In either of the cases, the soil is subjected to unequal settlement, and as such, the pressure on soil should be reduced to such a value that the difference in settlement between the two portions of structure is reduced to a minimum. In no case the pressure on the soil should exceed to safe-bearing capacity of soil. Durable material should be used for the construction, so as to avoid any danger of the disintegration of the foundations. As far as possible, the axis of the load due to structure should be made to coincide with the centre of gravity of the foundation bed. By adopting the said precautions, the danger to structures on acount of unequal settlement of sub-soil may be minimised.

(2) *Unequal settlement of masonry.* Mortar used as binding material in the masonry construction shrinks and gets compressed when loaded excessively before it has fully set. This defect may lead to the unequal settlement of masonry, as such, the following measures should be adopted to avoid it :

(*i*) The consistency of mortar should be such that it may provide easy workability. The mortar should neither be very lean nor very stiff.

(*ii*) As far as possible the work of structure should be so planned that the masonry is raised to the same uniform level throughout.

(*iii*) The progress of construction should be such that not more than 1·5 m. high masonry is constructed in a day.

(*iv*) To enable the mortar to secure its full strength, the whole masonry should be properly cured for a period of at least 10 days.

(3) *Horizontal movement of the soil adjoining the structure.* This defect is very common in clayed and black cotton soils. Such types of shrinkable soils have volumetric changes with the change of atmospheric conditions. They swell excessively when wet and shrink excessively when dry. The differential settlement caused by the movement of the ground on account of alternate swelling and shrinkage of soil result in formation of cracks in the structure. The following precautions are necessary to be observed to minimise the effect of soil movement :

(*i*) To limit the loads on the soil to 5·5 Tonnes/m^2. If water is liable to find an access to the foundation, the limit of load on the soil should be restricted to 4900 kg./m^2.

(*ii*) To take the foundations to such depths where the cracks cease to extend.

(*iii*) To prevent intimate contact of such soils with the part of the structure below ground level. This is achieved by digging trenches on either side of the foundation and filling them with granular material like sand or moorum. Similarly, a layer of sand or moorum is provided below the concrete block, or bottom face of masonry foundation.

For important structure, R.C.C. raft foundation or pile foundation should be used.

(4) *Shrinkage due to withdrawal of moisture from the soil below the foundations.* The root of an isolated tree generally acquires land equal to the circumference of a circle whose radius is more than the height of the tree. In some soils it has been found to cause significant

dying effect. The suction of sub-soil moisture by the roots, specially in abnormal spells of dry weather, affects the foundation adversely. On account of the differential shrinkage below the foundation, cracks are produced in the foundations, which can ultimately lead to the failure of structure. To avoid the damage due to the trees, certain safe distance should always be maintained between the trees and the foundations. It is considered reasonable to keep the foundations at least the hight (H) of the trees away from mature single tree and about 1·5 H from rows of trees. For mature trees the minimum distance should pre ferably be 15 m and for young trees, the distance should be suitably increased. In addition, the foundation of the structure should be taken to a depth of at least 90 cm. to minimise the cracking action.

This defect is also liable to occur in structure founded on damp soils overlying a band of gravel or sand or some other porous material. An abnormally dry weather may cause the sub-soil water level to descend to such a depth that the soil immediately below the foundations may loose its moisture. This will result in formation of cracks in the building on account of differential settlement. Pile foundations or raft foundations are found to be safe for such places.

(5) *Lateral pressure tending to overturn the structure.* This defect may be caused by a force which acts on a wall in such a way that the wall develops a tendency to tilt or overturn. The force may be the thrust due to a sloped roof, or an arch pressure or due to a violent storm or the effect of a wide cantilever projection. This defect can cause the foundation of the wall to yield due to the entire load being concentrated near the foundation edge. In such cases, the foundation of the wall should be so shaped and proportioned that the necessary conditions of stability are achieved.

(6) *Action of atmosphere.* A part of rain water finds its way inside the ground. The rain water during its passage downwards sometimes brings salt from the surface which react chemically with the material of foundation and cause it to disintegrate. Also if the foundation is not taken deep inside the ground, rain water may flow away the soil above the foundation and expose it. The changes in the sub-soil water table as a result of seasonal change, result in expansion or shrinkage of the soil which causes cracks in foundations. The following precautions are necessary to be observed to avoid the danger on this account :

(*i*) The foundations should be taken to such a depth that the effect of atmosphere will be nullified.

(*ii*) There should be adequate provision for the drainage of the sub-soil water when it rises up and causes danger to the foundation.

(*iii*) If possible, dense cement concrete, 1 : 2 : 4 or stone masonry should be adopted in the foundations at sites

where the ground water and soil contain excessive sulphates or other injurious compounds.

The sides of the foundation trenches should be well-filled and consolidated. At ground level, the outer surface adjacent to the wall should be given a good slope, so as to enable the rain water flow away from the wall sides. A 60 cm. to 90 cm. wide plinth protection serves the purpose more efficiently.

(7) *Lateral escape of the soil below the foundation.* This defect is liable to occur when the building is situated near a river bank, or deep cutting where there is danger of the soft or loose soil below the foundation being disturbed. Sheet piles, either of timber or of steel, should be driven to confine the soil and avoid the danger.

1·23 Setting Out. Before commencement of the excavation of trenches for foundation, a setting out plan is prepared on paper. The setting out plan is a dimensioned ground floor plan, usually drawn to scale of 1 : 50. The plan is fully dimensioned at all breaks and openings. One of the methods of laying out is to first mark the centre line of the longest outer wall of building by stretching a string between wooden pegs driven at its ends. This serves as the reference line for making the centre line of all the walls of the building. The centre line of a wall which is perpendicular to the long wall is marked by setting up a right angle. Right angle is set up by forming triangles with sides 3, 4 and 5 units long. If we fix

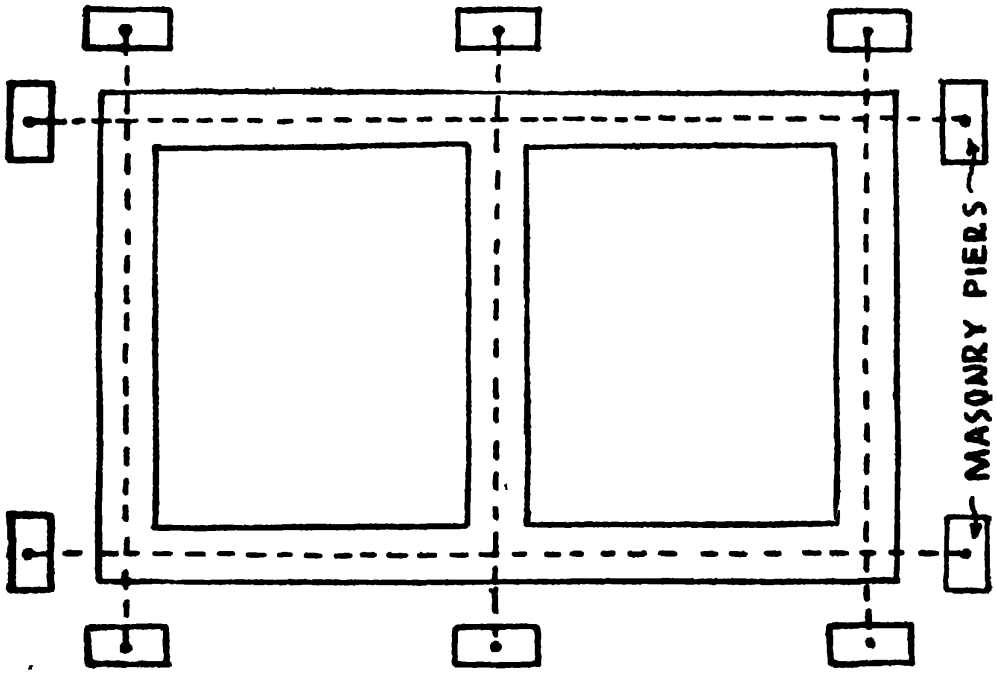


Fig. 1·33

Setting out of foundations with the elhp of masonry piers

the two sides of the triangle to be 3 m., 4 m. then the hypotenuse should be taken 5 m. The dimensions should be set out with a

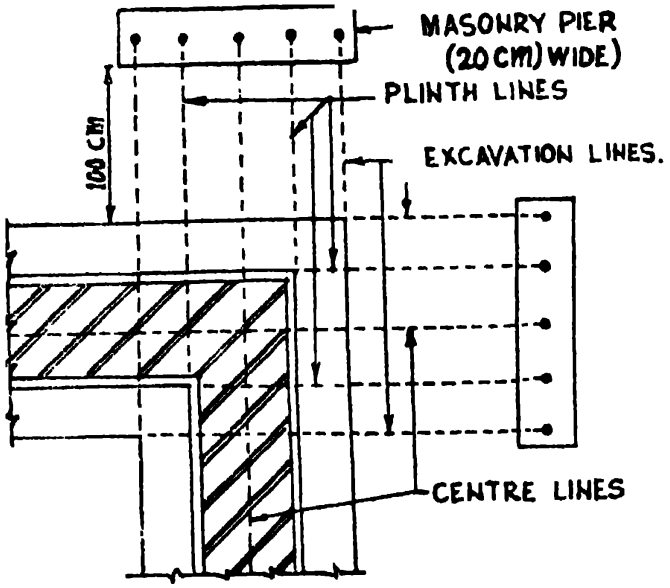


Fig. 1·34

Plan showing a corner of a building to illustrate how the marks are made on the top of masonry pier in the process of setting out of foundations

steel tape. The alternative method of setting out right angle is by the use of theodolite. The instrument is also helpful in setting out acute or obtuse angles. Small right-angled projections are usually set out with mason's square.

The method of setting out described above is not so reliable for important works as there is likelihood of the wooden pegs being pulled up or displaced. In an accurate method the centre lines of the building walls are carefully laid by means of small nails fixed into the heads of the wooden pegs driven at the quoins. In case of rectangular buildings, the diagonal from the opposite corners are checked for their equality. Small brick walls, pillars or platforms are constructed 90 cm clear of the proposed foundation trench. The platforms are about 15 cm wider than the trench width and are plastered at top. The tops of all platforms or pillars should be at the same level preferably at plinth or floor level of building. The strings are then stretched over the nails in the pegs and the corresponding lines are marked on the wet plastered platform top by pressing the stretch ed string on the plastered surface by a trowel. The outside lines of the foundation trench and the plinth lines are marked on the wet plastered platform top in the similar manner.

Before starting excavation, the strings are stretched between the outside lines of the foundation trench marked over the platform top and the cutting lines are marked on the ground by lime powder. If necessary, the lines may be marked by a daghbel or pick-axe.

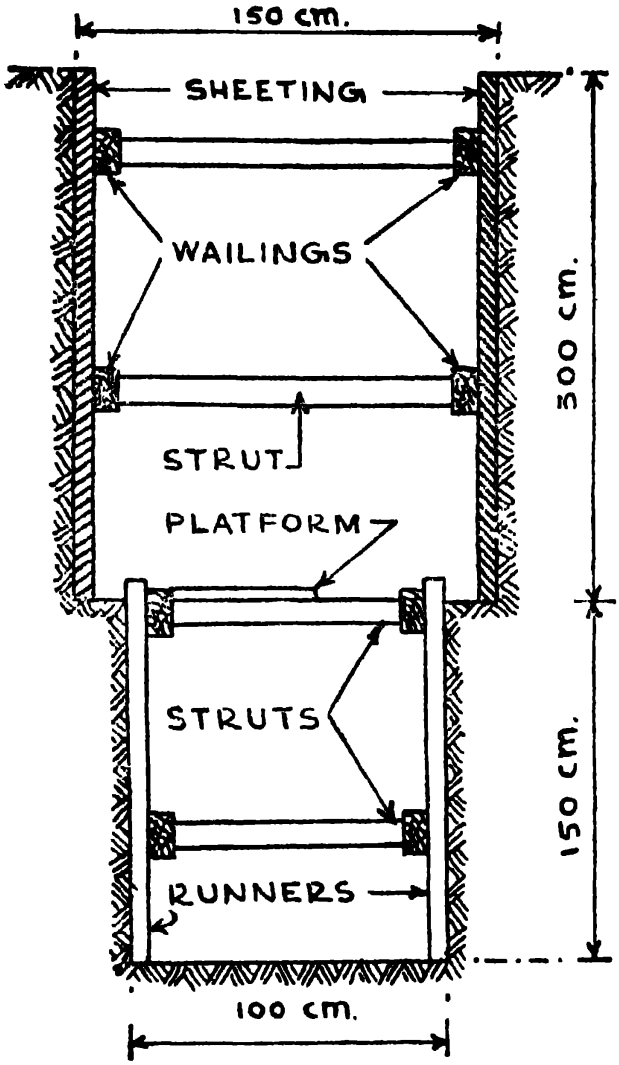
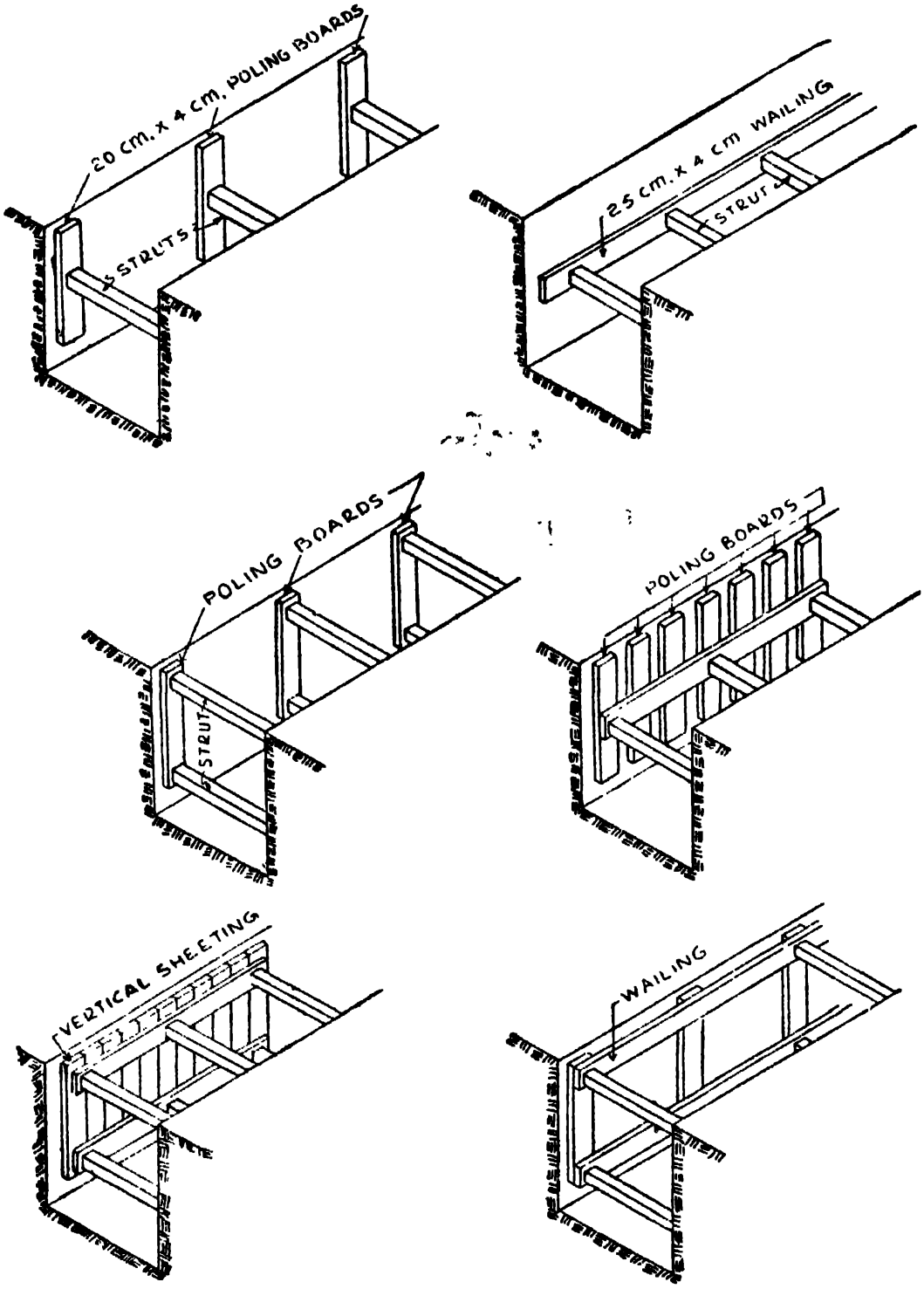


Fig. 1·35
Timbering of deep trench in loose soil

1·24 Timbering of trenches. Timbering of trenches also known as shoring consists of a temporary arrangement of boardings or poling boards, wailings and struts provided to give support to the sides of trench. In case of hard soils, where the depth of excavation is moderate, the sides of trench require no support. In firms soils, if the depth of trench is small, shoring may not be necessarry, but in case the depth of excavation is more it is safe to provide light support to check any possibility of the yielding of trench sides. As a rule all trenches in soil other than rock or hard compact soil more than 1·5 m deep should be properly shored and timbered. Similarly all trenches in soft or fissured rock or hard soil and more than 2 m deep should be properly shored and timbered. A pair of poling boards of size 20 to 25 cm × 4 to 5 cm and length varying with the depth of excavation are struted apart by 10 cm ϕ bullies or struts. and are spaced at a minimum distance of 1·8 m along the length of trench. Although one strut between two poling boards is sufficient, but sometimes, the site condition may require the use of two struts between boards.

In stiff clay or moderately firm soils, the support to sides of trench can be given by the use of horizontal boarding or wailing. The wailing of size 20 to 25 cm × 5 to 7·5 cm is run continuous along the length of trench on either sides and the pair of wailing is

struted apart as shown in the Fig. 1·37. In case of softer soil, the



Figs. 1·36 and 1·38 Figures showing various methods of the timbering of trenches in firm soil.

Figs. 1·37, 1·39 and 1·41 Figures showing various methods of the timbering of trenches in "Moderately firm soils"

Fig. 1·40 Figure showing timbering of trenches in loose soil

poling boards are placed closer, say 90 cm apart and are held by wailings. The wailing on either sides is struted apart as shown in

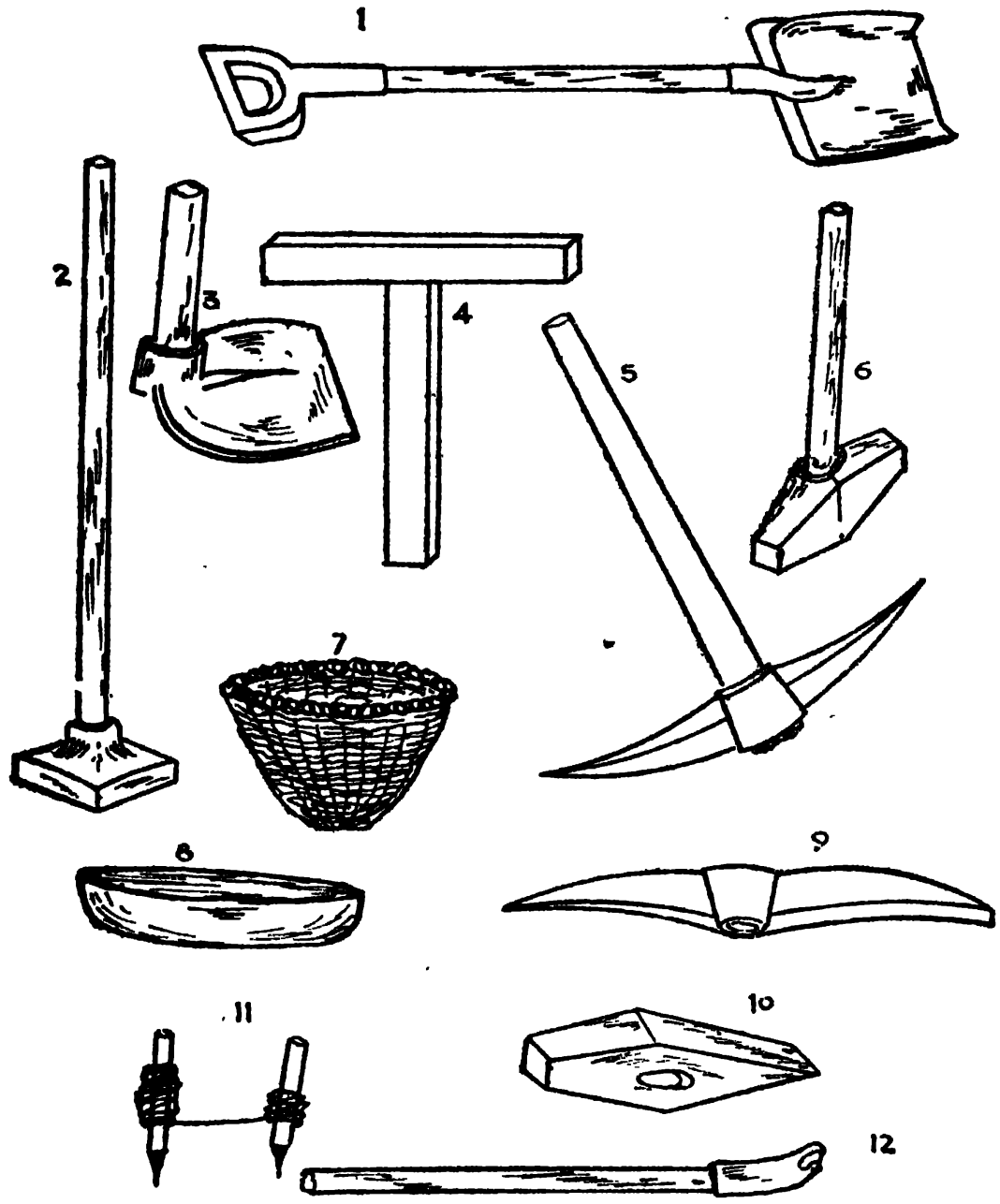


Fig. 1·42 Implements for excavation.

(1) Spade (2) Rammer (3) Kassi (4) Boning rod (5) Pick-axe (6) Sledge hammer (7) Cane basket (8) Iron-pan (9) Pick-axe with flat end (10) Wedge (11) Line and pins (12) Crow-bar.

Fig. 1·38. In this arrangement, it is assumed that the poling board resists the soil pressure and transfer the same to the wailing. The wailing acts as a beam between two struts and as such it must be of sufficient thickness to resist the stresses, safely.

In loose soils the poling boards are placed side by side vertically and are supported by wailings and struts at intervals as shown in Fig. 1·40. In case the nature of soil is such that it cannot stand unsupported even for a few cm., horizontal sheeting or boarding is necessary to be provided. For deep excavations in loose soil, the trench is excavated in stepped form so that the foundation trench width at the bottom is just sufficient to allow easy workability. The trench width is increased towards top. The arrangement of sheeting vertical props, struts and runners etc. in such cases is shown in Fig. 1·35.

Complete information regarding the under ground services like sewers, electrical conduits, gas mains, water pipe lines etc. passing through the site should be available before excavation work is taken up. These informations are essentially needed to enable the workman engaged in excavation work to take sufficient precautions to prevent accident and damage to these services.

1·25 Implements for Excavation. The common implements used for excavation of foundation trenches are shown in Fig. 1·42. These tools are useful for loose, moderately firm or firm soils when the depth of foundation is not much. In case of deeper excavation or cutting in hard bed like rock etc., explosives and other such materials become necessary of this purpose.

1·26 Excavation for Foundations in Water-logged Sites. Digging of foundation trenches in water-logged grounds poses a great problem for the site engineer. There are various methods of dealing with the situation which depend upon the depth of excavasion, depth of water table and many other factors. The following methods are generally adopted while digging foundation trenches in such sites.

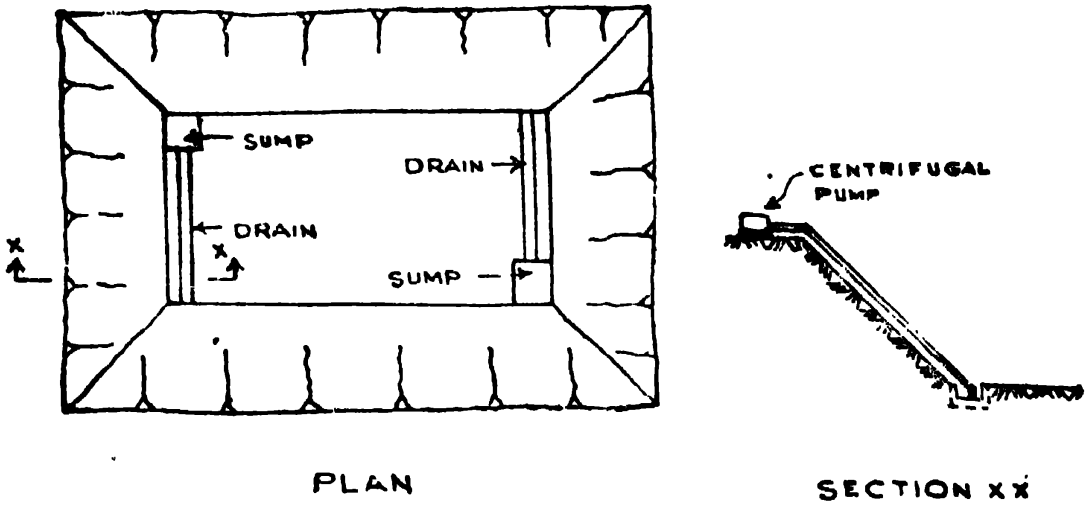


Fig. 1·43

Dewatering of foundations by constructing drains.

(1) *By constructing drains.* This method is generally adopted in shallow foundation in water-logged ground. In this method drains of suitable size are constructed by the sides of the foundation trench. The drains collect ground water from the sides and the enclosed area and flows it into a shallow pit or sump well. From the sump, the water is continuously bailed or pumped out. This is the cheapest method of draining excavation and can be easily adopted by use of unskilled labour and simple equipment.

(2) *By constructing deep wells.* In coarse soils, porous rock or in sites where the large quantity of sub-soil water is required to be drained out, 30 to 60 cm diameter wells are sometimes constructed at 6 to 15 m centre all round the site for temporary drainage of the ground. The water collected in the wells is pumped out continu-

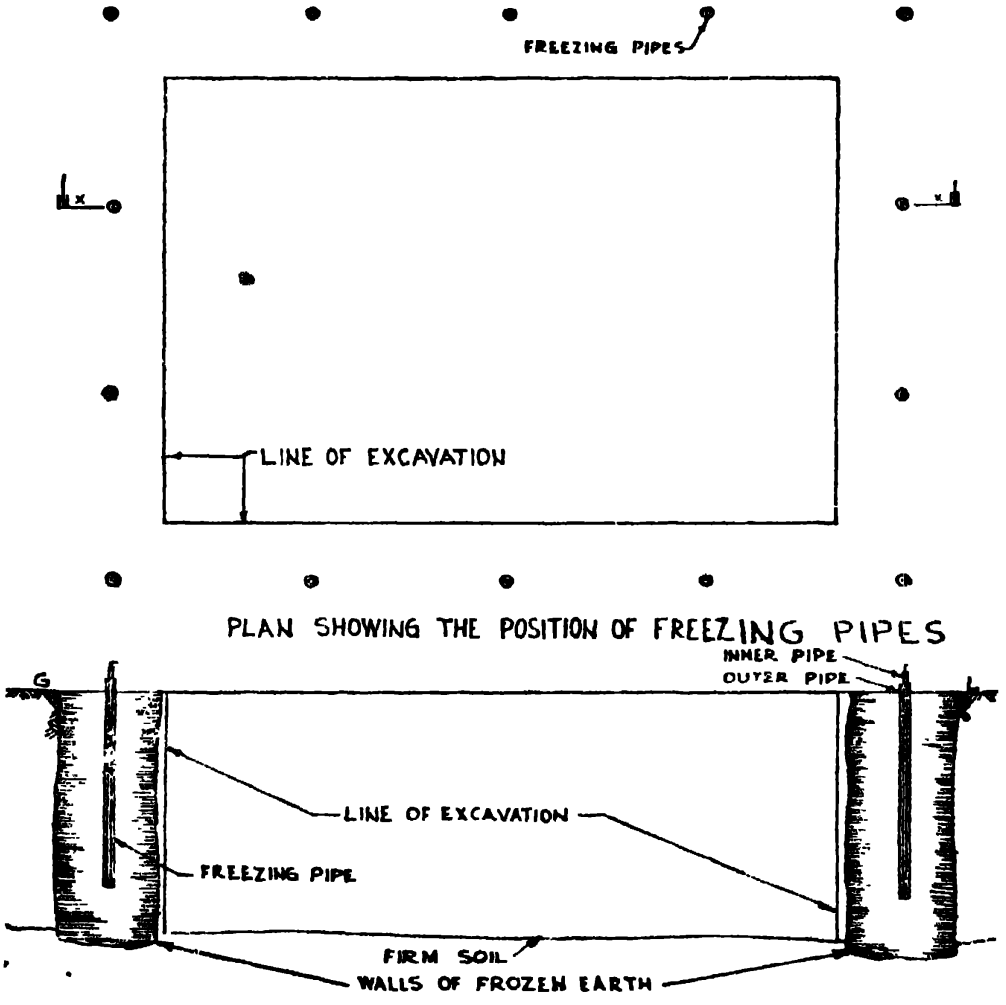


Fig. 1·44

ously. The method can be adopted for depths of excavation upto 24 m.

(3) *Freezing process.* The process is very suitable for excavation in water-logged soils like sand, gravel and silt. It is advantageously used for deep excavation such as foundation for bridges etc., specially when excavation is to be made adjacent to an existing structure or near some waterways. The process consists in forming a sort of cofferdam by freezing the soil round the area to be excavated. Freezing pipes encasing smaller diameter inner pipes are sunk about one metre centre to centre along the perimeter of the area to be excavated. The layout of the pipe should preferably be such that the area enclosed is circular in plan. Freezing liquid is then supplied to the freezing pipes by a refrigation plant. This makes the ground around the pipes to freeze and form a thick solid wall of frozen earth round the area to be excavated. This process can be used upto 30 m depth of excavation.

(4) *By chemical consolidation of soil.* In this method, the soft water-logged soil is converted into a semi-solid mass by forcing chemicals like *silicates of soda and calcium chloride* into the soil. This method is used in small works.

(5) *Well point system.* This is a method of keeping an excavated area dry by intercepting the flow of ground water with pipe wells driven deep into the ground. The main components of a well point system are the well, the riser pipe, the header pipe and the pump.

The well point consists of a perforated pipe about 120 cm long and 4 cm in diameter. This pipe has a ball valve to regulate the flow of water and a screen to prevent the mud from entering into the pipe. The well point tube is connected to 5 cm to 7·5 cm diameter pipe known as riser pipe and is sunk into the ground by jetting.

In the process of jetting, water is forced down through the well point at the rate of 20 to 25 litres per second. The water jet dislodges the surrounding soil and enables the well point to be sunk to the desired depth. After the well point has been sunk to the required depth, the water jet is allowed to run for some time (to ensure washing all sand silt out of the hole) till the return water from the whole is quite clean. Thereafter the water jet is closed and the annular space formed around the well point by the jetting action of water is filled with coarse sand and gravel to form a filter zone around the well point. The filter zone prevents the entry of fine particles of the surrounding soil into the well points and avoid clogging of well point screen. The filter sand around the well point should be filled upto water table. The depth of the hole above the water table is filled with tamped clay to act as a clay seal to minimise air getting into the well point through the sand filter.

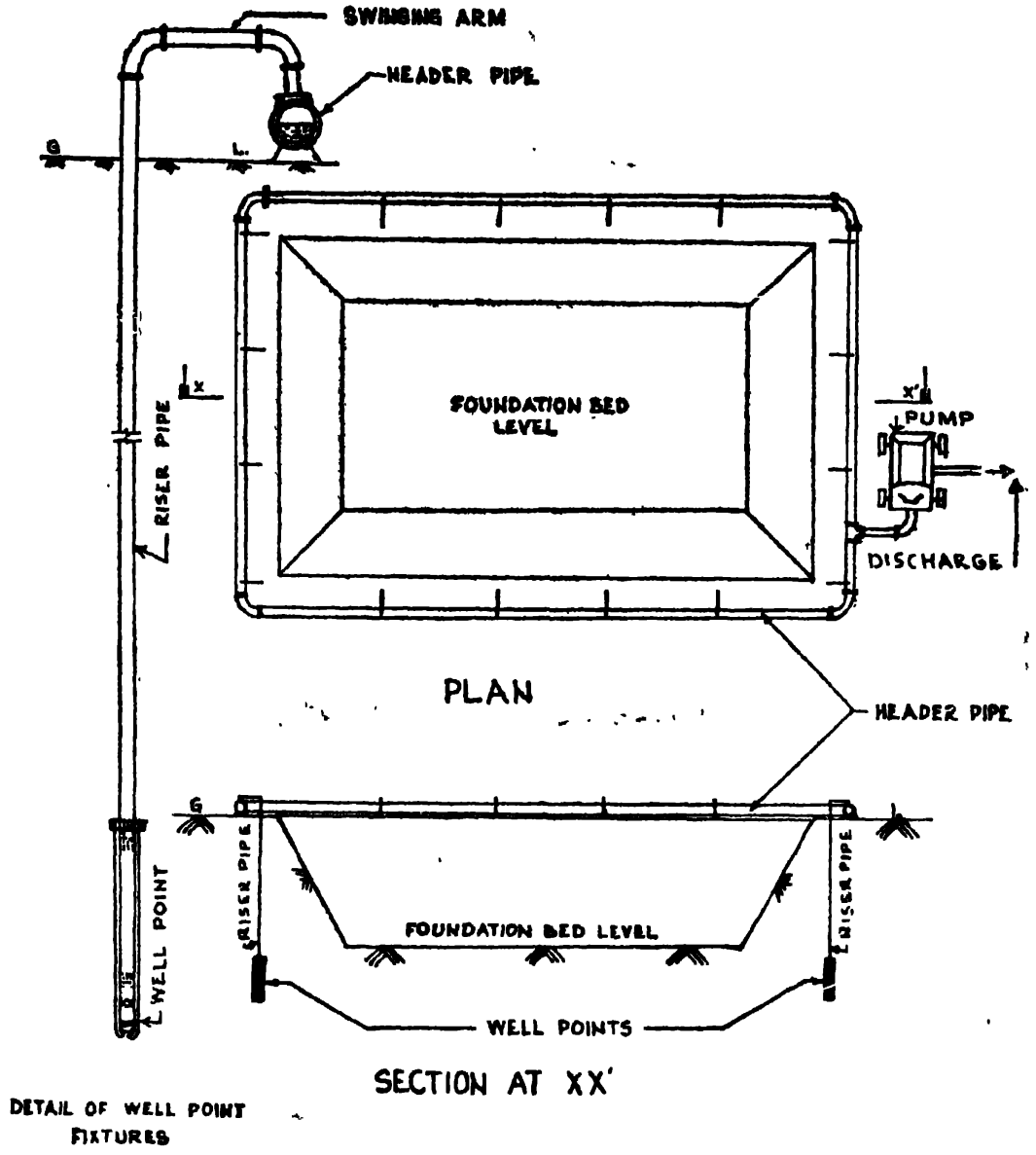


Fig. 1·45
Well point system

The well points are suitably spaced (normal spacing being 100 cm), so as to enclose the whole area to be excavated. The riser pipes at their upper ends are conneted to a header pipe which in turn is connected to a high capacity suction pump.

After all the well points are installed and connected the suction pump is put into operation. Due to suction, the ball valve in the well points get closed and the ground water is drawn in through the well point screen. The water from the well point is sucked up through the riser pipes, flows through the header pipe and is finally discharged away from the site of work.

This method can be successfully adopted for depth of excavation upto 18 m. Since the suction pump is normally not used to lift water above 6 m depth, in deep excavations where it is necessary to lower water table to a greater depth, multistage system of well point is used. A typical example of a two-stage well point system is illustrated in Fig. 1·46.

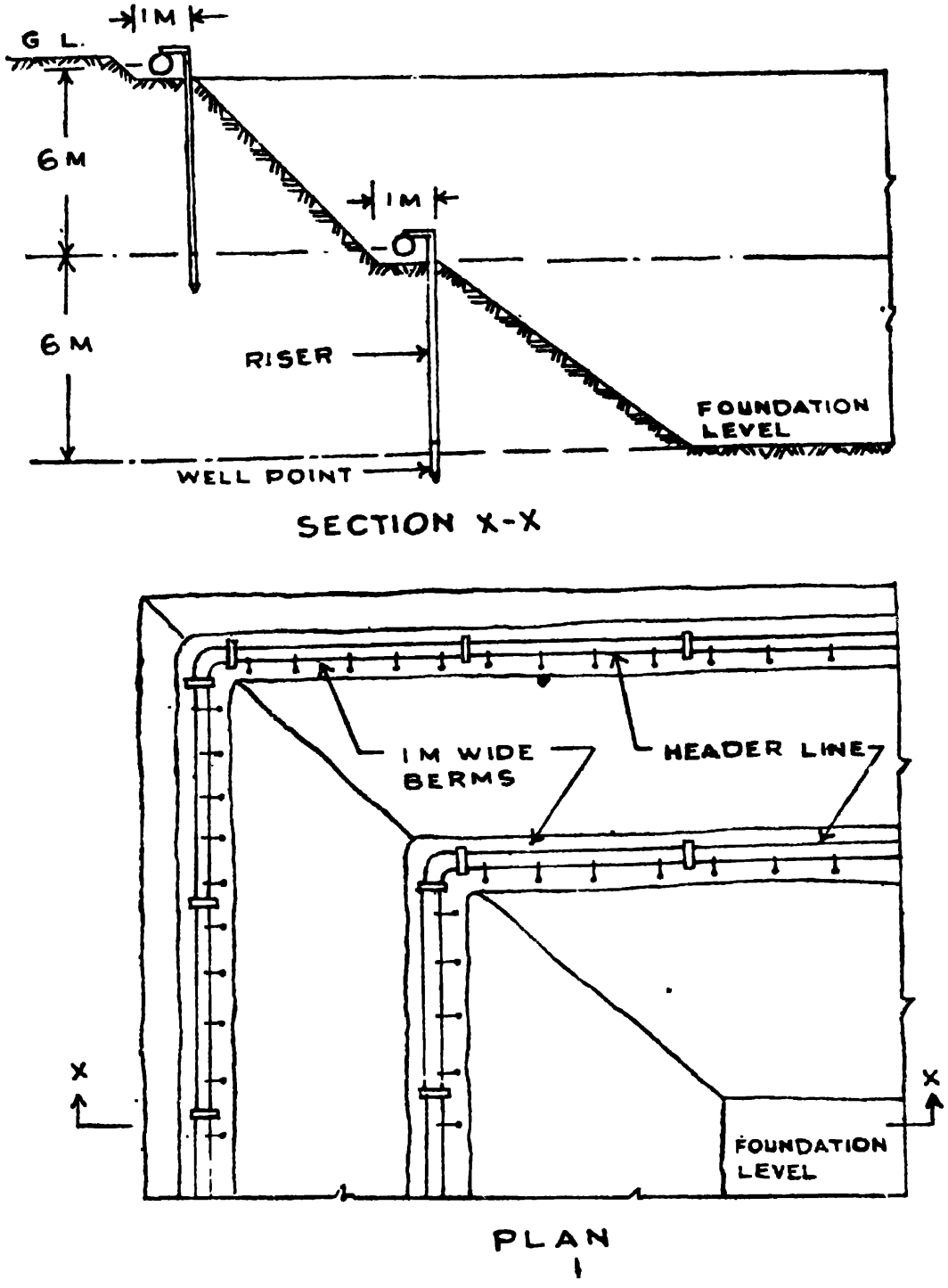


Fig. 1·46
Two-stage well point system.

(6) *By constructing sand drains* : Sand drains prove very effective in marshy soils. Soils become marshy by the process of deposition of thick layers of clays and silts mixed with organic matter by the passage of time. Marshy soil is subject to capillarity and has a high pore water pressure. When this type of soil is subjected to load, its wet soils are gradually pushed out on either side and results in subsidence of the ground. To avoid this, sand drains are made in the ground. The diameter of the sand drains normally varies between 300 mm to 450 mm and their centre to centre spacing may vary from 3 to 6 metres. The hole for making the sand drain can be made by driving steel pipe castings into the ground. The drain holes are driven deeper than the marshy layer possibly upto an underlying rock or firm base. The marsh in the pipe is removed by means of jets. The selected type of sand is then filled into the pipe and the pipe is withdrawn leaving a vertical sand pile in the

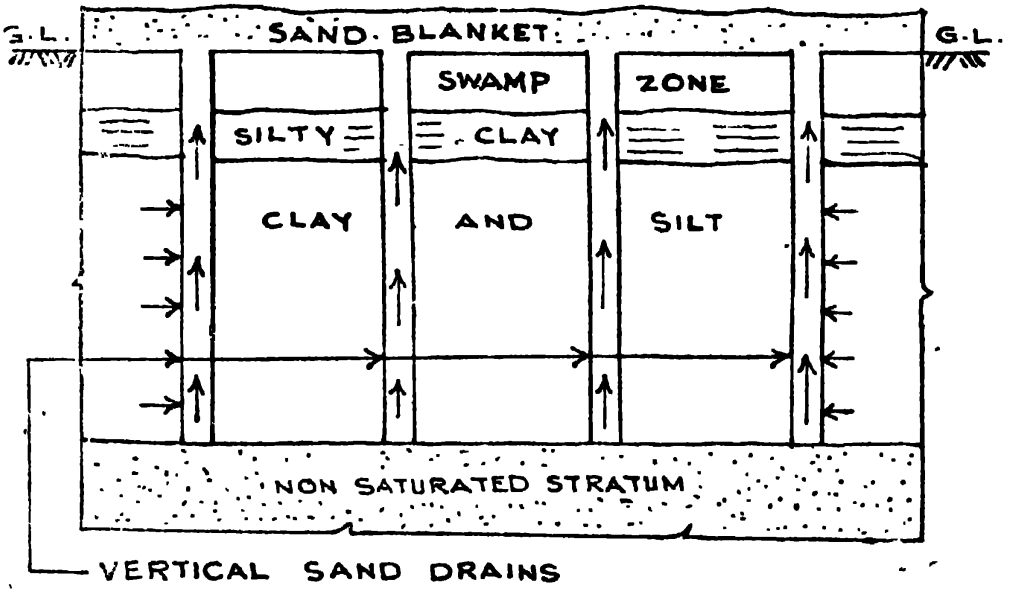


Fig. 1·47
Sand drains

ground. A thick layer of sand (sand blanket) is spread over the entire area to be consolidated. When the sand layer is subjected to load, the water from the muck of the marshy soil gets squeezed into the vertical sand drains.

By capillary action the water from the sand drains rises up and is fed into the sand blanket from where it can be drained out. The objective of consolidation of soil by this method is to develop increased soil resistance to superimposed loads usually consisting of earth fills in highway or airport constructions.

(7) *Electro-Osmosis.* Well point system is rendered ineffective in very fine sands, silts or clay, because such soils tend to hold the water by capillary action and offer great resistance to percolation. It has been established that if a direct current is passed through a

soil of low permeability, its rate of drainage is greatly increased. In the process of Electro Osmosis, steel rods forming the positive electrodes are driven into the soil, midway between the well-points, which are made to act as negative electrodes. When electric current is passed, the ground water flows towards the negative electrode (well-points) and is pumped out. This process requires very expensive equipment and hence it is rarely used.

1·27. Foundation Concrete. The type of concrete and the proportion of the ingredients used in its making depend upon the nature of the structure, quality of the materials used and the site conditions. Since lime is fairly cheap, lime concrete is generally used for foundations in dry sub-grade. Lime concrete is produced by mixing one cu. metre of wet ground lime mortar with 2·5 cu. metre of ballast. The proportion of ingredient in lime mortar may be 1 lime : 2 sand or 1 lime : 1 surkhi : 1 sand or 1 lime : 2 surkhi. The ballast may be of brick, stone or shingle. The maximum size of the ballast is generally restricted to 40 mm.

For moist subgrade with high sub-soil water, usually 1·5 m. or less below the foundation level, cement concrete should always be used. In such situations the concrete should not be leaner than 1 : 4 : 8 (1 cement : 4 sand : 8 stone ballast). For less important works in dry sub-grade (sub-soil water level below 1·5 m of foundation level) a leaner cement concrete as much as 1 : 8 : 16 may be adopted. In general practice however, cement concrete 1 : 5 : 10 is recommended for lean concrete.

The concrete should be mixed on a clean dry and water-tight platform. Concrete should be laid (and not thrown) in layers not exceeding 15 cm. in thickness. Each layer should be thoroughly rammed and consolidated before the succeeding layer is laid.

In case of lime concrete, the curing should start (by keeping the concrete damp with moist gunny bags, sand etc.) after 24 hours of its laying and should be continued for a minimum period of 7 days. The masonry work over the foundation lime concrete should be started only after 7 days. In case of cement concrete however, the masonry work over the foundation concrete may be started after 48 hours of its laying. The curing of the cement concrete which starts 24 hours after its laying is continued along with the masonry for at least 10 days.

1·28. Specification No. 1

Earth work in excavation for foundation trenches

1. All foundation pits and trenches shall be dug out to exact dimensions as shown on the drawings or as directed by competent authority. In firm soil the sides of the foundation trench shall be kept vertical upto a depth of 1·8 m. from the bottom and for greater

depth of excavation, the trench shall be widened by providing 45 cm. wide steps on either side for every 1·8 m depth measured from the bottom. In soft or loose soil, the sides of the trenches must be sloped down or shored up carefully to prevent the earth from the sides falling in.

2. The bed of all foundation trenches shall be dressed perfectly level and made firm by watering and ramming. Pit holes and soft sports shall be dug out square and filled with the concrete of the same mixture as the foundation concrete or any other material as approved by the competent authority.

3. If the foundation trenches are dug to depth greater than that shown on the drawing or as required by the competent authority, no earth filling shall be allowed in bringing the foundation bed to proper level. The excess depth shall be filled with the concrete of the same mixture as the foundation concrete or any other material as approved by the competent authority at the cost of the contractor.

4. Before laying foundation concrete the trenches must be inspected and passed by the competent authority.

5. No material excavated from foundation trenches shall be placed within 1·5 m. or half the depth of the trench, whichever is more, from the outer edge of the trench.

6. Soon after the concrete and masonry work in the foundations has been completed and measured, the spaces around the masonry in trenches shall be cleared of all debris, brick bats, mortar dropping etc., and refilled with earth in layers not exceeding 15 cm. to the original surface of the ground. Each layer of refilled earth shall be watered, rammed and consolidated before the succeeding one is laid.

7. The excavations shall be fenced and marked by red lights at night to guard against risk of accidents.

8. If the work is done by contract, the contractor's rate shall include the following :

(*a*) Excavation, including lifting and depositing the earth as specified.

(*b*) Shoring, pumping or bailing out water keeping the excavation free of water during the foundation masonry work is in progress.

(*c*) Protection and supporting of existing services, *i.e.* pipes, water mains, cables etc., coming across during excavation.

(*d*) Fencing to guard against accidents.

Questions for Revision

1. What do you understand by the term "Foundation" ? What is the purpose of providing foundations ? What are the causes of failure of foundations and what method would you adopt to ensure the stability of the structure ?

2. Why is surface exploration necessary ? State the different methods of exploration of the sub-soil conditions and describe one of the methods in detail.

3. Describe a method of determination of the safe-bearing pressure of soil at site. What will be the difference in the applicability of the result if the soil is (*a*) clay (*b*) sand ?

4. (*a*) Describe with the help of sketches one method of ascertaining "Bearing capacity of soils". Describe the various methods of improving "Bearing capacity of soils."

(*b*) What are the characteristics of "Black cotton soil" ? What precautions would you take in designing and laying foundations in Black cotton soil ?

5, (*a*) What is meant by 'safe bearing power' of a soil ? Explain how it is determined, by one method.

(*b*) Discuss the various methods of constructing foundations in a Black cotton soil.

(*c*) Sketch the foundation for a brick pillar 45 cm. square carrying 5 tonne of load on a soil where bearing capacity is 11 tonne/m^4. Weight of soil is 1800 kg./m^2 and the angle of friction is 25°.

6. What are the characteristics of "Black cotton soil" ? What precautions and measures will you take in designing the foundations of a three-storeyed hospital in such a soil ? Give a typical cross-section of the type of foundation you consider best.

7. Why do building constructed on shrinkable clays get damaged ? Describe briefly any two methods adopted to safeguard against this damage in new buildings being constructed on such soil.

8. (*a*) Describe a method of testing the bearing capacity of a soil.

(*b*) What are the minimum and maximum bearing powers of the following soils ?

(*i*) Black cotton soil.

(*ii*) Hard moorum.

(*iii*) Compact gravel.

(*iv*) Soft rock.

9. State the various investigations you would make and the different, methods you would adopt for the examination of soils to obtain data for the design of foundations.

What value of safe bearing pressure would you adopt in the following cases ?

(*i*) Compact clay nearly dry.

(*ii*) Compact sand prevented for spreading.

(*iii*) Hard rock.

10. Name the different types of foundations you recommend under different situations and soils. Explain them briefly.

11. Sketch and explain briefly the various types of footing you consider suitable for :

(*a*) Isolated R.C.C. column.

(*b*) Isolated steel column.

(*c*) Isolated timber column.

(*d*) R.C.C. column monolithically founded with the flooring.

12. (*a*) What type of foundation would you propose for a multi-storeyed office building in :

(*i*) Very soft soil.

(*ii*) Black cotton soil.

Describe briefly.

13. Trace the principal causes of unequal settlement of structures and mention the precautions to be taken to prevent uneven settlement of foundations.

14. Draw neat sketches to explain the following types of foundations :

(*i*) Grillage foundations.

(*ii*) Raft foundations.

(*iii*) Combined footing for steel stanchion.

(*iv*) Combined footing for concrete column.

(*v*) Treatment necessary for columns or walls carrying unequal loading.

15. Describe the process of 'setting out' for excavation of the foundation of a three storeyed building. The foundations are required to be taken 1·8 m. deep inside the ground which may be considered firm. Draw suitable sketches to show the necessary procedure.

16. What are the usual permissible loads on the following soils :

(*a*) Alluvial clay.

(*b*) Black cotton soil.

(*c*) Compact sand.

(*d*) Moorum.

If you were to construct a three-storeyed building on one of these soils ; what type of soil foundation would you adopt ? Give reasons.

17. Write short notes on any three of the following :

(*a*) Raft foundation.

(*b*) Typical footing of a brick wall and an R.C.C. column giving suitable dimensions.

(*c*), (*d*) and (*e*) from chapters other than foundations.

18. (*a*) What is meant by bearing capacity of a soil ? What are the soil properties on which the bearing capacity of soil depends ?

(*b*) Describe the various methods generally adopted to improve the bearing capacity of soils.

19. What type of foundation would you adopt under a heavy steel column over soft soil ? Explain with reasons and make a neat sketch.

20. (*a*) A five storeyed building is to be constructed on a site with black cotton soil. What investigations will you carry out before deciding the suitability and the choice of the type of foundation to be used ?

(*b*) Explain the method by which you will ascertain the bearing capacity of the soil after the excavation for the foundation is complete.

21. Describe different types of foundations used for buildings, load bearing masonry walls, abutments and piers of bridges. Sketch a suitable grillage foundation for a compound column consisting of ICHB 400 mm. × 250 mm. with flange plates 300 mm. × 18 mm. on each flange and carrying a load of 230 tonne. The allowable bearing pressure is 15 T/m^2.

22. Briefly describe the methods for dealing with foundations on bad soils. Illustrate with neat sketches.

23. Why are foundations necessary ? Name the various types of foundations used for buildings and bridges, giving brief description of each and its suitability.

24. Give in brief the tests you would carry out for finding the bearing capacity of soil at a site for constructing a multi-storeyed building.

25. (*a*) Enumerate and explain with sketches the various methods used in improving the bearing capacity of soils.

(*b*) Write short notes with sketches on (*i*) Deep and shallow foundations.

2

Deep Foundations

2·1 General. In case the strata of good bearing capacity is not available near the ground, the foundations of the stratum has to be taken deep with the purpose of attaining a bearing stratum which is suitable in all respects. In addition there may be many other conditions which may require deep foundations for ensuring stability and durability of a structure. For example, the foundation for a bridge pier must be placed below the scour depth, although suitable bearing stratum may exist at a higher level. The most common forms of deep foundations are :

(*a*) Piles

(*b*) Cofferdams and

(*c*) Caissons.

2·2 Pile Foundations. Pile foundation is generally used when simple spread foundation at a suitable depth is not practical either because the stratum of required bearing capacity is at a greater depth or steep slopes are encountered. In compressible soil or water-logged soil or soil of made-up type, piles are used with advantage for providing safe foundation for any type of structure. Pile foundation is used for foundation for buildings, trestles, bridges and water front installation (piers, docks, etc). In general, pile foundation provide a common solution to all difficult foundation site problems.

2·3 Types of Piles. Depending upon their function or use, piles may be classified in the following types :

(*i*) Bearing piles

(*ii*) Friction piles

(*iii*) Sheet piles

(*iv*) Anchor piles

(*v*) Batter piles

(*vi*) Compaction piles

(*vii*) Fender piles

(*i*) *Bearing piles.* Bearing piles are those which are driven into the ground until a hard stratum is reached. Such piles act as

pillars, supporting the super-structure and transmitting the load down to the level at which it can be safely borne by the ground. Thus bearing piles by themselves do not support the load, rather they act as a medium to transmit the load from the foundation to the resisting sub-stratum.

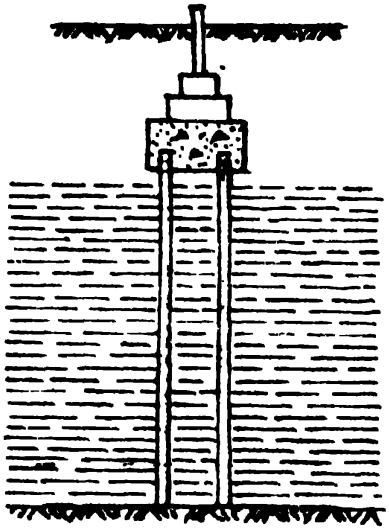


Fig. 2·1 Bearing piles

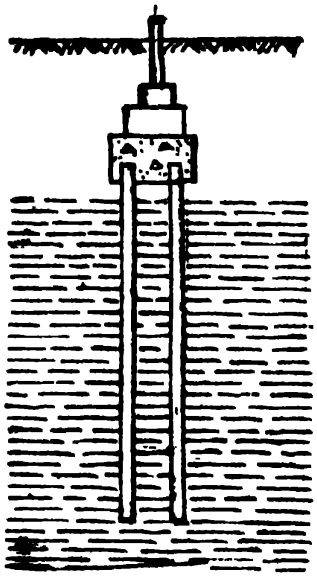


Fig. 2·2 Friction piles

(*ii*) ***Friction piles***. When piles are required to be driven at a site where the soil is weak or soft to a considerable depth, the load carried by a pile is borne by the friction developed between the sides of the pile and the surrounding ground (skin friction). In such cases the pile is named as friction or floating pile. Thus friction piles are driven in the type of soil whose strength does not increase with depth or, where the rate of increase in strength with depth is very slow.

(*iii*) ***Sheet piles***. Sheet piles differ from bearing or friction piles in that they are rarely used to furnish vertical support but are used to function as retaining walls. Sheet piles are used to retain soil that is liable to escape laterally when subjected to pressure or to enclose the area required for some foundation and protect it from the action of running water or leakage.

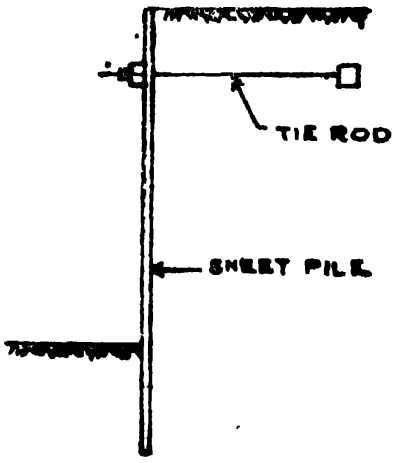


Fig. 2·3

(*iv*) ***Anchor piles***. When piles are used to provide anchorage against horizontal pull from sheet piling walls or other pulling forces, they are termed as anchor piles.

(*v*) ***Batter piles***. When piles are driven at an inclination to resist large horizontal or inclined forces, the piles are termed as batter piles.

(*vi*) *Compaction piles.* When piles are driven in granular soil with the aim of increasing the bearing capacity of the soil, the piles are termed as compaction piles.

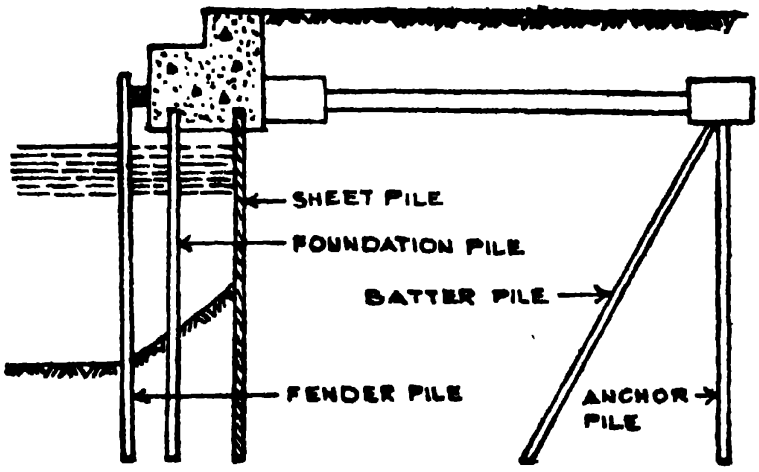


Fig. 2·4

(*vii*) *Fender piles.* When the piles are used to protect concrete deck or other water front structures, from the abrasion or impact that may be caused from the ships or barges (when they are tied up at the deck) they are called fender piles. The fender piles are ordinarily made up of timber.

2·4 Composition of Piles. Depending upon the material used in their manufacture, piles can be broadly classified as :

(*a*) *Timber piles*

(*b*) *Concrete piles*

(*c*) *Composite piles*

(*d*) *Steel piles*

The piles of various compositions are described below in details.

2·5 Timber Piles. Transmission of load through timber piles takes place by the frictional resistance of the ground and the pile surface. Since the pile will not have very much strength as a long column even if it rests on rock, timber piles are economically provided in compressive soils constantly saturated with water. The piles are made from timber obtained from trees like Sal, Teak, Deodar, Babul, Khair etc. It has been found that piles made from Khair wood can stand action of sea water better and is thus commonly used for marine works. Timber piles may be circular

or square in cross-section. Piles are driven with the help of pile-driving machine in which a drop hammer delivers blows on the pile head. To prevent the pile head from brooming, an iron ring about 25 mm. less in diameter than the pile head is provided at the pile top. To facilitate driving, the lower. end of the pile is pointed and is provided with a cast iron conical shoe. Piles should not be spaced less than 60 cm. centre to centre. By driving piles much closer, the frictional resistance of the pile is destroyed. The best spacing of timber piles is 90 cm. centre to centre. Maximum load on a wooden pile seldom exceeds 20 tonne. Piles made from sound timber free from any defect or disease and driven in the soils which are either permanently wet or permanently dry, will remain in good condition for centuries. But when subjected to alternate dry and wet conditions on account of variations in ground water level, they will soon be decayed. It is on this account that timber piles are cut a little below the lowest water-mark and capped with concrete, steel grillage, stone or timber. If timber capping is used, the cap should be permanently under water.

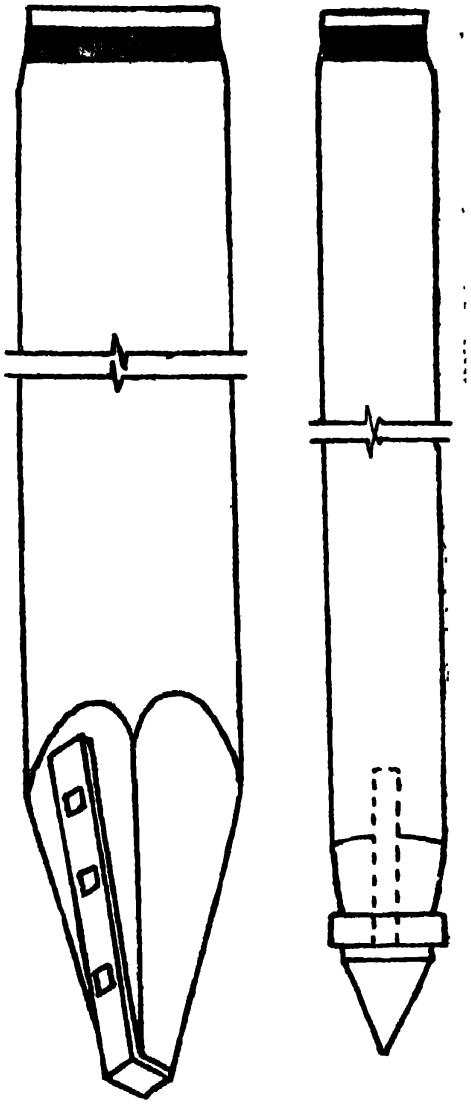


Fig. 2·5 Fig. 2·6
Timber piles

Advantages of timber pile :

(1) They are economical.

(2) They can be driven rapidly and as such there is great saving in time.

(3) On account of their elasticity, timber piles can be recommended for sites where piles are likely to be subjected to unusual lateral forces.

(4) They do not need heavy machinery and more technical supervision.

Disadvantages of timber piles :

(1) Timber piles when used must be cut off below the permanent ground water level to prevent them from decay and thus if the water table at a site is at a greater depth, extra cost of excavation needed to provide the pile cap will render the choice uneconomical.

(2) Timber piles cannot be driven in filled up ground without injury and as such they are not recommended for such sites.

(3) They are liable to decay or deteriorate by salt water or insects.

(4) On account of their restricted length, they cannot be used for jobs where long piles are needed.

(5) They have low bearing capacity.

2·6 Concrete Piles. Concrete piles may be classified as :

(*a*) *Pre-cast piles*

(*b*) *Cast in place or cast-in-situ piles*

(*c*) *Prestressed concrete piles*

(*a*) *Pre-cast piles.* Pre-cast pile may be defined as a reinforced concrete pile which is moulded in circular, square, rectangular or

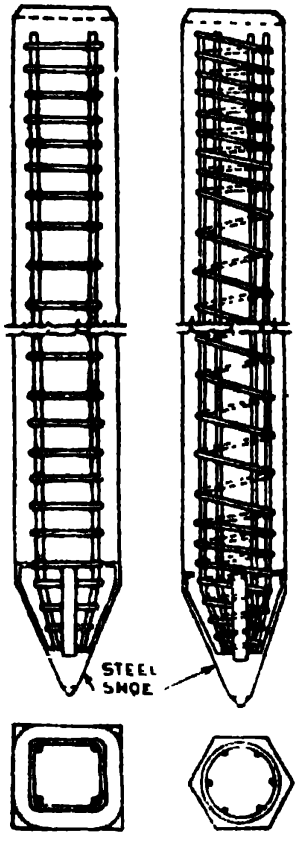


Fig. 2·7

Pre-cast piles

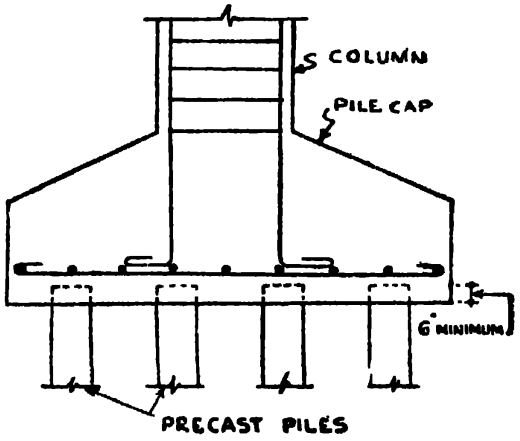


Fig. 2·8

Pre-cast piles supporting column footing

octagonal form. The piles are cast and cured in a casting yard and then transported to the site for driving. In case space is available, pile can also be cast and cured near the site of works. When

required they are driven in the similar manner as timber piles with the help of pile drivers. The diameter of the piles varies from 38 cm. to 64 cm. and their length varies from 4·5 m. to 30 m.

The function of reinforcement in a pre-cast pile is to resist the stresses produced on account of its handling, driving and the loading which the pile is finally expected to receive. Longitudinal reinforcement usually consists of a bar 20 mm. to 50 mm. in diameter at each angle of the section of the pile. The vertical rods are tied horizontally by bars 6 mm. in diameter. The horizontal bars may be provided in the form of stirrups or wound spirally round the verticals. For lengths of approximately 90 cm. at head and toe the spacing of the stirrups should be 8 cm. c/c. Circular piles are seldom tapered but when tapering of the piles becomes necessary due to site conditions, their length is restricted to 12 m.

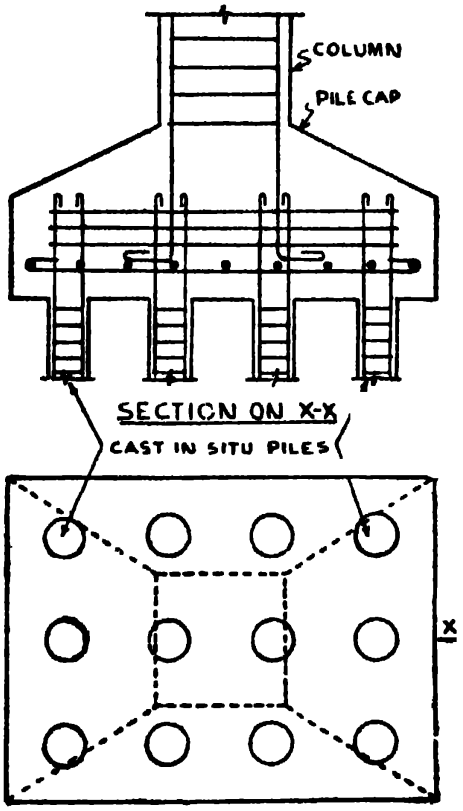


Fig. 2·9
Cast-in-situ piles for column footing

(*b*) *Cast-in-situ piles.* Cast-in-situ piles are those piles which are cast in position inside the ground. Since the pile is not subjected to handling or driving stresses, it is not necessary to reinforce the pile in ordinary cases or in places where the pile is completely submerged in the soil. Reinforcements are necessary to be provided in a cast-in-situ pile, when the pile acts as a column and is subjected to lateral forces. Cast-in-situ piles can be divided into two types. In one the metallic shell of the pile is permanently left in place inside the ground along with the core while in the other type the outer shell is withdrawn.

2·7 Concrete Piles Compared with Timber Piles.

Advantages of concrete piles :

(1) Durability of concrete piles is independent of the ground water level.

(2) On account of their larger size and greater bearing power, the number of piles required for supporting the structure is muchless.

(3) They can be cast to any length, size or shape.

(4) They can be used for marine work without any treatment.

(5) The material required for their manufacture is easily obtainable.

(6) Concrete piles can be monolithically bonded into pile cap or a grillage base while in wooden piles the bond between the pile and the pile cap is not perfect.

Disadvantages of concrete piles :

(1) They cost much more than timber piles.

(2) They cannot be driven as rapidly as timber piles.

(3) Concrete piles require elaborate technical supervision and heavy driving machines.

(4) They must be reinforced to withstand handling stresses.

2·8 Types of Cast-in-situ Piles. The names of the various types of commonly used cast-in-situ piles are :

(*a*) *Simplex pile*

(*b*) *Franki pile*

(*c*) *Vibro pile*

(*d*) *Vibro-expanded pile*

(*e*) *Raymond pile*

(*f*) *MacArthur pile*

(*a*) **Simplex pile.** This type of pile may be driven through soft or hard soil. A steel tube having an internal diameter equal to the dia. of the pile and 20 mm. in thickness, is driven into the ground. To facilitate the driving of the pile, the steel tube is fitted with a detachable steel shoe that completely closes the bottom of the tube. When the tube has been driven to the required depth, a charge of concrete is poured into the tube and the tube is gradually withdrawn leaving the charge of concrete below. Thus by alternately pouring the concrete and withdrawing the tube, the pile is constructed to its full length. The metallic shoe remains in place and hence a new one is needed for each pile. In case the pile is required to be reinforced, the reinforcement cage is lowered into the steel tube prior to the pouring of concrete.

(*b*) **Franki pile.** This type of pile has an enlarged base and a corrugated stem. A steel tube, having its internal diameter equal to the diameter of the pile required, is held vertical at the ground level with the help of leaders. A charge of concrete is poured at its base, filling the bottom 60 cm. to 90 cm. of the tube. The charge of concrete is consolidated into a solid plug by the blows of the drop hammer working inside the tube. Then the further blows of the hammer on the plug, pull the tube down on account of the friction developed between the concrete and the inside surface of the tube. When the tube has been driven to the required depth,

it is slightly raised and the plug is forced out of the tube by hammering. The reinforcement cage is then lowered inside the

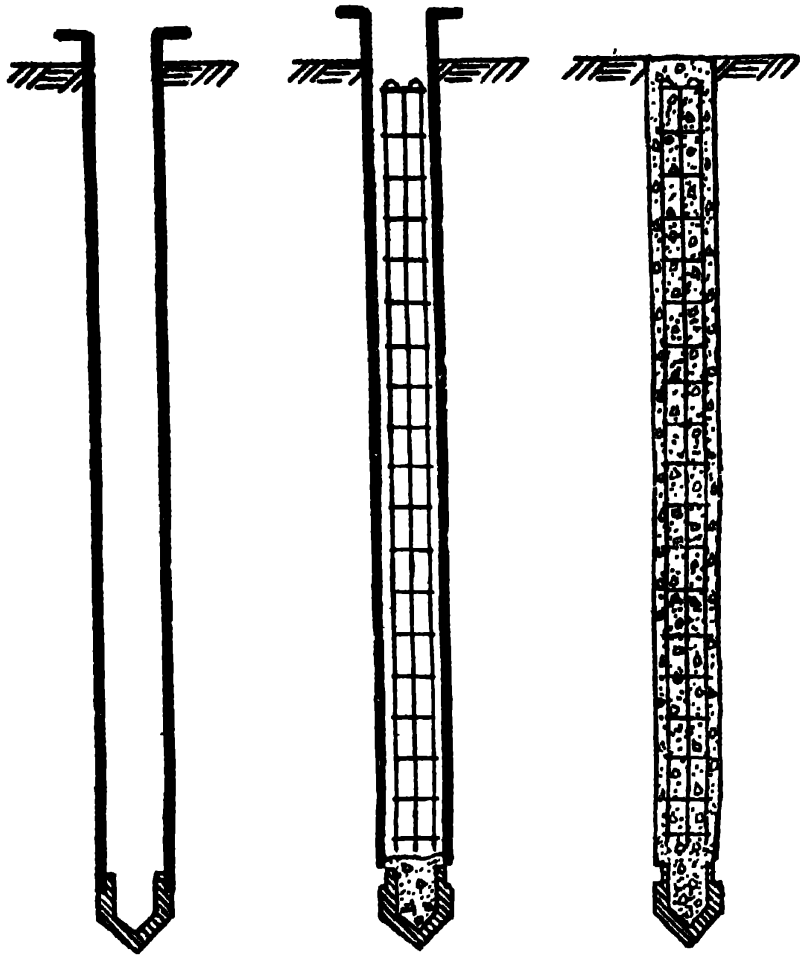


Fig. 2·10 Simplex pile tube driven in position
Fig. 2·11 Reinforcement cage lowered in the tube
Fig. 2·12 Completed simplex pile

tube if needed. Then a fresh charge of concrete is poured and rammed well by the drop hammer while the tube is pulled up a short distance. The repeated process produces a series of corrugations on the stem of the pile and the pile is thus completed.

(*c*) **Vibro pile.** This type of pile is best suited for places where the ground is soft and offers little resistance to the flow of concrete. A steel tube fitted with a cast iron shoe is driven to the required depth. There is a water-tight joint between the shoe and the casing so that even if the pile is to be driven in waterlogged ground, the soil and the sub-soil water cannot find an access in the tube before the concreting is done. The reinforcement cage (if needed) is lowered in the tube at this stage. The charge of concrete is then poured in the tube. The extraction of the tube and the ramming of concrete is effected by the upward and downward blows of the hammer. The tube is connected to the hammer by extracting links.

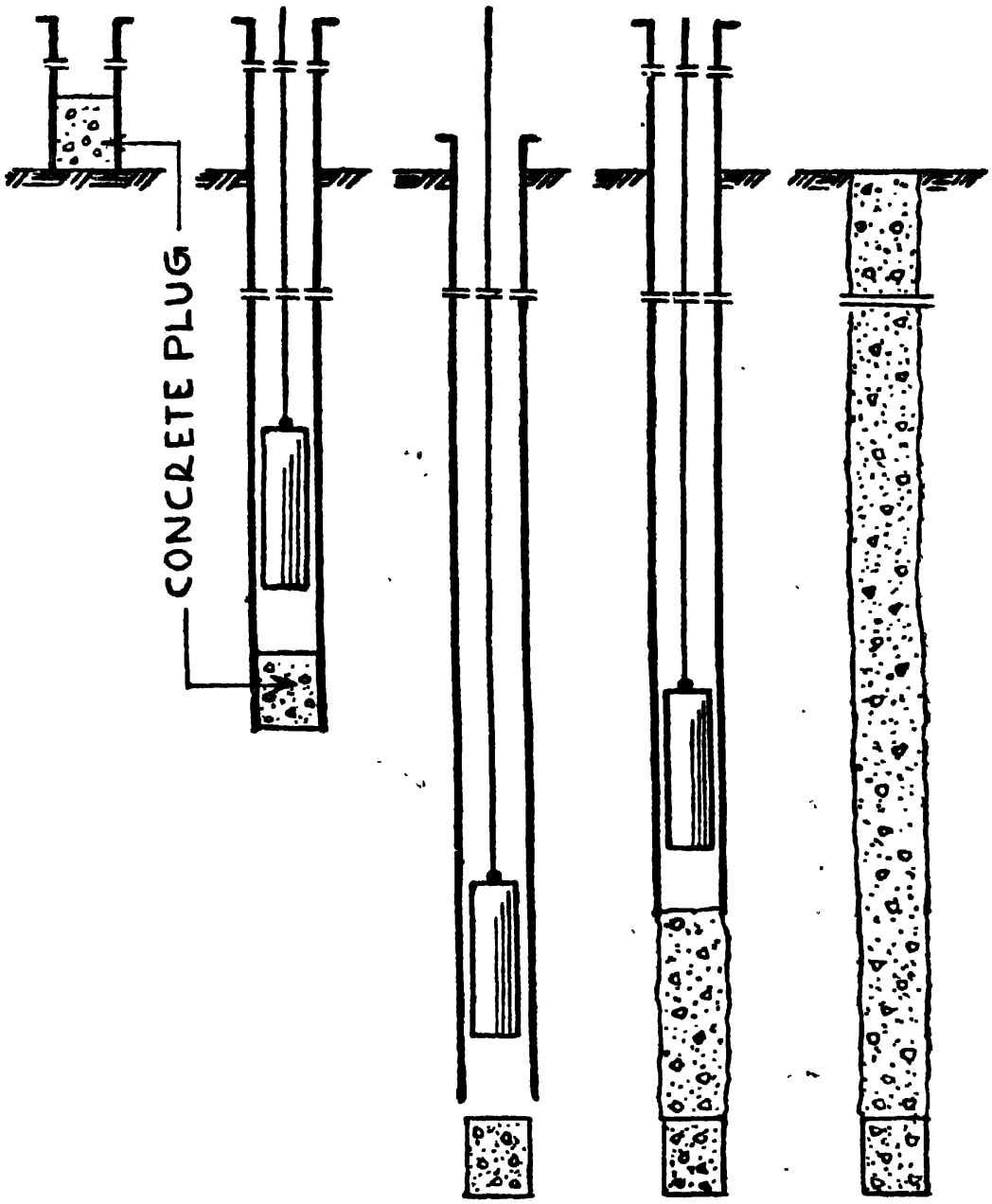


Fig. 2·13 Concrete plug at pile tube base

Fig. 2·14 Concrete plug dragging the pile tube on hammering

Fig. 2·15 Concrete plug forced out

Fig. 2·16 Concrete filled in the tube and tube partially withdrawn out

Fig. 2·17 Completed Franki pile

During the upward blow of hammer, the tube rises and the concrete moves down to fill the space left by the tube. During the downward blow, the friction of the tube on concrete tamps it and a corrugated surface is formed on the pile. This results in increased friction between the pile surface and the surrounding ground.

(*d*) **Vibro-expanded pile.** In situations where it is desired to have increased frictional resistance between the pile stem and the surrounding ground, the surface of a vibro-pile is expanded greatly

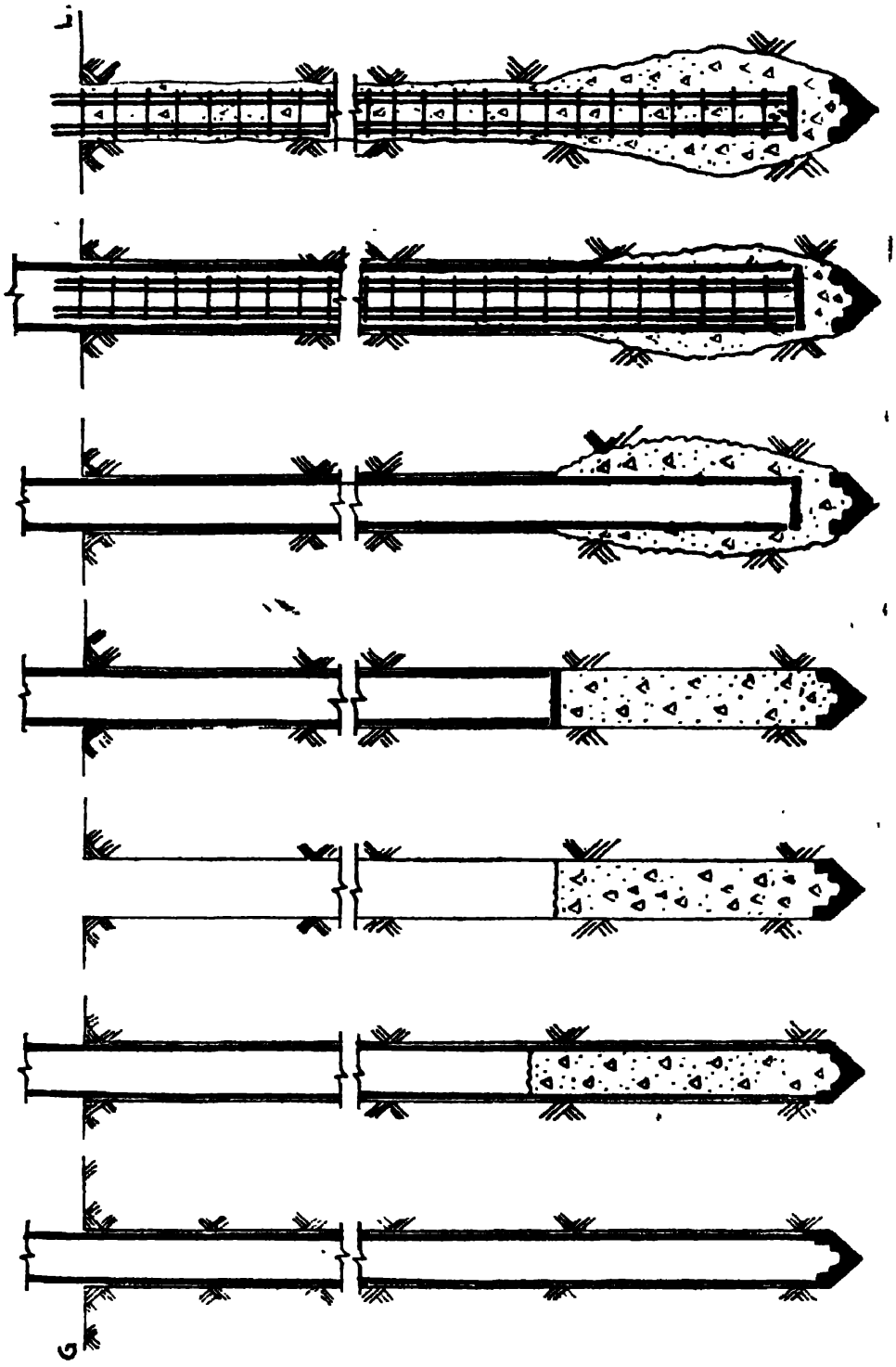


Fig. 2·18—2·24 Different stages in the construction of a vibro-expanded pile

to achieve the object. This increases the bearing resistance of a vibro pile. In this process, a steel tube of the required diameter of the pile having a detachable cast iron conical shoe at its base, is driven to the required depth. A charge of concrete filling a good length of tube is poured and the tube is completely withdrawn leaving the cast iron shoe and the charge of concrete down in the pile hole. The tube is fitted with a special flat shoe and once again driven in the same hole. The charge of concrete down below gets expanded to nearly double its area by this process. If required, another charge of concrete is poured and the process repeated. The reinforcement cage is lowered in the tube (if needed) and the pile completed as usual. The different stages in the construction of a vibro-expanded pile are shown in Figs. 2·18—2·24.

(*e*) **Raymond pile**. This type of pile is constructed in lengths varying from 6 to 12 m. The diameter of the pile varies from 40 to 60 cm. at top and the diameter at its base is slightly smaller, varying from 20 to 28 cm. so as to give a uniform taper to the pile. The thickness of the outer shell depends upon the pile diameter and site

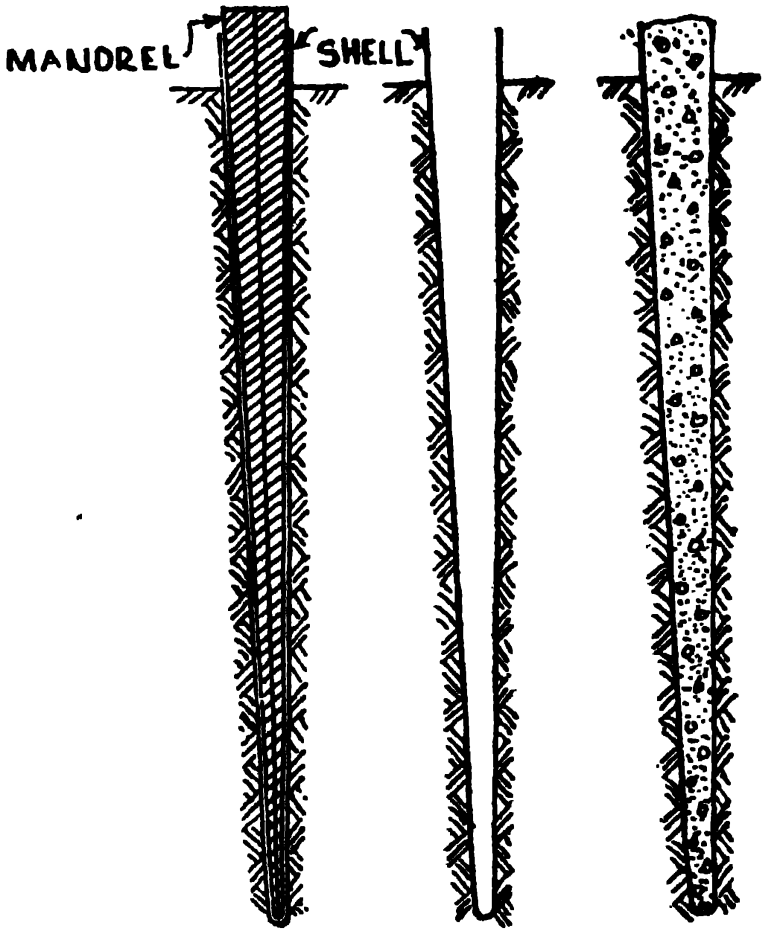


Fig. 2·25 Mandrel and shell driven in position
Fig. 2·26 Mandrel taken out
Fig. 2·27 Completed Raymond pile

conditions. The thin steel shell is reinforced with hard drawn wire spiral spaced at 8 cm. centre to centre. The shell is closed at the bottom with a steel boot. The shell is placed over a collapsible mandrel having the same taper as the pile and both are driven to the desired depth, The mandrel is then withdrawn leaving the shell in the ground. The shell is gradually filled with concrete. This forms a Raymond pile. The function of shell outside the concrete core is to prevent the adjoining soil and the sub-soil water coming in contact with fresh concrete.

(*f*) **MacArthur pedestal pile.** In this type of pile the apparatus consists of an outer casting (a hollow steel pipe) and an inner core. The bottom of the core is of such a size that it completely closes the open base of the casting when inserted inside. The core and the casting are together driven into the ground to the required depth. The core is removed and a charge of concrete is poured in the casting. The core is replaced in the casting, so that it is in con-

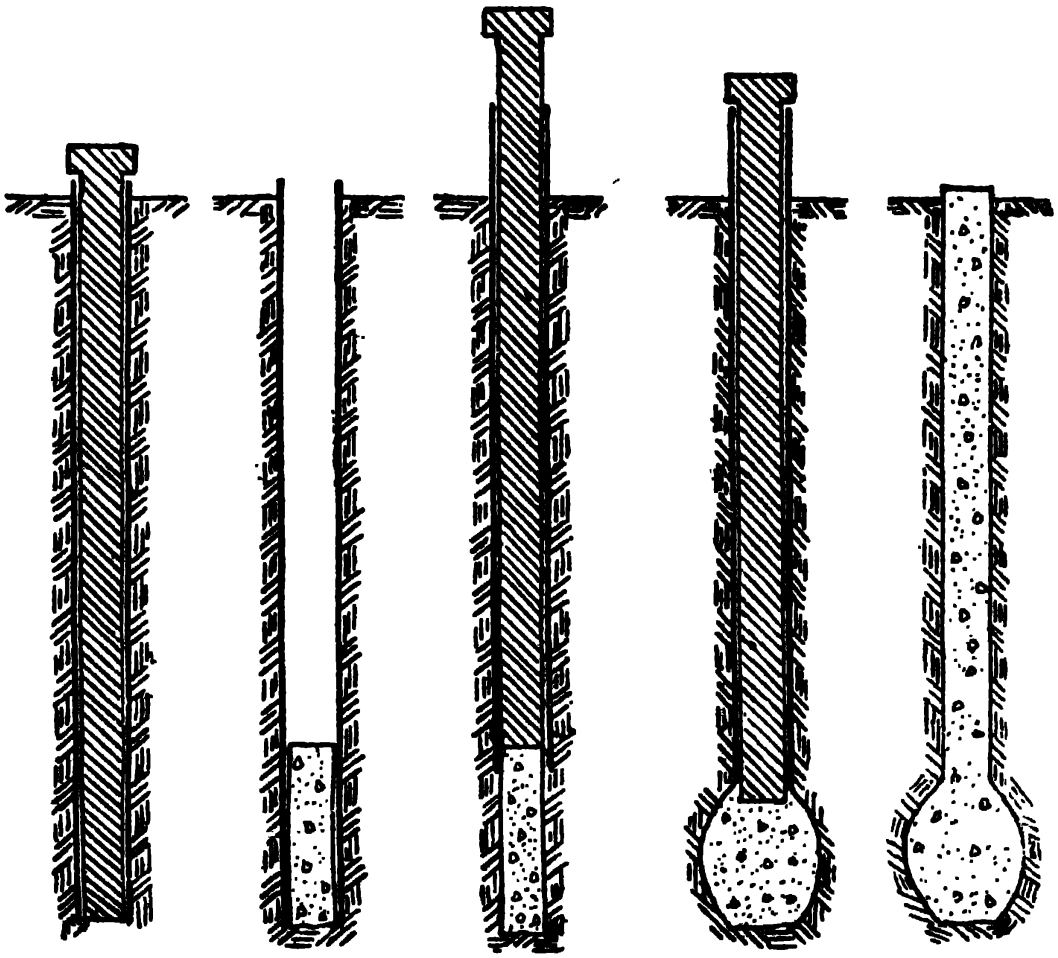


Fig. 2·28—2·32

MacArthur pedestal pile in different stages of construction

tact with the concrete. The casting is then pulled up a short distance of 60 cm. to 90 cm. and on account of the pressure of the core and the hammer, the concrete is rammed out. Again the core is removed, another charge of concrete poured and the operation repeated. When the bulb at the base has been formed to the required area, the casting is gradually withdrawn after filling with concrete so as to form a stem of constant diameter. If desired, the pile can also be reinforced.

2·9 Drilled Piles. This is a recent development in foundation engineering. This development owes its origin to the manufacture of large mechanical augers, capable of drilling holes up to about 160 cm. in diameter. In normal practice, however, the diameter of the drilled piles does not exceed 60 cm. In this method holes are drilled deep enough so as to penetrate a hard strata of required bearing capacity. The holes are then filled with plain or reinforced concrete. The holes may be drilled to a uniform diameter or they may have an enlarged diameter at the base. In places where it is not possible to dewater the pile bore, the piles may be drilled under water and concrete may be placed in position with the help of suitable tremie pipes. In cohesive soils drilling is carried out with the help of auger or bucket type drills. Steel shaft casings are used where needed to shut off water or keep the soil out of the pile holes. In such cases, the casing is gradually withdrawn as concreting proceeds.

2 10 Prestressed Concrete Piles. The biggest disadvantage of precast piles is their great weight. The precast pile is reinforced to take care of the handling and driving stresses rather than to strengthen the pile to act as a column. In some cases the handling stresses are anticipated to be so severe that the pile has to be lifted at a number of points (In normal practice the pile has to be lifted at two points only) to be able to withstand the handling stresses.

With the introduction of pre-stressed concrete piles, it has been possible to make pre-cast piles which are lesser in weight and can be lifted from one or at the most two points. The weight of very large pile is reduced by casting 200 mm. to 300 mm. diameter voids in them. The voids are formed by casting 200 mm. to 300 mm. diameter fibre tubes inside the piles at the time of concreting. In casting pre-stressed concrete piles, the pre-tensioning cables required for each pile are subjected to the required pull (tension) in the casting bed. The fibre tube for forming void in the pile (if needed) is securely held in position inside the formwork and the piles are concreted in a row. The casting bed can be made to accommodate 2 to 5 lines of piles 120 to 150 metre long. Prestressed piles are provided with lifting hooks at $\frac{1}{5}$th of the pile length from each end.

In general, square pre-stressed concrete piles of length 50 times the thickness can be handled with a single point pick-up and upto 60 times with two point pick-up. Piles 500 mm. square and smaller are usually cast solid, whereas pile above 500 mm. square are cast with 200 mm. to 300 mm. diameter cored hole (void).

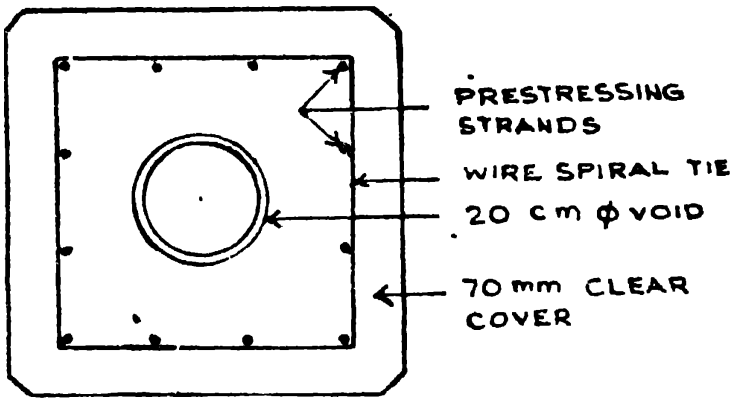


Fig. 2·33

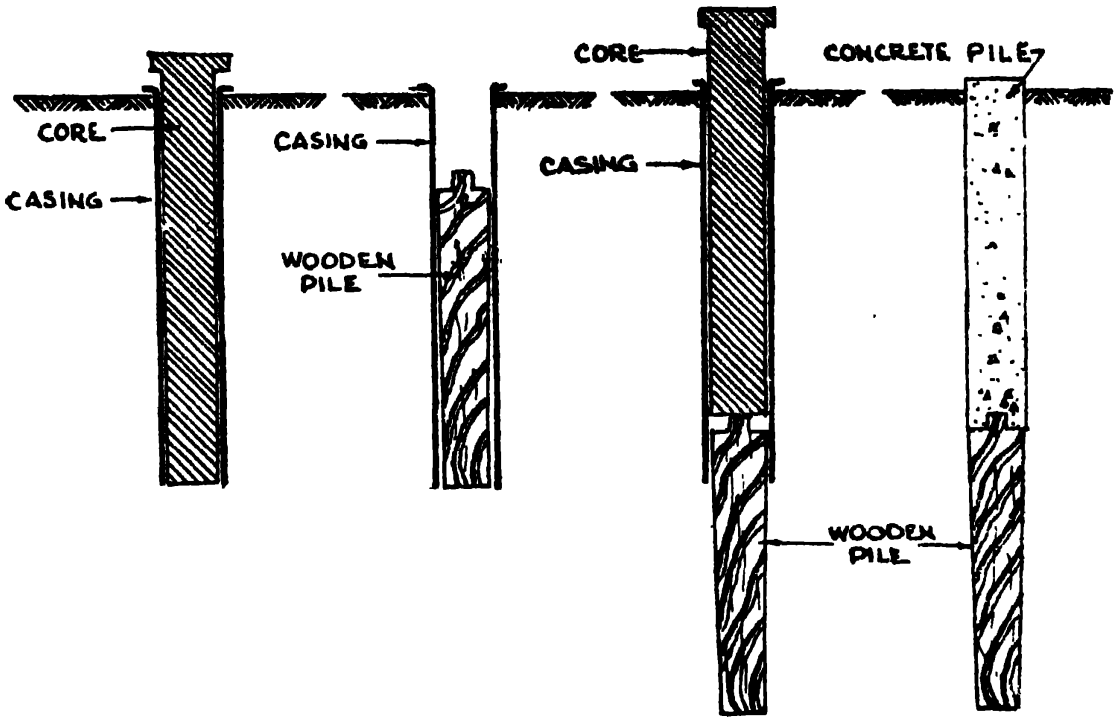
Cross-section of a typical pre-stressed concrete pile

On account of their reduced weight, prestressed concrete piles have definite handling advantage over precast piles and as such they are getting increasingly popular these days. When compared with reinforced concrete piles, pre-stressed piles have proved to be extremely durable in tidal zones and for harbour installations, where the unsupported length of the pile become considerable. Their load carrying capacity is high and they are capable of resisting uplift forces and combined moments. In addition they can withstand extremely hard driving which may be far more than that which a conventional type of reinforced concrete pile can bear.

2·11 Composite Piles. This is a type of construction in which piles of two different materials are driven one over the other, so as to enable them to act together to perform the function of a single pile. In such a combination advantage is taken of the good qualities of both the materials. Composite piles prove economical as they permit the utilization of the great corrosion resistance property of one material with the cheapness or strength of the other.

The different stages in the construction of a composite pile having a timber pile at its lower part and pre-cast concrete pile above is shown in Figs. 2·34 to 2·37. This type of composite pile is used with the object of reducing the cost of the pile.

Another type of composite pile commonly used consists of a steel pipe or H-pile at the bottom and cast-in-situ concrete pile at the top. This type of composite pile is recommended in cases



Figs. 2·34 to 2·37

Different stages in the construction of composite pile

where the designed length of the pile works out to be greater than that available for the cast-in-situ type of pile.

2·12 Steel Piles. The type of steel piles commonly used are :

(*a*) *H-piles*

(*b*) *Pipe-piles*

(*c*) *Screw piles*

(*d*) *Disc piles*

(*a*) *H-piles.* The use of rolled steel *H*-beams to function as bearing piles is a comparatively recent development in piling industry. *H*-piles can withstand large impact stresses developed during hand driving. This type of pile has proved to be especially useful when the pile is expected to penetrate a rock or through hard substratum. On account of the smaller cross-sectional area of the pile, it can be driven to the desired depth without jetting, coring or adopting other methods of soil displacement. They require less storage space and can be handled without much difficulty. *H*-piles can be advantageously driven close to an existing structure as they produce very small volume of soil displacement. *H*-piles can be securely spliced. Spliced *H*-piles have been driven to a maximum depths of 100 m. In situations where the piles are liable to corrode,

they are coated with coal tar or some other type of suitable coating or they are encased in concrete. The smaller cross-sectional area of *H*-pile make them function less effectively as friction or compaction piles. After the piles have been driven to the required depth, the pile heads are cut square and a steel plate cap is welded to each pile and finally the pile heads are embedded in reinforced concrete pile cap. *H*-piles are commonly used in the construction of bulkheads, trestles, retaining walls, bridges and cofferdams etc.

(*b*) *Pipe-Piles.* Seamless or welded steel pipes are often driven to function as end bearing or friction piles. The pipe piles may be driven either open ended or close ended. When the driving end of the pipe is left open, (without any driving point) it is called open end pile. Open ended piles are usually driven to penetrate rock or hard pan. As the open ended piles are sunk in the ground, the soil inside the pipe is cleaned out (by means of compressed air, water jet etc.) simultaneously. When the pipes have been driven to the required depth, they are cleaned from inside and the hollow space inside the pipes is filled with concrete.

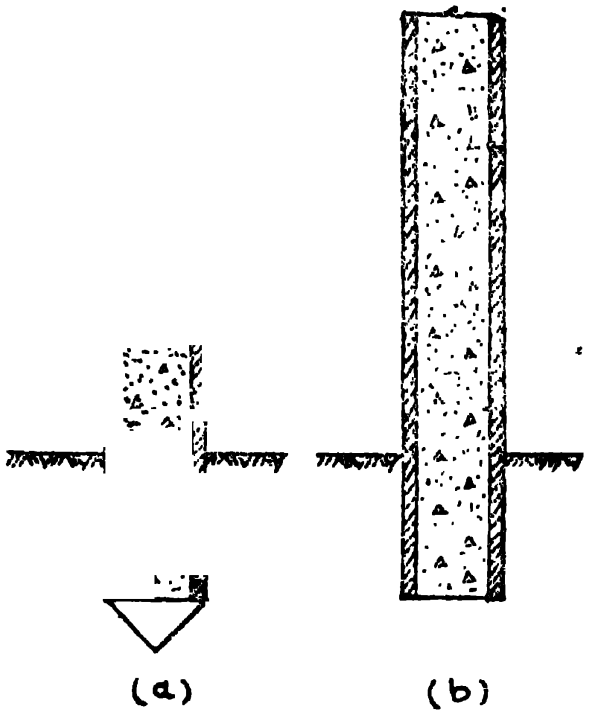


Fig. 2·38
(*a*) Closed end pipe pile
(*b*) Open end pipe pile

In case of closed end piles, the driving end of each pipe is closed by welding a conical steel or cast iron shoe to the pipe end. In this case also, after driving, the hollow space inside the pipe is normally filled with concrete. The diameter of the pipes used for piling varies from 25 cm to 122 cm and their shell thickness vary from 8 mm to 12 mm. The use of pile for depths of 30 m or more is quite common.

(*c*) *Screw piles.* A screw pile consists of a cast iron or steel shaft of external diameter normally varying from 15 to 30 cm. and terminating into a helix or screw base. The pile shaft may be hollow or solid. The diameter of the screw at its base varies from 45 cm to 150 cm. The pile is sunk by screwing the pile down inside the ground by use of an electric motor. Screw piles function most efficiently in soft clay or loose sand. In such a ground is it easy to install the

piles and also the large bearing area provided by the screws makes the best use of the low bearing capacity of the soil.

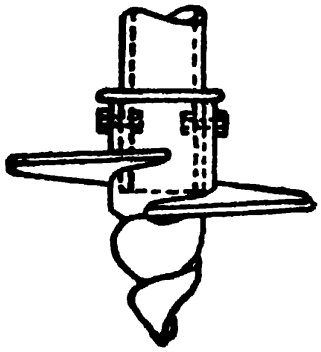


Fig. 2·39

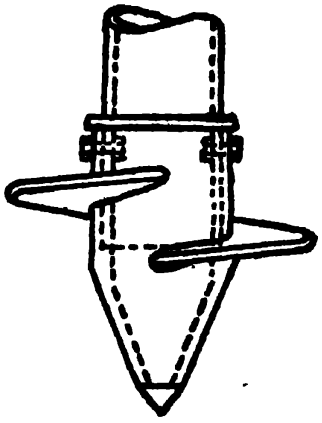
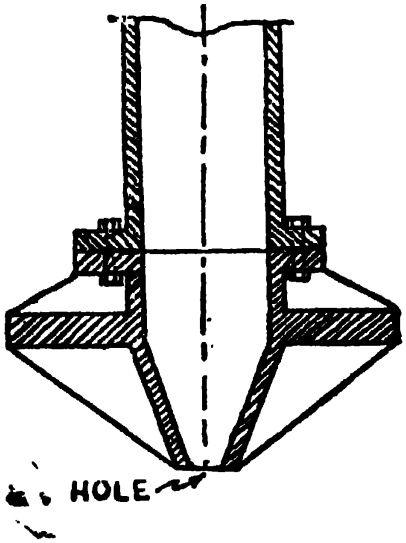


Fig. 2·40

Different forms of screw piles

(*d*) *Disc piles.* Similar to screw piles a disc pile consists of hollow metallic pipe attached with a cast iron disc to its foot so as to



Section X-X

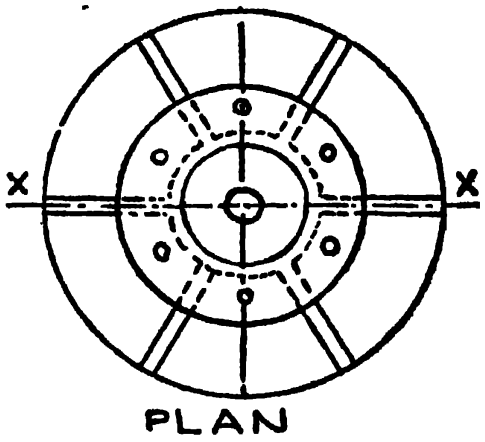


Fig. 2·41
Disc pile

enlarge the bearing area of the pile. There is a hole at the bottom of the pile to permit the water jet pipe to pass through, during the sinking of the pile by jetting. Disc pile can be used only in sandy or soft soil which may permit sinking of the pile by water jets. Disc piles are used mostly in marine installations in situations, where the total penetration of the pile in the ground is not required to be large.

2·13 Sheet Piles. Sheet piles may be made up of wood, concrete or steel. Steel piles are driven side by side into the ground

to form a continuous vortical wall for retaining soil. The alignment and resistance to thrusts are normally provided by horizontal walers, braces or tiebacks. Factors affecting the choice of a particular type of pile, include, nature of ground, cost, ease of installation, availability of material, ability to withstand driving, lateral strength and case of making connection. Depending upon the material used in their manufacture, sheet piles can be divided into the following categories :

(*a*) *Wooden sheet piles*

(*b*) *Pre-cast concrete sheet piles*

(*c*) *Pre-stressed concrete sheet piles*

(*d*) *Steel sheet piles.*

(*a*) **Wooden sheet piles**. Wooden sheet piles are made in various sizes and forms. The nature of site conditions determine the choice of a particular type. In places where excavation is small and the ground water problem is not very serious, 5 cm × 30 cm or 10 cm × 30 cm wooden planks arranged in a simple row will serve the purpose. If the water-tightness is required to a great extent lapped sheet piling is used. In this case each pile is made up of two planks, either spiked or bolted to one another. Thus if only earthen banks of small height are to be supported, a single or double row of planks properly erected will perform the function of sheet piling. If complete water tightness is desired or pressure of the retained material is large, wakefield or tongue and grooved sheeting is generally used. To facilitate the driving of the piles, they are usually bevelled at foot. This not only assists driving but also prevents bruisings, if the piles encounter hard stratum.

Wakefield pile. This type of pile is made with three planks, 5 cm, 8 cm or 10 cm in thickness. The planks are nailed together with the middle plank offset forming a tongue on one edge and a groove on the other.

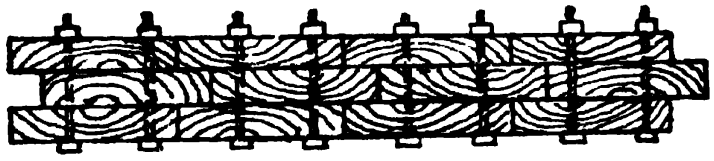
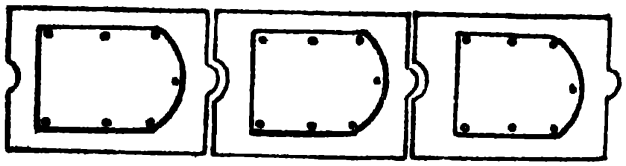
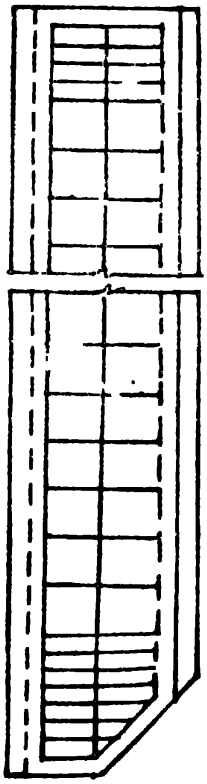


Fig. 2·42
Sectional plan of a Wakefield pile

The planks are connected by using pair of staggered bolts at 180 cm centre to centre at intermediate points. The tripple lap



PLAN



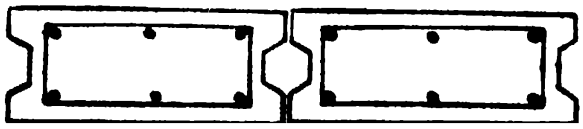
ELEVATION

Fig. 2·43
Precast Concrete Piles

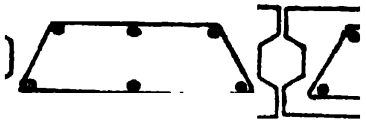
An alternative method of providing joint between two piles is shown in Fig. 2·44. In this method, after the piles are driven to the required depth, the joint is grouted with cement mortar 1 : 2 (1 cement : 2 sand).

The piles are reinforced to avoid formation of cracks due to rough handling or shrinkage stresses In order to reduce the possibility of piles prove stronger in driving. There is no wastage in forming the tongue and groove joints and the piles have less tendency to warp. Timber sheet piles have light weight and as such the equipment required for pile driving is also light. This is considered to be an important advantage timber piles have over piles of other material.

(*b*) **Precast concrete sheet piles**. Precast concrete sheet piles are made in square or rectangular cross-section and are driven similar to wooden piles to form a continuous wall. The interlock between two piles is normally provided with the help of tongue and groove joint. The tongue and groove extend to the full length of the piles in most of the cases.



(*a*)



(*b*)

Fig. 2·44. Sectional plans of different types of precast concrete piles

damage due to driving impact, the stirrups should be spaced closely near the top and bottom of the piles. The piles are normally bevelled at their feet to facilitate tightly close driving of a pile against the alredy driven one.

Reinforced concrete sheet piles are bulky and heavy and as such they are gradually being superseded by prestressed concrete piles.

(*c*) **Prestressed concrete sheet piles.** On account of the numerous advantages the prestressed concrete members have over the conventional type of reinforced concrete members, prestressed concrete sheet piles are commonly used for sheet piling jobs. Similar to concrete sheet piles, they are reinforced on both the faces so that they could be handled from either side. They are comparatively lighter in weight, more durable and economical in the long run. They are advantageously used in sea water, since the danger of cracking of concrete is negligible and also the corresponding danger of corrosion of pile reinforcement is reduced.

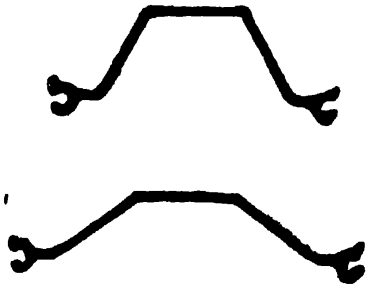


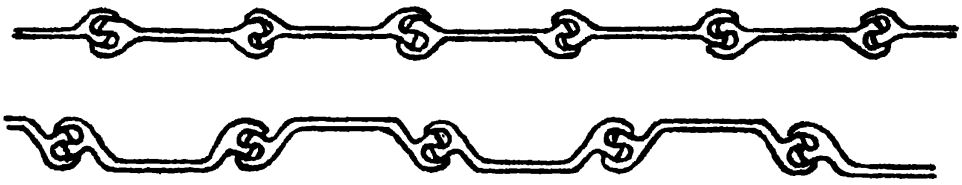
Fig. 2·45
Straight web type of steel sheet pile

Fig. 2·46
Arched web type of steel sheet pile

(*d*) **Steel sheet piles.** Steel sheet pile is a rolled steel section consisting of a plate called the web with integral interlocks on each edge. The interlocks consists of a groove, one of whose legs has been suitably flattened. This flattening forms the tonque, which fits into the groove of the second sheet. Commonly used sheet piles can be broadly divided into the following three categories.

(*a*) *Straight-web type*

(*b*) *Shallow or deep arched-web type*



Figs. 2·47—2·48

Locking arrangement of different forms of steel sheet piles

(c) *Z web type.*

Special shapes and sizes of steel sheet piles are manufactured for meeting the requirement of junctions and other similiar situations. Each of the above mentioned type of piles is manufactured in varying widths and weight. The selection of the type of pile and the section to be adopted depend upon the depths upto which the pile is to be sunk, the nature of the soil to be penetrated, the elevation of the earthen embankment, ground water level etc.

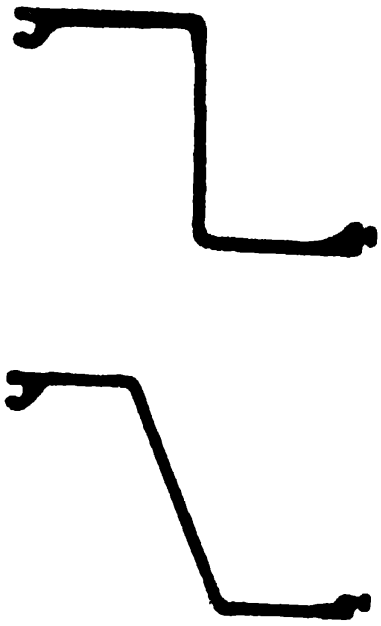


Fig. 2·43

Z-type of steel sheet pile

In general straight-web type of piles are used where the piles are liable to be subjected to tensile forces and interlocking strength is of prime importance (cellular cofferdam etc.). Arched-web type are used where the piles are required to resist bending stresses (in cantilever retaining walls etc.) and Z-web type of piles are used where the piles are required to resist bending stresses of very large magnitude.

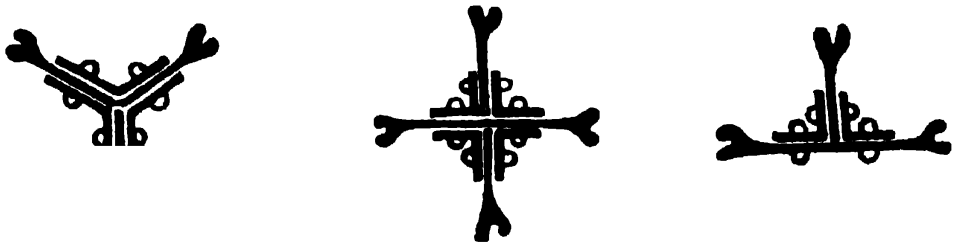


Fig. 2·50

Junction details

Steel sheet piles are driven with the help of pile drivers which may be drop hammer type or single or double acting hammer driven

by steam or air. The outstanding feature of steel sheet piles is that they can be driven to greater depths. The continuous interlocking arrangement of the piles give strength and rigidity to the supported structure. A wall made from properly driven sheet piles, leaks very little, hence steel sheet piling is used with advantage in the construction of deep cofferdams. They are commonly used in coast defence works which are likely to be subjected to tidal action.

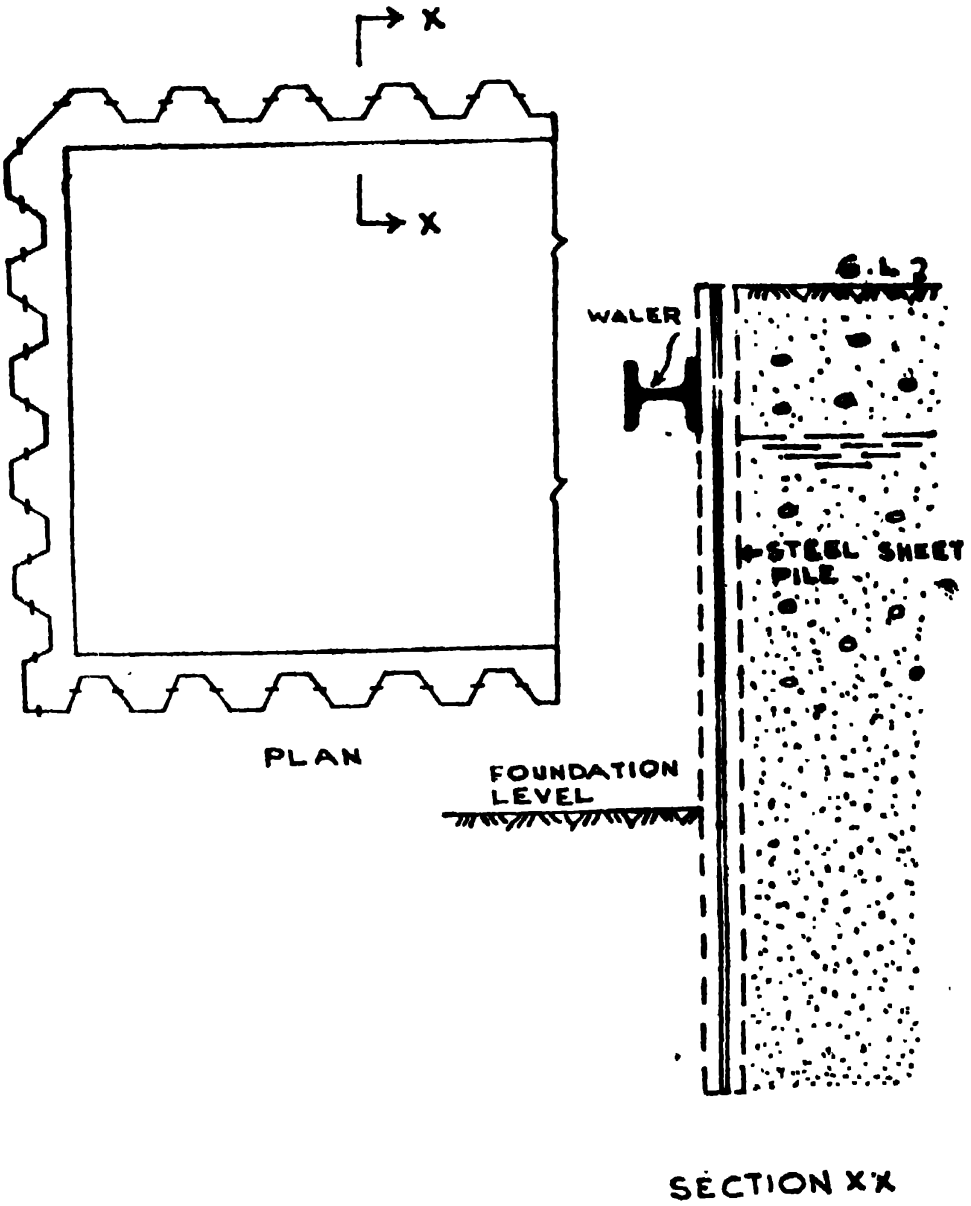


Fig. 2·51

2·14 Comparative Advantages and Disadvantages of cast-in-situ and Precast Piles :

(*a*) *Advantages of* **cast-in-situ** *piles* :

(1) Cast-in-situ piles are cast in exact lengths and as such there

is no wastage of time, money and material as is common in precast piles.

(2) They are not subjected to the vibrations due to hammers, thus they are sound in construction.

(3) Cost of transporation of the piles is nil.

(4) They can be made to bear heavier loads by adopting simple methods. (Pedestal pile is an the example for this).

(5) There is saving in time required for curing, as is necessary in case of precast piles.

(6) Since the strata through which the pile is sunk, is known and also the nature of the bearing stratum in the case of end bearing pile is known, it is possible to calculate nearly exact load carrying capacity of the pile for design accuracy.

Disadvantages of **cast-in-situ** *piles* :

(1) They cannot be used under water.

(2) If the piles are to be reinforced, there is every possibility of the reinforcements getting displaced.

(3) As the concrete has got to be dumped from great heights the quality of work is not appreciably good.

(4) The ramming of the concrete mass cannot be inspected and as such there is every possibility of the voids being left, rendering the construction unsound.

(5) In uncased piles, green concrete is liable to loose its water by coming into contact with the dry soil and hence it may result in making the pile structurally weak.

(6) Freshly laid concrete in the cast-in-situ pile is more susceptible to attack by corrosive constituents in the soil and the sub-soil water.

(7) The driving of adjacent piles may rapture shell-less cast in place pile on account of the tensile stresses set up in the ground during driving.

(*b*) *Advantages of* **precast** *piles* :

(1) They can be cast well before the commencement of the work and as such there can be rapid execution of work.

(2) Their construction can be well supervised and any defect detected can be rectified before use.

(3) The reinforcements remain in their proper positions and do not get displaced.

(4) They can be driven under water.

(5) The driving of adjacent pile cannot produce any adverse effect upon the already driven pile.

(6) They can be loaded soon after they have been driven to the desired depth.

Disadvantages of **precast** *piles* :

(1) They are heavy and hence great difficulty is experienced for their handling and transportation.

(2) The exact length of a pile can rarely be pre-determined and as such it has to be lengthened sometimes, rendering the pile weak at the joint.

(3) If a pile is found to be too long after driving, it has got to be cut down which involves extra labour, time and expense.

(4) They are subjected to the driving shocks after the concrete has fully set. This may result in unsound construction.

2·15 Pile Driving. Piles are driven in the ground by the following methods :

(*1*) *By drop hammer*

(*2*) *By steam hammer*

(*3*) *By water jets*

(*4*) *By boring*

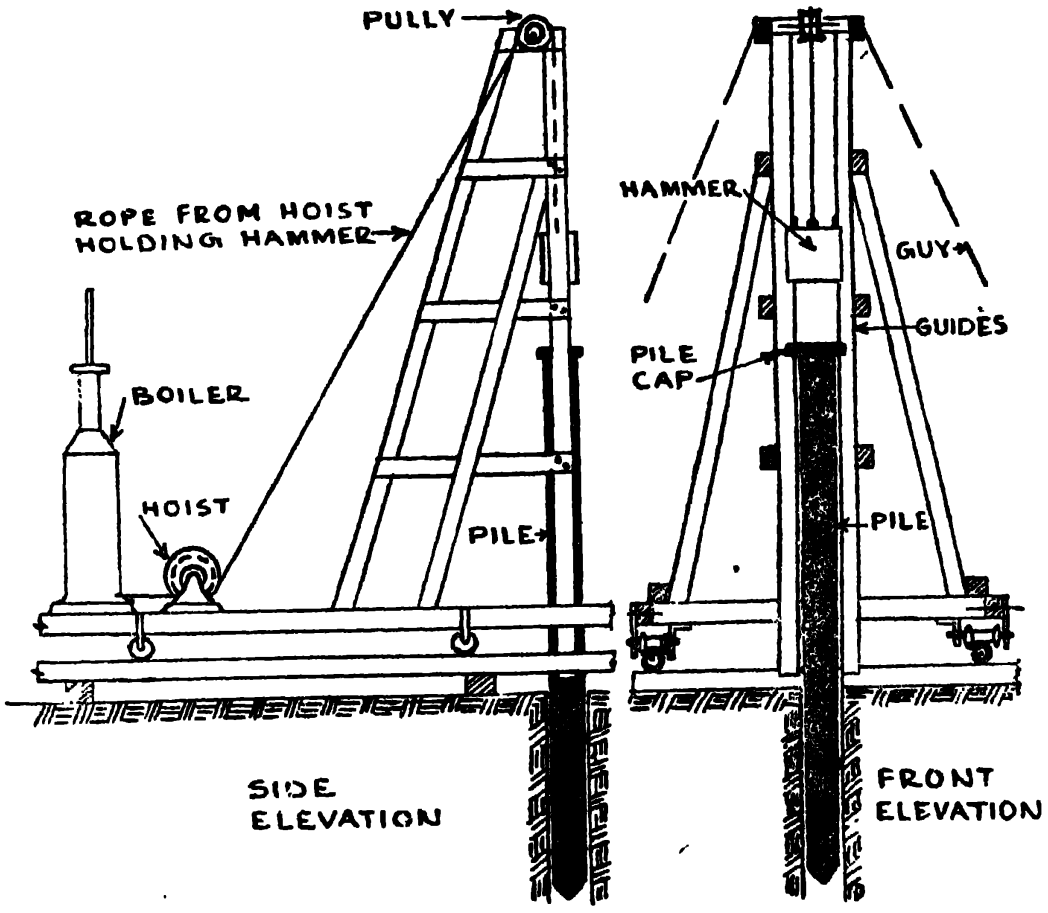


Fig. 2·52
Drop hammer type of pile driving machine

(1) **By Drop Hammer**. It is a pile driver in which the hammer is raised by a rope or steel cable and then allowed to drop on the pile cap. The drop hammer type of pile driver essentially consist of :

(*i*) A solid casting with jaws on each side that fit into the guides of the pile driver leads. (*ii*) A pin near the top for attaching the hoisting rope. (*iii*) A broad base on which it strikes the pile.

The driving of pile by drop hammer takes a lot of time and thus it is being replaced by steam hammer these days. The weight of drop hammer varies from 230 to 1800 kg. The exact weight of the drop hammer to be used is governed by the shape and length of pile as well as the nature of ground to be penetrated.

(2) **By Steam Hammer.** In this type of pile driver the hammer is automatically raised and then dropped a short distance by means of a steam cylinder and piston. The frame-work supporting the hammer also has pile lifting device. On account of uniform steam pressure, the rate of hammer blows on the pile is also uniform. Thus the short, uniform and quick blows keep the pile in continuous motion.

There are two types of steam hammer pile drivers :

(*a*) *Single acting type.*

(*b*) *Double acting type.*

In *single acting type*, the hammer is operated by steam pressure conveyed from the boiler of the pile driver. The force of each stroke depends upon the weight of the hammer and the height of fall. Depending upon the steam pressure, the number of blows of the hammer varies from 50 to 60 per minute.

In *double acting type*, the steam pressure plays its part both in the upward and downward movement of the hammer. The number of blows in this case varies from 100 to 200 per minute. For small size hammers weighing less than a tonne, the number of blows per minute may be as much as 300. The rapid blows result in quick penetration of the pile. Thus there is a great saving of time in the execution of the operation. It has many advantages over the single acting type :

(*i*) The hammer is light and compact.

(*ii*) It requires less room in the leads of the pile driver.

(*iii*) Rapid operation.

The hammers usually weigh 2000 to 4000 kg. and have a stroke length upto 1·5 m. In case of single-acting steam hammer or drop-hammer, the stroke length or length of fall should not exceed 1·35 m. The weight of the hammer should be at least half the weight of the pile. Small number of heavy blows with a small fall should be

preferred to large number of light blow with a large fall. During the process of driving, the pile head should be protected by a cast

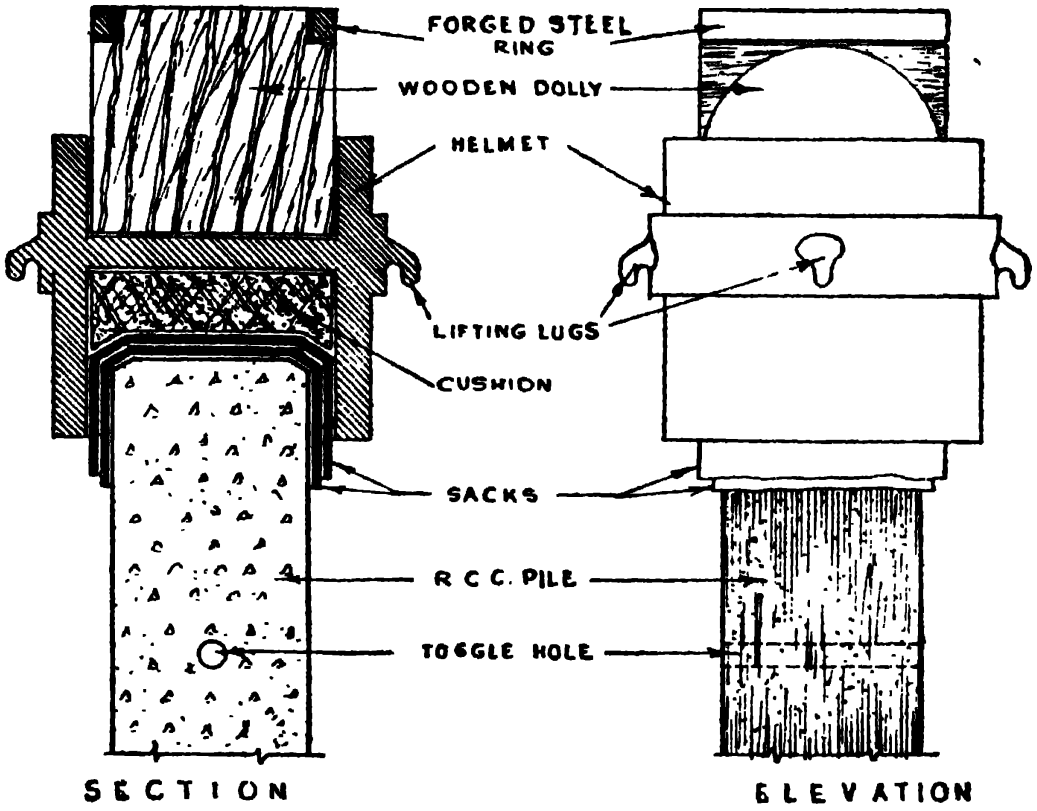


Fig. 2·53

steel helmet. The helmet is fitted with a timber stub-dolly at its top and a cushion or packing of saw dust, coir-mat, coiled hemp rope, asbestos fibre or other similiar material is placed between the timber dolly and the pile head. The hammer blow is taken on the timber dolly.

Pile Shoes : To facilitate easy penetration in the ground the pre-cast pile may be tapered or cast blunt at its lower end or it may be provided with pile shoes made up of cast iron, steel or steel plate. The most usual type being a cast iron conical shoe attached to the concrete by wrought iron straps (Fig. 2·55). For deciding the type of shoe, nature of the soil to be penetrated is the guiding factor. For driving into soft soil like loose filling vegetable earth, river silt etc., the metallic shoe may not be used and the pile cast with a blunt end will meet the requirements. This type of pile is shown in Fig. 2·54.

When driving into hard rock or where heavy boulders are anticipated, steel tapered shoe having a 7·5 cm. to 10 cm. diameter, hardened steel rod projected 15 to 25 cm. is found satisfactory

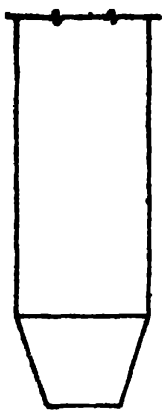


Fig. 2·54

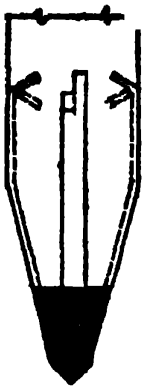


Fig. 2·55

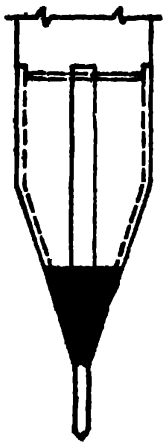


Fig. 2 56

(refer Fig. 2·56). In all other cases the pile shoe shown in Fig. 2·55 is commonly used.

(3) **By water jets.** This method of driving piles consists in displacing the soil below the shoe of the pile by means of one or more jets The jet consists of a 5 to 6 cm. diameter pipe with its lower end decreasing in diameter and forming a nozzle of about half the diameter of the pipe at top Water is forced through the jet pipe under a pressure of 7 to 17 5 kg /sq. cm Precast concrete piles which are required to be driven by jetting often have the jet pipe cast inside the pile along its axis In other cases the jet pipe is not attached to the pile, but it is handled separately. The nozzle of the jet pipe is usually kept about 15 to 30 cm below the pile shoe The jet of water coming out of the nozzle washes the soil below and the pile sinks down into the hollow space Some quantity of water from the jet rises along the sides of the pile and helps in reducing the friction between the pile surface and the surrounding soil. Thus driving and jetting proceed simultaneously. The water jet is stopped a few metre before the pile reaches its required depth and it is driven by hammering for that distance.

(4) **By boring.** If the pile is required to penetrate beds of hard soil, or soft rock, to reach its required depth, driving of the pile by boring is an economical solution In dry soils, boring may be done by auger while in soft rocks, rotary well drills may be used. The bore is made to the required depth of the pile. Precast pile is then put in the bore hole In case of continuously stiff soils, cast-in-situ piles may be made in the bore holes.

2 16 Length and Safe Bearing Capacity of Pre-cast Piles. The load bearing capacity of pre cast pile depends upon the following factors :

(*i*) Nature of surface to be penetrated.

(*ii*) Depth of penetration.

(*iii*) The area of cross-section of the pile and its centre to centre distance in a group.

(*iv*) The manner in which the pile supports the load, *i.e.* whether the pile acts as an end bearing pile or a frictional pile or it acts bothways.

Sometimes even the data of complete soil investigation may not be helpful to accurately assess the length and the load bearing capacity of a pile. Most reliable design can only be made by driving test piles at various sites over the construction site. However, in the absence of loading test, or test piles informations, a large number of penetration formulae are now available to make a reliable estimation of the length and the safe load bearing capacity of a pile.

2·17 Formula to Find the Length of a Pile. Let the properties of the soil penetrated be represented by the symbol given below :

Weight of the soil $=w$ kg/cu m.

Angle of repose of soil $=\phi$

Co-efficient of friction between concrete and soil $=\mu$

Bearing capacity of the soil at the foot of the pile $=p$

If P be the load bearing capacity of the pile and "h" be its depth of penetration, by Rankine's theory, we have

$$P = p \times \text{Area of the cross-section of pile} + \text{Friction resistance of the pile}$$

$$= p \times A + C_p \times \frac{wh^2}{2} \times \mu \times \text{perimeter of the pile}, \quad \ldots(i)$$

where A = area of cross-section of the pile and

C_p = coefficient of pressure, which is

$$= \frac{1+\sin\phi}{1-\sin\phi}$$

For wet soil ϕ may be assumed to vary between 15 to 22° and μ between 0·3 to 0·35.

For known values of ϕ, μ, p, w, A and P, h can be determined by equation (*i*).

2·18 Pile Formula. The commonly used formulae for determining the load bearing capacity of a pile are given below :

1. For piles driven by drop hammer

$$P = \frac{WH}{\left(1+\frac{w_1}{W}\right)S}$$

In this formula, the safe load on the pile is obtained by dividing P, by a factor of safety which varies between 4 to 6.

2. *Engineering News formulae*

(*i*) For piles driven by drop hammer

$$P = \frac{16\,WH}{s + 2{\cdot}5}$$

(*ii*) For piles driven by steam hammers

$$P = \frac{16\,WH}{s + {\cdot}25}$$

The safe load in this case is obtained by dividing P by a factor of safety which is taken as 6. The symbols used above stand for :—

P = Load bearing capacity of the pile in kilogram.

W = Weight of a drop hammer or the weight of the striking part of a steam hammer in kilogram.

w_1 = Weight of the pile, including the weight of all stationary parts resting on pile head, in kilogram.

H = Free height of fall of drop hammer or the length of the stroke of a steam hammer in metres.

S = Average penetration in metres per blow for last few consecutive blows of hammer.

s = Average penetration in centimetres per blow for last few consecutive blows of hammer.

2·19 Grouping of Piles. It has been observed both theoretically and practically that the total bearing value of a group of friction piles is less than the product of the load bearing capacity of an individual pile multiplied by the number of piles in that group. Some reduction takes place on account of the overlapping of the zone of stresses in the soil supporting the piles. The magnitude of reduction per pile depends on the size and shape of the pile group and the size, spacing and length of the individual pile.

However, in case of end bearing piles where assistance for supporting the load by friction is not made use of, no such reduction takes place. Hence the load bearing capacity of a group of piles in cohesionless soils, should be taken as the product of the load bearing capacity of an individual pile multiplied by the number of piles in that group.

2·20 Basic Rules for the Design of Pre-cast R.C. Piles

1. *Main reinforcement.* The area of main longitudinal reinforcement in a pile should not be less than the following values :

(*i*) 1·25 per cent of the gross cross-sectional area of the pile for piles of length upto 30 times their least width.

(*ii*) 1·5 per cent of the gross cross-sectional area of the pile for piles of length between 30 and 40 times their least width.

(*iii*) 2 per cent of the gross cross-sectional area of the pile, for piles of length upto 40 times their least width.

2. *Lateral reinforcement.* Similar to columns, the lateral reinforcement in the piles may be provided in the form of links made out of *m.s.* bars of diameter not less than 5 mm. The volume of the lateral reinforcement in the body of the pile should not be less than 0·2% of the gross volume of the pile and their c/c spacing should not exceed a distance equal to half the least width of the pile. The volume of lateral reinforcement at either end of the pile for a distance equal to 3 times the least width of the pile should not be less than 0·6% of the gross volume.

The transition between the close spacing of the laterals at the end of the pile and the wider spacing in the body of the pile should be made gradually. If the pile is required to penetrate through hard strata, additional reinforcement in the form of helix should be provided in the top of the pile for a distance equal to three times the least width.

The longitudinal bars should be held apart by pairs of 12 mm. to 15 mm. ϕ mild steel bars known as forks or spreader spaced at centre to centre distance not exceeding 1·5 m. To prevent the outward displacement of the bars, 6 mm. ϕ links should also be provided with the spreaders as shown in Fig. 2·57.

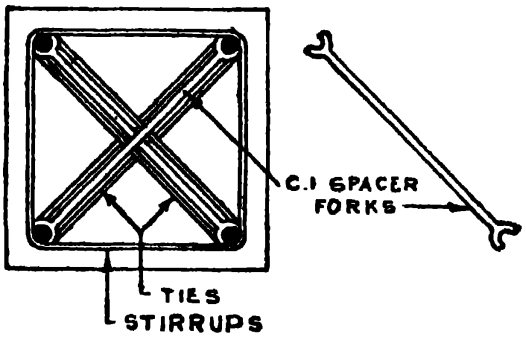


Fig. 2·57

3. *Concrete mix.* Concrete used should preferably be of higher grade than MI50 (1 : 2 : 4). Concrete mix, of M200 (1 : $1\frac{1}{2}$: 3) with well-graded aggregate should be recommended.

4. *Clear cover.* The thickness of concrete covering the main bars should not be less than 5 cm. In places where the steel is liable to corrode say in sea water, the cover should be increased to 6 cm.

5. *Stripping pile heads.* In order to ensure a monolithic behaviour of the piles and the pile cap, the concrete from the pile heads of the driven piles is stripped and the longitudinal reinforcement exposed for a length, sufficient for bonding in the pile cap.

6. *Arrangement of piles.* The arrangement of piles and their spacing in a group needs a careful consideration. It mainly depends upon the sub-soil properties, type of loading and the manner in which piles transfer the load to the ground. Close spacing of piles may result in reduced bearing capacity of the soil, uneven distribution of

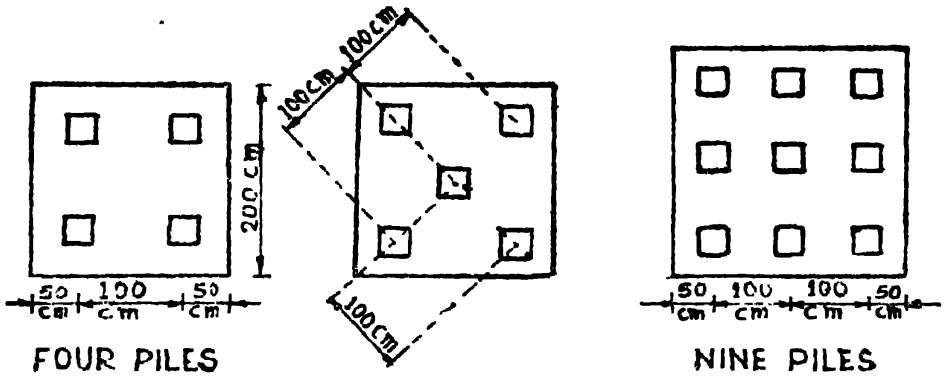


Fig. 2·58

loads, heaving or up-lifting of the piles, which may finally lead to the settlement of foundations. In order that each pile in a group may carry an equal share of load, the centre of gravity of the group should coincide with the centre of the superimposed load. The c/c distance between any two piles should generally be not less than 100 cm.

Example 2·1 *Determine the safe bearing capacity of a pile if a drop hammer weighing 2000 kg. and falling through a height of 35 cm. results in an average penetration of 0·5 cm. in the last few blows. The weight of the pile with all stationary parts resting on its head may be taken as 1500 kg.*

Solution. The load bearing capacity for piles driven by drop hammer is given by

$$P=\frac{WH}{\left(1+\frac{w_1}{W}\right)S}$$

It is given that

$W=2000$ kg.

$H=35$ cm. $=0{\cdot}35$ m.

$w_1=1500$ kg.

and $S=0{\cdot}5$ cm. $=0{\cdot}005$ m.

$$P=\frac{2000\times 0{\cdot}35}{\left(1+\frac{1500}{2000}\right){\cdot}005}$$

$=80000$ kg.

Using a factor of 4 the safe bearing capacity of the pile

$$= \frac{80000}{4} = 20000\text{kg.}$$

Example 2·2 *A pre-cast reinforcement concrete pile is driven by steam hammer. The striking part of the hammer weighing 2500 kg. has a stroke length of ·75 m which results in an average penetration of ·3 cm. in the last few blows of the hammer. It is required to find the safe bearing capacity of the pile.*

Solution. The load bearing capacity for piles driven by steam hammer is given by

$$P = \frac{16\,WH}{s + \cdot 25}$$

It is given that

$W = 2500$ kg.

$H = \cdot 75$ m.

$s = \cdot 3$ cm.

$$P = \frac{16 \times 2500 \times \cdot 75}{\cdot 3 + \cdot 25}$$

$$= 54545 \text{ kg.}$$

Using a factor of safety of 6, the safe bearing capacity of the pile

$$= \frac{54545}{6} = 9090{\cdot}83 \text{ kg.}$$

2·21 **Selection of Type of Pile.** Broadly speaking the different types of piling have been devised to suit different ground conditions. Hence the nature of the ground where piling operation is to be carried out determines to a large extent the choice of type of pile to be used. In addition the other important factors which must be considered in this regard are :

(*i*) The nature of the structure.

(*ii*) Loading structure.

(*iii*) Elevation of ground water level with respect to the pile cap.

(*iv*) Probable length of pile required.

(*v*) Availability of materials and equipment.

(*vi*) Factors which may cause deterioration of pile.

(*vii*) Probable cost of pile.

Unless the information about the identities, strength and compressibilities of the sub-soil stratum is known, it is difficult to determine as to how the pile will transmit the load to the ground, *i.e.* whether by end-bearing or by skin friction.

If the sub-soil consists of silt on alluvium for appreciable depth the pile will act as a friction pile. Depending upon the load, suitable pile, such as vibro pile, vibro expended pile or a tapered pile may be used.

In case the ground is very weak or loose and it is intended to use a cast-in-situ pile, a casing will be required to prevent the inflow of soil into the pile hole. In adverse conditions where the ground water flow is strong, pile with permanent casing should be used. Alternatively precast piles may be used.

In case the strata is comparatively firm, uncased cast-in-situ pile or precast pile may be selected. Pedestal pile will be more effective, where the pedestal can help in reducing the length of a pile in firm strata. In situations where it is necessary that the pile should penetrate into rock for some depth, H-piles may work out to be a good selection. In case the soil is firm clay, drilled piles with or without enlarged base may work out to be an economical choice.

In case piling is to be done very near to some existing structure, open ended tube piles on H-pile may work out to be good choice. Piles used to support marine structures or structures above open water should be precast type. In situation where there is possibility of the soil being chemically aggressive, high quality precast concrete piles should be selected. The piles should, however be suitably treated before driving. Timber piles may work out to be economical, if they are used for the foundation of timber trestles, structures with moderate loads or if the piles are to be used for protecting concrete docks etc.

2·22 Cofferdams. A cofferdam may be defined as a temporary structure constructed in a river or a lake or any other water-bearing surface for excluding water from a given site to enable the building operation to be performed on dry surface. The walls of the temporary structure should be practically water tight or at least they should be able to exclude water to such an extent that the quatity of water that leaks inside the enclosed area, can be easily pumped out. Cofferdams are classified according to the function and type of construction. The type of construction is dependent upon the depth, soil conditions, fluctuations in the water level, availability of material etc. Cofferdams are advantageously constructed where a large area of site is to be enclosed and the hard bed is at reasonable depth.

Considering the material used in their construction, cofferdams may be divided into the following categories.

(*a*) *Earthen cofferdam*

(*b*) *Rock-fill cofferdam*

(*c*) *Single-walled cofferdam*

(*d*) *Double-walled cofferdam*

(*e*) *Crib cofferdam*

(*f*) *Crib cofferdam (Circular or diaphragm type)*

(*a*) **Earthen cofferdam.** It essentially consists of an earthen embankment built round the area to be enclosed. It is constructed in places where the depth of water is not much, say 1·4 to 1·8 m.

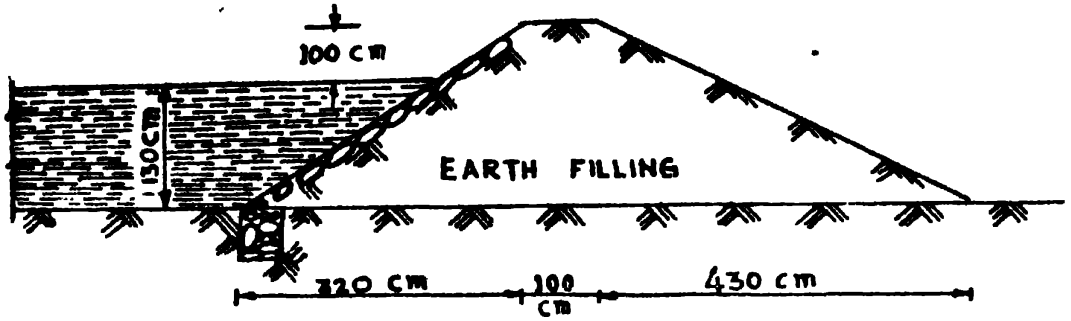


Fig. 2·59

Section of an earthen cofferdam

and the velocity of the current is very low. As a precautionary measure the earth bank is carried about one metre above the water level. The top width of the bank should not be less than 1 m. and the side slopes vary from 1 : 1½ to 1 : 2. The earth embankment should be build from a mixture of clay and sand or clay and gravel. If the estimated quantity of clay is not easily obtainable, the banks may be constructed with a central clay wall with slopes of sand on either side. In order to prevent the embankment from scouring due to the action of water, side slopes of the bank on water side should be pitched with rubble boulders. If the current of water is such that there is a danger of the earthen embankment getting washed away, canvas bags half filled with material of embankment (mixture of clay, sand or gravel) are stacked one over the other to form the embankment. When the cofferdam is constructed, the water from the enclosed area is pumped out so as to leave a dry surface inside. Excavations can then be performed to the required depth.

(*b*) **Rockfill cofferdam.** If the depth of water to be retained by the embankment is of the order of 1·8 to 3 m., stone or rubble is used for the embankment. This construction is adopted only if the stone is easily available in the nearby areas. The stones are assembled in the required shape of the embankment and the voids are partially filled with earth and stone-chips. The side slope on the water side is protected by pitching.

(*c*) **Single-walled cofferdam.** This type of cofferdam is used in places where the area to be enclosed is very small and the depth

of water is more, say 4·5 to 6 cm. Timber piles known as guide piles are first driven deep into the firm ground below the river bed. Depending upon the velocity of the current of the water in the river, the centre to centre spacing of the piles may vary between 1·8 to 4 m.

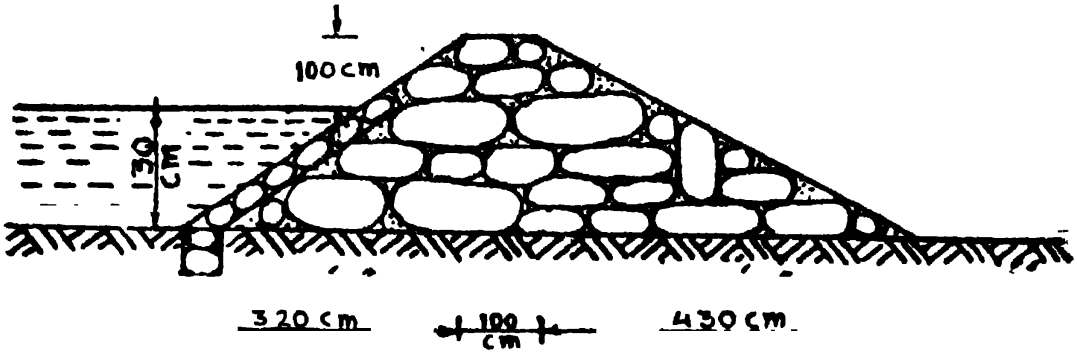


Fig. 2·60

Section of a rockfill cofferdam

Longitudinal runners called wales are then bolted to the guide piles at suitable distance apart. Steel or wooden sheet piles are then driven into the river bed along the wales and are secured to the wales by bolts. The sheets on the two faces are braced by trussed arrangement of struts. This helps in increasing the stability of walls against the water pressure Half-filled bags of sand stacked on the inside and the outside faces of the sheets help in increasing the stability of cofferdam. After the cofferdam is constructed, the water in the enclosed area is pumped out and the construction work is then started.

(*d*) **Double-walled cofferdam.** For cofferdams required to enclose larger areas in deep water, single wall type becomes uneconomical due to larger sections of trussed struts necessary to be used to resist the thrust. Double-walled cofferdam is provided in such situations. Its construction is essentially the same as that of a single-walled cofferdam except that in place of one wall, a pair of walls with a gap in between is used all along the boundary of the space to be enclosed. This type of cofferdam can be used in depth of water up to 12 m. As the depth of water increases, the wall should be made wider in order to make it stable against overturning and sliding. The distance between the two walls depend upon the depth of water The thickness of wall should be equal to the depth of water upto 3 m. For greater depths of water the thickness of wall should be 3 m. plus $\frac{1}{3}$ the depth of water in excess of 3 m. At their top, the two faces of the walls are connected by steel rods spaced at close intervals. To prevent the leakage from the ground below, the sheet piles are driven to a good depth in the bed.

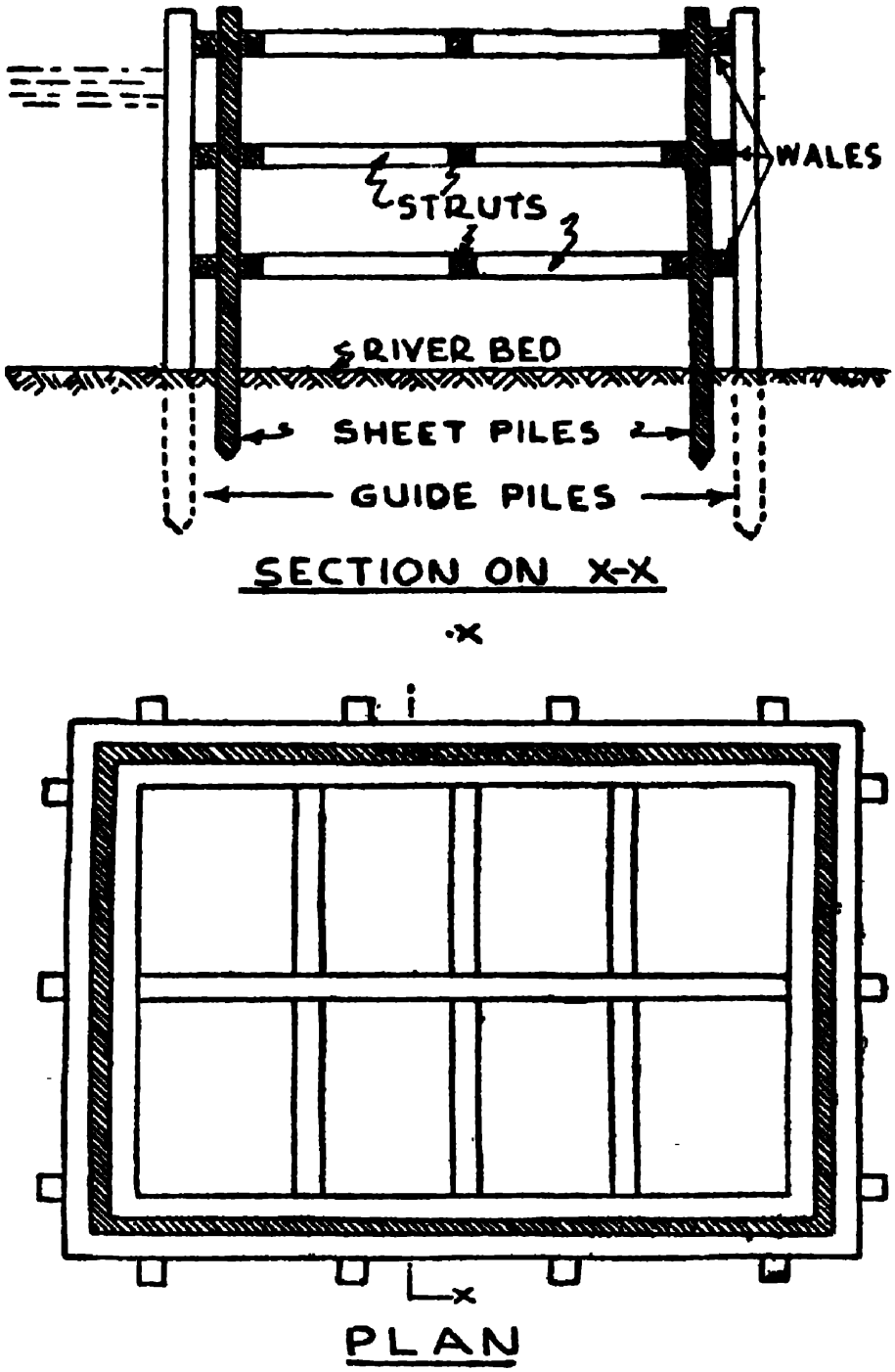


Fig. 2·61

Single-wall cofferdam

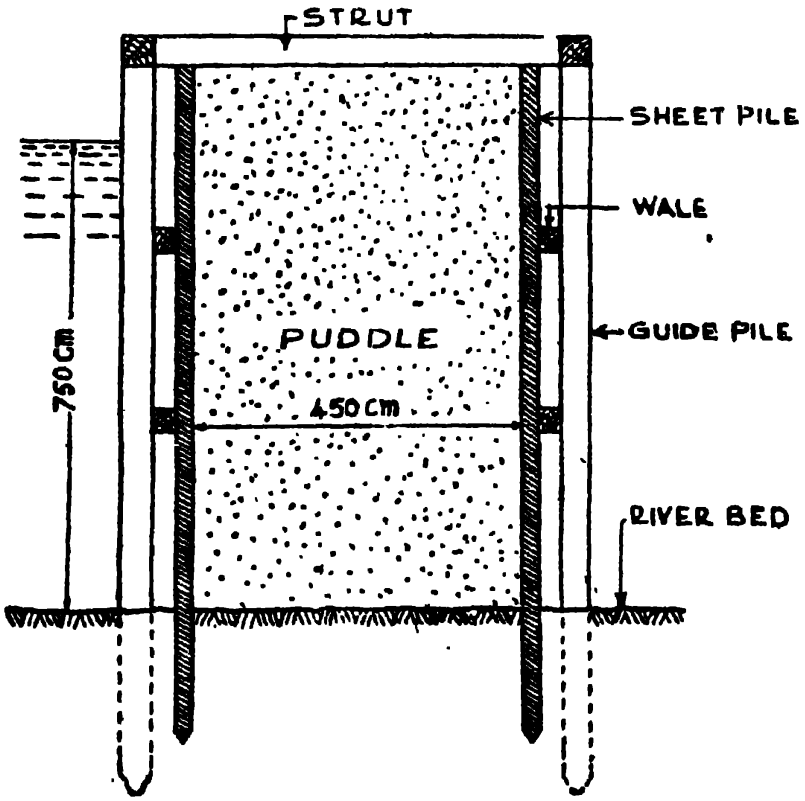


Fig. 2·62
Double-walled cofferdam

(*e*) **Crib cofferdam.** In deep waters where it is difficult to

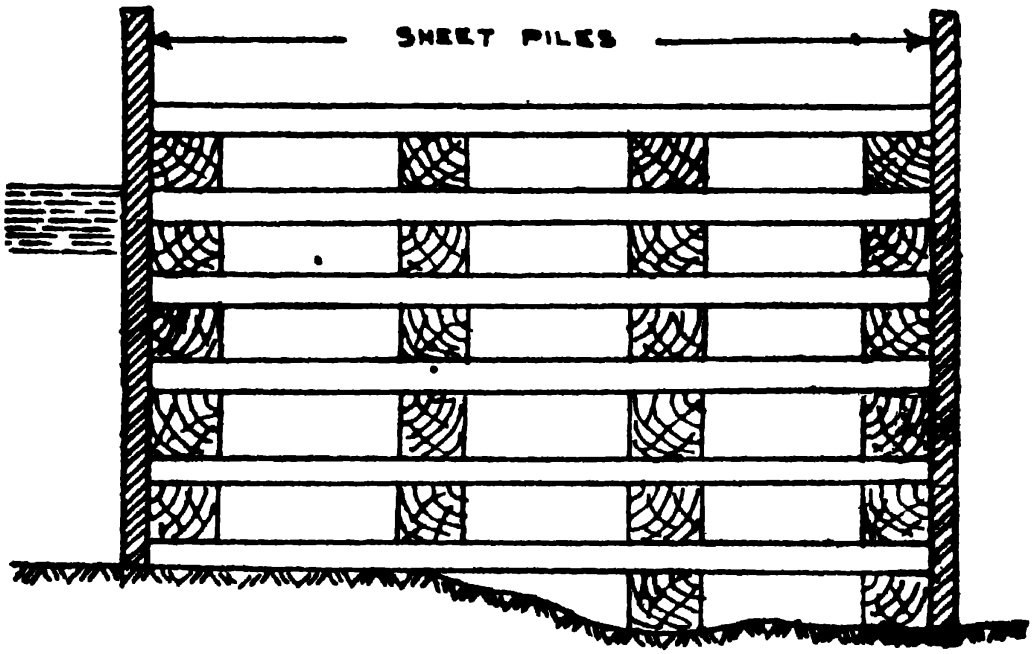


Fig. 2·63
Crib cofferdam

penetrate the guide piles or sheet piles into the hard bed below, crib cofferdam is used. In this type of construction, the sheet piles are supported by a series of wooden cribs. A crib is a framework of horizontal timbers installed in alternate courses to form pockets which can be filled with earth or stones. The length and breadth of each crib depend upon the depth of water and the current of flow. The formwork of the cofferdam consisting of logs of wood is prepared on ground and then floated to the site where the cofferdam is to be constructed. The layers of sand and the other loose material overlying the impervious hard bed is dredged out. Crib is then sunk to the bed rock. In order that crib may rest on the firm bed in stable position, the bottom of each crib is given a shape to fit in the variation of the surface of bed rock. The space inside the crib is then filled with stone or any other material, so as to make it stable against sliding and overturning. Timber or steel sheet pile is then driven around the crib.

(*f*) **Cellular cofferdam.** This type of cofferdam is mostly used for de-watering large areas in places where the depth of water may be of the order of 18 to 21 m. Cellular cofferdams are mostly used during the construction of marine structures like dams, locks, whares etc. Cellular cofferdam is made by dividing straight web steel sheet piles, arranged to form a series of inter-connected cells. The cells are constructed in various shapes and styles to suit the requirements of site. Finally the cells are filled with clay, sand or gravel to make them stable against the various forces to which they are likely to be subjected to. The two common shapes of the cellular cofferdam are

(*i*) *Circular type cellular cofferdam*

(*ii*) *Diaphragm type cellular cofferdam.*

(*i*) *Circular type cellular cofferdam.* The circular type of cellular cofferdam has the advantage that each cell may be filled completely to the top before starting the construction of the next cell without causing any distortion to the shell of the cofferdam. Thus when one cell is completely filled up it can be used for placing crane or other equipment required for the construction of other cells. In addition, each cell acts as a self-supporting independent unit and in case one of the cells gets collapsed due to scour or interlock damage or some other reason, it does not produce any adverse effect on the neighbouring cells. It is found that the interlock stresses reach their maximum permissible value when the diameter of cells is about 21 metre. Hence in case, from design consideration it is necessary to have effective width of the cofferdam more than 21 metre, diaphragm type of cofferdam must be used.

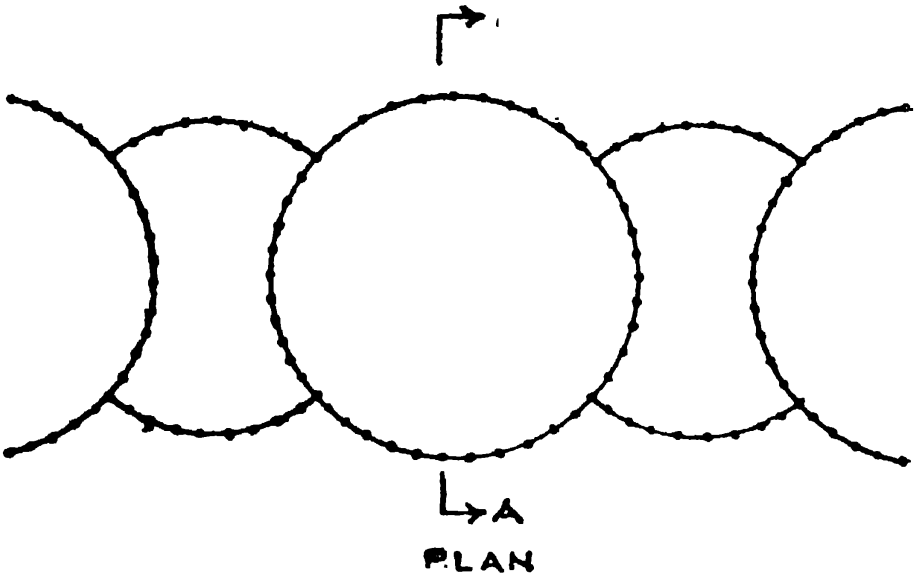


Fig. 2·64

Circular type cellular cofferdam

(*ii*) *Diaphragm type cellular cofferdam.* This consists of a series of diaphragm of steel sheet piles connected as shown in Fig. 2·65. The straight diaphragm walls are connected to each other by steel piles arranged in the form of arches on either sides. The radius of the connecting arcs is generally made equal to the distance between the straight diaphragm walls. With this arrangement, the tensions in the arcs and cross walls remain equal. After the cells are driven to the required depth, they are filled with earth, sand, gravel or other filling material. In this type of cofferdam, as the diaphragm

which separates the two cells is a straight wall, it is necessary to fill adjacent cells at approximately the same rate. If this is not done, the unbalanced pressure from the fill will distort the diaphragm (cross-walls), which may result in the failure of the interlocks. In

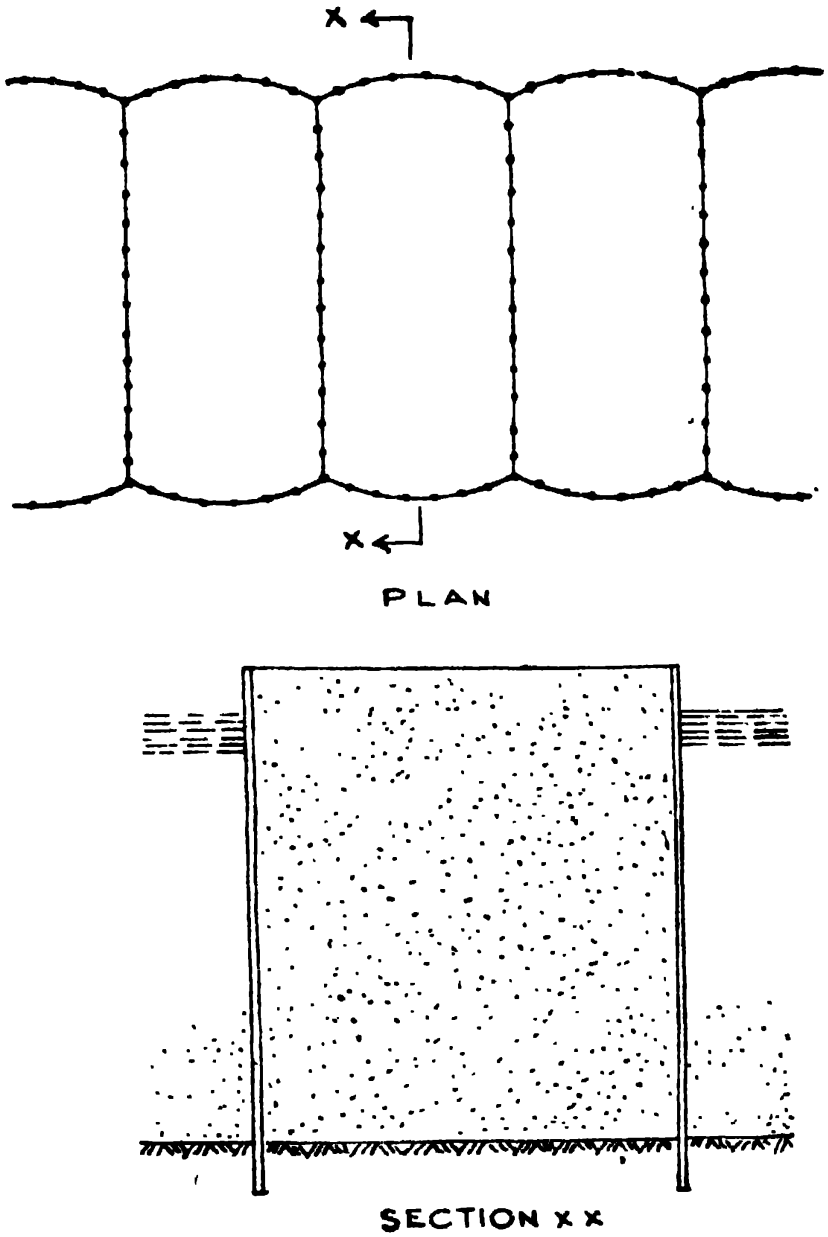


Fig. 2·65

Diaphragm type cellular cofferdam

this respect, the circular type cofferdam has the advantage over the diaphragm type cofferdam because in the former it is not necessary to fill the adjacent cells at the same time. This type of cofferdam has the advantage that the effective width of the cofferdam can be increased to desirable limits without increasing the interlock stresses.

2·23 Caissons. A caisson may be defined as a watertight structure made up of wood, steel or reinforced concrete, constructed in connection, with excavations for foundations of bridges, piers, abutments in rivers and lakes, dock structures for shore protection, break waters, lamp house etc. The caisson remains in its position and ultimately becomes an integral part of the permanent structure. They are mostly used for deep foundations under water where the foundations must extend upto or below the river bed from stability considerations.

2·24 Types of Caissons. The shape and size of a caisson depends upon the nature of structure for which it is to be built and the depth upto which it is required to be sunk. Caissons can be broadly classified in the following three different types.

(*1*) *Open caisson*

(*2*) *Box caisson*

(*3*) *Pneumatic caisson.*

(1) Open Caissons. Depending upon their shapes, open caissons can be further classified as :

(*i*) *Single wall open caisson*

(*ii*) *Cylindrical open caisson*

(*iii*) *Open caisson with dredging wells.*

(*i*) *Single wall open caisson.* This is a box type structure having no top or bottom (during construction) and mainly consists of vertical walls. The method of construction of a typical single wall open caisson is described below :

Wherever necessary the site is made dry by dewatering the area by adopting suitable methods (By constructing cofferdams, sheet piling etc.). A pit of suitable size and about 3 to 4 metre deep is excavated at the site where the caisson is to be sunk. The cutting edge is then placed at the bottom of the pit. Above the cutting edge the wall reinforcements are suitably tied up and the shuttering for casting the concrete wall is erected. The caisson walls are then concreted in lifts to a suitable height. When the freshly laid concrete has gained sufficient strength, sinking operation is started. The caisson sink due to its own weight when the soil from the space inside is removed by use of clam shell or any other method. As sinking proceeds, additional sections of the caisson wall are successively cast. Sinking is stopped while each section is concreted and it is resumed only after the concreted section has gained sufficient strength. When the caisson is sunk to the required depth, its base is pluged by providing 1·5 to 4·5 m. thick layer of concrete (concrete seal). The concrete for the seal is placed by use of a

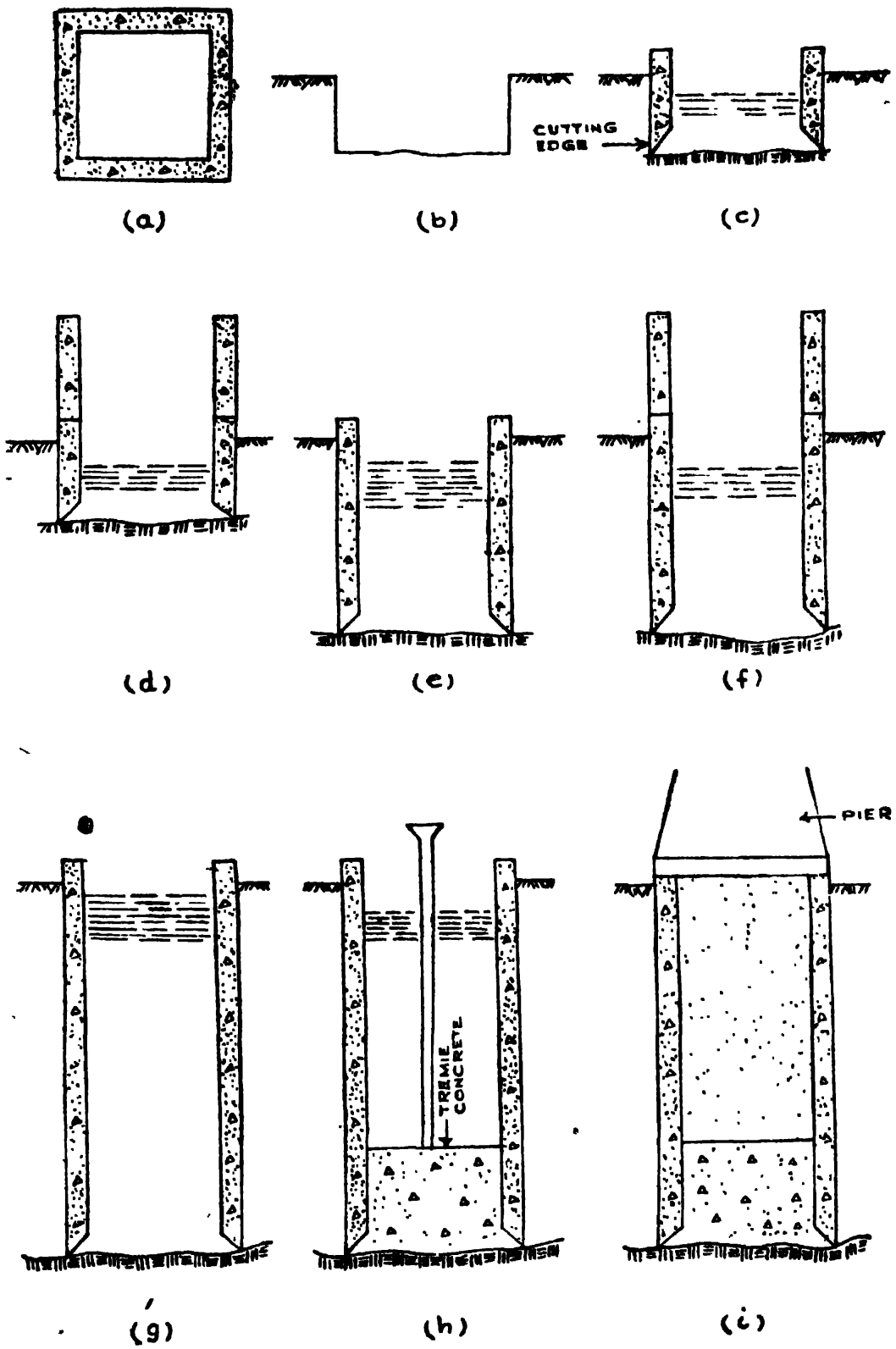


Fig. 2·66

(*a*) Shows sectional plan of the single wall open caisson required to be constructed.

(*b*) to (*i*) Show the different stages in the construction of the caisson.

tremie pipe or by a bottom dump bucket. After the concrete seal has set, the water inside the caisson is pumped out and the empty space is filled with sand gravel or concrete.

The rate of sinking of the caisson is always slow because the downward moment of the caisson is resisted by the skin friction of the ground on its walls. At times the skin friction becomes so great that the caisson does not sink even after all the earth has been druged out from the inside clean down the cutting edge. In such situations, sinking is resorted to by loading the caisson with additional weights in the form of rails, ingots etc. which are removed afterwards.

(*ii*) *Cylindrical open caisson (wells)*. This may, be defined as a cylindrical shell made up of timber, masonry steel or reinforced

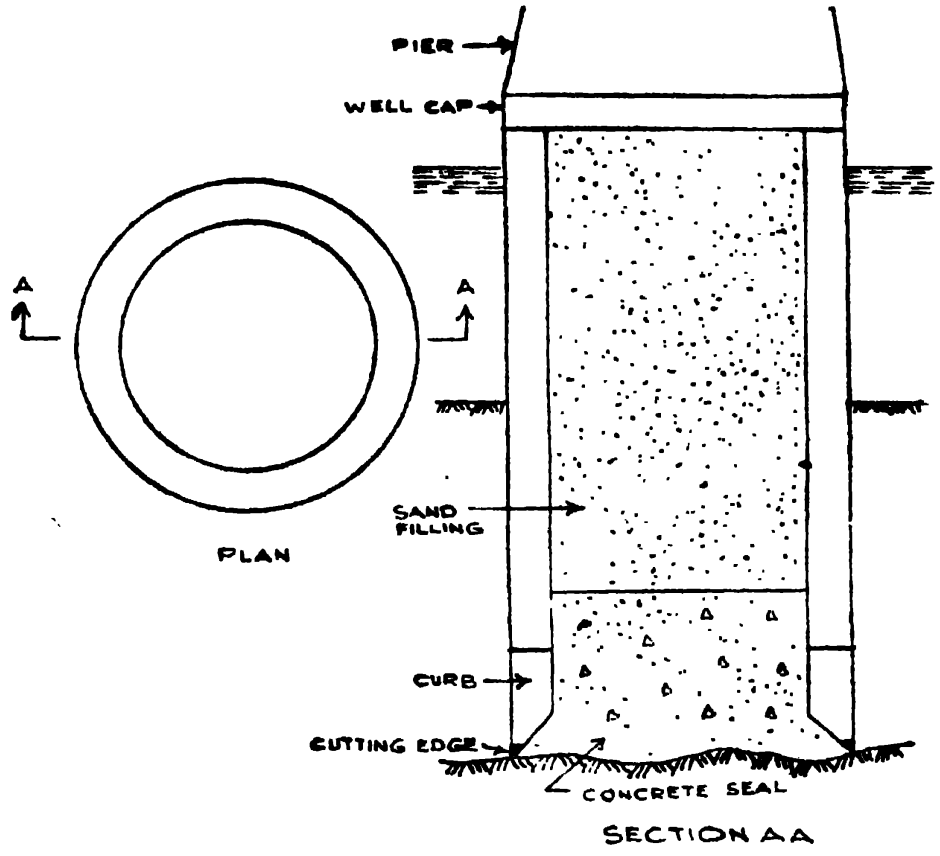


Fig. 2·67

Cylindrical open caisson (well foundation)

oncrete, shod with a cutting edge and which is sunk by excavating ıe soil within the shell. The thickness of the caisson wall must be dequate so that when the inside soil is dredged out, it sinks under s own weight. To facilitate sinking of the caisson water jets are ımetimes used around the sides, which decrease the skin friconit.

Cylindrical open caisson is also known as well caisson. This type of caisson is similar in all respect to the single wall open caisson except that its wall is circular in plan.

The method of construction of well caisson is exactly similar to that of a single wall open caisson described earlier. After the well is sunk to the desired depths its bottom is sealed with concrete. This type of caisson is commonly adopted for providing foundation for bridges, and other structures to be built in rivers and water-ways.

(*iii*) *Open caisson with dredging wells.* This type of caisson has the distinction of being employed for the deepest foundation for bridge piers, abutments and other similar structures. The caisson in this case is rectangular or square in plan and is further sub-divided into smaller sections from inside forming open walls. The

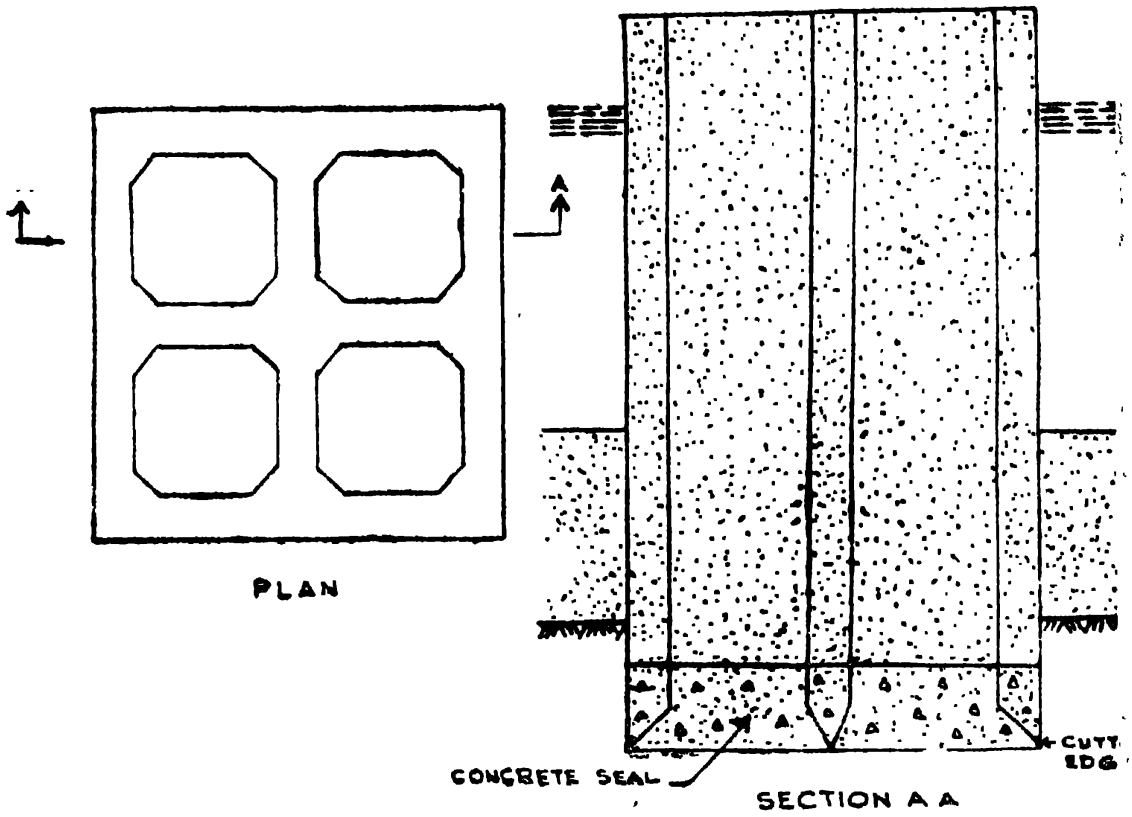


Fig. 2·68

Open Caisson with dredging wells

outside walls as well as the inside divider walls are normally made up of reinforced concrete. The caisson is sunk by excavating soil through the wells by means of dredges. After the caisson is sunk to the required depth, its base is plugged with a concrete seal and the walls are filled with sand or concrete. From the point of view of

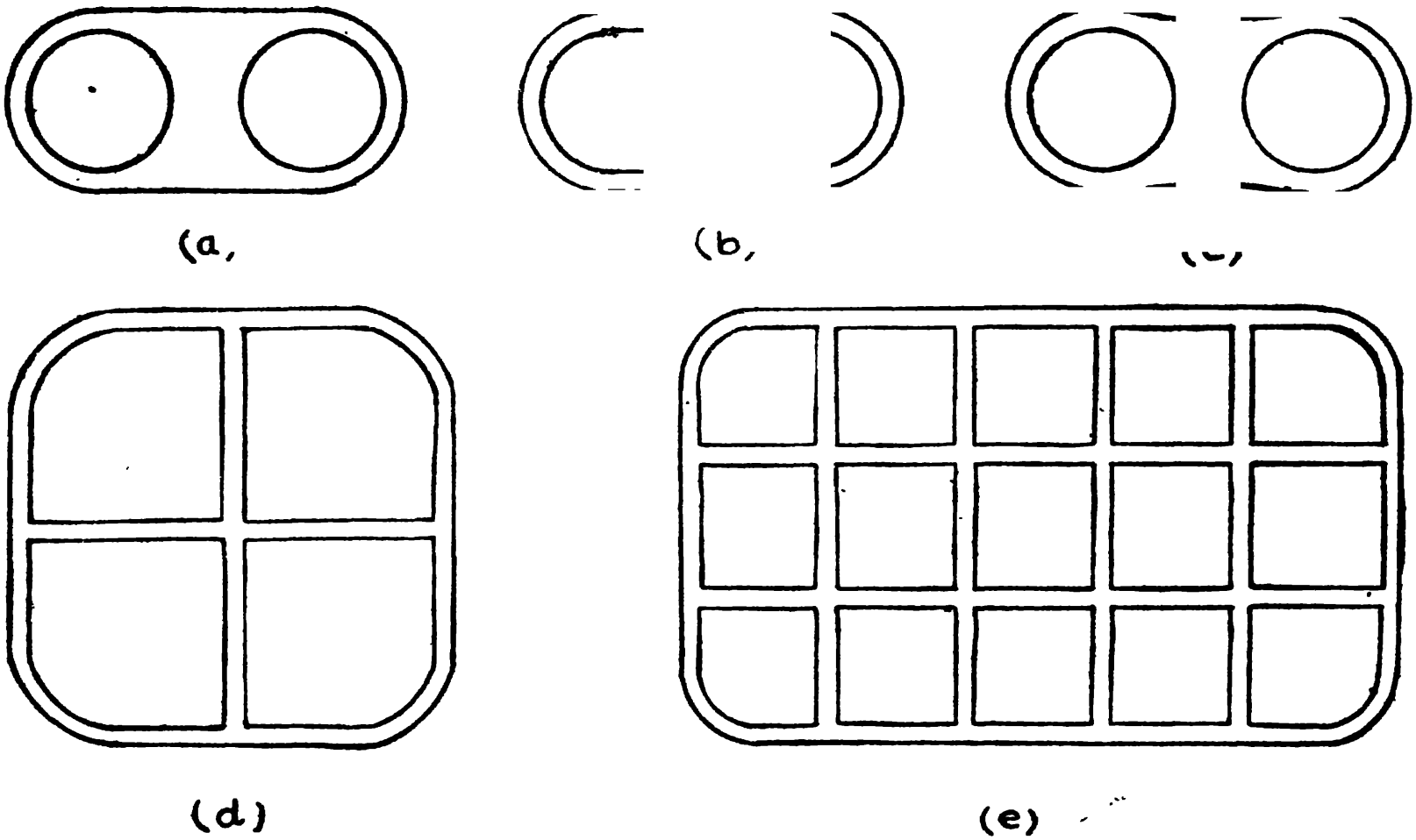


Fig. 2·69

Different types of open caisson with dredging wells

(*a*) Twin circular type (*b*) Double-D type (*c*) Dumb-well type (*d*) square type (*e*) Rectangular type

control during sinking this type of caisson has definite advantage over the other types described earlier. In this case, any tendency of the caisson to tilt or to drift from its position during the process of sinking, can be checked by dredging the soil from the approaprite wells.

(2) **Box caisson.** This type of caisson is similar to open caisson except that it is closed at bottom. The caisson is cast and cured on land and when required, it is launched in water and towed to the site of sinking. The caisson is sunk by filling sand,

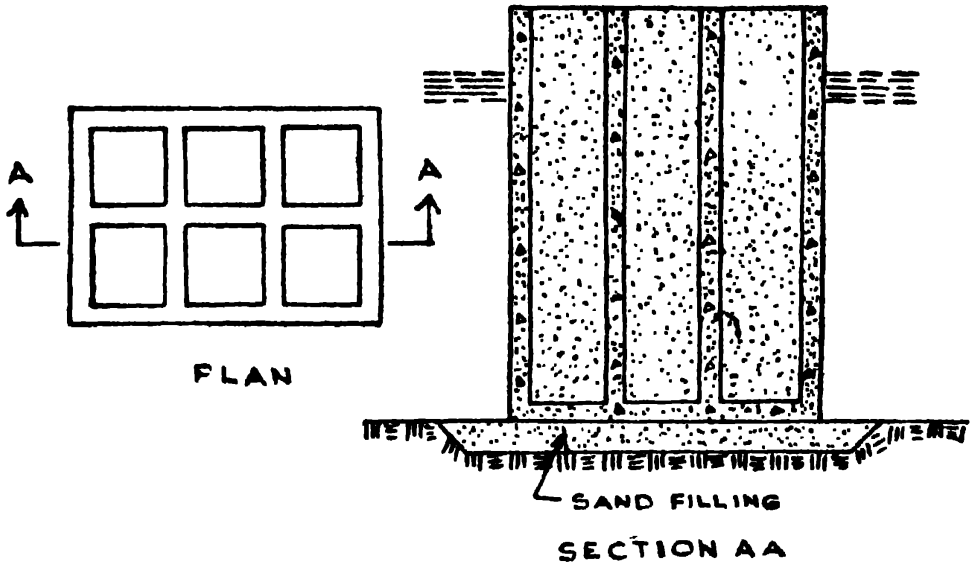


Fig. 2·70
Box Caisson

gravel, or concrete in the empty space inside. The place where the caisson base is to rest must be levelled and as such box caisson are used in places where the strata of sufficient bearing capacity is available near the ground. In normal practice the soft natural bottom soil of the river bed is dredged out to some depth. The trench thus formed is filled with sand to form a levelled base. The function of the sand layer is to uniformly distribute the superimposed loads over the soil below and thus avoid tilting of the caisson.

(3) **Pneumatic caisson.** This type of caisson is closed at top and open (during construction) at the bottom. The water is excluded from the caisson chamber by means of compressed air. The construction of the pneumatic caisson is similar to the types described above, except that, the working chamber and shaft are made air-tight. In order that the workmen may carry out excavation work underneath the caisson and the water may not find its way inside from below, the pressure of the compressed air in the shaft is kept

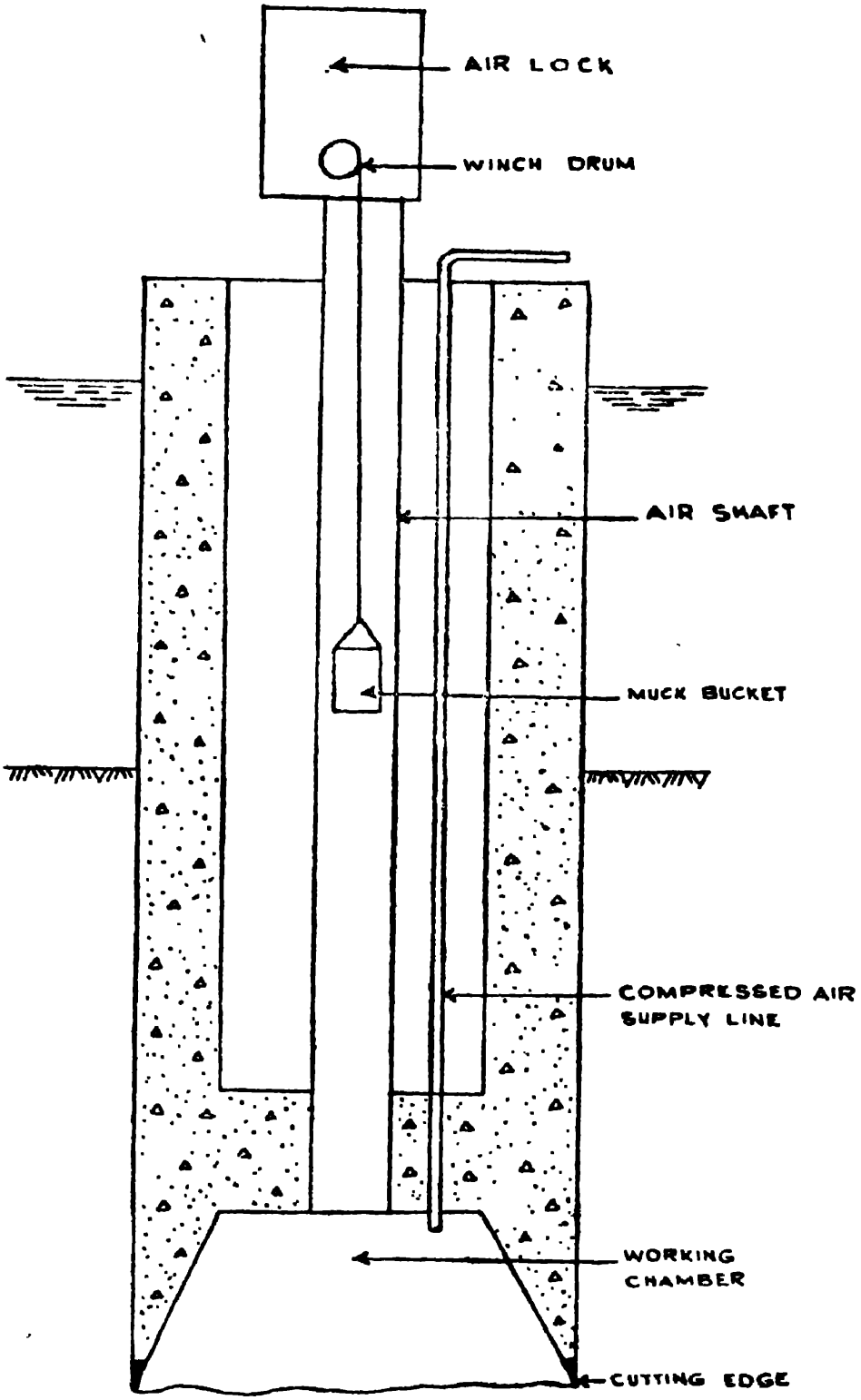


Fig. 2·71
Pneumatic caisson

just higher than that of the water at that depth. Each caisson has two air locks. Through one air lock workmen go down for working while through the other excavated material is taken out. An air lock essentially consists of a steel chamber having two air-tight doors. One door of this chamber serves as an entry of men or material from outside into the steel chamber and the other door leads to the air shaft. When a workman enters the airlock from outside, the pressure inside the airlock is the same as that of outside atmosphere. Thereafter the outside door is closed and the pressure inside the air-lock is raised slowly. When the pressure inside the airlock becomes equal to the pressure in the caisson, the door of the airlock which leads to the air shaft is opened and the workman goes down the airshaft with the help of a ladder installed therein. Exactly reverse procedure is followed when the workman comes out of the caisson. Airshaft provides means of access for the worker from airlock down to the working chamber.

This method of providing foundation is complicated, expensive and very slow. However, in places where it is rather difficult to use bulky equipment required for alternative method, pneumatic caissons appears to be the only choice. The chief advantage of this method is that entire operation of sinking the caisson can be carried out under controlled conditions. This method provides better facilities for removing obstructions, inspection of work and concreting of foundations and bed. This type of caisson is suitable for depths ranging from 25 m to 40 m. At higher depths, the persons working inside the caisson for sinking operation are liable to get caisson disease (resulting from the expansion of bubbles of air trapped on joints, muscles etc.).

Questions for Revision

1. (*a*) Name the different types of piles used for supporting vertical loads.
   (*b*) How do piles bear load ?
   (*c*) How would you determine the load bearing capacity of a pile.

2. Write short notes on :
   (*i*) Wooden piles.
   (*ii*) Vibro piles.
   (*iii*) Raymonds pile.
   (*iv*) MacArthur pedestal pile.

3. What are screw piles ? State the circumstances under which they are used.

(University of Poona)

4. (*a*) Describe any one method of driving cast-in-situ piles.
   (*b*) How would you determine the safe bearing power or capacity of a pile ?

   (*c*) Compare the advantages and disadvantages of cast-in-situ and pre-cast piles.

5. State under what conditions the following types of foundations are adopted :

(*i*) Well foundations.

(*ii*) Pier foundations.

(*iii*) Inverted arch foundations.

(*iv*) Timber grillage.

(*v*) Steel grillage.

(*vi*) Raft.

(*vii*) Piles.

6. A six-storeyed R.C.C. framed building has to be constructed on an old tank bed with loose soil over 12 m deep and water logged upto 1·2 m from ground level. What type of foundation would you adopt ? Explain in detail the process of carrying out such a foundation.

7. What are cofferdams ? Draw neat sketches to explain the different types of cofferdams used during the construction of foundation for structures.

8. Explain with the aid of sketches the types of cofferdams you would recommend for the following sites of work, assigning reasons for your recommendations :

(*i*) Shallow water with low velocities of current. Rock foundation is available at a depth of 1·52 m below bed level.

(*ii*) Depth of water not more than 1·52 m but the velocity of current very high. Rock is found at a depth of 2·14 m below bed of river.

(*iii*) Depth of water 3 to 3·66 m above bed and the bed consists of compact blue clay. The space for the cofferdam is not restricted.

Describe the construction of cofferdam recommended by you in each of the above cases.

9. What are the different types of caissons ? Describe in short the distinction between the three different types of caissons commonly adpoted. Sketch the types selected to justify your answer.

10. Write short notes on any five of the following :

(*i*) Boundary footings.

(*ii*) Steel sheet piles.

(*iii*) Core drilling.

(*iv*) Spread footings.

(*v*) Shoring of trenches.

(*vi*) Foundations on sloping ground.

(*vii*) Raft foundation.

11. Enumerate the different types of piles and describe each type briefly. Give advantages and disadvantages of each type.

12. (*a*) What are the advantages of concrete piles over other types of piles ?

(*b*) What are the factors governing the choice of the most appropriate type of foundations for a given structure ?

(*c*) What are the factors governing the minimum depth of shallow foundations ?

13. What are cofferdams ?

Explain how they could be constructed and used for the construction

of bridge pier in a river with a minimum depth of water (3 m.), where the river bed is rocky.

14. What type of foundation would you propose for a multistoreyed office building in :

(*i*) Soft soil.

(*ii*) Black cotton soil.

(*iii*) Make up ground.

(*iv*) Over soft rock.

15. What do you mean by the Bearing Capacity of a soil ? Give the bearing capacity of various types of soils.

Distinguish between spread and pile foundations. Describe with sketches the method of constructing any one of them.

16. (*a*) What is bearing capacity of soils ?

Describe the various methods of improving the bearing capacity.

(*b*) What are the advantages and disadvantages of

(*i*) Pre-cast and

(*ii*) Cast-in-situ, concrete piles.

17. While excavating the foundation, 90 cm wide × 90 cm deep of the main wall of a building, an abandoned 2·44 m dia well, with 25 cm thick walls and filled up with earth was encountered. Explain what measures you should take to build the foundation of the wall at this portion.

18. Describe with sketches the method of timbering in a trench of size 180 cm. deep × 120 cm wide for laying underground sewers in moderately firm ground.

19. Explain with diagram a grillage foundation under steel stanchion. What type of foundation is replacing grillage foundation in modern structure ?

20. Calculate the safe load which an R.C.C. pile will support if a hammer weighing 500 kg. falling from a height of 2 m. drives the pile by 6 mm. per below.

(*A.M.I.E. Nov. 1968*)

21. What are the different types of foundations used in the construction of buildings and bridges ? What is a well foundation ? Describe in details the well foundation and its method of construction. Under what circumstances it is preferred to the other types of foundations ?

(*A.M.I.E. Nov. 1969*)

22. What are the different types of piles that are used in high rise buildings ? Describe in details the construction of a typical pile foundation used for a tall building. What do you understand by sheet piling ? When and where are they used in practice ?

(*A.M.I,E. Nov. 1969*)

23. State in detail the differences between the pre-cast and the cast-in-situ piles, and explain the Simplex pile in detail. What do you understand by uneven settlement of the foundation and how it could be avoided ?

(*A.M.I.E. May 1970*)

24. State the different kinds of piles used for building purposes. Discuss the methods of construction and suitability of each under varying conditions.

(*A.M.I.E. Nov. 1971*)

3

Structural Design of Foundations

3·1. Design Loads. The basic requirement to be satisfied in structural design is that the member must be strong enough to support all the possible types of loads to which it is liable to be subjected. Hence assessment of the design load is essentially the first step that should be taken before proceeding for the design proper. The loads coming on the foundation of a structure can be classified in three different categories :

(1) *Dead load*

(2) *Live load*

(3) *Wind load*

3·2. Dead Load. It is the sum of loads comprising the self-weight of the structure, weight of its footings, foundations and other permanent load on the structure. These loads can be calculated by finding the weights of the cubical contents of the different material used in the structure. Table 3·1 gives the weight of the different substances for facility of load estimation.

TABLE 3·1

WEIGHT OF STRUCTURAL ITEMS

Description of material	*Weight in kg per cubic metre*
Concrete	
Reinforced cement concrete	2400
Plain concrete M 150 (1 : 2 : 4)	2240
Concrete with brick aggregate	1920
Breeze concrete	1120 to 1180
Lime concrete	1920
Pumic concrete	800 to 1100
Saw-dust concrete	1120
Aerated concrete	260

Table 3·1 Continued

Description of material	*Weight in kg per cubic metre*
Masonry	
Granite ashlar masonry	6400
Granite rubble masonry	2400
Dry rubble masonry	2080
Lime stone ashlar masonry	2560
Sand stone masonry	2240
Brick masonary in cement mortar	1920
Brick masonry in lime mortar	1760
Mortars	
Lime mortar	1760
Cement mortar	2080
Gypsum mortar	1200
	Weight in kg./m²
Flooring	
25 mm. thick terrazzo flooring	60
25 mm. thick granolithic flooring	60
25 mm. thick tile flooring (excluding screeding)	20
28 mm. thick hard wood flooring laid in mastic...	22
28 mm. thick soft wood flooring laid in mastic ...	15
Partitions	
10 cm. thick brick partition	195
6 cm. thick hollow concrete block partition ...	61·5
6 cm. thick hollow clay block partition ...	61·5
10 cm. thick hollow glass block partition ...	90
Roofing	
Thatch roofing on battens... ...	35
Mangalore tiles with battens in single layer ...	65
Country tiles with battens in single layer ...	70
Country tiles with battens in double layer ...	120
Allahabad tiles with battens in single layer ...	85
Allahabad tiles with battens in double layer ...	160
Complete roofing with A.C. sheets	49
Complete roofing with G.I sheets	20
First class mud roofing with 12 mm. thick boarding and a simple layer of tiles	342
First class mud roofing with a double layer of tiles	390
Jack arch roofing with 85 mm. concrete filling over crown and 85 mm. mud plaster on level ...	730
Timber trusses and purlins	12
Asbestos cement sheet	12 to 75
G.1. sheets and bolts	15
5 mm. thick Bitumen macadam roof finishing ...	11

TABLE 3·2

WEIGHT OF STORED MATERIALS

Description of material	*Weight in kg. per cubic metre*
Ashes	640
Bitumen	1040
Cement	1440
Coal solid	1300
Coal crushed	850
Charcoal	300
Coke	520
Hay and straw	290
Paper in rolls	700
Lime stone	2650
Granite stone	1640
Slaked lime	800 to 1020
Surkhi	1010
Brick ballast	1010 to 1450
Stone ballast 38 mm.	1440
Stone ballast 13 mm.	1920
Fire wood (chopped)	1400
Dry sand	1600
Dry earth filling (moderately rammed)	1520
Compacted earth filling	2200
Puddled clay stiff	2160
Slag wool	270
Gravel (loose)	1600
Gravel (rammed)	1920
Stocks of books and files	850
Building rubbish	1440
Glass in sheets	2600
Timber	640 to 960
Wheat	830
Water	1000

3·3. Live Load. Also called as super-imposed load consists of moving or variable loads like that of people using the structure, temporary stores etc. The live loads to be used for the design of floors and roofs in buildings are shown in Table 3·3.

TABLE 3·3
SCHEDULE OF LIVE LOADS AS GIVEN BY I.S.I
(LIVE LOADS ON FLOOR)

Loading class No.	*Types of floors*	*Minimum live loads* — *Kg/m² of floor area*	*Alternative minimum live loads*
(1)	(2)	(3)	(4)
200	Floor for residential purpose including dwelling houses, Floors of tenements hospitals, wards, bedrooms in hotels and dormitories.	200	Subject to a minimum total load of 2·5 times the values in column (3) for any given slab panel and 6 times the value in column (3) for any given beam.
250	Office floors other than entrance halls, floors of light work-rooms.		
	Note : The lower value of 250 kg/m² should be taken where separate storage facilities are provided and the higher value of 400 kg/ m² should be taken where such provisions are lacking	250—400	This total load shall be assumed to be uniformly distributed on the entire area of the slab panel or the entrie length of the beam.
300	Floors of banking halls, office entrance, halls and reading rooms.	300	
400	Shop floors used for the display and sale of merchandise; floors of work-rooms generally; floors of class-rooms in schools; floor of places of assembly with fixed seating, churches, chapels, restaurants; circulation space in machinery halls, power stations etc., where not occupied by plant or equipment.	400	Subject to a minimum total load of 2 5 times the value in column (3) for any given panel and 6 times the value in column (3) for any given beam.
500	Floor of warehouse, workshops, factories and other building or parts of building of similar category for light weight loads; office floors for storage and filling purposes; floors of places of assembly without fixed seating public rooms in hotels, dance halls, waiting halls, etc.	500	This total load shall be assumed to be uniformly distributed on the entire area of the slab panel or the entire length of the beam.

(1)	(2)	(3)	(4)
750	Floors of warehouses, workshop, factories and other buildings or parts of building of similar category for medium weight loads.	750	—
1000	Floors of warehouses, workshops, factories, and other buildings of similar category for heavy weight load. floors of book stores and libraies roof and pavement lights over basements projecting under the public footpath.	1000	—
	Stairs, corridors, landings and balconies not liable to/liable to overcrowding :		
Stairs	Stairs, landings and corridors for class 200 loading but not liable to over-crowding.	300	Subject to a minimum of 130 kg. concentrated load at the unsupported end of each step for stairs constructed out of structurally independent cantilever steps.
	Stairs landings and corridors for class 200 loading but liable to over-crowding and for all other classes.	500	
Balconies	*Balconies not liable to overcrowding* :		
	(*i*) For class 200 loading.	300	—
	(*ii*) For all other classes.	500	—
	Balconies liable to overcrowding	500	—
Garage (light)	Floors used for garages for vehicles not exceeding 2·5 metric tonnes gross weight.		
	(*ii*) Slabs.	400	Or the combination of actual wheel load whichever is greater.
	(*ii*) Beams.	250	-do-
Garage (heavy)	Floors used for garages for vehicles not exceeding 4 metric tonnes gross weight.	750	Subject to a min. of $1\frac{1}{2}$ × max. wheel load but not less than 900 kg. considered to be distributed over 75 cm. square.

TABLE 3·4

LIVE LOADS ON ROOFS

Type of roof	*Live load as measured on plan*	*Minimum live load as measured on plan*
1. Flat, sloping or curved with slope upto and including 10°.		375 kg. uniformly distributed over any span of one metre width of the roof slab and 900 kg. uniformly distributed over the span in case of beams.
(*a*) Access provided.	150 kg./m²	
(*b*) Roof to which access is not provided except for repairs or maintenance etc.	75 kg./m²	190 kg. uniformly distributed over any span of one metre width and 450 kg. uniformly distributed over the span in case of beam.
2. Sloping roof with slope greater than 10°	75 kg/m² minus one kg./m² for every degree increase in slope over 10° upto and including 20° and 2 kg./m² for every degree increase in slope over 20°.	Subject to a minimum of 40 kg./m².

These loads are considered as uniformly distributed "dead loads" on the plain area of the floor or roof and also include the effects of normal impact. These loads do not take into account special loads like heavy concentrated loads, vibrational effect on moving machinery, cranes etc. While calculating the total load coming on the foundations of a column. pier or wall of a multi storeyed building (except the buildings in which the super-imposed load exceeds 500 kg/m²), the super-imposed loads for the roof and topmost storey are calculated in full accordance with the schedule of loadings, but for the lower storey a reduction of the super-imposed load may be allowed in accordance with the table 3·5.

3·4 **Provision of Loads for Partition Walls.** In places where it is possible to fix the position of the partition walls which may be of brick or wood or other desired material, the actual load due to partition walls should be calculated separately and then included in the dead load for the design of the floors and the supporting

TABLE 3·5

S. No.	*Description of storey*	*Reduction in live load*
1	First storey below the topmost storey	10%
2	Second storey below the topmost storey	20%
3	Third storey below the topmost storey	30%
4	Fourth storey below the topmost storey	40%
5	Fifth storey and each storey below the topmost Storey	50%

structures. If it is not possible to decide the exact position of the partition wall beforehand, the floors and the supporting structures should be designed to carry, in additions to other loads, a uniformly distributed load per square metre of not less than $33\frac{1}{3}\%$ of the weight per metre run of the finished partition over the entire floor area subject to a minimum uniformly distributed load of 100 kg./m^2 in the case of floors used for office purposes.

3 5 Wind loads Wind acts horizontally on the exposed vertical forces of wall and inclined roof of the structure. It is assumed to exert uniform pressure which tends to disturb the stability of the structure. Wind pressure or wind loading is based on the measurements of wind velocities and characteristics of the structure acting as obstruction. In designing a structure and its foundation, separate as well as combined effect of imposed loads and wind loads are considered. The cross-walls and floors play an important part in stiffening the structure against wind pressure. In a building whose height is less than three times its effective width and it is adequately stiffened by cross-walls and floor, the effect of wind pressure is neglected. In case, the building is situated in coastal areas, the height of the building should not exceed two times the effective width for no wind effects.

The wind pressure to be considered on vertical surfaces is given in Table 3·6.

Wind pressure on sloped roofs.

In case of sloped roofs, the wind pressure varies with the degree of slope. It is assumed to be acting on one side of the roof and that side is termed as windward side. The opposite face of trusses is termed as leeward side in wind load estimation. A minimum wind

pressure of 50 kg./m² on windward side and a suction pressure due to wind of 50 kg./m² on the leeward side is allowed in sloped roof design. Table 3·6 gives the wind pressure for various exposed heights that should be considered in load estimation.

TABLE 3·6

WIND VELOCITY AND PRESSURE AT VARIOUS EXPOSED HEIGHTS

H (m)	V (km/hr)	p (kg/m²)
0	80	40
3	96	58
5	109	76
10	120	92
15	127	104
20	132	112

3·6 Case I : Design of Wall Foundation. This consists in calculating (*i*) the depth upto which the foundation of a structure should be taken below the ground level, (*ii*) depth of the concrete bed block and (*iii*) the width of foundation.

(*i*) *Depth of foundations.* The decision regarding the depth upto which foundation should be taken below the natural ground level basically depends upon the following factors :

(*a*) The depth at which required bearing capacity of soil is available.

(*b*) When the foundation has to be constructed in a pond, water course, ditch, filled up soil or some similar situation, it should either be taken to such a depth where such conditions, do not produce any adverse effect or the problem should be tackled by resorting to other suitable remedial measures like constructing raft, grillage, etc.

(*c*) In case of rock, it is not necessary to make deep trenches for foundation. It is sufficient to remove the top soil and construct the foundations over a cleaned and prepared bearing surface.

(*d*) In case of black cotton soil or clayey soils, it is dependent upon this depth upto which the effect of volumetric changes in soil (due to atmospheric conditions) do not produce any adverse effect.

(*e*) The depth upto which the soil is weakened by root holes or cavities produced by animals, worms etc. In addition the foundation should be taken deep enough to eliminate the possibility of rain water scouring below the footing.

(*f*) With the exception of shrinkable soils and rocks all simple types of spread foundation should be taken to a minimum depth of 90 cm. below the finished ground level.

The minimum depth of foundation to prevent the soil moving laterally under pressure is given by commonly adopted formula known as Rankines formula. According to this formula the depth (*D*) of foundation necessary to be provided is given by

$$D \quad \frac{p}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

where

p = safe permissible pressure on base in kg/m^2

w = weight of soil in kg/m^3

ϕ = Angle of repose of the soil.

The minimum depth of foundation for the load bearing wall of a building is restricted to 90 cm. The depth is very much essential to protect the foundation from destructive effects of weather.

In case of black cotton soils or clayey soils, which are liable to considerable shrinkage, footings should necessarily be taken down to such a depth below which there is little likelihood of variation in the moisture content of the soil.

(*ii*) *Depth of concrete bed block.* The depth of foundation concrete bed block depends upon the type of concrete used (whether cement or lime concrete), the projection of the concrete block beyond the bottom-most course of wall footing and the upward pressure of the soil below. The concrete of block may fail by shearing, crushing or by bending. It is usual to design the depth from consideration of maximum bending moment and the depth thus obtained is found to render the concrete block safe against shear or crushing.

Thus if d = depth of concrete block in cm.

j = projection of concrete block on either side of the lowermost course of wall footing in metre.

m = safe modulus of rupture of concrete mix, used in kg/cm.^{2}

p = load on foundation in kg./m^2.

The depth "*d*" of the concrete block can easily be worked out from consideration of maximum bending moment.

Consider the cantilever projection *AB* or "*j*" of the concrete block.

Bending moment (M) in kg.m. about a vertical plane through B

$$= \frac{p \cdot j^2}{2}$$

The moment of resistance of the concrete block

$$= \frac{md^2}{6} \text{kg. m.}$$

Equating the moment of resistance to the minimum bending moment, we have

$$\frac{md^2}{6} = \frac{pj^2}{2}$$

or
$$d^2 = \frac{6 \times pj^2}{m \times 2}$$

$$= \frac{3pj^2}{m}$$

$$\therefore \quad d = \sqrt{\frac{3pj^2}{m}} \text{cm.}$$

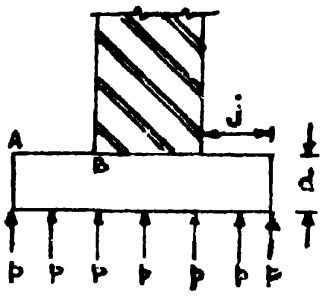


Fig. 3·1

In F.P.S. units where d and j are in inches while m and p in lb/sq in. and ton/sq. ft. respectively, the value of d comes out to

$$\sqrt{\frac{46{\cdot}7\ pj^2}{m}}$$

The value of m for various concrete mix is given in the table below :

TABLE 3·7

MODULUS OF RUPTURE OF VARIOUS CONCRETE MIX

S. No.	Type of concrete	(m) in kg./m²	(m) in lb./sq. in.
1	Pure lime and surkhi concrete (1 mortar : 3 stone ballast)	1·55	22
2	Moderately hydraulic lime and sand concrete (1 mortar : 3 stone ballast)	1·55	22
3	1 : 4 : 8 Plain cement concrete	2·46	35
4	1 : 3 : 6 Plain cement concrete (M 100)	3·52	50
5	1 : 2 : 4 Plaint cemen concrete (M 150)	5·27	75

Since the resistance of concrete to tensile and shear stresses is very low, the value of j must be limited. The least value of j should vary between 10 to 15 cm. Thus it is important to note that the depth of cement lean concrete should in no case be less than its projection beyond the masonry face. However, in case of lime concrete the depth of the bed block should be at least $1\frac{1}{2}$ times its projection beyond the masonry face. For heavy loading conditions reinforced concrete bed proves economical.

(*iii*) *Width of foundation.* The width of foundation is obtained by dividing the total load per unit length on the foundation bed by the safe bearing capacity of the soil. Thus, if W be the total load in tonnes per metre and p be the safe bearing capacity of the soil in tonnes/m^2.

$$\text{The width of foundation} = \frac{W}{p} \text{ metre} \qquad \ldots(i)$$

If the wall is to rest on a hard substratum the width obtained from the above equation will be very small and as such it may not be sufficient to make the wall safe against tilting. In order that the wall may be stable, the lowermost course of the wall footing is made twice the width of the wall (T) and the concrete bed block is made to extend at least 10 to 15 cm. on either side of the lowermost course, this extension being denoted by j.

Hence the width of foundation

$$= 2T+2j \qquad \ldots(ii)$$

The greater of the two results obtained from equations (*i*) and (*ii*) should be adopted as the final width of foundation.

Example. *Design the foundation of a residential building three-storey high. The foundation is to rest on sandy soil having an angle of repose of 30° and safe bearing power of 16 tonnes per sq.m. The soil weighs 1680 kg. per cu. metre. The main walls are 30 cm. thick and 13·5 m. high above ground level (this includes the height of parapet wall). The roof consists of 15 cm. thick R.C.C. slab finished with 10 cm. thick (average) lime concrete terracing. The floors consist of 12 cm. thick R.C. slabs finished with 25 mm. terrazzo flooring. The maximum span of the R.C.C. slab for the roof or floors between two main walls is 4 metres. The roof is accessible. The weight of R.C.C. may be taken =2300 kg./m^3 and for L.C.=1920 kg/m^3.*

Solution. The depth of foundation as given by Rankine's formula,

$$D = \frac{p}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

$$\frac{16\times 1000}{1680}\left(\frac{1-\sin 30^\circ}{1+\sin 30^\circ}\right)^2$$

$$=\frac{16\times 1000}{1680}\times\frac{1}{9}=1{\cdot}057 \text{ m. say } 1{\cdot}1 \text{ m.}$$

Hence adopt the depth of foundation as 110 cm. It is assumed that 1 : 3 lime concrete is to be used for foundation bed and the bed-block projects 15 cm. or ·15 m. from the lowermost course of footing.

Depth of concrete bed block

$$d=\sqrt{\frac{3\,p\,j^2}{m}}$$

$$=\sqrt{\frac{3\times 16\times 1000\times 0{\cdot}15^2}{1{\cdot}55}}$$

$$=26{\cdot}4 \text{ cm.}$$

Hence adopt the depth of concrete bed block

$$=27 \text{ cm.}$$

Width of foundation. In order to calculate the width of foundation, the total load per running metre on the foundation bed must be estimated.

(1) *Load due to wall per running metre.* In order to account for the weight of wall below ground level including the extra weight due to its increased base width above the concrete bed block, weight of one metre height of wall is added to the weight of wall above ground level while calculating the total wall load.

Hence wall load per running metre

$$= L\times B\times H\times \text{Weight per cu. metre of masonry}$$

$$= 1\times 0{\cdot}30\ (13{\cdot}5+1)\times 1920 = 8350 \text{ kg.}$$

(2) *Load due to concrete bed block per running metre* :

$$= L\times B\times d\times \text{Wt. per cu. metre of concrete}$$

$$= 1\times(2\times 0{\cdot}30+2\times 0{\cdot}15)\times{\cdot}27\times 1920$$

$$= 466 \text{ kg.}$$

(3) *Load due to roofing per running metre.* Load due to roofing consists of the following :

(*i*) Self wt. of 15 cm. thick R.C. slab

$= 2300 \times \cdot 15$

$= 345 \text{ kg/m}^2$

(*ii*) Weight of 10 cm. thick concrete terracing $= 192 \text{ kg/m}^2$

(*iii*) Live load $= 200 \text{ kg/m}^2$

Total $= 737 \text{ kg/m}^2$.

As the maximum span of the roof slab between two main walls is 4 metres, load per metre on each wall

$= 737 \times \frac{4}{1} = 1474$ kg.

(4) *Load due to R.C.C. floors.* As the building is three-storeyed high, the live load on the floor will be reduced as specified in Table 3·5 on page 106 and hence the dead loads and the live load due to floor are calculated separately.

Dead load per sq. m. due to flooring consists of :

(*i*) Self weight of 12 cm. thick R.C. slab

$= 2300 \times 0 \cdot 12$

$= 276$ kg.

(*ii*) Wt. of 25 mm. terrazzo flooring

$= 0 \cdot 025 \times 1920$

$= 48$ kg

Total $= 324 \text{ kg/m}^2$.

Dead load due to each floor on the each main wall per running metre

$= 324 \times \frac{4}{2} = 648$ kg.

Since there are two floors, total dead load per running metre

$= 2 \times 648$

$= 1296$ kg.

(5) Live load for the floors of residential building as given in Table 3·3 on page 100 = 200 kg/m².

As per table 3·5, reduction in total live load shall be made as below :

(*i*) Live load per running metre on each main wall due to 2nd floor

$$= 200 \times \frac{4}{2} \times \frac{90}{100} = 360 \text{ kg.}$$

(*ii*) Live load per running metre on each main wall due to 1st floor

$$= 200 \times \frac{4}{2} \times \frac{80}{100} = 320 \text{ kg.}$$

Total live load/metre = (*i*)+(*ii*) = 680 kg.

Total load (dead and live) per metre length of wall

= (1)+(2)+(3)+(4)+(5)

= 8350+466+1474+1296+680

= 12266 kg.

= 12·266 Tonnes.

$$\text{Required width of foundation} = \frac{12 \cdot 266}{16}$$

$$= 0 \cdot 767 \text{ m.}$$

which is less than the width assumed from practical consideration.

Hence, adopt the width of foundation = 2×30+15×2

= 90 cm.

Result : (*1*) *Depth of foundation* = *110 cm.*

(*2*) *Width of foundation* = *90 cm.*

(*3*) *Depth of concrete block* = *27 cm.*

3·7 Case II. Design of Foundations for a Brick Pier

Example. *Determine the necessary dimensions of brick footing and width of foundation concrete for a brick pillar 80 cm. square stressed to 55 tonne/m² of the section. Permissible pressure on concrete and earth may be taken as 33 tonne/m² and 11 tonne/m² respectively. Give a dimensioned sketch.*

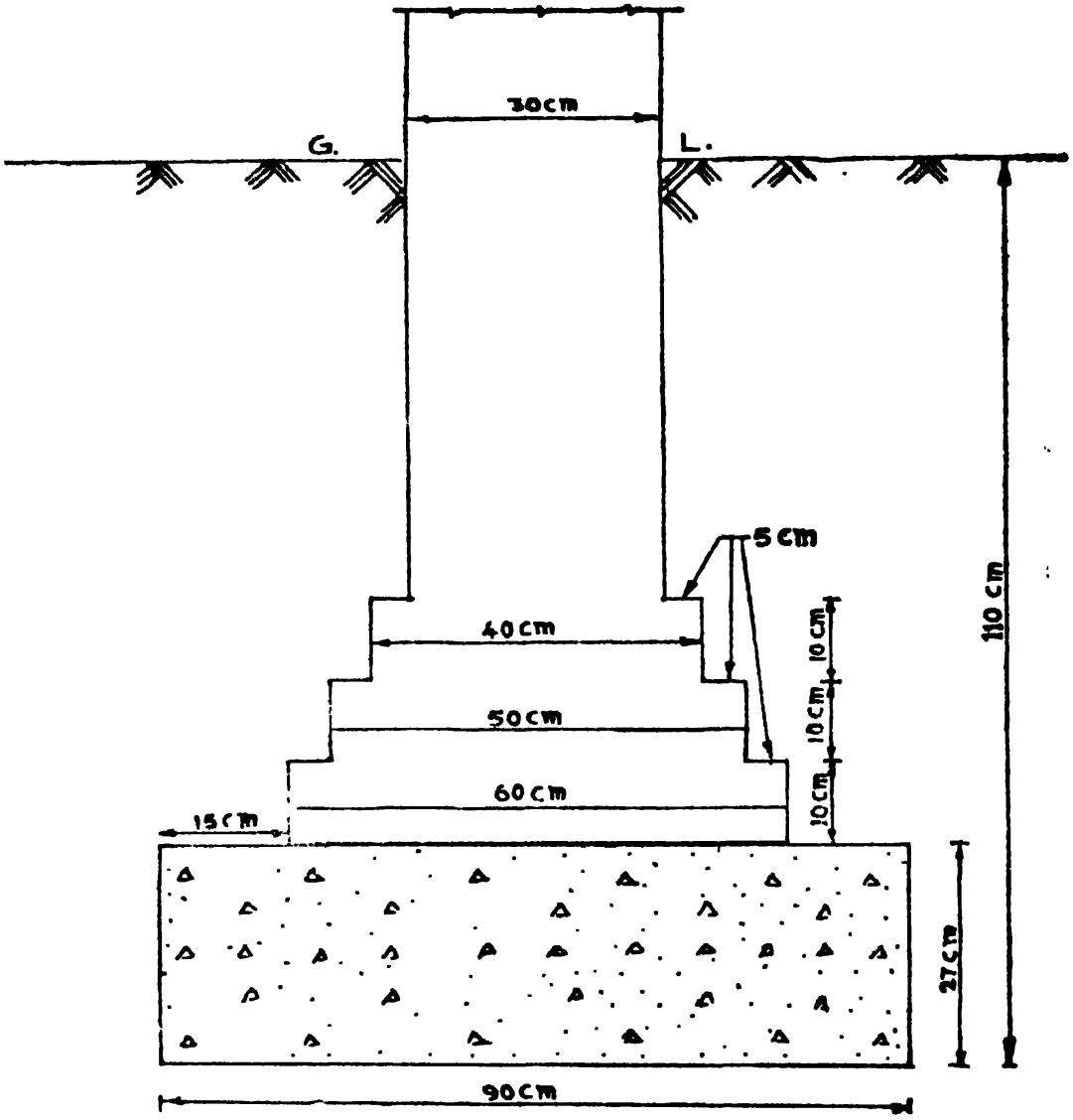


Fig. 3·2

Determine the depth of foundation for the above pillar, assuming angle of repose of earth as 30° and its weight as 1920 kg/m³.

Solution

Load on the brick pillar

$$= 0{\cdot}8 \times 0{\cdot}8 \times 55 = 35{\cdot}2 \text{ tonne.}$$

Sèlf-weight of foundation

(assumed) = 10% of 35·2 = 3·52 tonne.

Total load on soil = 35·2 + 3·52

= 38·72 tonne.

The base area of concrete block

$$= \frac{38{\cdot}72}{11}$$

$$= 3{\cdot}52 \text{ sq. m.}$$

One side or width of the square concrete block $= \sqrt{3{\cdot}52}$

$= 1{\cdot}875$ m say 1·9 m.

Necessary area of the bottom-most footing course of the pillar in contact with concrete bed block

$$= \frac{38{\cdot}72}{33}$$

$$= 1{\cdot}173 \text{ sq.m.}$$

One side of the square footing $= \sqrt{1{\cdot}173}$

$= 1{\cdot}08$ m.

Although the width of the bottom-most course of pillar footing works out to 1·08 m yet from consideration of economy and stability, the width of the bottom-most course of the pillar footing will be kept equal to $2 \times 80 = 1{\cdot}60$ m.

The increased base width will be obtained by means of regular offsets which will run symmetrically alround.

Depth of concrete block

$$d = \sqrt{\frac{3.p.j^2}{m}}$$

Assuming the concrete mix to be used is 1 : 3 : 6,

$$m = 3{\cdot}52$$

$$j = \frac{1{\cdot}9 - 1{\cdot}6}{2}$$

$$= {\cdot}15 \text{ m.}$$

$$\therefore \quad d = \sqrt{\frac{3 \times 11 - 0\,15^2 \times 1000}{3{\cdot}52}}$$

$$= \sqrt{211}$$

$$= 14{\cdot}5 \text{ cm.}$$

Depth of foundation :

It is given by the formula

$$D = \frac{p}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

$$= \frac{11\times 1000}{1920}\left(\frac{1-\sin 30°}{1+\sin 30°}\right)^2$$

$$= \frac{11\times 1000}{1920}\times\frac{1}{9}$$

$$= 0{\cdot}637 \text{ m},$$

$$= 63{\cdot}7 \text{ cm}.$$

But as per rule, a minimum depth of 90 cm. will be adopted.

Result :

Size of concrete block = *190 cm.* × *190 cm.*

Depth of concrete block = *14·5 cm.*

Size of lowermost course of brick pier = *160 cm.* × *160 cm.*

Depth of foundation = *90 cm.*

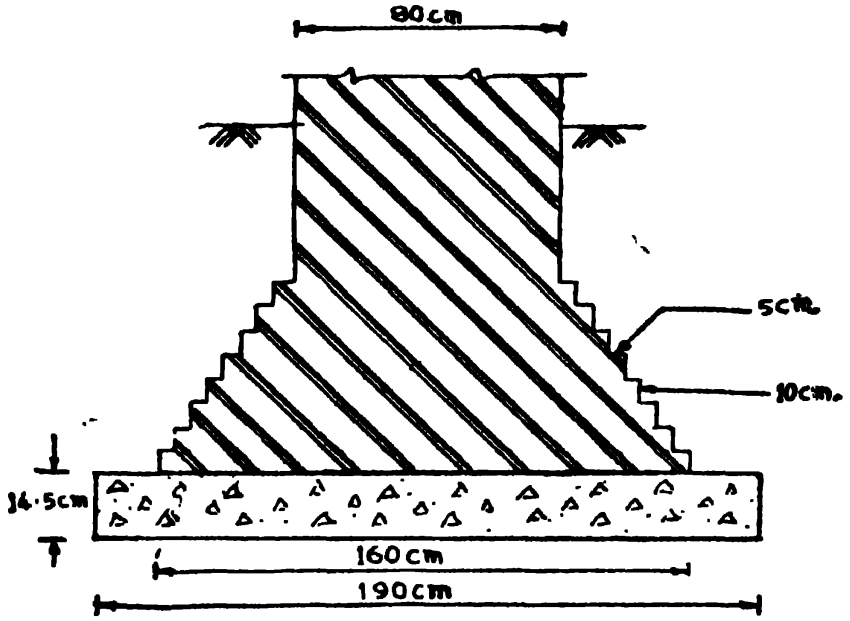


Fig. 3·3.

3 8. Case III. Design of Plain Cement concrete Footing for a Rolled Steel Stanchion

Example. *A rolled steel stanchion carries a load of 45 tonne and is to be bolted to a stone template on cement concrete base. The*

safe bearing strength of stone template and concrete may be assumed to be 230 tonne/m² and 145 tonne/m² respectively. Design a suitable foundation for this stanchion if the soil below the concrete bed block has a safe bearing capacity of 23 tonne/m².

Solution

The stanchion will transmit the load to the stone template through the steel base plate at its foot. The size of steel base plate depends upon the safe bearing strength of the stone template on which the base plate is to be bolted.

∴ The area of a square steel base plate for the stanchion

$$= \frac{45}{230}$$

$$= 0{\cdot}196 \text{ sq. m.}$$

One side of the square base plate $= \sqrt{0{\cdot}196}$

$$= 0{\cdot}444 \text{ m.}$$

$$= 0\ 45 \text{ m. say.}$$

$$= 45 \text{ cm.}$$

Thickness of the base plate may be taken to be 12 mm.

The size of the stone template depends upon the safe bearing strength of the concrete bed block on which it rests.

∴ The area of the stone template $= \frac{45}{145}$

$$= 0{\cdot}31 \text{ sq. m.}$$

One side of the stone template

$$= \sqrt{3{\cdot}1}$$

$$= 0{\cdot}557 \text{ m.}$$

$$= 0{\cdot}56 \text{ m. say.}$$

Thickness of the stone template may be taken as 20 cm.

Area of the concrete bed block depends upon the safe bearing strength of the soil on which it rests.

∴ Area of concrete bed block (neglecting the self-weight of the concrete bed block)

$$= \frac{0{\cdot}45}{23}$$

$$= 1{\cdot}96 \text{ sq. m.}$$

One side of the square concrete bed block

$$= \sqrt{1{\cdot}96}$$

$$= 1{\cdot}4 \text{ m.}$$

Depth (Thickness) of concrete bed block is given by the formula

$$d = \sqrt{\frac{3.p.j^2}{m}}$$

Assuming that 1 : 3 : 6 concrete mix is used for bed block construction.

$\therefore \quad m = 3{\cdot}52$

$$j = \frac{1{\cdot}4 - {\cdot}560}{2}$$

$$= 0{\cdot}42 \text{ m.}$$

$$d = \sqrt{\frac{3 \times 23 \times 1000 \times 42^2}{3{\cdot}52}}$$

$$= 59 \text{ cm.}$$

Divide this thickness in 2 steps of $\frac{59}{2} = 29{\cdot}5$ cm., say 30 cm. each.

Results : (*i*) *Size of stanchion base pate*

$= 45$ *cm.* $\times 45$ *cm.* $\times 12$ *mm. thick.*

(*ii*) *Size of stone template*

$= 56$ *cm.* $\times 56$ *cm.* $\times 20$ *cm. deep.*

(*iii*) *Size of concrete bed block*

$= 140$ *cm.* $\times 140$ *cm.* $\times$ *depth as shown.*

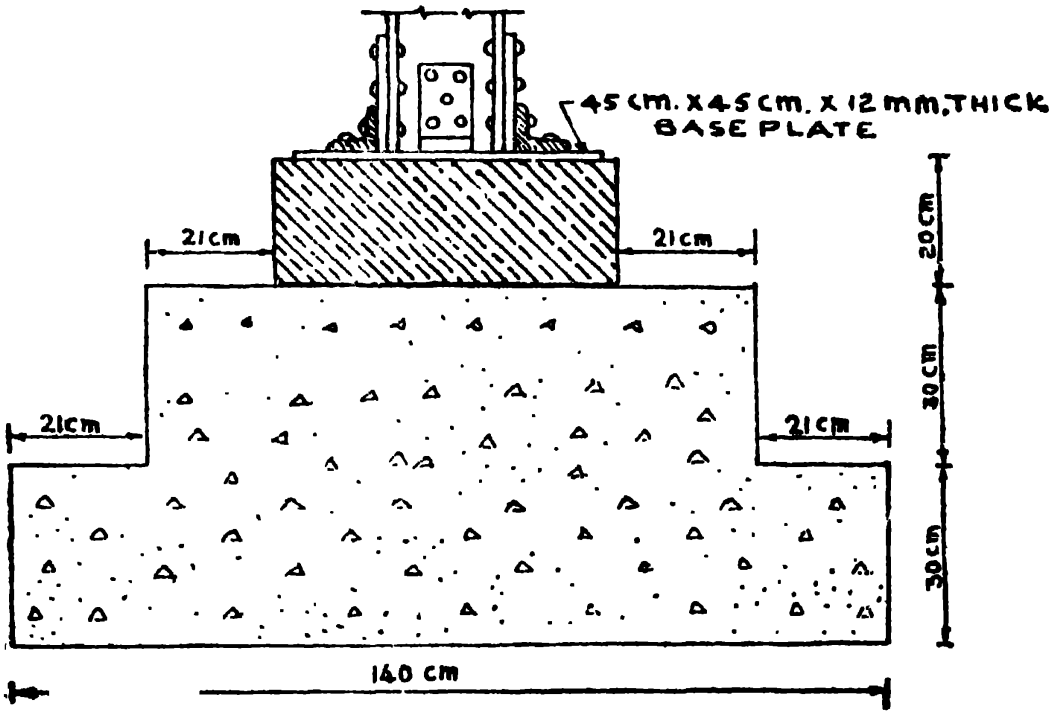


Fig. 3·4

3·9. Case IV. Design of Grillage Foundations. Fig. 3·5 shows a simple arrangement of one tier grillage for a steel stanchion. The formulae for the bending moment and shear force required for the design of grillage beams can be arrived at by the method described below :

Let W = load supported by one beam in kg.

L = length of the beam in cm.

l = length of the base plate in cm.

The load distribution is shown in the Fig. 3·5. It is evident that maximum bending movement in the beam

$$= \frac{W}{2} \times \frac{L}{4} - \frac{W}{2} \times \frac{l}{4}$$

$$= \frac{W}{8}(L-l) \text{ kg. cm.}$$

Maximum shear on the beam occur at the edge of the base plate.

Upward soil pressure on the beam per cm. length

$$= \frac{W}{L} \text{ kg.}$$

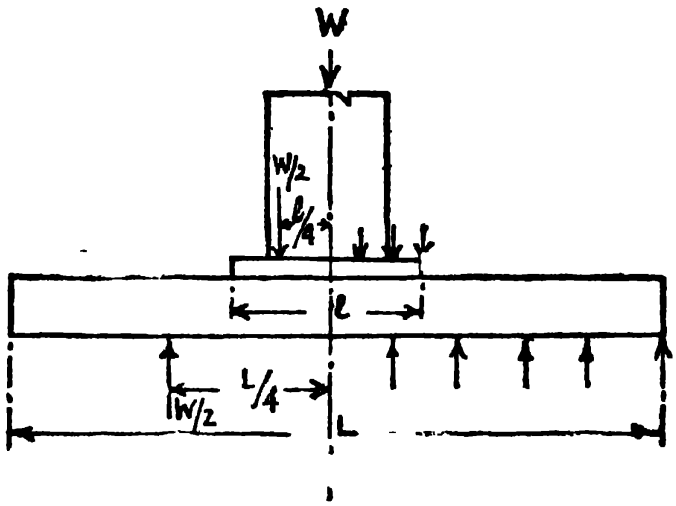


Fig. 3·5

Cantilever projection of the beam, beyond the edge of the base plate

$$= \left(\frac{L-l}{2}\right) \text{cm.}$$

$\therefore$ Maximum shear force on the beam $= \frac{W}{L}\left(\frac{L-l}{2}\right)$ kg.

Example. *Design a suitable grillage foundation for a steel stanchion, bearing load of 100 tonne and give suitable sketch drawings.*

The safe bearing power of the soil is 11 tonnes/sq. m.

The base of the stanchion is 60 cm. × 60 cm.

Solution

Load on stanchion (W) = 100 tonne.

add 10% of (W) being the assumed weight of foundation = 10 tonne.

Total = 110 tonne.

Area of the base of foundation $= \frac{110}{11}$

$= 10$ sq. m.

One side of the square base $= \sqrt{10}$

$= 3{\cdot}16$ m.

or $L = 316$ cm.

Adopt an over-all size of one side of the square base as $316+2\times 12 = 340$ cm.

(12 cm. being the assumed side cover for the grillage beams).

One side of the stanchion base plate = 60 cm.

or $l = 60$ cm.

It is proposed to provide grillage beams in two tiers.

Design of grillage beams in upper tier :

Max. bending moment in the beams

$$= \frac{W}{8}(L-l)$$

$$= \frac{100}{8}(316-60)$$

$= 3200$ tonne cm.

$= 32,00,000$ kg. cm.

It is proposed to provide 3 rolled steel joists in the upper tier.

$\therefore$ Bending moment per joist

$$= \frac{32,00.000}{3} \text{kg. cm.}$$

Since $M = fZ$

$\therefore$ $Z = \frac{M}{f}$

$$= \frac{32,00,000}{3} \times \frac{1}{1400}$$

$= 762$ cm^2.

Referring steel tables, adopt 350 mm. × 140 mm. × 52·4 kg./m. R.S.J. having the following properties :

$$Z_{xx} = 778{\cdot}9 \text{ cm}^3$$

Web thickness = 8·1 mm, = 0·81 cm.

Check for the clear distance between the beams :

Space occupied by flange width of three beams

$$= 3 \times 140$$
$$= 420 \text{ mm.}$$
$$= 42 \text{ cm.}$$

Width of column base plate = 60 cm.

$$\text{Clear space between the beams} = \frac{60-42}{2}$$
$$= 9 \text{ cm.}$$

which is more than minimum allowable distance of 8 cm., hence safe.

Check for shear : Total max. shear force is given by the formula

$$\text{S.F.} = \frac{W}{L}\left(\frac{L-l}{2}\right)$$
$$= \frac{100}{316}\left(\frac{316-60}{2}\right)$$
$$= 44{\cdot}5 \text{ tonne.}$$
$$= 44500 \text{ kg.}$$

$$\text{Shear force per joist} = \frac{44500}{3} \text{ kg.}$$

(As per I.S.I., web area resisting shear should be taken equal to depth of beam multiplied by the web thickness.)

$$\therefore \text{ Shear stress per joist} = \frac{44500}{3 \times 0{\cdot}81 \times 35}$$
$$= 523 \text{ kg./sq. cm., which is much}$$

less than 910 kg./sq. cm., the safe allowable shear stress in beam, hence safe.

Design of grillage beams in the lower tiers

Total max. bending moment as calculated before

$$= 32{,}00{,}000 \text{ kg. cm.}$$

It is proposed to provide 10 (R.S.J.) in the lower tier.

$\therefore$ Bending moment per joist

$$= \frac{32{,}00{,}000}{10} = 3{,}20{,}000 \text{ kg. cm.}$$

Again, since $M = fZ$

$$\therefore \quad Z = \frac{M}{f}$$

$$= \frac{320{,}000}{1400}$$

$$= 228{\cdot}5 \text{ cm}^3$$

Referring steel tables adopt :

250 mm. × 125 mm. × 27·9 kg./m. R.S.J.'s having the following properties :

$$Z_{xx} = 297{\cdot}4 \text{ cm}^3$$

Thickness of web = 6·1 mm. = 0·61 cm.

Since the base width is 316 cm., as such ample space will be available between the centre of the two successive beams and hence there is no need of giving check for clear distance between the beams.

Check for shear : Total max. shear force as calculated earlier

$$= 44500 \text{ kg.}$$

Shear force per joist $= \frac{44500}{10} = 4450$ kg.

Web area resisting shear = 0·61 × 25 sq. cm.

$$S = \frac{4450}{0{\cdot}61 \times 25}$$

$$= 292 \text{ kg./sq.cm.,}$$

which is less than 910 kg./cm², hence safe.

Result :

(*i*) *Size of foundation base = 340 cm. × 340 cm.*

(*ii*) *Beams in upper tier = 3 Nos. 350 mm. × 140 mm. × 52·4 kg./m. R.S.J.*

(*iii*) *Beams in lower tier = 10 Nos. 250 mm. × 125 mm. × 27·9 kg./m. R.S.J.*

(*iv*) *Side cover for the beams = 12 cm.*

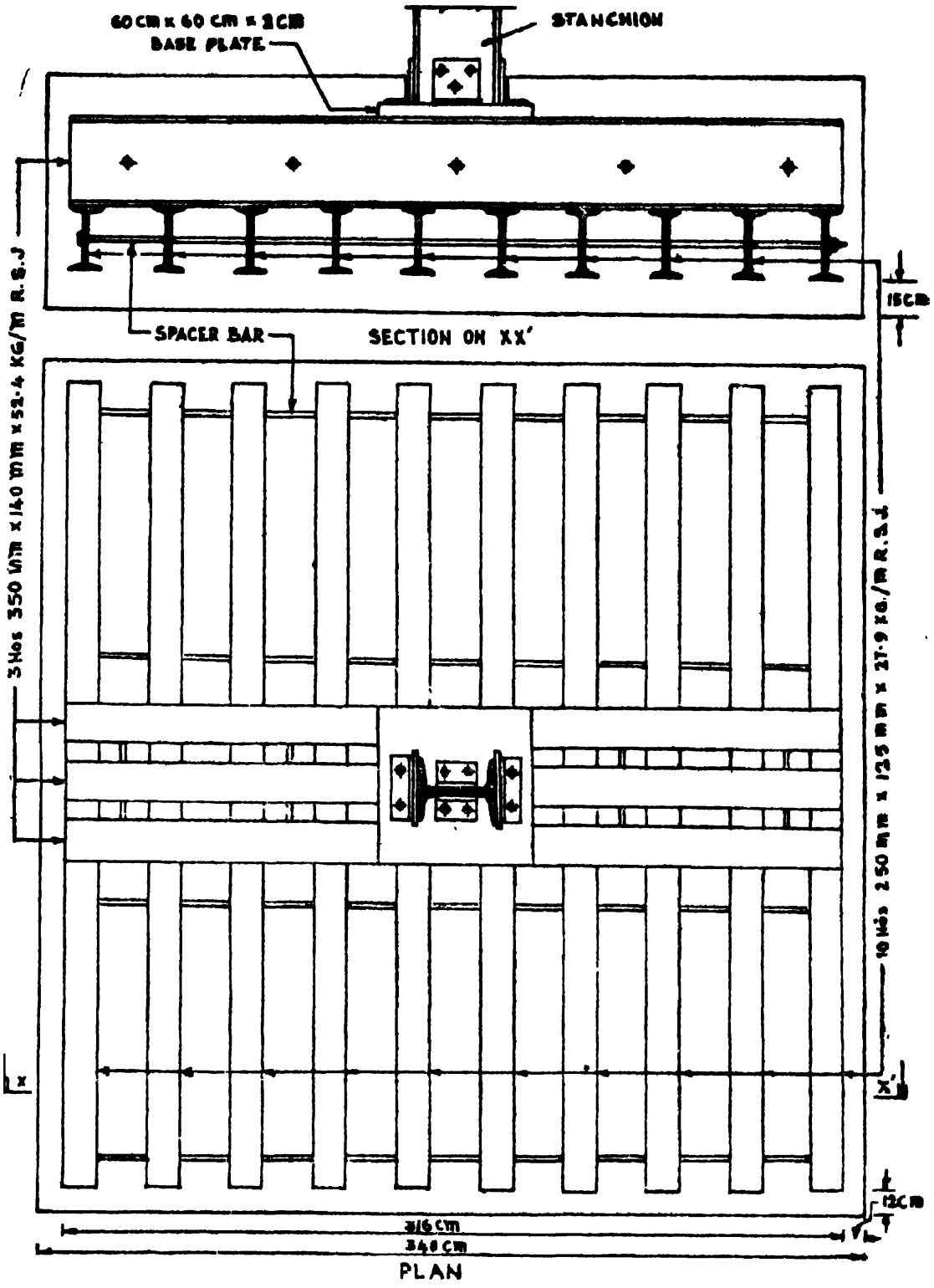

60 cm x 60 cm x 2 cm
BASE PLATE
STANCHION
SPACER BAR
SECTION ON XX'
3 Nos 350 MM x 140 MM x 52·4 KG/M R.S.J
10 Nos 250 MM x 125 MM x 27·9 KG/M R.S.J
15 cm
12 cm
X
X'
346 cm
340 cm
PLAN

Fig. 3·6

Common Data for R.C.C. Designs

The following data has been adopted in design problems in this book.

Concrete Mix : M150 (1 : 2 : 4)

$m=18$

Description	*Metric system*	*Foot-lb. system*
Stress in steel (t)	1400 kg/sq. cm.	18000 lb./sq. in.
Stress in concrete (c)	50 "	750 "
Average bond stress	6 "	100 "
Local bond stress (S_b)	10 "	175 "
Shear stress (s)	5 "	75 "
Neutral axis factor (n_1)	0·39	0·429
Lever arm factor (a_1)	0 87	0·857
Resisting moment co-efficient (Q)	8·48	137·5
Weight of R.C.C.	2400 kg./cu. m.	144 lb./cu. ft.

COMMON CONVERSION FACTORS

Multiply by	*To convert*	*to*
2·54	Inches	Centimentres
0·3048	Feet	Metres
0·4536	Pounds	Kilograms
1·488	lb. per ft.	kg./metre
0·07	lb. per sq. in	kg./sq. cm.
4·883	lb. per sq. ft.	kg./sq. metre
16	lb. per cu. ft.	kg./metre^3
1·016	Tons	Tonne
3·333	Ton per ft.	Tonne/metre
10·937	Ton per sq. ft.	Tonne/sq. metre
0·138	Ft. lb.	kg. metre
1·15	In. lb.	kg. cm.

3·10 Case V—Design of R.C.C. Footings for a Wall. In this case, the width of foundation bed is obtained by dividing the load per m. run of the wall by the bearing capacity of the soil. The footing is assumed to be acting as a fixed beam and the projection of the footing from either face of wall acting as cantilever. Thus the maximum bending moment in the footing is assumed to occur at the wall face and the footing section is suitably designed as described in the example on Page 125.

Example. *Design a R.C.C. raft foundation for a wall carrying 20 tonne per running metre at foundation level on loose soil having a safe bearing capacity of 5 tonne/m².*

Solution

Load on foundation = 20 tonne/m.

Safe B.C. of soil = 5 tonne/m²

$\therefore$ Width of foundation $= \frac{20}{5} = 4$ metres.

Assuming the safe compressive stress in masonry (of which the wall is built to be) 70 tonnes/m².

Thickness of wall $= \frac{20}{70} = 0{\cdot}286$ m.

$= 28{\cdot}6$ cm.

$= 30$ cm. say.

Projection of concrete raft beyond wall face on either side

$= \frac{4-0{\cdot}3}{2}$

$= 1{\cdot}85$ m.

Upward soil pressure per metre length of wall = 5 tonne/m = 5000 kg./m. 1·85 metre projection of concrete raft slab on either side of wall face acts as cantilever slab loaded from below with a uniformly distributed load of 5000 kg/m.

Max B.M. occurs at the face of wall, its value being

$= 5000 \times 1{\cdot}85 \times \frac{1{\cdot}85}{2}$

$= 8550$ kg. m.

$= 8,55,000$ kg. cm.

Effective depth of concrete raft slab :

or $$d = \sqrt{\frac{M}{Q.b}}$$

$$= \sqrt{\frac{80,55,000}{8{\cdot}48 \times 100}}$$

$$= \sqrt{1011}$$

$$= 31{\cdot}8 \text{ cm.}$$

Providing a cover of 7 cm. for the slab, adopt an over-all depth of raft slab = 39 cm. and an effective depth = 32 cm.

Area of steel per metre length of slab

$$= \frac{M}{a_1 . d.t}$$

$$= \frac{855000}{0{\cdot}87 \times 32 \times 1400}$$

$$= 21{\cdot}9 \text{ sq. cm.}$$

Provide 20 mm. ϕ bars @ 14 cm. c/c.

Max. S.F. at the face of wall :

or $S = 5000 \times 1{\cdot}85$

$= 9250$ kg.

Check for bond :

$$\sigma_b = \frac{S}{a_1 . d.\Sigma O}$$

No. of bars in one metre length = 8

Perimeter of one mm. ϕ bar = 6·28

$$\therefore \quad S_b = \frac{9250}{0{\cdot}87 \times 32 \times 8 \times 6{\cdot}28}$$

$$= 6{\cdot}61 \text{ kg/cm}^2.$$

which is less than 10 kg./cm², hence safe.

The slab need not be kept of uniform thickness and may be sloped at ends.

Let the sides of the slab be sloped so as to get the thickness of slab at ends = 23 cm.

The critical section XX for shear will be located at a distance equal to the effective depth of footing slab from the face of wall. Hence the shear is checked at this depth.

Effective depth of footing at 32 cm. from face of wall

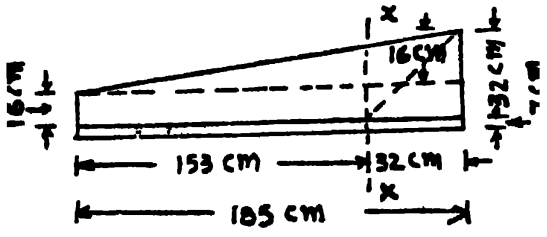


Fig. 3·7

$$16 + \frac{16 \times 153}{185}$$

$$= 16 + 13{\cdot}22$$

$$= 29{\cdot}22 \text{ cm.}$$

Shear force at the critical section = $500 \times 1{\cdot}53$

$= 7650$ kg.

Check for shear :

$$s = \frac{S}{a_1.d.b}$$

$$= \frac{7650}{0{\cdot}87 \times 29{\cdot}22 \times 100}$$

$$= 3{\cdot}01 \text{ kg./cm}^2$$

which is less than 5 kg./sq. cm., hence safe.

Distribution bars @ 0·15% of the average gross-sectional area of concrete

$$= \frac{0{\cdot}15\ (40+23) \times 100}{2 \times 100}$$

$$= 4{\cdot}73 \text{ cm}^2.$$

Provide 10 mm. bars @ 16 c/c.

Result :

(*i*) *Width of foundation* = *400 cm.*

(*ii*) *Depth of raft slab* = *39 cm. reduced to 23 cm. at ends.*

(*iii*) *Main reinforcements* = *20 mm. ϕ bars @ 14 cm c/c.*

(*iv*) *Distribution bars* = *10 mm. ϕ bars @16 cm. c/c.*

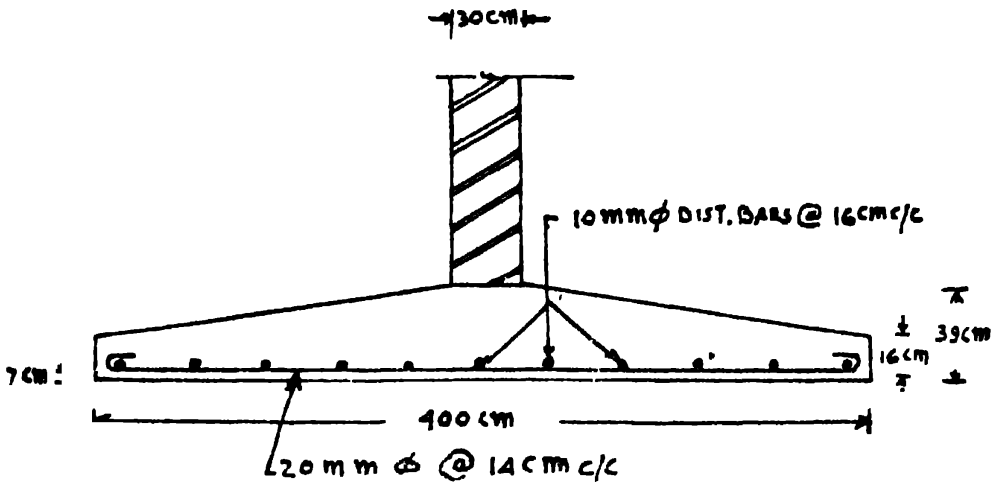


Fig. 3·8

3·11 Case VI—Isolated Column Footing, Isolated column footing consists of a square or rectangular slab which may be of uniform thickness or may be tapered or stepped. The section of footing must satisfy the following conditions :

(i) It should be safe against punching shear. Punching shear is one of the deciding factors in fixing the depth of footing slab.

Punching shear. In punching shear, the following equation holds good :

The perimeter of the column × Depth of footing × Safe punching stress = Total punching load.

or $$4 \times b \times d \times Sp = p(a^2 - b^2)$$

where Sp = allowable punching shear stress. Its value for M150 (1 : 2 : 4) concrete mix is 10 kg/cm². In general, the value of Sp is twice the value for safe shear stress in concrete.

$$p = \text{Net upward pressure} = \frac{\text{Load on column}}{\text{Area of footing}}.$$

(2) It should be safe in bending. The depth of the footing must be sufficient to provide a moment of resistance equal to the maximum bending moment which occur at the face of the column.

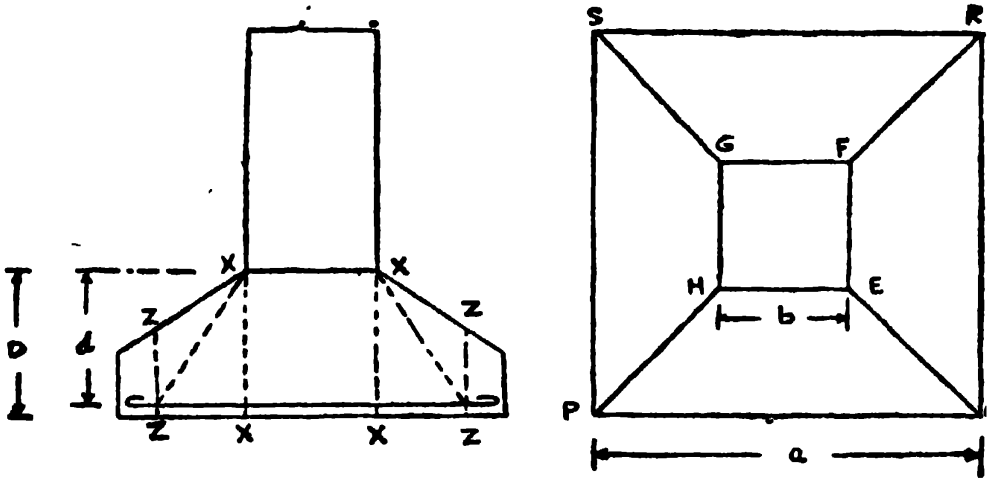


Fig. 3·9

The max. B.M. about a vertical plane through H.E.

= Total reaction on the trapezium $PQEH$ × Distance of *e.g.* of the trapezium from H.E.

or $$M = \tfrac{1}{2}\, p(a+b)(a-b)\left\{\left(\frac{b+2a}{b+a}\right)\left(\frac{a-b}{2}\right)\frac{1}{3}\right\}$$

$$= \frac{1}{24}\, p(a-b)^2(2a+b)$$

(3) The depth of the footing at the section Z-Z must be sufficient to keep the shear stress at the section within safe limit.

Steps to be followed in the design

(*a*) To the load W on the column add 10% of the load W, (which being the assumed weight of footing) to get the total load on foundation.

(*b*) Find out the area (A) of the footing by dividing the total load calculated in (*a*) by the safe bearing capacity of the soil.

(*c*) Find the net upward pressure of the soil given by :

$$p = \frac{W}{A}$$

(*d*) Calculate the effective depth of the footing from consideration of punching shear and bending moment.

(*e*) Adopt the bigger of the two depths as the effective depth of footing and add 7 cm. to it to get the total depth of footing.

(*f*) Calculate the area of steel given by the formula

$$A_t = \frac{M}{a_1.d.t}$$

As per the revised Indian Standard Code of Practice, I.S. 456—1964, the area of reinforcement as calculated above should be provided in the full width of footing.

(*g*) Usually the footing slab is sloped down to say 15 to 25 cm. at the ends. Calculate the depth (d') of footing and find the S.F. (S') at the section Z-Z (a vertical section located from the face of column at a distance equal to the effective depth of the footing).

S.F. at section Z-Z (Refer Fig. 3·9) is given by,

$$S' = \frac{p}{4}\{a^2-(b+2d)^2\}.$$

(*h*) Check for shear at section Z-Z

$$S = \frac{S'}{a_1 d'.b'}$$

where $$b' = b+2d$$

(*i*) *Check for bond* : The bond stress should be checked at the face of column.

Example. *Design a reinforced concrete foundation footing for a column bearing a vertical load of 101 tonne. The bearing power of soil is 11 tonne/m².*

Given : $f_c = 50$ *kg/sq. cm.*
$f_s = 1400$ *kg/sq. cm.*
$m = 18$.

The base size of the column is 60 cm. × *60 cm.*

Solution

Load on column = 101 tonne.

Add 10% due to assumed weight of footing = 10·1

Total = 111·1 tonne.

Required area of the base of footing

$$\frac{111{\cdot}1}{11} = 10{\cdot}1 \text{ sq. metre.}$$

One side of the square base $= \sqrt{10{\cdot}1}$

$= 3{\cdot}175$ m.

Adopt one side the footing as 3·2 metre.

Net upward pressure on the foundation

$$p = \frac{101}{3{\cdot}2^2} = 9{\cdot}87 \text{ tonne/m}^2$$

$$= 9870 \text{ kg/m}^2,$$

Depth of foundation

(*i*) From consideration of punching shear.

Total punching shear round the column

$$= p(a^2 - b^2)$$

$$= 9870(3{\cdot}2^2 - 0{\cdot}6^2)$$

$$= 97600 \text{ kg.}$$

Assuming d to be the depth of the footing in cm., total force resisting punching shear

$$= 4 \times b \times d \times Sp$$

$$= 4 \times 60 \times d \times 10$$

$$= 2400d$$

$$\therefore \quad 2400d = 97600$$

or $$d = \frac{97600}{2400}$$

$$= 40{\cdot}7 \text{ cm.}$$

(*ii*) From consideration of bending moment

$$M = \frac{1}{24} p(a-b)^2(2a+b)$$

$$= \frac{9870}{24} (3{\cdot}2-0{\cdot}6)^2(2\times 3{\cdot}2+0\ 6)$$

$$= 19470 \text{ kg. m.}$$

$$= 1947000 \text{ kg. cm.}$$

$$d = \sqrt{\frac{M}{Q\,b}}$$

$$= \sqrt{\frac{1947000}{8{\cdot}48\times 60}}$$

$$= 61{\cdot}8 \text{ cm.}$$

Hence the depth of footing from bending moment consideration is more, and as such, provide an over-all depth of footing = 69 cm. and an effective depth = 69−7 = 62 cm.

Area of steel required for the full width of footing.

$$A_t = \frac{M}{a.d.t}$$

$$= \frac{1947000}{0{\cdot}87\times 62\times 1400}$$

$$= 25{\cdot}8 \text{ sq. cm.}$$

According to revised I.S. Code of Practice, this area of steel should be provided in full width of footing.

∴ Area of reinforcement per metre width of footing

$$= \frac{25{\cdot}8}{3{\cdot}2} = 8{\cdot}06 \text{ sq. cm.}$$

Provide 14 mm. ϕ bars at @ 19 cm. c/c. Let the footing be sloped to an overall depth of 25 cm. at the edges.

Shear force at the critical section or at a vertical section 62 cm. away from the face of the column.

$$S' = \frac{p}{4}\{a^2-(b+2d)^2\}$$

$$= \frac{9870}{4}\{3{\cdot}2^2-(0{\cdot}6+2\times 0{\cdot}62)^2\}$$

$$= 16940 \text{ lb.}$$

Effective depth of footing at the critical section

$$d' = 18+\frac{44}{130} \times 68$$

$$= 41 \text{ cm.}$$

Width of footing slab at critical section

$$b' = b+2d$$
$$= 60+2\times 62$$
$$= 184 \text{ cm.}$$

Check for shear

$$s = \frac{S}{a_1.d'.b'}$$

$$= \frac{16940}{0\,87\times 41\times 184}$$

$$= 3{\cdot}2 \text{ kg./sq. cm.}$$

which is less than 5 kg./sq. cm., hence safe.

Check for bond :

Total shear force (Punching shear) around the column faces

$$= 97600 \text{ kg.}$$

Shear force on one face of column

$$= \frac{97600}{4}$$

$$= 24400 \text{ kg.}$$

Total No. of 14 mm. ϕ bars provided along one face of column

$$= \frac{320}{19}+1$$

$$= 16{\cdot}87+1 = 17{\cdot}87 \text{ say } 18 \text{ Nos.}$$

$$S_b = \frac{S}{a_1.d\,\Sigma 0}$$

$$= \frac{24400}{0{\cdot}87\times 62\times 18\times 4{\cdot}4}$$

$$= 5{\cdot}72 \text{ kg./sq. cm.}$$

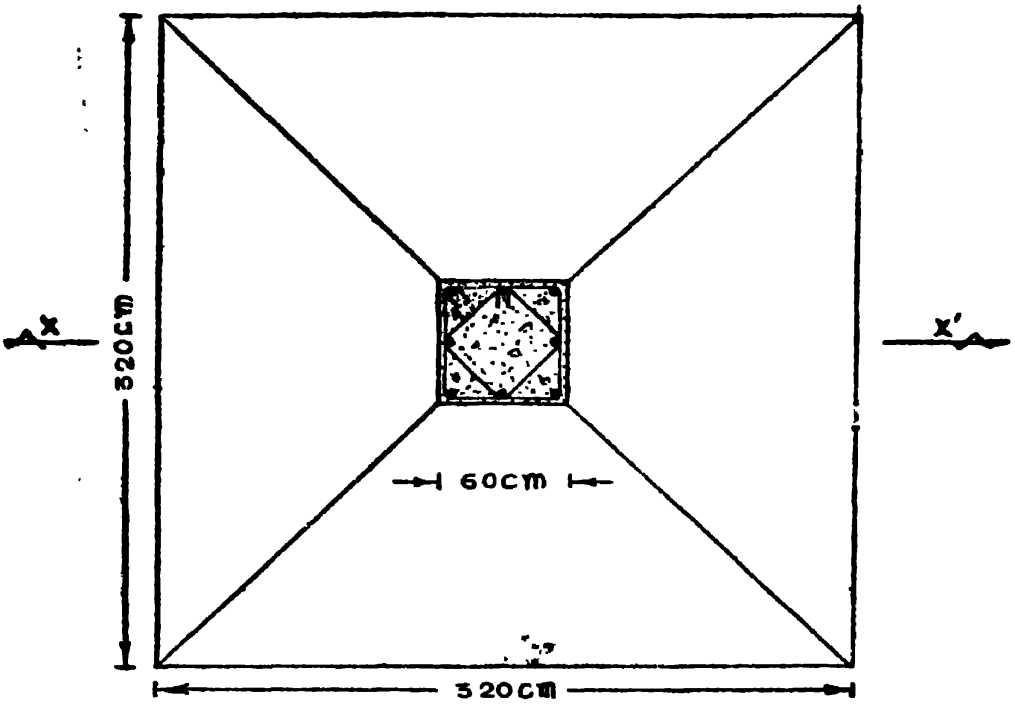
which is less than 10 kg./sq. cm., hence safe.

Result :

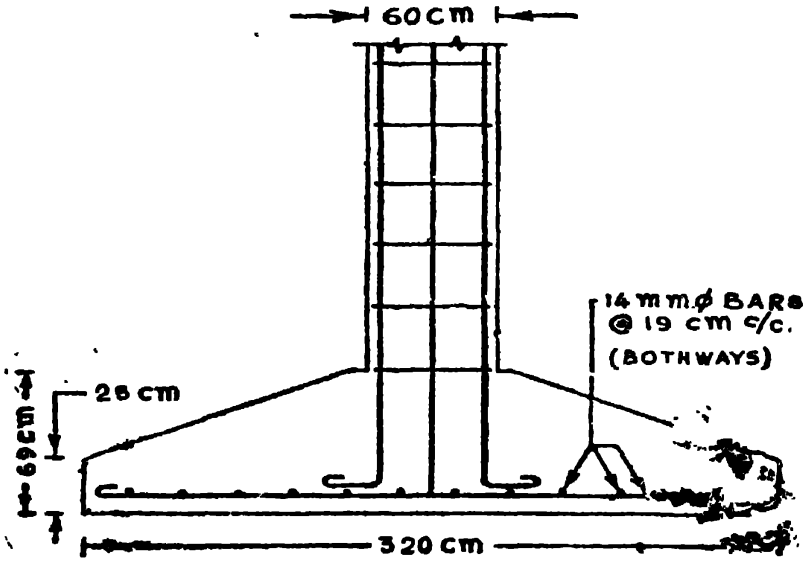
(*i*) *Size of column footing* = *320 cm.* × *320 cm.*

(*ii*) *Depth of column footing* = *69 cm. reduced to 25 cm.*

(*iii*) *Main reinforcements* = *14 mm. ϕ bars @ 19 cm. c/c. both ways.*



PLAN



SECTION AT XX

Fig. 3·10

3·12 Design of a Circular Column Footing. The design procedure of a circular column footing is the same as that of a two-way reinforced square R.C. column footing. The only difference in this case is that the value of "*b*" is taken to be equal to $\frac{1}{4}$th the circumference of the column.

Example. *Design the foundation for an axially loaded circular R.C. column 60 cm. in diameter and carrying an axial load of 113 tonne. The safe bearing capacity of the soil is 12·2 tonne per sq. m.*

Solution

(*i*) Load on the column = 113 tonne

Add 10% of (*i*) for the assumed weight of the footing = 11·3 tonne

Total 124·3 tonne

Required area of the footing

$$= \frac{124·3}{12·2} = 10·20 \text{ m}^2.$$

It is purposed to provide a circular footing. If "*d*" be the diameter of the footing, then

$$\frac{\pi}{4}d^2 = 10·2$$

$$\therefore \quad d = \sqrt{\frac{10·2 \times 4}{\pi}} = 3·61 \text{ m.}$$

Adopt the diameter of the footing = 3·7 m. (say)

Net upward pressure of the soil

$$= \frac{113 \times 1000}{\frac{\pi}{4} \times 3·7^2}$$

$$= 10500 \text{ kg./sq. m.}$$

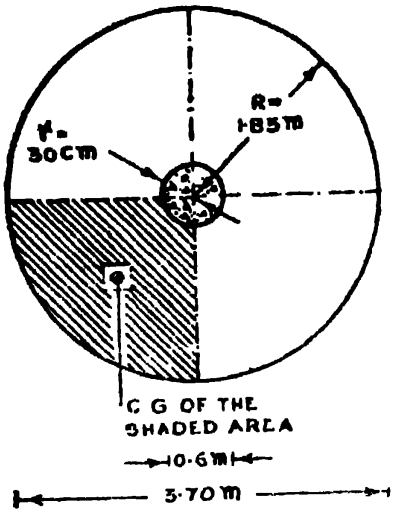


Fig. 3·11

To fix the depth of the footing :

(*i*) From consideration of bending moment.

The distance of the centroid of the shaded area from the axis of the column is given by the expression

$$= \frac{0·6\,(R^2 + R.r + r_2)}{(R + r)}$$

$$= \frac{0·6\,(1·85^2 + 1·85 \times 0·3 + 0·3^2)}{(1·85 + 0·3)}$$

$$= 1·136 \text{ m}, = 113·6 \text{ cm.}$$

Value of b, the breadth of the shaded portion in front of the column face

$$= \frac{\pi d}{4} = \frac{\pi \times 60}{4} = 47{\cdot}13 \text{ cm.}$$

Area of the shaded portion of the footing

$$= \frac{1}{4}(\pi R^2 - \pi r^2)$$

$$= \frac{\pi}{4}(1{\cdot}85^2 - 0{\cdot}3^2) = 2{\cdot}62 \text{ sq. m.}$$

Load on the shaded area due to net upward pressure

$$= 2{\cdot}62 \times 10500 \text{ kg.}$$

B.M. at the face of the column

$$= 2{\cdot}62 \times 10500 \times (113\ 6 - 30)$$

$$= 2300000 \text{ kg. cm.}$$

Required effective depth of the footing

$$d = \sqrt{\frac{M}{Q\,b}}$$

$$= \sqrt{\frac{2300000}{8{\cdot}48 \times 47{\cdot}13}} = 75{\cdot}9 \text{ cm.}$$

(*ii*) Depth from consideration of punching shear.

Total punching force

$$= p\left(\frac{\pi}{4} \times 3{\cdot}7^2 - \frac{\pi}{4} \times 0{\cdot}6^2\right)$$

$$= 10500 \times \frac{\pi}{4}(3{\cdot}7^2 - 0{\cdot}6^2)$$

$$= 110000 \text{ kg.}$$

If d' be the depth of the footing, then total force preventing punching

$$= 10 \times \pi \times 60 \times d'$$

$$\therefore \quad 10 \times \pi \times 60 \times d' = 110000$$

$$\therefore \quad d' = \frac{110000}{10 \times \pi \times 60} = 58{\cdot}4 \text{ cm.}$$

Hence adopt the over-all depth of the footing

$$= 83 \text{ cm.}$$

and effective depth $= 76$ cm.

Area of steel required $= \dfrac{2300000}{0{\cdot}87 \times 76 \times 1400}$

$= 24{\cdot}85$ sq. cm.

No. of 16 mm. ϕ bars needed

$= \dfrac{24{\cdot}85}{2\,01} = 12{\cdot}35$ say 13 Nos.

The bars should be arranged in the form of a square mesh centrally located under the column. The width of the square being equal to the length of one side of the square that can be inscribed in the circular footing of diameter $= 3{\cdot}7$ m.

$\therefore$ Length of the side of inscribed square

$= \dfrac{D}{\sqrt{2}} = \dfrac{3{\cdot}7}{\sqrt{2}} = 2{\cdot}61$ metre.

Check for shear

It is proposed to taper the footing slab to 25 cm. at the edges. The critical section for diagonal tensile stress or shear occur at a distance of effective depth of the footing from the face of the column.

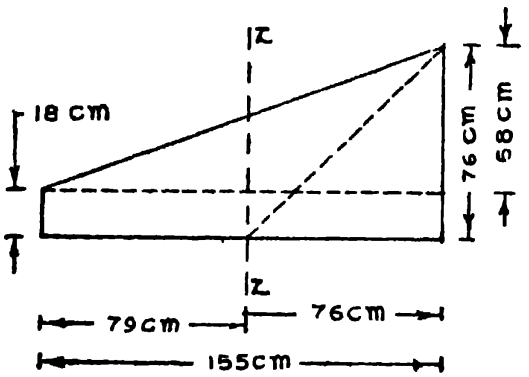


Fig. 3·12

The effective depth of the footing at the critical section Z-Z

$= 18 + \dfrac{58}{155} \times 79$

$= 47{\cdot}6$ cm.

Radius of the footing at the critical section

$= 76 + 30 = 106$ cm.

$= 1{\cdot}06$ m.

Shear force at the critical section

$= p.\pi(1{\cdot}85^2 - 1{\cdot}06^2)$

$= 10500 \times \pi \times (1{\cdot}85^2 - 1{\cdot}06^2)$

$= 75650$ kg.

Breadth of the footing at the critical section (b')

$= 2\pi \times 1{\cdot}06$ m.

$2\pi \times 1{\cdot}06 \times 100$ cm.

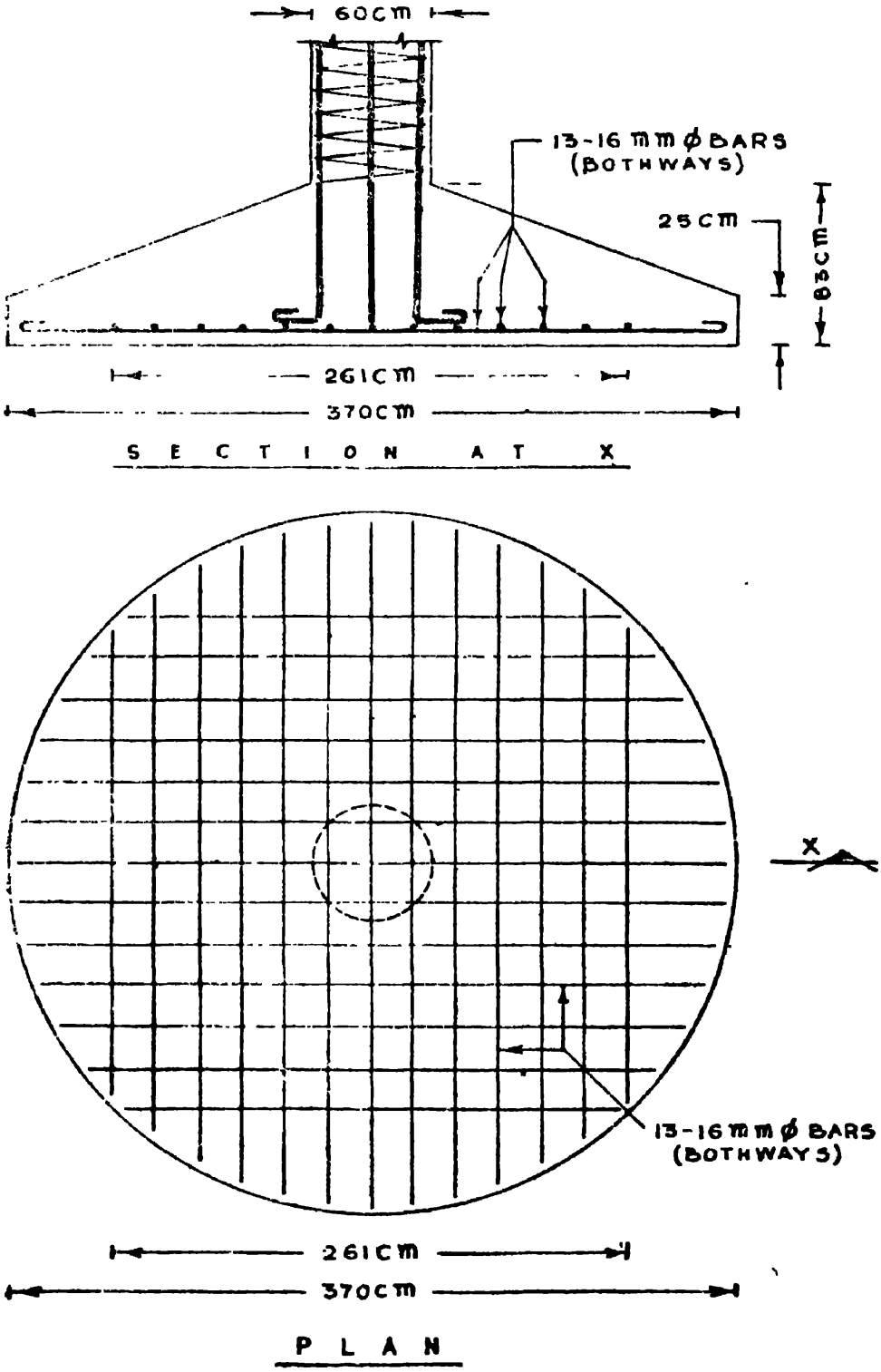

60cm
13-16 mm ϕ BARS
(BOTHWAYS)
25cm
83cm
261cm
370cm
SECTION AT X
X
13-16 mm ϕ BARS
(BOTHWAYS)
261cm
370cm
PLAN

Fig. 3·13

$$s = \frac{S}{a_1.d.b}$$

$$= \frac{75650}{0.87 \times 47.6 \times 2\pi \times 1.06 \times 100}$$

$$= 2.745 \text{ kg./sq cm}$$

which is less than 5 kg/sq. cm., hence safe.

Check for bond :

Max. S.F. at the column face

$$= 10500 \times 2.62 \text{ kg.}$$

$$S_b = \frac{S}{a_1.d\Sigma 0} = \frac{10500 \times 2.62}{0.87 \times 76 \times 13 \times 5.03}$$

$$= 6.36 \text{ kg./sq. cm. (safe)}$$

Questions for Revision

1. A room 3 m by 3·66 m. internally has 30 cm. wall all round. Load transferred to foundation per running metre is 10 tonne and the bearing capacity of soil at 90 cm. depth is 14 tonne/sq. m. Plinth is to be kept 60 cm. above the ground level. Design a suitable section for the footing and wall upto plinth level and estimate the quantities involved. Weight of earth is 1760 kg./m³ and angle of repose is 30°.

2. A shed is to be constructed 12 m. long and 7·4 m. wide internally having 30 cm. thick walls on the shorter sides. Four pillars 30 cm. × 30 cm. are provided on each longer side with clear spacing of 2·1 m. Draw a trench plan of the shed having the following data :

(*i*) Angle of repose 30°:

(*ii*) Wt. of earth : 1760 kg/m³.

(*iii*) Safe bearing capacity of soil : 11 tonne/sq. m.

(*iv*) Plinth 45 cm. above ground.

(*v*) Load on wall at plinth level : 10 tonne/running metre.

(*vi*) Load on each pillar at plinth level 10 tonne.

3. A steel column carrying an axial load of 255 tonne is to be founded on a soil having its safe bearing capacity of 16 tonne/sq. m. The column base plate is to be 60 cm. square. Design a suitable steel grillage foundation and make a detailed sketch of the same.

4. A weight of 27 kg. is dropped vertically on the bottom of foundation trench from a height of 3 metres and makes an impression of 6 mm. The base of the weight is 18 cm. × 18 cm. in size. Calculate the safe bearing pressure per sq. metre assuming a factor of safety of 8.

5. Calcutate the width and depth of a plain cement concrete foundation supporting a wall carrying a load of 33 tonne/metre run at the foundation level. The safe allowable pressure on the soil is to be limited to 11 tonne/sq. m. The soil weighs 1760 kg/m³ and has an angle of repose of 30°.

6. Design the foundation of a four-storeyed office building to be constructed on a soil having its safe bearing capacity of 22 tonne/m^2. The soil weighs 1920 kg/m^3 and has an angle of repose of 30°. The main walls of the building upto first two floors are 40 cm. thick and for the rest of the height 30 cm. thick. The floors consist of 13 cm. thick R.C.C. slab finished with 25 mm. thick mosaic flooring. The maximum span between the two main walls is 3·7 m. The roof slab is finished with 10 cm. thick grading.

7. Determine the size of footings and depth of foundation for a brick pillar 40 cm. square. The concentrated load carried by the column at the footing top is 15 tonne. The bearing capacity of the soil at the depth of foundation is 16 tonne/m^2. The soil weights 1920 kg./m^3 and has an angle of repose of 30°.

8. Design a R.C.C. raft foundation for a 30 cm. thick brick wall carrying a load of 13 tonne/metre run at foundation level. The safe bearing capacity of the soil is 5·5 tonne/m^2. Also design the depth of the foundation for the above wall if the soil weighs 1760 kg./m^3 and has an angle of repose of 28°.

9. Design a reinforced concrete foundation for a steel stanchion carrying an axial load of 40 tonne and is desired to be founded on loose soil having a safe bearing capacity of 5·5 tonne/m^2. Also determine the depth of foundation if soil weighs 1760 kg/m^3 with an angle of repose of 30°.

10. An R.C.C. column of a framed structure office building carrying axial load of 81 tonne is to be provided with a R.C.C. footing. The column is to rest on a soil of bearing power of 16 tonne/m^2 at the depth of 1·5 m. below the general ground level. Design the footing and draw a neat sketch showing the arrangement of reinforcements.

11. A steel stanchion carries a load of 122 tonne and has to be founded on a soil of safe bearing capacity 5 tonne per sq. metre. Design R.C.C. base for this column and sketch a plan and section to show all details including the base connections of the steel stanchion. The steel stanchion is made of 45 cm. × 20 cm. heavy beam section.

12 A 45 cm. square R.C.C. column carries an axial load of 101 tonne. Design an R.C.C. footing for the column to limit the pressure on the soil to 8·33 tonne/sq. m. Sketch the reinforcement in the footing. Design for shear is not required.

13. The ground floor R.C.C. column of a residential building, 76 cm. diameter, carries a load of 244 tonne. Design the column footing, if the permissible soil pressure is 8·33 tonne per square metre. Assume the weight of the footing suitably. Permissible stresses are

(*i*) Concrete—70·30 kg./sq. cm.

(*ii*) Tensile stress in reinforcing bar—1400 kg./sq. cm.

(*iii*) Punching shear—8·4 kg./sq. cm.

(*iv*) Adhesive stresses—7 kg./sq. cm.

(*v*) Modular ratio—15.

14. Design a reinforced concrete footing for a 38 cm. × 38 cm. reinforced concrete column carrying an axial load of 71 tonne.

Draw :

(*a*) The plan of the footing, and

(*b*) a longitudinal section of the footing.

The following data is given.

(*i*) Safe bearing capacity of soil=10 tonne/sq. m.

(*ii*) Permissible stresses in concrete—

Compressive stress in flexure=50 kg./sq. cm.

Shear stress =5 kg./sq. cm.

Bond stress =6 kg./sq. cm.

Punching shear =10 kg/sq. cm.

(*iii*) Permissible tensile stress in steel=1400 kg./sq. cm.

(*iv*) Modular ratio =15.

15. A 23 cm.×23 cm. R.C.C. column which is 6·1 metre high carries a 35 tonne load on top of it placed centrally. Design suitable R.C.C. foundations for the column if the bearing capacity of the soil is 3·33 tonne/sq. m. Show the sketches giving reinforcement.

16. Design a square pyramidal footing for a 45 cm. square column reinforced with 8 Nos. 25 mm. diameter longitudinal bars to carry a total axial load of 106 tonne, if the bearing power of the soil is 6·66 tonne/sq. m.

17. A reinforced concrete column of square section 38 cm.×38 cm. is required to carry an axial load of 101 tonne. Calculate the longitudinal reinforcement required.

Also design a square R.C. footing for the column and show by a neat sketch the dimensions of the footing and the arrangement of reinforcement. Working stresses are given below:

Steel stress—1400 kg./sq. cm.

Direct compressive stress in concrete—53·2 kg./sq. cm.

Bending strss in concrete—70 kg./sq. cm.

Punching shear in concrete—10·5 kg./sq. cm.

Modular ratio—15.

Bearing pressure on soil = 6·66 tonne/sq. cm.

18. A circular R.C. column 40 cm. in diameter transmits a load of 130 tonne to the circular base which is to be founded on a soil having a safe bearing capacity of 6 tonne/sq. m. Design the circular base and sketch the details of reinforcement in the base slab.

19. The load, transmitted on the R.C.C. footing by an R.C.C. column 43 cm.×43 cm. consisting of 12—25 mm. diameter bars as vertical reinforcement is 81 tonnes. The bearing capacity of the soil on which the footing rests is 11 tonnes/sq. m.

Design the footing assuming your own data and draw to 1 : 24. scale. plan and section of the footing showing clearly the reinforcement.

20. Enumerate the general conditions of stability of a masonry structure.

A wall 90 cm. thick imposes a load of 50 tonne/m. on the concrete

footing at ground level. If the width of concrete is 120 cm. find the depth. The density of concrete is 2080 kg/cu. m. and that of earth is 1760 kg/cu. m. $\tan \theta = 0{\cdot}7$ where θ is the angle of repose of earth.

(State Board of Tech. Education, 1965)

21. Design and sketch the details of foundation for 20 cm. thick brick plinth wall 90 cm. high above ground level and carrying on top a load of 13·33 tonne/m.

Assume, weight of brickwork as 1792 kg/cu. m. ; weight of concrete as 2240 kg,/cu. m. and safe bearing capacity of soil as 11 tonne/sq. m.

(A.M.I.E. May, 1966)

22. Design and sketch the foundation for a brick square pillar 625 mm × 625 mm × 3 m. high above ground level and carrying a superimposed load of 16 tonne The soil is soft and requires pilling. Timber piles 20 cm. dia × 6 m. long when driven in foundation pit at a depth of 1·8 m. below ground level penetrate on average 10 mm per stroke for last few strokes when a monkey weighing 254 kg. was dropped from a height of 1·5 m. Assume weight of brick work as 1792 kg/cu. m. and weight of concrete 2240 kg/cu. m.

(A,M.I.E. Nov., 1966)

23. Sketch a suitable foundation for a wall of a building with the following data :

(*i*) Type of wall : R masonry 45 cm. thick ;

(*ii*) Height of wall above ground level : 4·0 m.

(*iii*) Weight of masonry : 2200 kg/cu. m.

(*iv*) Super-imposed load on wall : 12·5 *T*/m length of wall

(*v*) Bearing capacity of soil : 27 *T*/sq. m.

(*iv*) Angle of internal friction soil : 30 degrees

(*vii*) Density of soil : 1800 kg./cu. m.

(*viii*) Assume the load of masonry below ground level as 1·5 *T*/m. The sketch should be fully diamensioned.

(A.M.I.E., Nov. 196.7

24. Sketch the foundation for a brick masonry pillar 45 cm. square transmitting a load of 5 tonnes to the soil whose bearing capacity is 11 tonne/sq. m. ; density 1920 kg./cu. m. and angle of re ose = 30 degrees.

(A.M.I.E., May 1968)

4

Damp-Proof Course

4 1 Definition. A damp-proof course is a continuous layer of damp-resisting material provided with the object of protecting the super-structure of a building against dampness. Dampness adversely affects the life of the structures. It results in insanitary conditions, which may seriously affect the health of the occupants.

4 2 Effect of Dampness. The various defects caused by dampness in the buildings may be summarised as below :

1. It causes efflorescence which may ultimately result in the disintegration of bricks, stones, tiles, etc.
2. It may result in softening and crumbling of plaster.
3. It may cause bleaching and flaking of the paint with the formation of coloured patches.
4. It may result in the warping, buckling and rotting of timber.
5. It may lead to the corrosion of metals.
6. It may deteriorate the electrical fittings.
7. It promotes the growth of termites.

4·3 Cause of Dampness. Absorption of moisture by the materials is one of the chief cause of dampness. On account of the granular nature of the materials, moisture finds an easy access through the voids and this aided by the capillary action assists the moisture to travel in different directions. Thus, either on account of bad workmanship or by use of defective materials, moisture may find its way on the interior either through the wall, floor or the roof.

4·4 Sources of Dampness. The important sources of dampness may be summarised as below :

1. Dampness rising through the foundation walling. Moisture from wet ground may rise well above ground level on account of capillary action.

2. Splashing rain water which rebounds after hitting the wall surface may also cause dampness.

3. Rain water may perculate through roof coverings. Faulty eave course and eave gutters may also allow the rain water to descend through the top of the outer wall.

The aim of the modern building designer should be to check the effect of dampness by providing proper damp proof course in appropriate places. While laying the damp proof course, the following points should be kept in view :

1. The damp-proof course should be continued unbroken throughout the length and thickness of the wall.

2. The base of the damp-proof course layer should be even. The uneven base will cause the retension of air voids between the base and the damp-proof course layer which is not desirable.

3. The lap-joints should be sealed with bitumen.

4·5 Methods of Damp-proofing. The following methods are generally adopted to prevent the defect of dampness in a structure.

1. *Membrane damp-proofing*
2. *Integral damp-proofing*
3. *Surface treatment*
4. *Guniting*
5. *Cavity wall construction.*

(1) Membrane damp-proofing : This consists in providing a layer of a water-repellent substance between the source of dampness

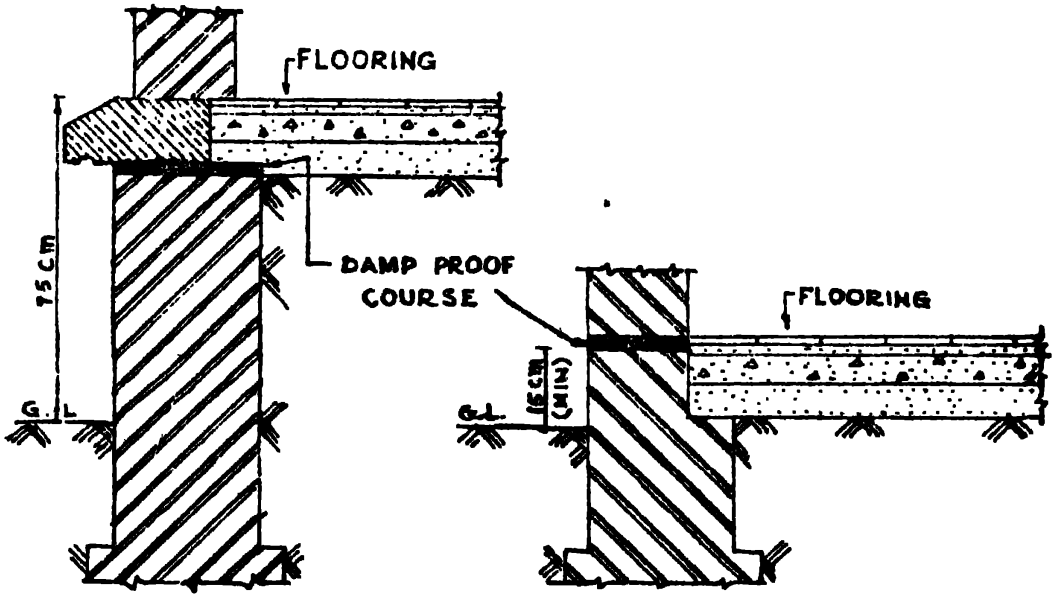


Fig. 4·1 Fig. 4·2

and the part of the structure adjacent to it. In case of building without basements the best position for damp-proof course lies at the plinth level or in case of structures without plinth it should be laid at least 15 cm above the ground level. If the damp-proof course is laid just at the ground level, earth, dust or leaves might accumulate outside the wall and by the passage of time the level of outside earth may be raised above the damp-proof course level. Thus moisture would easily be absorbed through the dust or leaves etc. into the bricks and the purpose of providing damp-proof course will not be served.

(2) **Integral damp-proofing**: This method consists in adding certain water-proofing compounds into the concrete mix. Such compounds are available in market in powdered as well as liquid form. Pudlo, Permo, Sika etc. are some of the many commercially made preparations of water-proofing compound commonly used. These are mixed with cement in specified proportions and the resultant concrete or mortar gets very dense impermeable and quick setting. Such mortars or concrete must be used quickly as owing to its quick setting properties, it will start setting partially before it is put in position.

(3) **Surface treatment**. As described earlier, the moisture finds its way through the pores of materials used in finishing. In order to check the entry of the moisture into the pores, they must be filled up. Surface treatments consists in filling up the pores of the surface subjected to dampness. The use of water repellent metalic soaps such as calcium and aluminium oletes and stearates is much effective in protecting the building against the ravages of heavy rain. Bituminous solution, cement coatings, transparent coatings, paints and varnishes fall under this category. In addition to other surface treatments given to walls, the one commonly used is lime cement plaster. The wall plastered with cement, lime and sand mixed in proportions of 1 : 1 : 6 is found to serve the purpose of preventing the dampness from penetrating inside the structural walls. The plastered surface gets wet during rains and afterwards the soaked water gets evaporated leaving the wall dry. The coating of plaster, when wet, acts as a barrier to check the seepage.

(4) **Guniting**. This consists in forming an impervious layer of rich cement mortar for water-proofing the exposed concrete surface or for resisting the water-pressure. In this process an intimate mixture of cement and water is forced through a machine named as "cement-gun" on the surface to be treated. Cement and sand are usually mixed in proportion of 1 : 3 to 1 : 4 and the mixture is shot by means of compressed air by holding the nozzle of the cement-gun at a distance of 75 to 90 cm. from the face of the wall.

(5) **Cavity wall construction.** This consists in shielding the main wall of the building by an outer skin wall leaving a cavity in between the two. The cavity prevents the moisture from travelling from the outer to the inner wall. The cavity wall in detail has been described in chapter VI.

4·6 Materials Used for Damp-proof Courses. The materials commonly used to check dampness may be divided into the following three categories :

1. Flexible materials like bitumen sheeting, plastic sheeting (polythene sheets) etc.

2. Semi-rigid materials like mastic asphalt.

3. Rigid materials like first class bricks, stones, cement concrete, slates etc.

4·7 Selection of Material for D.P.C. The choice of material to function as an effective damp-proof course requires a judicious selection. It depends upon the availability of the material, nature of the structure and the situation where D.P.C. is to be provided. Points to be kept in view while making selection of D.P.C. material are briefly discussed below.

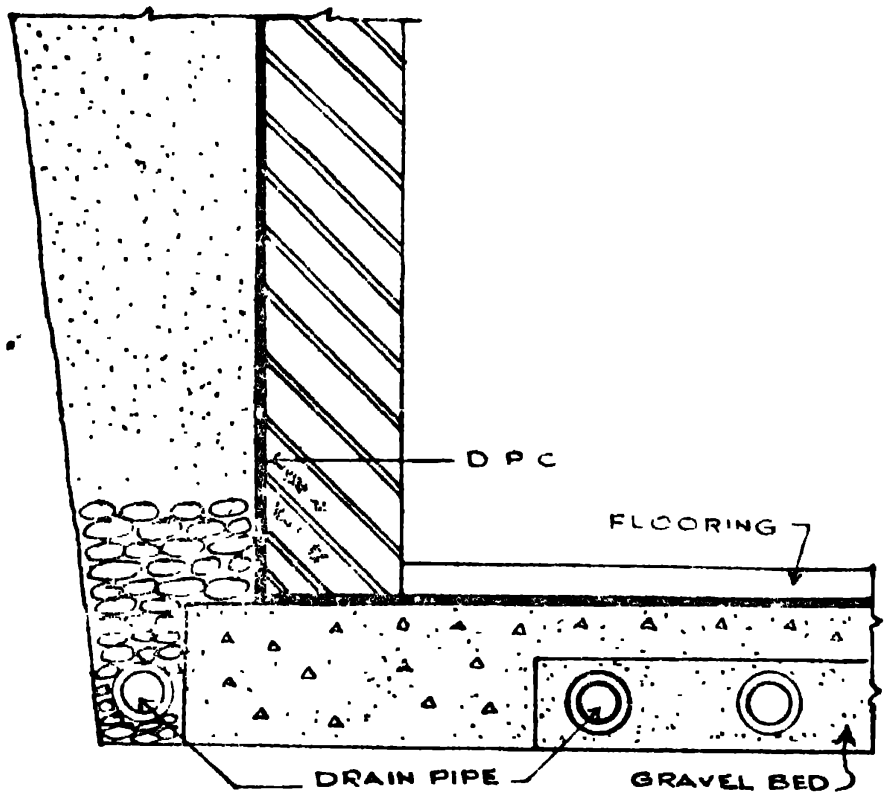
1. For D.P.C. above ground level with wall thickness generally not exceeding 40 cm. any one of the type of materials mentioned above may be used. Cement concrete is, however, commonly adapted for D.P.C. at plinth level. 38 mm. to 50 mm. thick layer of cement concrete of 1 : 2 : 4 mix serves the purpose under normal conditions. In case of damp and humid atmosphere, richer mix of concrete should be used. The concrete is further made dense by adding water-proofing materials like pudlo, impermo, waterlock etc. in the concrete during the process of mixing. It is usual to apply hot bitumen over the dried surface of concrete D.P.C.

2. For greater wall thickness or where D.P.C. is to be laid over large areas, such as floors, roofs etc. the choice is limited to materials like mastic asphalt or flexible sheeting of bitumen or plastic laid with joints properly lapped and sealed.

3. In parapet walls and other such situations material like mastic asphalt, bitumen felt and metal (copper or lead) are recommended. It is important to ensure that the D.P.C. material is flexible so as to avoid any damage or puncture of the material due to the differential thermal moments between the material of the roof and the parapet wall.

4. In cavity wall construction, the cavity over the door or window openings should be bridged over by use of a D.P.C of flexible material like strips of lead, copper, bitumen sheet, etc.

4·8 Construction of Basement in Damp Ground. The basement walls may be kept free from dampness by spreading a layer of impervious material like bitumastic felt or mastic asphalt over the whole area of the floor. The impervious layer is continued through the external walls extending vertically up and stopped at least 15 cm. above the ground level. The basement floor should consist of a 10 to 15 cm. thick concrete base. This should be converted with two



Fig, 4·3

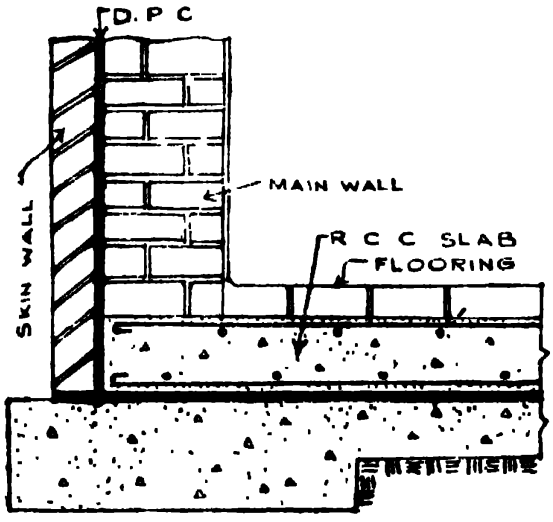


Fig. 4·4

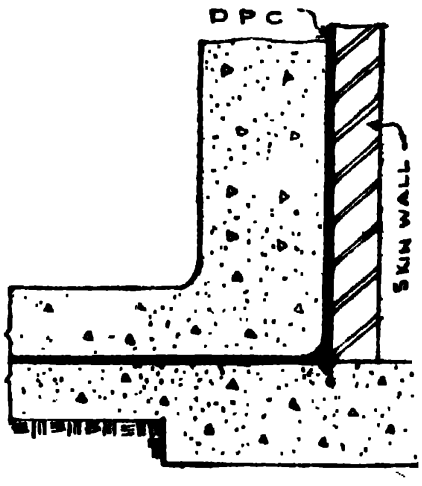


Fig. 4·5

layers of mastic asphalt applied over the entire area of the base concrete. This damp-proof course layer is further covered by cement concrete flooring. The thickness of flooring should be at least 5 cm. and the concrete used must be blended with water-profing compounds.

If the basement is subjected to hydrostatic pressure, the mere provision of continuous damp-proof course may not give satisfactory results. In such cases the basement should be relieved of the hydrostatic pressure by suitably draining the sub-soil water. Sub-soil water is drained by means of drainage-pipes laid with open joints below the concrete base slab and adjacent to wall footings as shown in the figure 4·3. The open joints easily permit the sub-soil water to be left in without the pipe getting clogged or closed by silt. The pipes are given a bed-slope so that the water is discharged in an outlet, outside the building from where the collected water is allowed to flow away in some natural drain or sewer. To be more effective, the drainage pipes should be laid on a bed of gravel and covered with selected filter material. The gravel bed helps to accumulate the sub-soil water by seepage and perculate the same in the pipes.

In some situations where the underground water pressure is severe, mere provision of drainage pipes or pumping out the sub-soil water may not solve the problem. The basement slab in such cases should be designed and properly reinforced to withstand the hydrostatic pressure safely. In some basement under high under ground water pressure, both wall as well as the floor slab have to be reinforced to sub-stain outside pressure.

The external face of the wall is well grouted with water-proofed cement plaster. This forms the base for the asphalt layer which is continued from the basement floor and extended unbroken vertically up covering the whole area of the external wall face. This asphalt layer is further protected by an outer skin-wall.

4·9 Damp-proofing Treatment for Roofs. Damp-proofing treatments commonly adopted for different types of roofs are described below.

Flat roofs. Flat roofs require relatively heavier and costlier water proofing treatment as compared with pitched or sloped roofs. The specifications of material used for the purpose should be such that it performs the function of waterproofing as well as to provide adequate thermal insulation. Stagnation of water on the roof is considered to be the root cause of leakage and dampness in flat roofs. This can be avoided by providing adequate slope and rain water pipes. In case of R.C.C. or R.B.C. slab roofing, with proper grading above a slope of 1 in 40 to 1 in 60 is considered desirable. This may be achieved either by varying the thickness of the terracing material or by constructing the roof slab with a slope, or by providing part slope in the roof slab and part in the terracing material.

In addition to the slope the size and the spacing of the rain water pipes or the outlets require due consideration for the proper drainage of the roof. In general practice, one 10 cm. diameter pipe is considered suitable for every 30 sq. im. of the roof area to be drained.

In cases where slopes for the drainage of the roof are given in the roof slab itself or in situations were thermal insulation is not important and the problem of slopes in flat roof is tackled suitably the water-proofing treatment for the roof may consists in laying bitumen felts directly over the surface of roof slab after painting the roof top with hot bitumen. The bitumen felt may be hessian based or fibre based. Depending upon the type of building, climatic and atmospheric conditions of the site, the treatment may be with four courses, six courses or eight courses. The four course treatment is recommended for moderate conditions whereas the six and eight course treatment are recommended for severe and very severe conditions respectively.

The method of laying a four courses treatment may be broadly divided with the following steps.

(*a*) Apply hot bitumen at the rate of 1·2 kg/m² on the roof surface.

(*b*) Lay the hessian-base bitumen felt in single layer over the hot bonding material laid in (*a*). The end and side laps for the felt being not less than 100 and 75 mm. respectively.

(*c*) Apply hot bitumen at the rate of 1·2 kg/m² over the bitumen felt laid in (*b*).

(*d*) Spread Pea-sized gravel or grit at the rate of 0·006 m³ per square metre over the layer of hot bitumen in (*c*).

The other commonly adopted water-proofing treatment for flat roofs in the various regions of this country consists in providing a grading (terracing) of selected materials over the roof slab. In general, one of the following methods of grading is adopted to meet the requirements of water-proofing :

(*a*) *Grading of lime concrete*

(*b*) *Grading of lime concrete with tiles*

(*c*) *Grading of mud phuska with tiles*

(*a*) *Grading of lime concrete.* This method of water-proofing consists in laying lime concrete grading (terracing) over the roof slab. The process of laying may be split up in the following order :

(*i*) Laying lime concrete of 10 cm. average thickness directly over the roof slab. The slope for proper drainage of roof being given to the lime concrete layer.

(*ii*) Applying a priming coat of hot bitumen solution over the dried layer of lime concrete.

(*iii*) Laying bitumen sheets over the primed surface.

In some places, the laying of bitumen sheets over the grading is not considered necessary and only the lime concrete is finished to an impervious surface. This practice is common in some parts of Bombay and Calcutta.

(*b*) *Grading of lime concrete with tiles.* In case the roof is likely to be used for sleeping or other such purpose, the grading provided must be strong enough to withstand the wear and tear due to the traffic of the users. The lime concrete layer in such places is covered with two courses of brick tiles set in cement mortar. The following operations are generally involved in laying such grading :

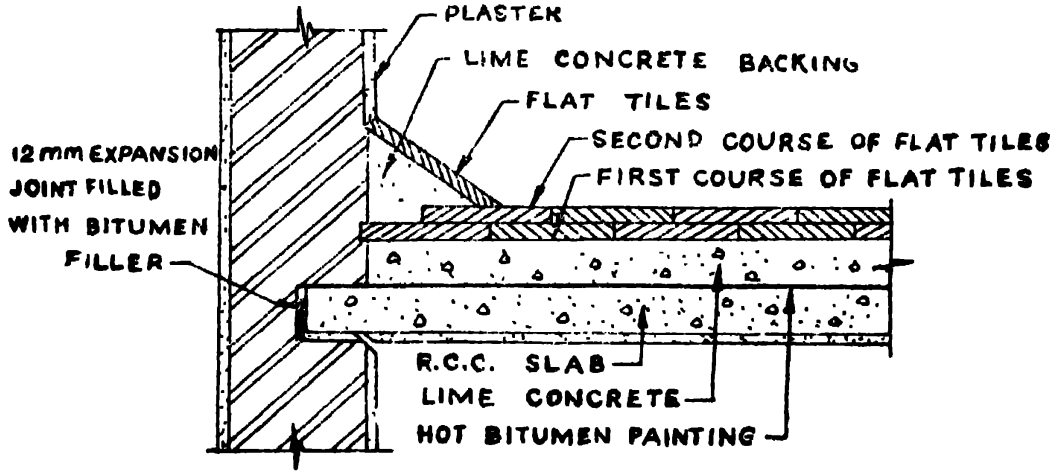


Fig. 4·6

(*i*) Painting the top of roof slab uniformly with a layer of hot bitumen spread at the rate of 1·71 kg. of bitumen per sq. m. of roof surface.

(*ii*) Spreading immediately coarse sand at the rate of 0·6 cu.m. of sand per 100 sq. m. of roof surface, when the bitumen is still hot.

(*iii*) Laying lime concrete in an average thickness of 10 cm. The slope for proper drainage of roof being given to the lime concrete layer.

(*iv*) Laying two layers of brick tiles (with breaking joints) over the compacted layer of lime concrete, in cement mortar 1 : 3. The joints of the top course of tile being pointed with cement mortar 1 : 3.

Water-proofing of flat roof, by adopting this method, is very common in the southern region of this country. This type of treatment is best suited for buildings in hot and humid regions like Calcutta, Bombay and Madras. This is shown in Fig. 4·6.

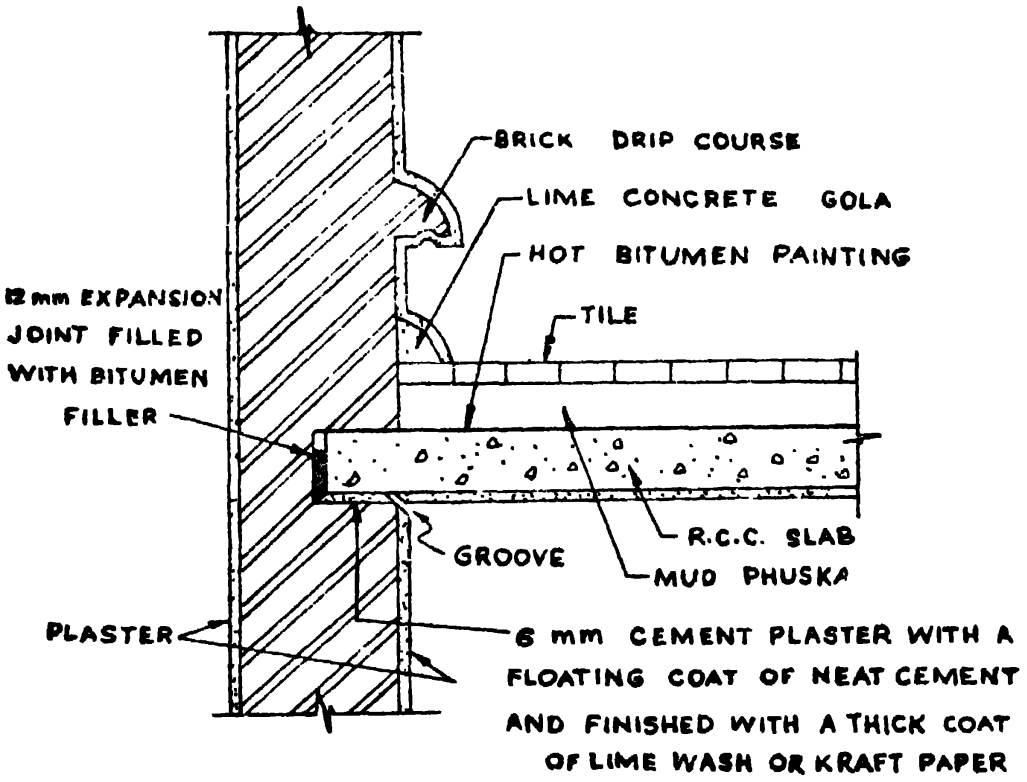


Fig. 4·7

(*c*) *Grading of mud phuska with tiles.* This method of water-proofing flat roofs is best suited for hot and arid regions. It is commonly adopted in Delhi, Punjab, Rajasthan and U.P. and in other regions where the rainfall does not exceed 1000 mm. The various operations involved in this process may be divided in the following steps :

(*i*) Painting the top of roof slab uniformly with a layer of hot bitumen spread at the rate of 1·71 kg. of bitumen per sq. m. of roof surface.

(*ii*) Spreading immediately coarse sand at the rate of 0·6 cu.m. of sand per 100 sq. m. of roof surface, when the bitumen is still hot.

(*iii*) Laying 10 cm. thick (average) mud phuska prepared from puddled clay mixed with bhusa at the rate of 8·1 kg. of bhusa per cu.m. of clay, the slope for the proper drainage of roof being given to this layer. The slope should not be less than 1 in 40. If,

however, it is not possible to give the entire slope by the mud phuska layer, a part of the slope required for the roof drainage may be given in the roof slab itself.

(*iv*) Plastering the consolidated layer of mud phuska with a 13 mm. thick coat of mud gobri mortar 3 : 1 (mud : 1 cowdung).

(*v*) Laying tile bricks flat on the plastered surface and grouting the joints with cement mortar 1 : 3. This grading is illustrated in Fig. 4·7.

4·10 Treatment to Parapet Wall. If the flat roof has a parapet and there are cracks in it or its plaster is very porous or defective, rain water may find an easy access to the wall below and make the wall and some portion of the cailing damp. Rain water

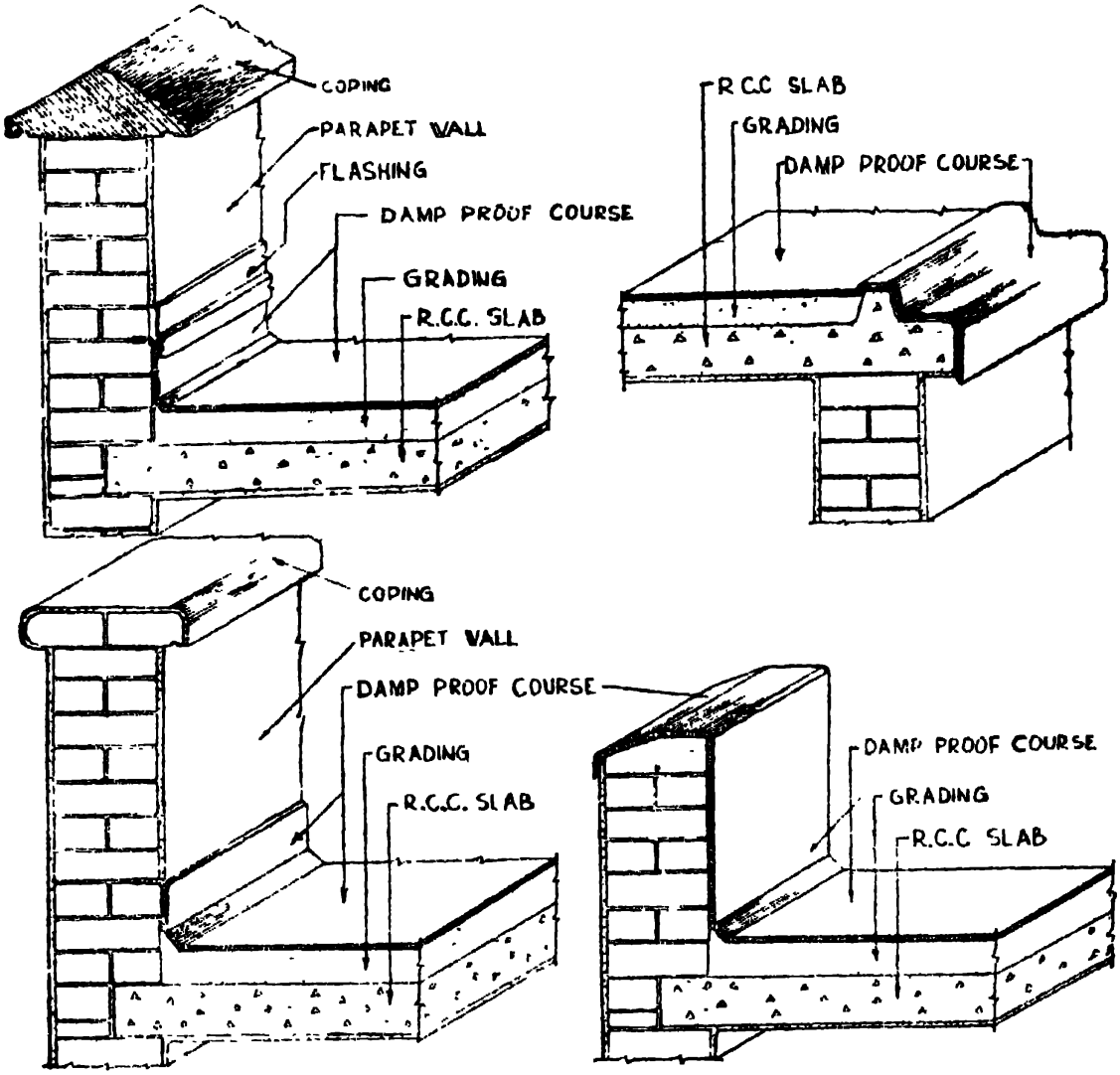


Fig. 4·8—4·11

Figures showing damp-proof treatment of the flat roofs with or without parapet walls.

may also leak through cracks at the junction of the parapet and the roof slab. In cases where asphalt layer in provided over the grading material for the water proofing treatment to roof slab, the asphalt layer covering the roof is turned up against the parapet for a height of at least 15 cm. The parapet wall is further protected by providing coping of brick, concrete or stone on its top (Refer Fig. 4·8-4·11).

In case the water proofing of roof is carried out by providing lime terracing, the layer of terracing is taken right upto the edge of the roof and a 15 cm. high rounded triangulated fillet is built up there. This is necessarily done to prevent the soakage of water through the parapet in case the rain water pipes get chocked up and the water stands on the roof. In addition a drip course is also some times provided over the lime gola to prevent water from parapet to fall directly over its junction with roof (Refer Fig. 4·7).

4·11 Water-proofing Treatment for the Roofs of Multi-storeyed Buildings. In case of multi-storey buildings, thermal insulation is an equally important factor to be kept in view. This is achieved by increasing the thickness of the grading by using economical and effective materials. The water-proofing treatment generally given to the roof of multi-storey buildings and other important structures may be divided in the following steps :

1. Painting the top of roof slab uniformly with a layer of hot bitumen spread at the rate of 1·71 kg. of bitumen per sq. m. of roof surface.

2. Spreading immediately coarse sand at the rate of 0·6 cu.m. of sand per 100 sq. m. of roof surface when the bitumen is still hot.

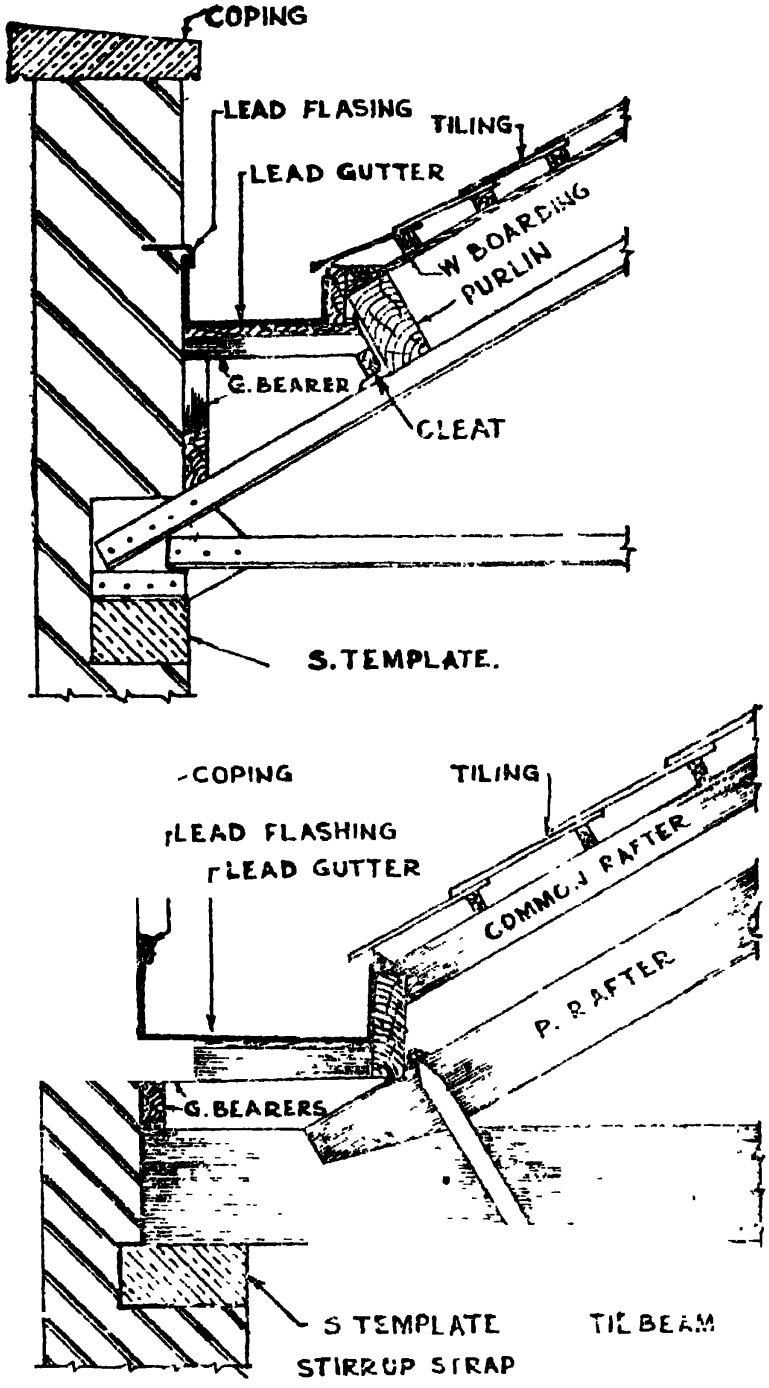
3. Laying cinder concrete 1 : 15 (1 cement : 15 cinder of 13 mm. and down guage) in an average thickness of 15 cm, the slope for the proper drainage of roof being given to this layer.

4. Laying 7·6 cm. thick layer of lime concrete over the consolidated layer of cinder concrete. The lime concrete being prepared by mixing 50% of mortar consisting of lime and sand mixed in the ratio of 1 : 2 with brick ballast 25 mm. and down gauge.

5. Spreading a 13 mm. thick layer of cement mortar 1 : 3 and laying tile bricks flat and open jointed over the mortar. Finally grouting the joints in tile brick with cement mortar 1 : 3.

4 12 Pitched Roofs. In case of sloping roofs the material used for roof covering, *i.e.* C.G.I. sheets, corrugated asbestor cement sheet, tile cladding etc. does not need water-proofign treatment if laid properly. However, in the case of sloped roots, valley gutters are the chief source of dampness. Hence, installation of ain water gutters require careful attention to their capacity, position ; fixing, water-tightness and accommodation for expansion.

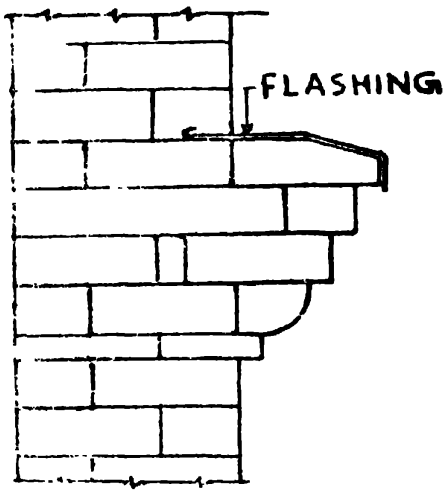
or contraction. The gutters should be leak-proof and all the joints in the gutters should be made water-tight. Due provision should



Figs. 4·12—4·13

Damp-proof course treatment for sloped roofs of steel and wood

be made for the expansion of gutters due to temperature variations. The work of laying roofing should be carefully supervised and it



STRING COURSE

Fig. 4.14

should be ascertained that the tiles project beyond the edge of the gutter. Lead flashing should be continued upto the vertical face of the parapet wall and should stop inside the body of the wall. As in case of flat roof, the parapet wall should itself be protected by stone or brick coping. The provision of damp-proof course layer in a lead gutter is shown in Figs. 4·12—4·13.

If the architect wants to provide a projection in the face wall to decorate the structure, a sloped junction should be stressed. The junction should further be protected by a layer of damp-proof course, as shown in Fig. 4·14.

4·13 Specification for laying 38 mm. thick damp-proof course with cement concrete 1 : 2 : 4 at plinth level

1. The damp-proof course shall cover the full thickness of the wall.

2. The base of the damp-proof course shall be clear, even and free from projections liable to cause damage to the D.P.C.

3. The side shuttering shall be strong and so fixed that it does not get disturbed during compaction and the concrete slurry does not leak out.

4. The concrete prepared by mixing ingredients in the proportion of 1 : 2 : 4 (1 cement : 2 sand : 4 stone ballast 12 mm. and down gauge) shall be of workable consistency.

5. The concrete shall be laid and tempered roughly to make a dense mass.

6. After 24 hours of its laying, the concrete layer shall be cured for at least seven days.

7. After curing is complete the surface shall be left to dry out to receive the coat of hot bitumen.

8. The dried surface of concrete shall be properly cleaned with brushes and finally with a piece of cloth soaked in kerosine

oil. Hot bitumen in specified quantity shall be applied uniformly all over the treated surface of concrete.

4·14 Water Stops. Water stops are provided to check the possibility of the leakage of water through a construction, contraction or expansion joint. Water stops are installed in the joints during construction and they become a part of the structure itself. Depending upon their composition, water stops may be divided in following three categories :

(*i*) *Rubber water stops*

(*ii*) *Metal water stops*

(*iii*) *Mastic type water stops.*

(*i*) **Rubber water stops.** Rubber type of water stops are made up form rubber or some similar plastic meterial and are manufactured in a variety of different forms such as dumbell type, centre bulb type etc. The water stops, should be properly bonded with the concrete to prevent its being lifted or blown up by water pressure.

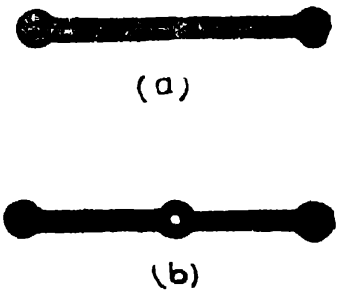


Fig. 4·15
Rubber water stops

(*ii*) **Metal water stops.** Metal water stops consists of thin strips of steel, zinc, copper, bearing steel or other corrosion resisting metal. The metal strip is normally 15 to 20 cm in width and 14 to 16 guage thick. Half the strip width is embedded in the concrete on either side of the joint. In case of expansion or contraction joints when there are chances of relative moment between the slab on either side of the joint, the metal strip is normally bent in the form of *V* in the middle.

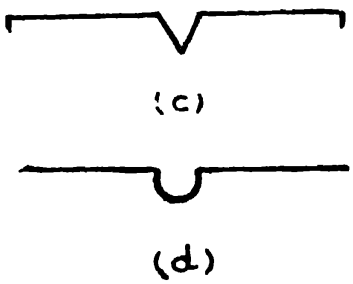


Fig. 4·16
Metal water stops

(*iii*) **Mastic types water stops.** The mastic type of water stop is made by poured in place mastic material consisting of commercially made compounds. Mastic type of water stops are not suitable in places where intensities of pressure or thrust is more.

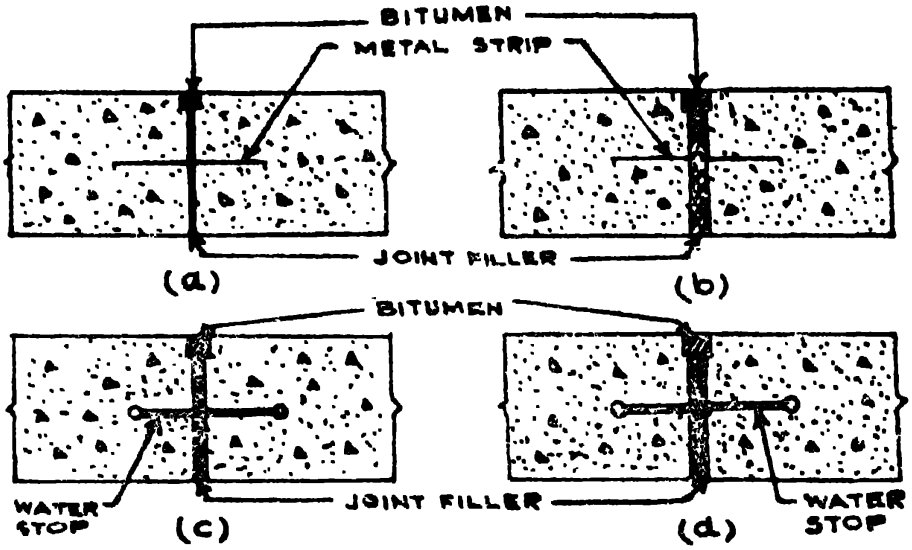


Fig. 4·17

Sections showing different types of water stops embedded in concrete

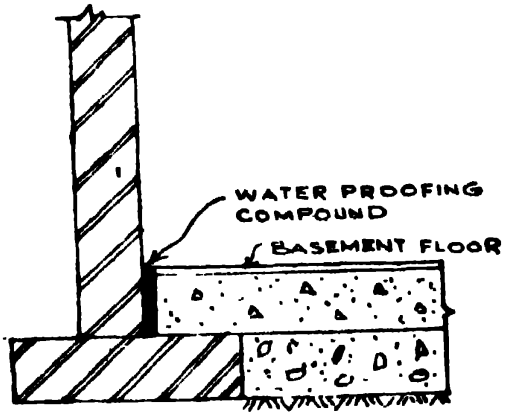


Fig. 4·18

Mastic type water stop

Questions for Revision

1. What are common causes of leakage and dampness in flat roofs and what precautions would you take in new ouildings to avoid possibility of leakage ?

(U.P. Service of Engineers, Aug., 1961)

2. *(a)* Discribed three different methods you know for water-proofing "Roofs and Terraces".

(b) Give sketches and state what precautions you would take to make the following water-proof :

(i) A pitched roof with valleys and gutters.

(ii) A flat-terraced roof.

3. What do you understand by Damp-roof course ? Where it is placed in a building and why ? Write short specification on damp-proof course laying to brick masonry walls both in foundation and plinth and super-structure.

(A.M.I.E., Nov., 1956)

4. What is meant by damp-roof construction and what are the materials used for the damp-roof construction ?

Describe, with sketches, how you would make a cellar floor of a building which has a floor 2·4 m. below ground level, damp-proof. The sub-soil water level is 90 cm. below ground level, that is 1·5 m. above the cellar floor.

(A.M.I.E., Nov., 1960)

5. Discuss the problem of drainage of foundation of residential and public buildings.

How will you ensure water-proofing and damp-proofing of such building constructed in localities where water table rises quite high during the mansoon season ?

Illustrate your answer with sketches.

6. What are the visible signs of the action of dampness in a building and what precautions are necessary to avoid the same ?

(A.M.I.E., May, 1964)

7. An underground R.C.C. drinking water reservoir is proposed at a place having high sub-soil water level. What specification would you suggest for water-proofing treatement ? Explain in brief the specification of materials and also method of execution of the entire work.

(National Diploma in Architecture, April, 1965)

8. What is dampness ? What are its ill effects ? Explain with sketches how damp-proofing is done in buildings.

(State Board of Tech. Education, 1965)

9. (*a*) Indicate the type of water-proofing treatement you would recommend for flat R.C.C. roof slabs in :

(*i*) Hot and dry regions like Rajasthans.

(*ii*) Hot and humid regions like U.P. and Andhra Pradesh.

(*iii*) Hot and very humid regions like West Cost and Assam.

(*b*) What points will you ensure before lying the water-proofing treatment with bitumen felt of a large building in a coastal region with annual rainfall exceeding 250 cm.

(A.M.I.E., May, 1965)

10. (*a*) What is damp-proof course ? Where and how is it used ?

(*b*) Explain how you will damp-proof a basement floor 2·4 m. below plinth level with R.C. walls and R.C. floor slab over 7·6 cm. lean concrete. Height of plinth is 60 cm. above the ground level.

(A.M.I.E., Nov., 1965)

11. The floor of a basement is 3 m. below the ground level. The parmanent water table is 2 m. above the basement floor level. Draw a neat sketch showing the damp-proofing arrangement for the external wall of the basment. *(A.M.I.E., 1968)*

12. Describe in details the construction of a basement in a building to be used as a store. How will you ensure water proofing and proper ventilation ? Draw a cross-section showing all the details.

(A.M.I.E., Nov., 1970)

5

Cavity Walls

5·1 General. Cavity wall consists of two walls with a 5 cm. to 8 cm. cavity between them. The outer wall also known as outer leaf, consists of a 10 cm. (half brick) thick wall and the inner wall is sufficiently thick and strong to carry the imposed load safely. The minimum thickness of the inner wall is restricted to 10 cm. (half brick). The provision of a continuous cavity in the wall efficiently prevents the transmission of dampness to the inner wall.

5·2 Advantages. The advantages of the cavity walls may be summarised as below :

(*i*) As there is no intimate contact between the two leaves except at the wall ties, there is no possibility of the moisture travelling from the outer leaf to the inner.

(*ii*) The layer of air in the cavity reduces the transmission of heat from the external face to the internal one and as such they are best suitable for a tropical country like India. Tests have revealed that cavity walls have 25% greater insulating value than solid walls.

(*iii*) They have good sound insulation property.

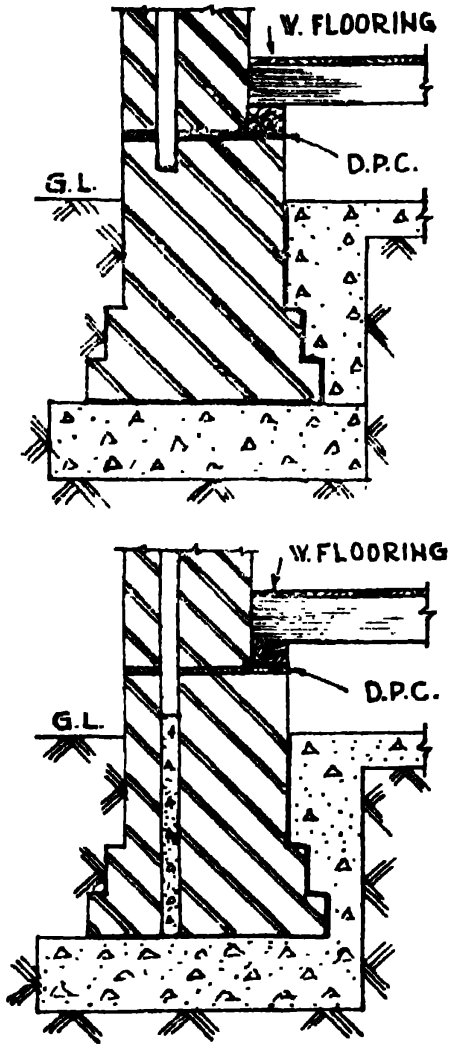
(*iv*) They are economical.

5·3 Position of Cavity. The cavity should start near ground level and terminate near eaves level in case of sloping roof or near coping in case of flat roof with parapet wall. The cavity should preferably start 15 cm. below the damp-proof course level. This has the advantage of draining any condensed moisture below the level of damp-proof course. The damp-proof course for the two leaves is laid separately although at the same level. This is necessary to continue the cavity below damp-proof course. The cavity is kept fully ventilated by providing air bricks in the external wall immedietely above damp-roof course. The air bricks should be kept 90 cm. apart. Similarly, air bricks are provided near the top of the cavity.

5·4 Wall ties. The two walls are tied together with metallic or terracotta ties to obtain structural stability. They are spaced

90 cm. apart horizontally and 30 to 45 cm. vertically in staggered positions.

5·5 Constructional Details. The constructional treatment given to the cavity wall at the door or window openings requires special consideration.



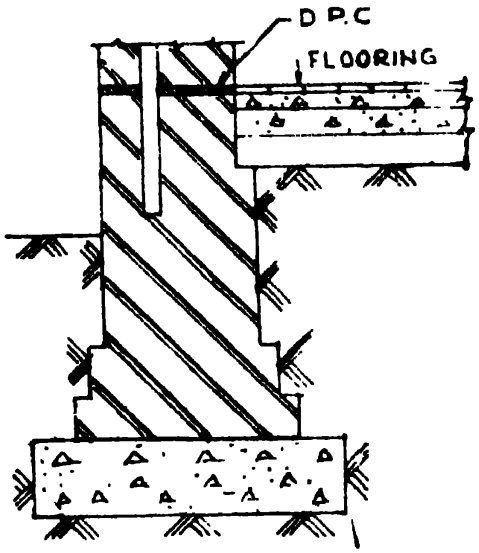


Fig. 5·1—5·3

Figures showing the various positions of cavity and the relative positions of damp-proof course layer.

Since the object of cavity is to separate the two leaves, a vertical damp-proof course is essential to be provided when sealing the cavity at window and door reveals, as the openings can provide an easy access to the dampness to pass into the cavity. At the sill level it is always advantageous to keep the back of the sill flush with the back face of the external wall. In case of wooden sills a horizontal damp-proof course is introduced under the timber still. The damp-proof course used should be flexible.

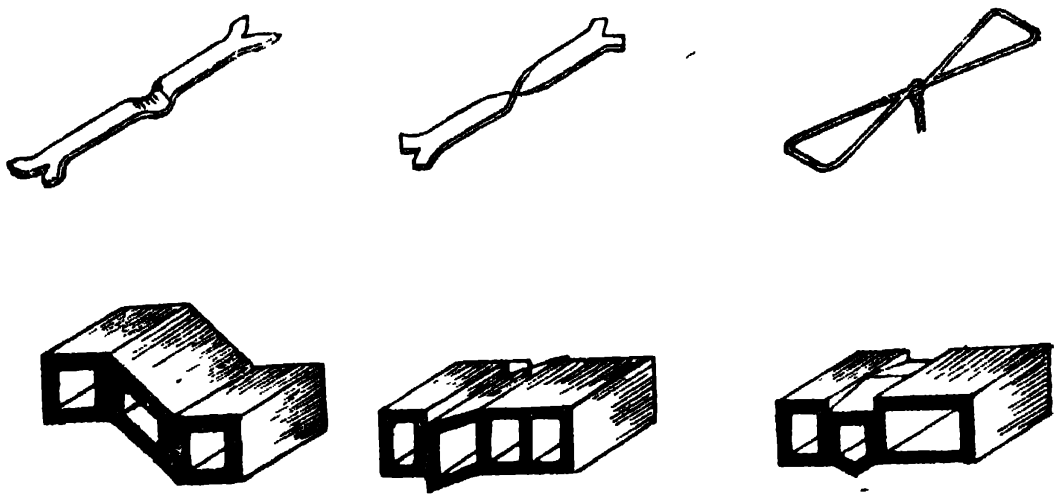


Fig. 5·4—5·9

Figure showing different types of wall ties

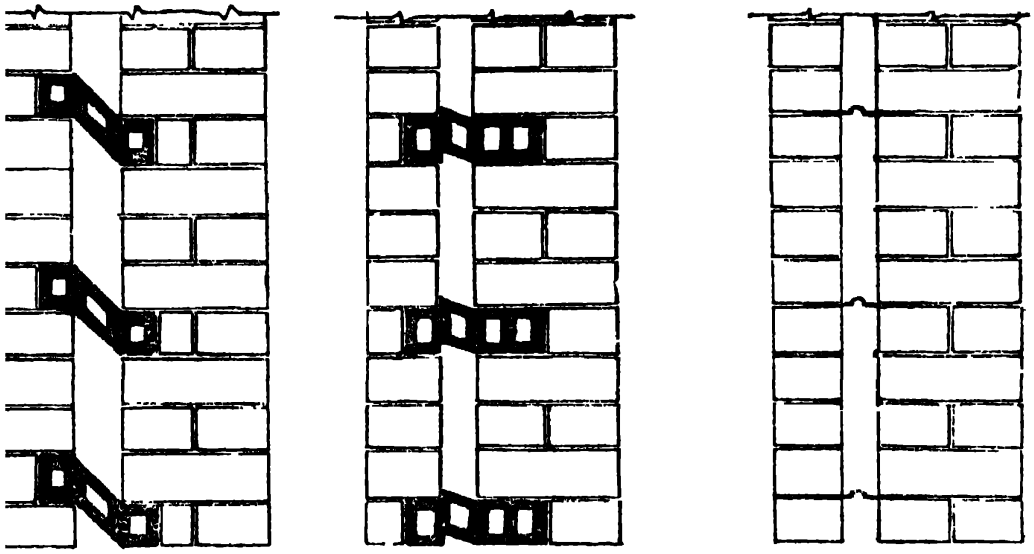


Fig. 5·10—5·12

Sectional elevations of brick cavity walls showing different types of wall ties

At the top of openings of doors and windows, stone or brick arch or concrete lintel is provided to carry the structure above the opening. In order that this cavity may be continuous, the two walls should have separate lintels or arches. Sometimes a common lintel is provided for both the leaves as shown in Fig. 5·13. In such a case, an inclined strip of lead or any other flexible damp-proof course membrane is built so as to bridge over the cavity. The damp-proof course should extend lengthwise beyond the frame for a distance of

about 15 cm on either side. This treatment helps in draining any condensed moisture beyond the side of the frame.

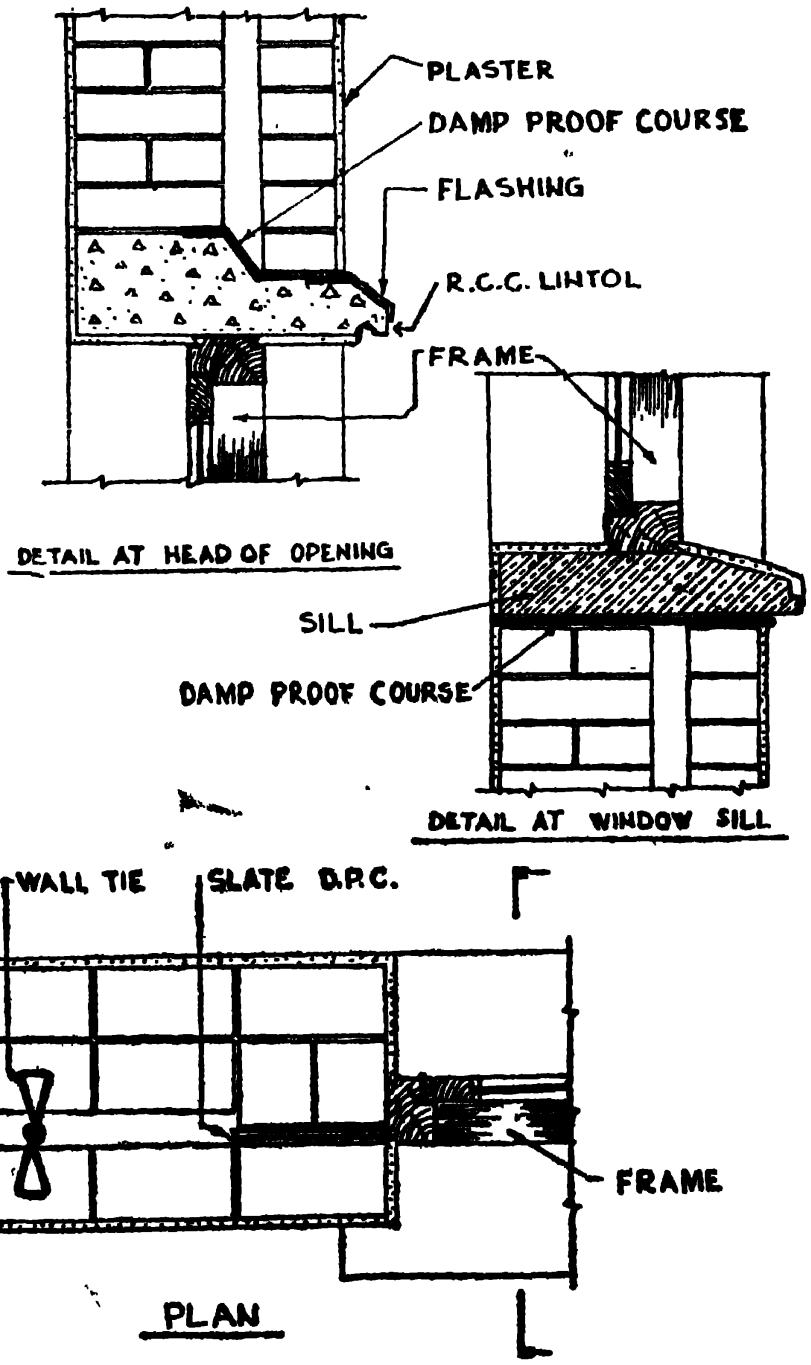


Fig. 5·13—5·15

Figures showing necessary treatment for cavity walls at door or window openings

In case of flat roof the cavity is continuous for the full height of parapet wall and sealed by the coping. In case of inclined roofs, cavity is closed at caves level. It is important to take special precautions so that no mortar should fall inside the cavity during the process of construction. The treatment of cavity to parapet walls is shown in Figs. 5·16—5·18. If the cavity is to be continued to the coping level, the layer of damp-proof course should be laid continuous covering the full thickness of wall immediately below the coping. In case it is desired to stop the cavity at the mid-height of the parapet wall, damp-proof course layer is laid to the full thickness of the wall at level where the cavity joints the solid wall.

Exposure of the two faces of a solid parapet wall may develop cracks due to temperature variations or on account of bad workmanship which may invite dampness. By constructing two separate wall thicknesses, this danger can be successfully overcome. Each wall thickness is exposed to the weather on one side and to the drying out condition on the other. In places of heavy rainfall when the storage capacity of the material used in the outer wall gets exceeded, the rain water finds its way into the cavity and harmlessly drained off at suitable points. Thus the cavity system of construction is equally useful for parapet walls. The important precautions necessary to be observed in cavity wall construction are given below :

5 6 Precautions. (1) As far as possible there should be no intimate contact between the two leaves of the cavity wall.

(2) The half brick thick leaf of the cavity wall should be constructed with stretcher bond.

(3) The damp-proof course layer should be laid separately for the two leaves.

(4) The horizontal damp-proof course layer should be laid at least 15 cm. above the bottom of the cavity.

(5) The cavity should be properly drained and ventilated by providing weep-holes immediately below the main horizontal damp-proof course. In door or window openings the weep-holes should be provided above the damp-proof course.

(6) The opening should be specially treated as described before.

(7) It should be ascertained that the cavity is kept clear of droppings of mortar or brick rubbish etc. during construction.

(8) Ties used should be rust-proof and should preferably be protected by galvanising.

(9) Special attention should be paid to see that the vermins or mosquitoes do not find access in the cavity.

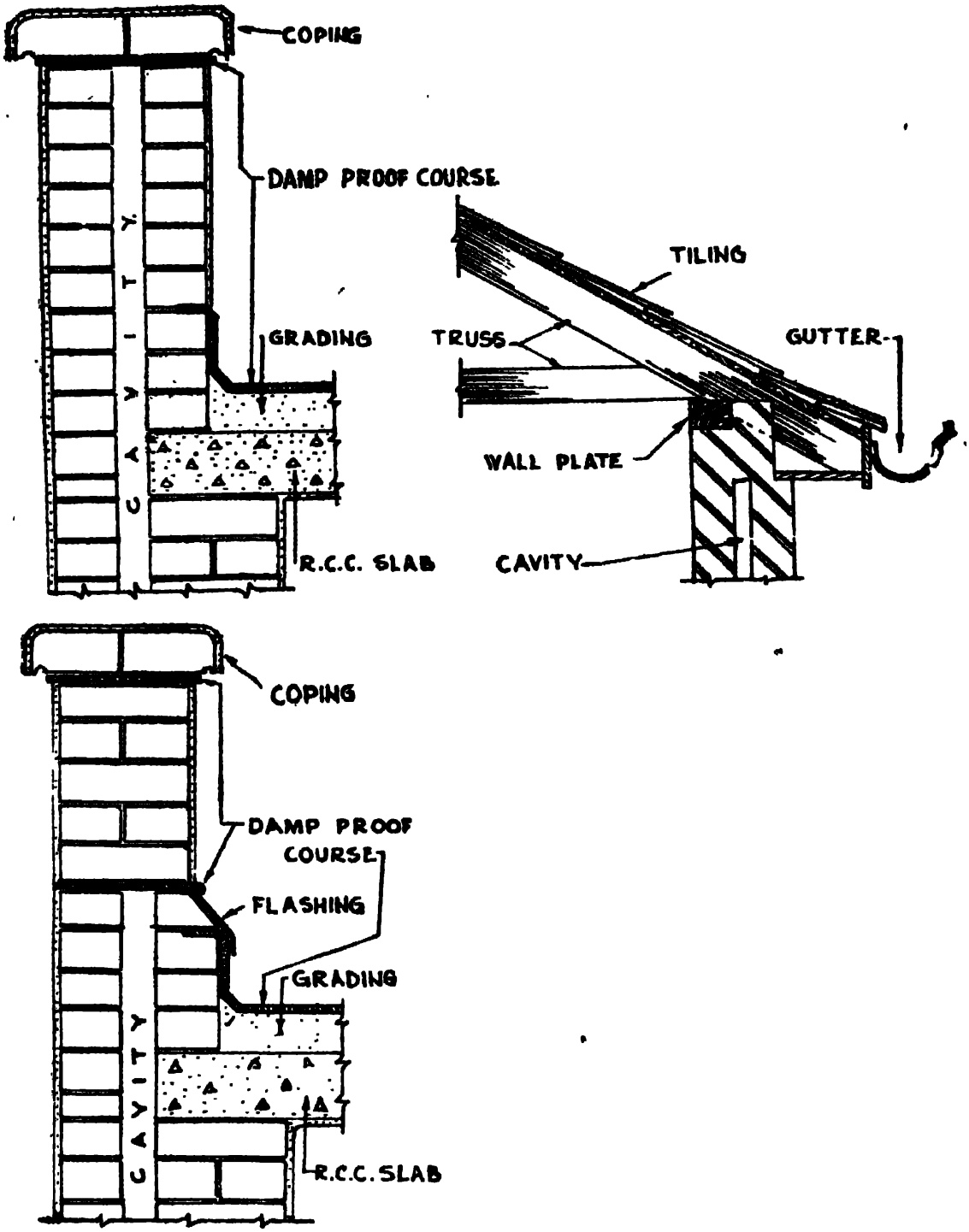


Fig. 5·16—5·18

Figures showing necessary treatment for a cavity wall at eaves level or at parapet wall level

Questions for Revision

1. What is the purpose of providing cavity walls ? What advantages cavity walls have over solid wall construction ? Draw a neat sketch of a cavity wall indicating the different treatments necessary for strengthening the two leaves of the wall at various levels.

2. At what levels the cavity should be started and terminated in a cavity wall construction ? What adverse effect can take place if the cavity is started or terminated at random ? Draw neat sketches to justify your answer.

3. What is the function of cavity in a wall ? What is the treatment necessary to be given in cavity wall construction, at sill or lintel level ? Draw neat sketches showing the treatment rendered for a window and door opening

4. Explain with the help of sketches the construction of a cavity wall starting from the trench level to the eaves level. Mention the necessary precautions at various stages of construction.

6

Shoring, Underpinning and Scaffolding

6·1 Shoring. The term 'shoring' is applied to the construction of a temporary structure required to support an unsafe structure.

The main objects of shoring may be summarised as below :

1. When the walls of a building develop signs of bulging or leaning outwards, shoring is necessary to prevent further development of the defects.

2. When defective walls of a building are to be dismantled and rebuilt, shoring is resorted to for supporting the floors or roofs connected to that wall.

3. Shoring is necessary to support the super-structure when large openings are required to be made in the main walls. Shoring may be essential to give support to the walls of two adjacent buildings when the intermediate building is to be pulled down and rebuilt.

6·2 Types of Shoring. There are three different types of shoring :

1. *Raking shores*
2. *Flying shores*
3. *Dead shores*

1. **Raking shores.** This is a system of giving temporary support to an unsafe wall. The construction of raking shore also known as inclined shore varies with the conditions of site. In all cases wall-plate 23 cm. × 5 cm. to 23 cm. × 7·6 cm. in size is fixed against the unsafe wall with hooks. The wall-plate is further secured to the wall by means of needles. The needles which are 10 cm, × 7·6 cm. in section penetrate inside the wall for a distance of about 11 cm. In turn, the needles are strengthened by providing wooden cleats. The top end of the inclined rakers rest against the needles. At their base the rakers are supported by a sole piece bedded in an inclined position in the ground. The rakers are secured to the sole piece by cleats and dogs. In soft ground the area of the sole piece is

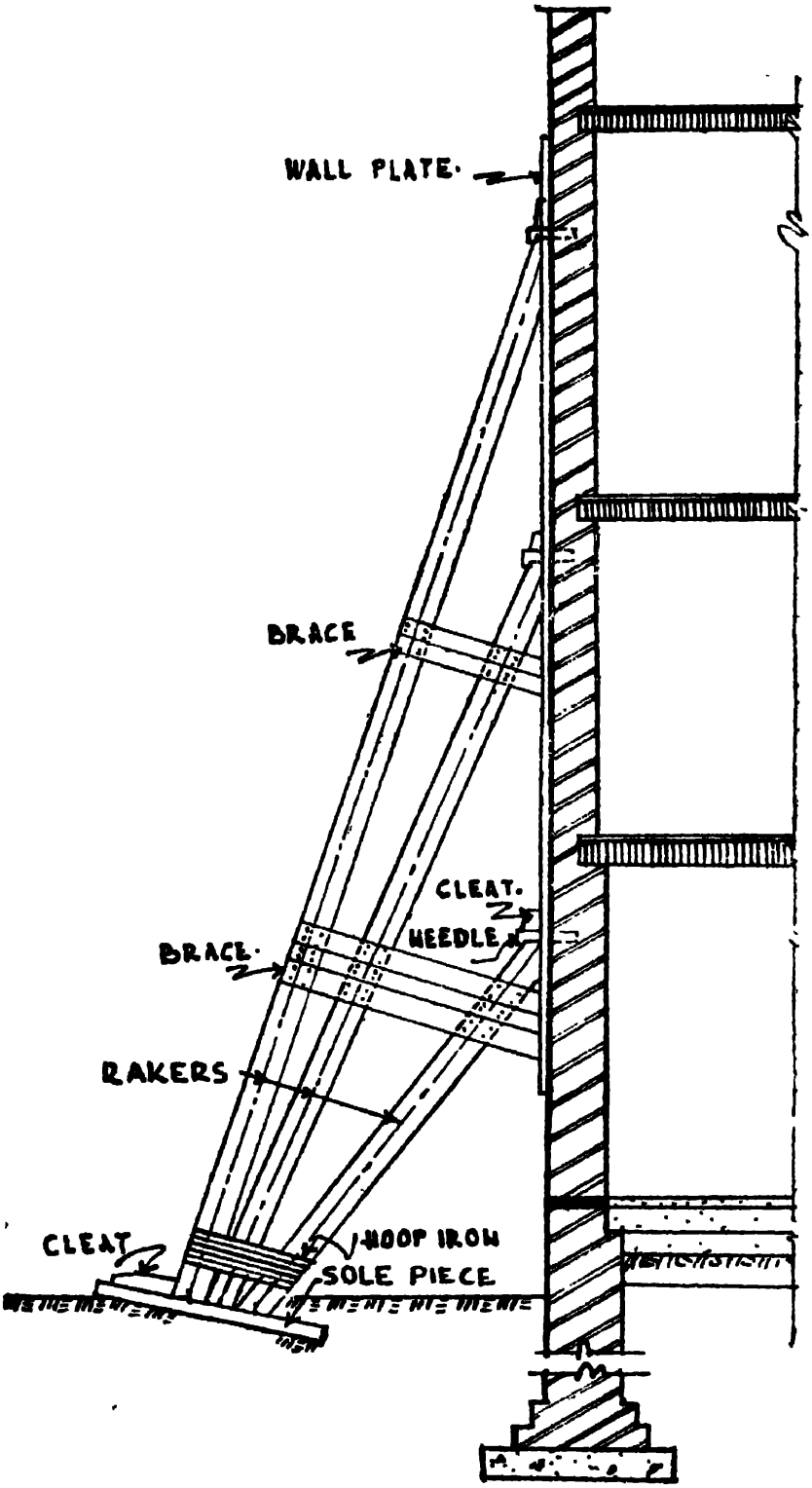


Fig. 6·1
Raking shore

increased so as to distribute the pressure over large area. In places where more rakers are provided, they are bound together by means of hoop iron or braces 2·5 cm. thick and 15 cm. wide. The inclination of the outer raker to the ground should vary between 60° to 75°.

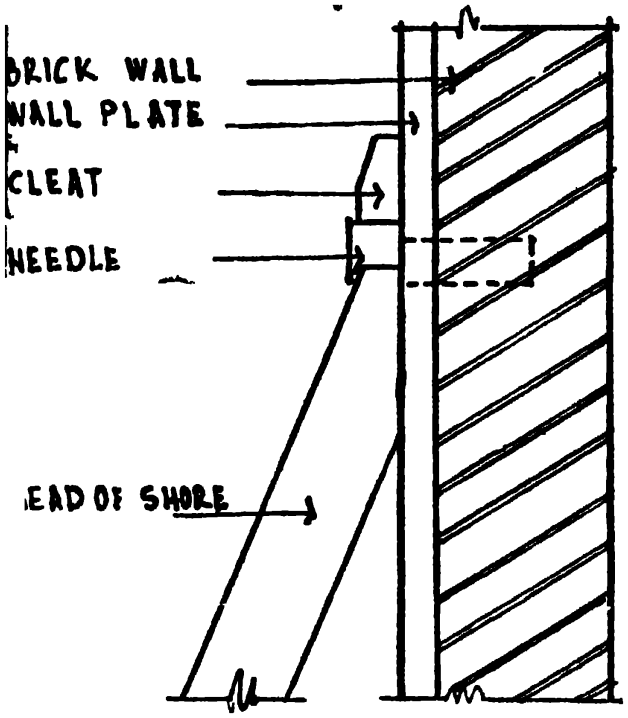


Fig. 6·2
Detail at head of the raker

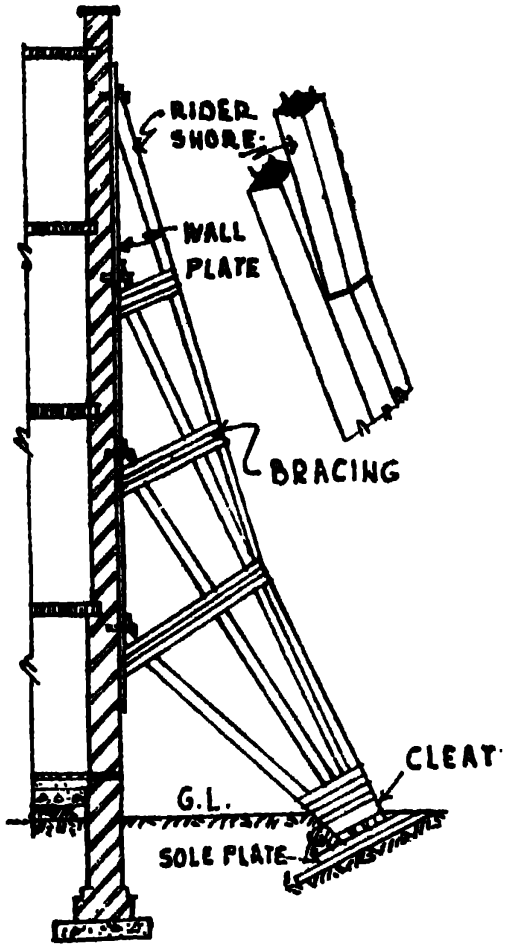


Fig. 6·3

Racking shore for multistoreyed building where inclination of the rackers has to be limited due to short land width available

The sets of shores should be usually placed at 3 to 4·6 m. centre to centre along the wall length.

(2) **Flying shores.** It is a system of providing temporary support to the party walls of two buildings where the intermediate building is to be pulled down and rebuilt. All types of arrangements of supporting the unsafe structure in which the shores do not reach the ground come under this category. The flying shore consists of wall plates, needles, cleats, horizontal struts (commonly known as horizontally shores) and inclined struts arranged in different forms which varies with the situation. In this system also the wall-plates

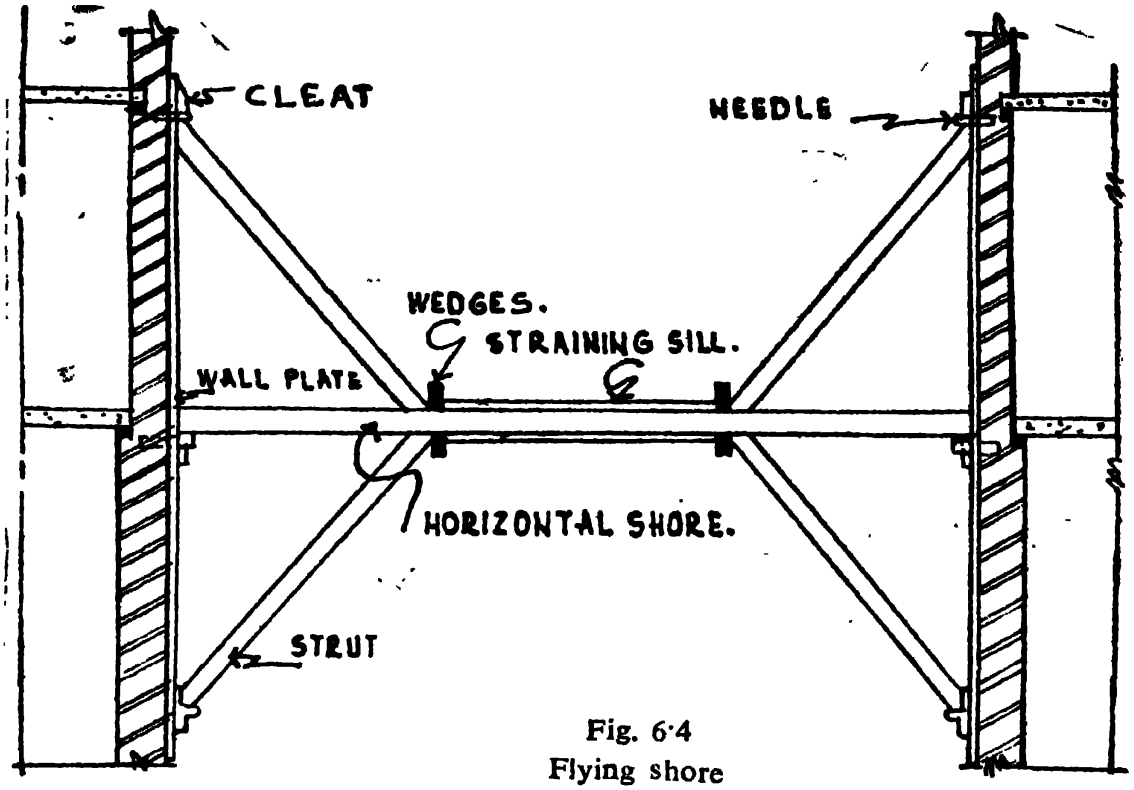


Fig. 6·4
Flying shore

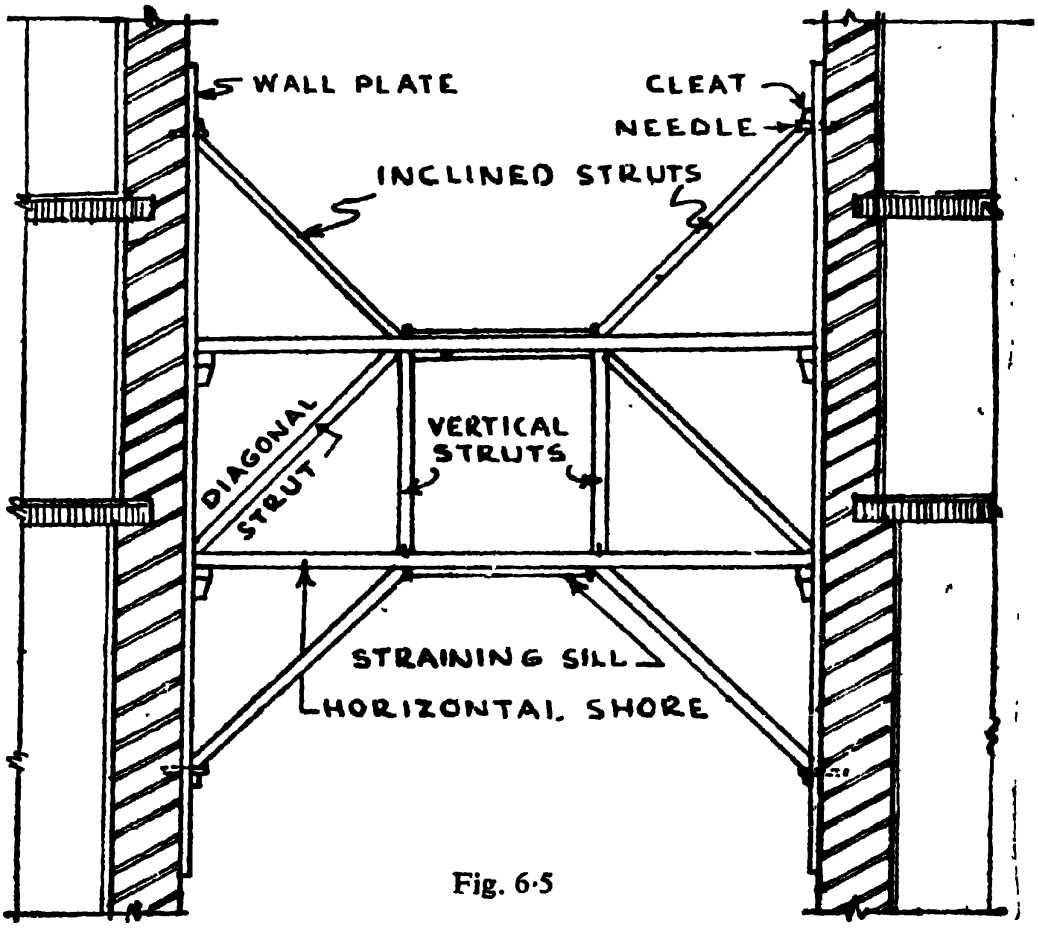


Fig. 6·5

Flying shore : when the distance between the two wall is considerable

are placed against the wall and secured to it. A horizontal strut is placed between the wall plates and is supported by a system of needle and cleats. The inclined struts are supported by the needle at their top and by straining pieces at their feet. The straining piece also known as straining sill is spiked to the horizontal shore. The width of straining piece is the same as that of the struts.

When the distance between the walls (to be struted apart) is considerable, a horizontal shore cannot be safe and a trussed frame work of members is necessary to perform the function of flying shore.

(3) **Dead shores.** This is the system of shoring which is used to render vertical support to walls and roofs, floors, etc., when the lower part of a wall has to be removed for the purposes of providing

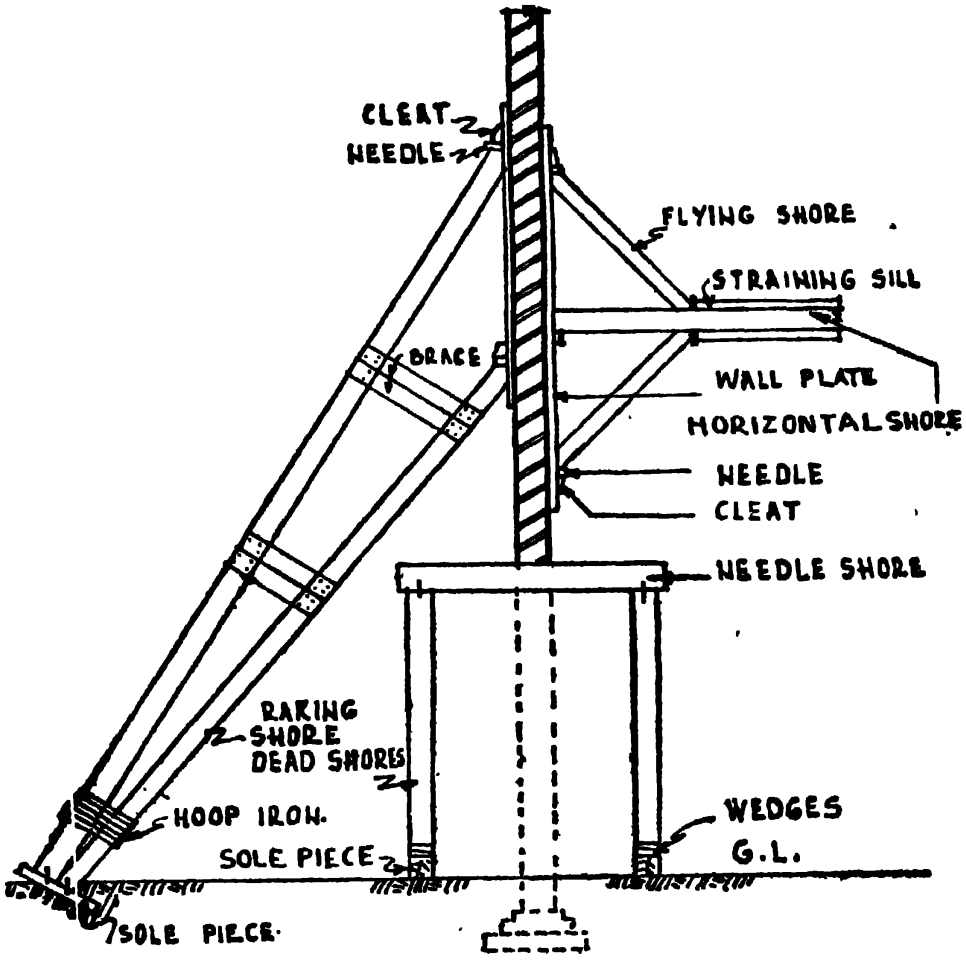


Fig. 6·6

Dead shore

an opening in the wall or to rebuild a defective load bearing wall in a structure. The dead shore consists of an arrangement of beams and

posts which are required to support the weight of the structure above and transfer the same to the ground on firm foundations below.

When openings in the wall are to be made, holes are cut in the wall at such a height as to allow sufficient space for insertion of the beam or girder that will be provided permanently to carry the weight of the structure above. Distance at which the holes are cut depend upon the type of masonry and it varies from 1·2 m. centre to 1·8 m. centre. Beams called needles are placed in the holes and are supported by vertical props called dead shores at their ends, on either side of the wall. The needles may be of timber or steel and are of

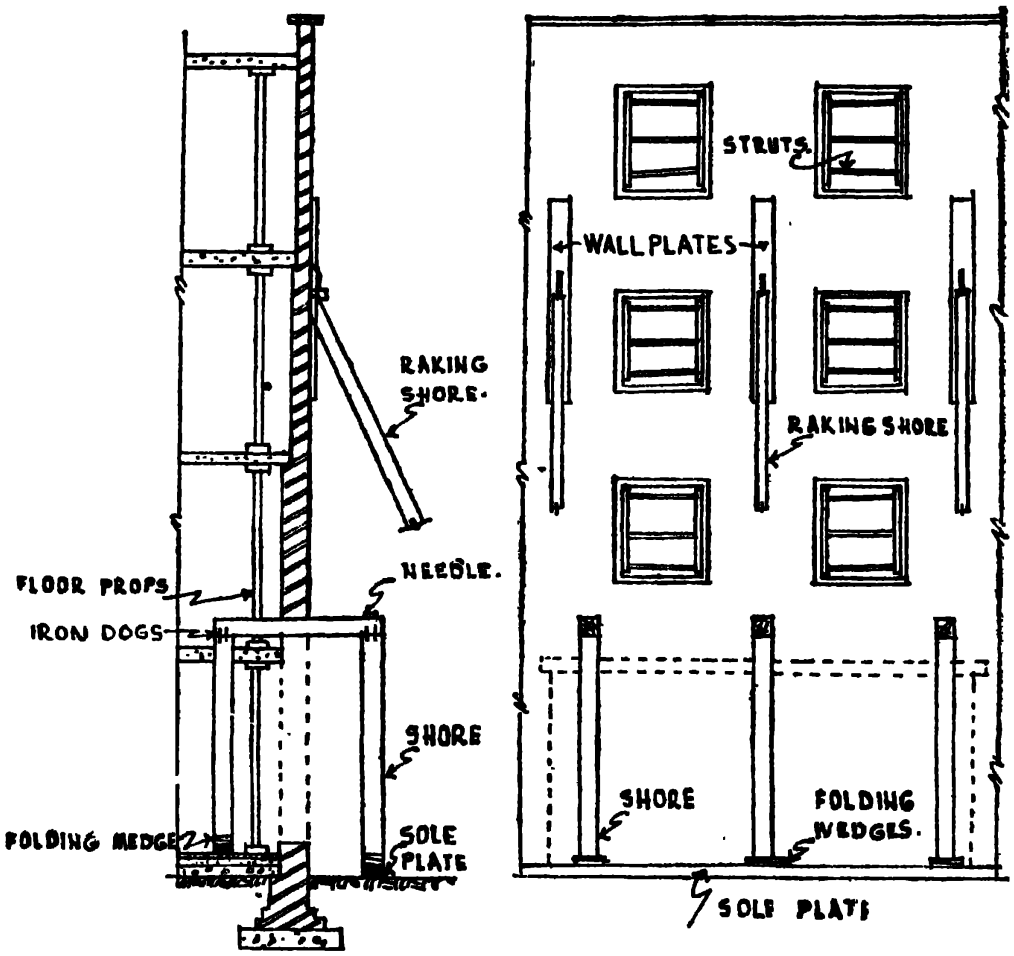


Fig. 6·7

Section and elevation showing arrangement of dead shores for making an opening in an existing wall

sufficient section to carry the load above. The dead shores stand away from wall on either side so as to allow for working space when the needle and the props are in position. The props are tightened up by folding wedges provided at their bases while the junction between the prop and the needle is secured with the help of dogs.

Before the dismantling work is started, all the doors, windows or other openings are well struted. In order to relieve the wall of the weights of floors and roof, they are independently supported. Vibrations and shocks are bound to occur when wall cutting is done, thus as a safety measure against overturning, raking shores are sometimes erected before the commencement of wall-cutting operation.

6·3 Underpinning. This term is applied to the building of new work underneath an existing structure without disturbing its

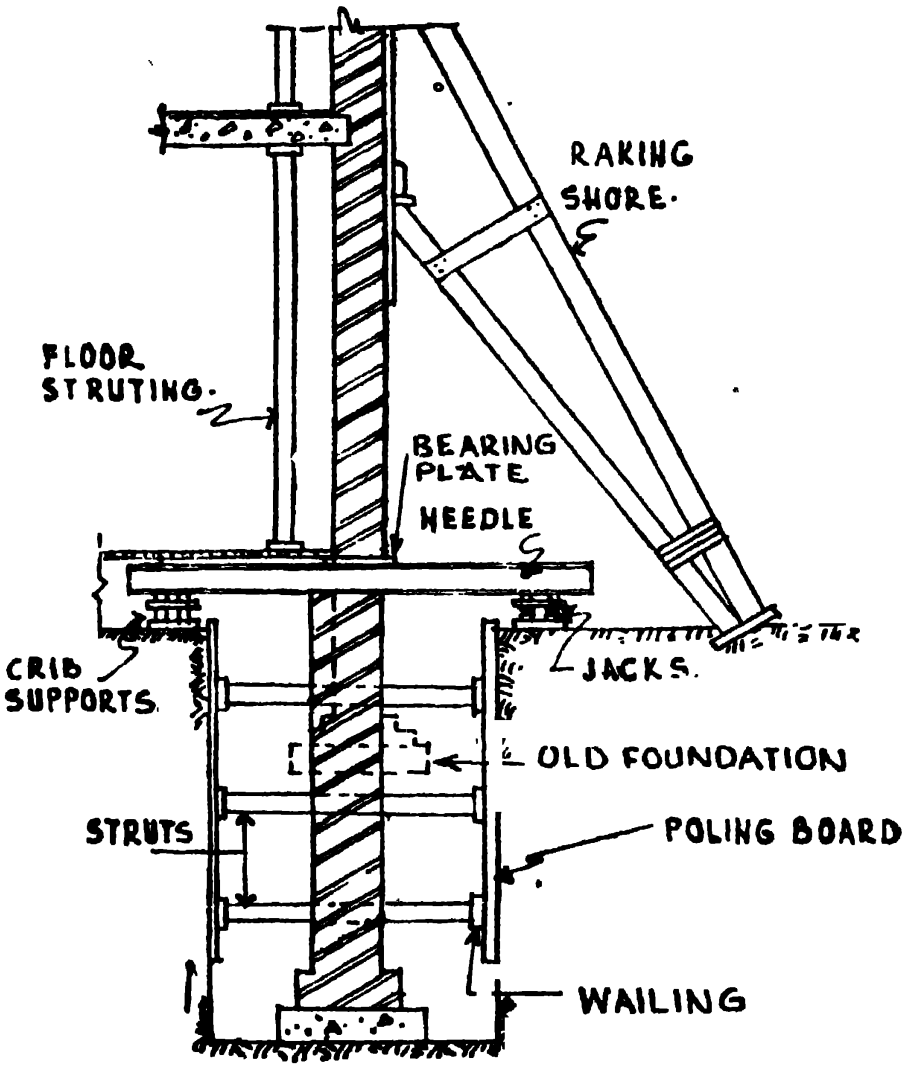


Fig. 6·8

Underpinning

stability. This may be necessary to replace the defective foundation of a wall or to build a new foundation under the existing foundation.

Underpinning is done in short lengths of 1·2 m. to 1·8 m. Holes are cut into the walls at intervals and the entire load of the wall is supported by the needles which rest on sole pieces at ground level. The section of the needle depends upon the load to be supported. The needle may be a timber beam or a rolled steel joist. Thus the structure is held secured and the footings are relieved of the weights from the wall above. When the R.S.J. beams are used as needles, wooden bearing plates are inserted between the beams and the supported wall to avoid crushing of masonry. A pit of sufficient width to provide easy workability and of the required depth is excavated along the length of the wall. When the foundations of a wall are to be replaced, the section of wall is cut to a length of 90 to 120 cm. and new work built. Again, the next 90 to 120 cm. length of wall is cut and rebuilt, thus the entire wall foundation is replaced. When long walls are to be underpinned, the work is started from the centre of the wall and progress is made sideways. The needles are removed only when the new work is completely set.

6·4 Scaffolding. Scaffold is a temporary rigid structure having platforms raised up as the building increases in height. Scaffold enables the mason to work at different stages of a building and to hoist the materials for the immediate use at various heights.

6·5 Types of Scaffolds. The following different types of scaffolds are in common use :

1. *Brick-layer's scaffold*
2. *Mason's scaffold*
3. *Steel or tubular scaffold*
4. *Needle scaffold*
5. *Wooden Gantries.*

(1) **Brick-layer's scaffold.** It consists of vertical members called standards firmly secured in grounds at 2·4 to 3 m. apart. The standards are connected to each other by longitudinal horizontal members called ledgers at every rise of 120 to 150 cm. They are provided on the building side of the standards and are secured in position by rope-lashings. Transverse horizontal members called putlogs are lashed on the ledgers at one end and into the holes in the wall at the other end. Putlogs are 90 cm. in length and are generally spaced 120 cm. apart. They are provided to support the working platform. In high scaffolding, cross braces are used to stiffen the temporary structure. Braces consist of poles tied by rope-lashing on the standards.

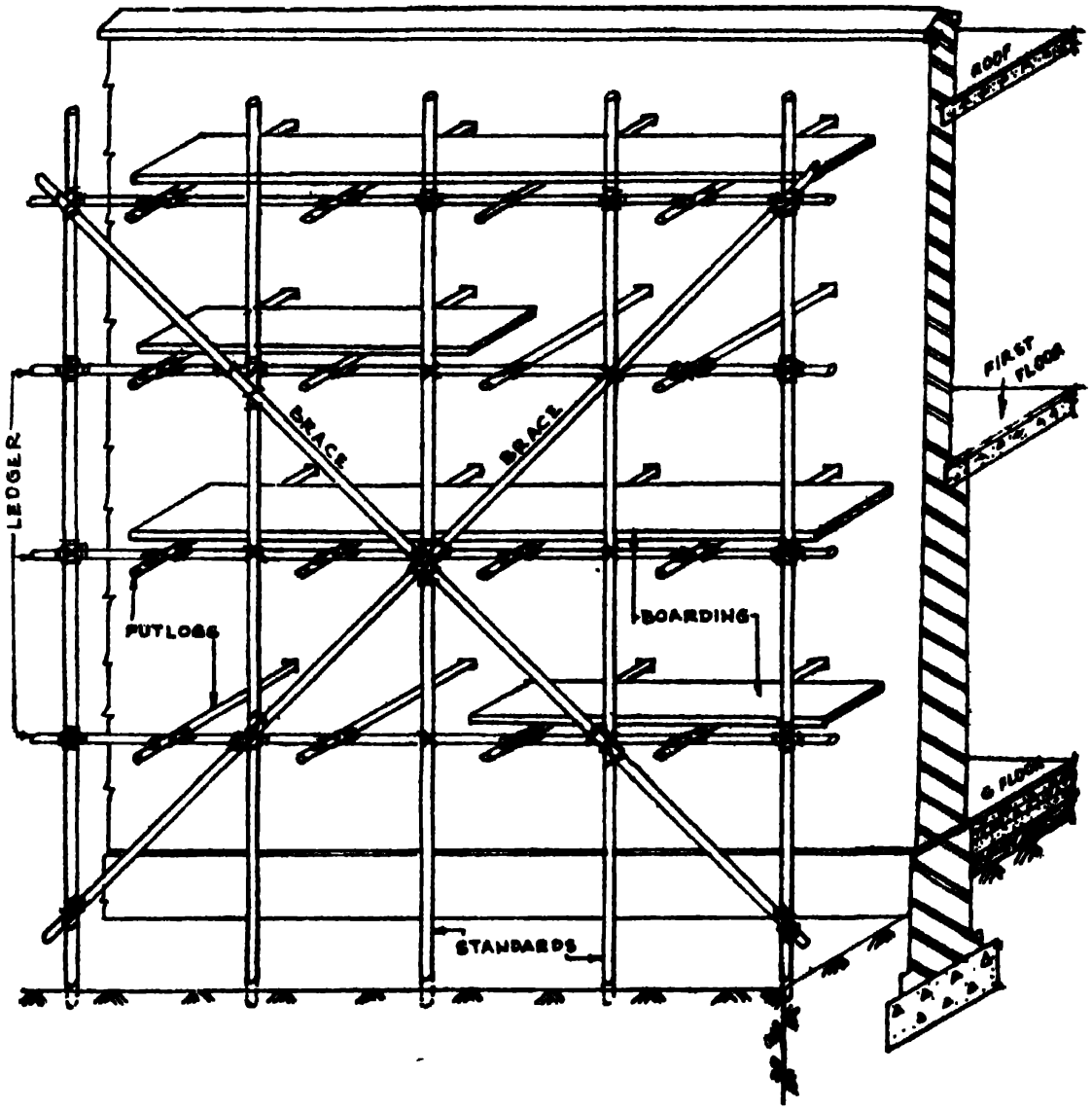


Fig. 6·9

View of bricklayer's scaffold

(2) **Mason's scaffold.** Since it is difficult to leave holes in the stone masonry to provide bearing for the putlogs, in mason's scaffold two frames of standards, ledgers and braces are used. One is placed close to the wall and the other at a distance of 1·5 m. from the first one. Thus the mason's scaffold is entirely independent of the stone wall.

Close mason's scaffold : They are supposed to carry the loads of heavy blocks of stones and the stresses produced on account of the lifting device and hence they are made stronger by placing the standards at fairly close distance apart.

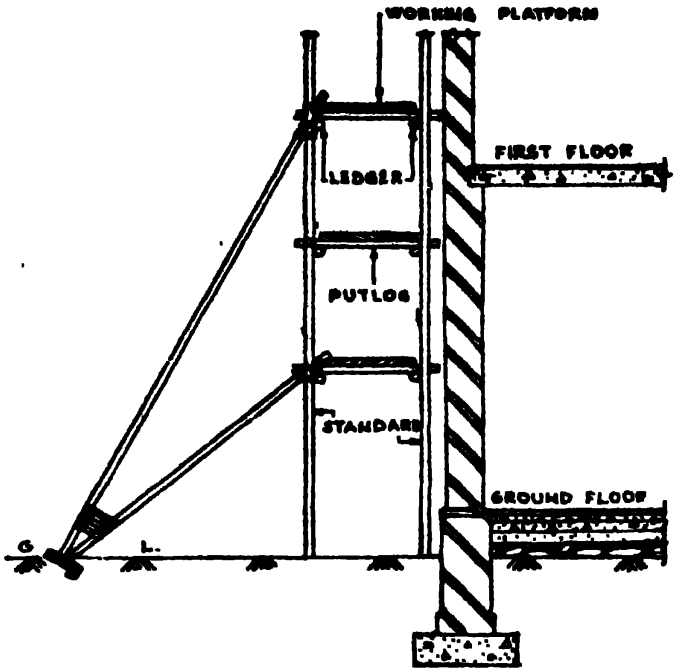


Fig. 6.10

Mason's scaffolding with raking shore

(3) **Steel scaffold.** The construction of steel scaffold is essentially the same as that of timber scaffold. In this the wooden members are replaced by 38 mm. to 64 mm. diameter steel tubes and instead of rope-lashings, patent couplets are used for connecting different members. In this type of scaffold the vertical tubes called upright or standards are spaced 3 m. apart. Each standard is welded to a base plate, square or circular in plan. The base plate has holes so that it can be spiked to a timber or concrete base, thus forming a rigid foundation for the scaffolding. Ledgers or the longitudinal tubes connecting the standards are spaced at 1·8 m. vertically apart. Short tubes or putlogs are 1·2 m. to 1·8 m. in length. The putlogs have special end of fit into the joints in the wall and thus no big holes are required to be left in the wall for their bearing. Tubular scaffolding has the advantage of rapid erection and dismantling, Tubular scaffolding, mounted on bogie wheels can be used for painting the walls, underside of roofs, etc.

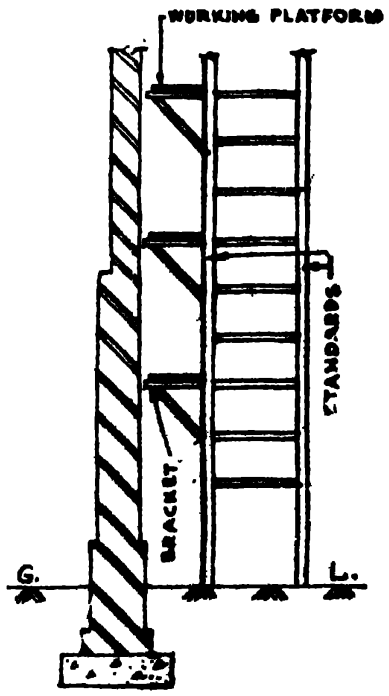


Fig. 6·11

Steel Scaffold

(4) **Needle scaffold.** When scaffolding is to be provided for a building on the side of a busy street where the construction of ordinary scaffolding will obstruct the traffic on road, needle scaffold is used. The scaffold is erected from window corners or string courses by means of projection with needles. The needle is a timber beam which cantilevers out through the holes cut in the wall. From inside the needles are supported on sole pieces and are prevented from lifting up by vertical struts wedged between the needles and the head pieces. The projected end of needle is supported by an inclined strut which rests on the window sill. The joint between the raking or inclined strut and the needle is clamped by means of dogs. This arrangement provides the staging for erection of ordinary type of scaffold.

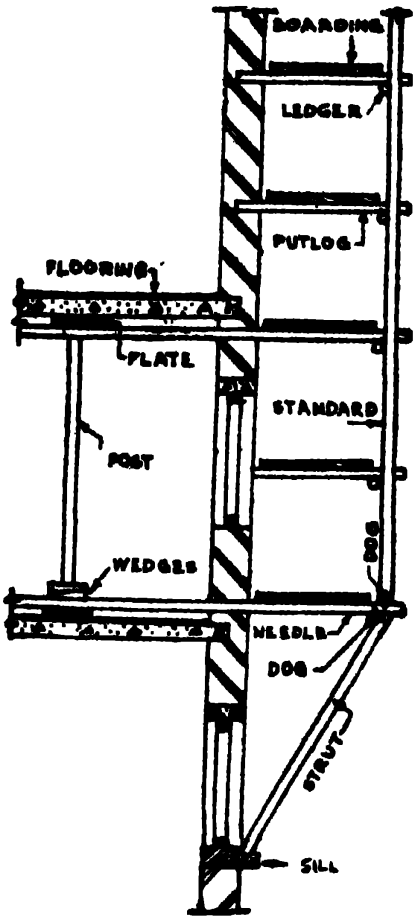


Fig. 6·12
Needle Scaffold

(5) **Gantries.** There are two different types of wooden gantries :

(*a*) *Gantry with traveller or crane*

(*b*) *Platform gantry.*

(*a*) *Gantry with traveller or crane*: When the stone blocks used in the wall construction are too heavy, crane travellers have to be used. The framework of gantry consists of timber standards raised on either side of wall. Longitudinal members called runners are fixed on the top of the standards, while at the bottom, the standards are fixed to common sole piece. Rails are fixed on the runners to carry the travelling platform. The travelling platform consists of trussed beams carrying lifting tackle, which can run on wheels on rails fixed on runners. This enables the travelling platform to move parallel to the wall along its length.

Again the beams of travelling plateform have rails so that the lifting tackle can move in a direction perpendicular to the wall.

Thus the blocks of stones can be placed in any desired direction while building the wall.

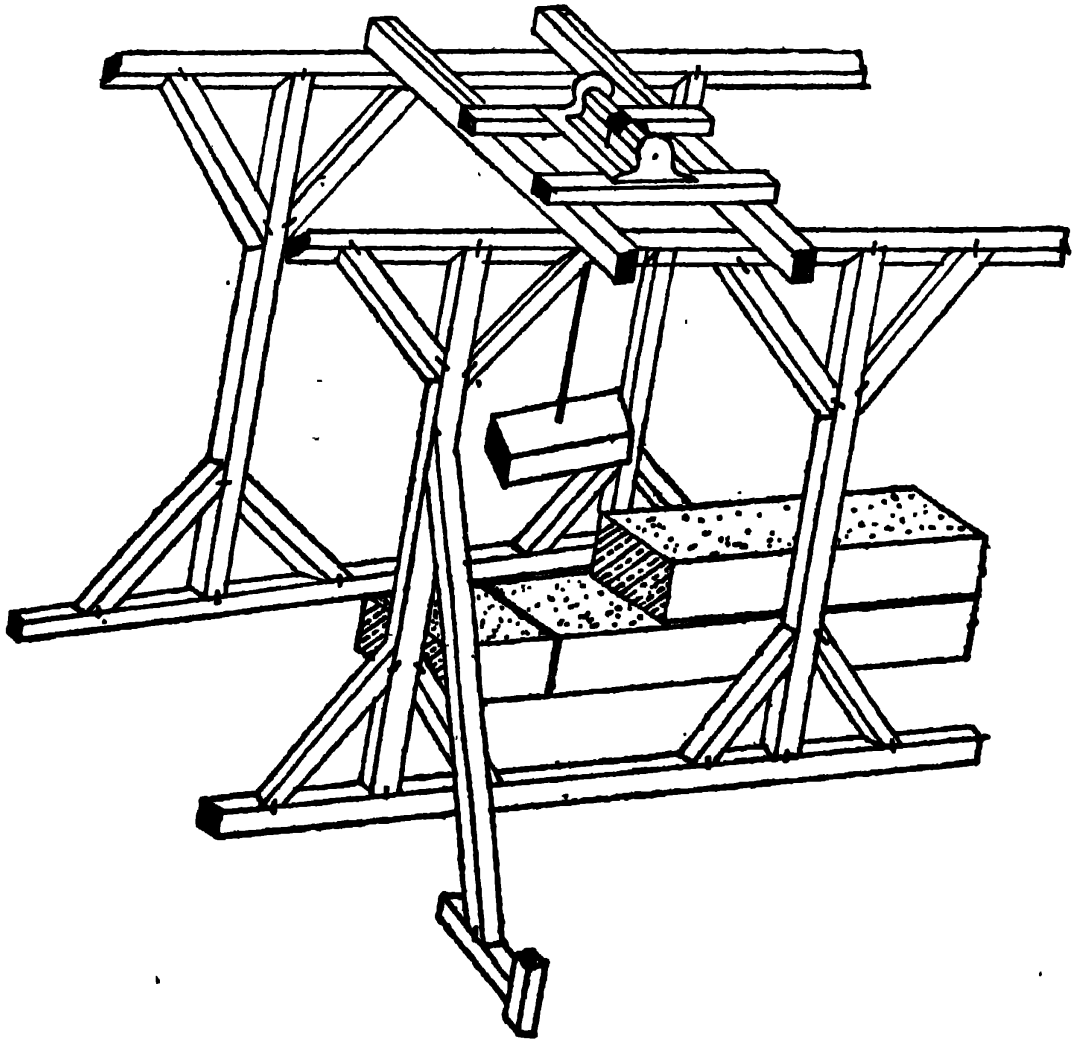


Fig. 6·13

Gantry with a traveller or crane

(*b*) *Platform gantry* : This is needed for providing a working platform above ground level and leaving the space below free from obstruction. This is adopted in the stone masonry construction as it can be used independent of wall. The gantry consists of vertical posts fixed to common sole piece at its base and to a head-piece at the top. The head-pieces support the joists on which working platform is laid. The entire frame-work is thoroughly braced and dogged.

A 90 cm. high boarding is fixed on the outside of the gantry to prevent the material on the platform falling down.

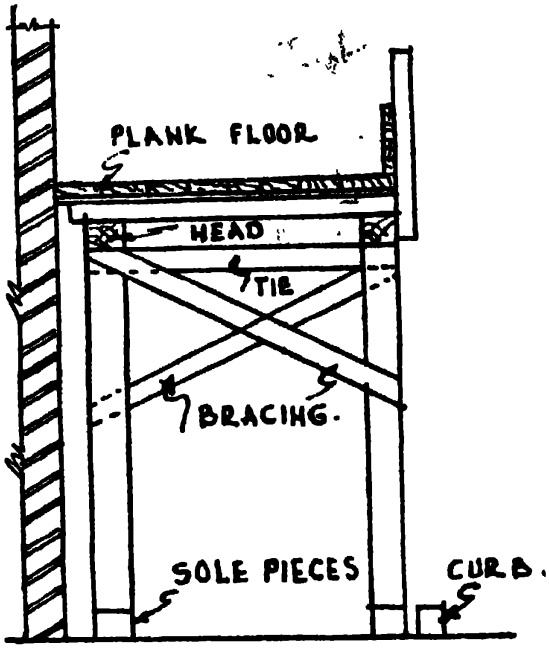


Fig. 6·14

Platform gantry

Questions for Revision

1. (*a*) Explain with sketches what you understard by the terms 'underpinning' and 'shoring'.

(*b*) It is proposed to form an opening 7·6×3 7 m. high in a front wall of an existing two-storey building with a steel beam supported by stanchions at both ends to support the load from above. The existing building is 24 m.×9 m. on plan. The floor to floor heights for ground and first floor respectively are 5 m. and 3·7 m. Detail and explain briefly the method of executing the above work.

Explain with sketches what you understand by the terms 'underpinning' and 'shoring'.

2. The roadside wall of a big hotel in 'Calcutta, situated in a very busy street, cracked dangerously right from the foundation to the third storey. It was ordered to demolish tbe said wall and construct a new brick wall in its place. Show by sketches the various operations involved in carrying out the work without causing much dislocation to the traffic and ensuring the safety of the occupants.

3. Write short note on :

(*i*) Raking shore.

(*ii*) Flying shore.

(*iii*) Dead shore.

Draw neat sketches showing the position of the various shores in an existing building.

4. What are the types of scaffolding commonly used ? Draw a neat sketch to illurtrate the difference between the various types giving short notes in favour of the sketches shown.

5. What is the difference between a gantry and scaffolding ? Explain with sketches the different types of gantries used in building operation.

6. How do the steel scaffold differ from timber scaffold ? Discuss the advantage of steel scaffold and suggest the type of scaffold you would recommend in the construction of a four-storeyed public building.

7. Write short notes on :

(*i*) Needle scaffolding.

(*ii*) Tubular scaffolding.

(*iii*) Gantry.

8. Describe in detail the essential components of raking shore showing neat sketches to illustrate your statement.

9. It is proposed to raise one more storey on an existing three-storey building. No provision for future extension was made in the design of foundations of the said building. Explain with sketches the operation of new construction, including the process of strengthening of the foundation.

10. An opening of size 3 m. × 4·6 m. is to be provided in a solid brick wall above which there are two floors. What measures do you propose and how do you go ahead with the work ? Recommend the type of lintel you purpose to provide above the opening.

11. In a brick masonry-wall building five-storeyed high, outer walls on the ground floor in between shop-doors have developed cracks below the floor beams at the first floor level. Show, by neatly drawn sketches, how you would rectify the and strengthen the structure so as to make it safe ?

12. What do you understand by the terms 'under-pinning' and 'shoring' ? Explain where these operations are made use of and why. Give sketches.

13. Describe how will you provide a 1·2 m. wide door opening in a 38 cm. thick load carrying wall of an old building.

14. (*a*) Describe with sketch the method of timbering in a trench of size 1·8 m. deep × 1·2 m. wide for laying underground sewers in moderately firm ground.

(*b*) State how will you provide a steel joinst in place of an old rotten timber beam supporting burga tiled roofing. Sketch the details and mention all precautions to be taken.

15. Describe briefly with necessary sketches method of under-pinning used in foundation work of a building.

7

Masonry—Stone Masonry

7·1 Definition. The construction of stone, brick or tile, which is hardened by heat, is termed as masonry. It may also be defined as construction of building units bonded together with mortar. The characteristics of brick and stone, *i.e.* compressive strength, fire resistance, and durability, are responsible for their usage in masonry construction. Masonry can be divided into two main classes, *i.e. stone masonry* and *brick masonry.*

7·2 Comparison between stone masonry and brick masonry

(1) From times immemorial, stone has been used both for residential as well as public buildings. Historical building that stand today are the living examples of the strength, durability and the excellent weather-resisting qualities of stone masonry. Brick on the other hand has much less strength, durability and weather-resisting qualities.

(2) On account of its high crushing strength stone is used in the construction of piers, docks, dams and other marine structures. Brick, on the other hand, is not considered suitable in all such places.

(3) Shining texture of good class of stone masonry requires no treatment to enhance its appearance. On the other hand, plastering is necessary to conceal the defects in brick masonry.

(4) In buildings of monumental nature, where architecture requires heavy mouldings with large projections, stone is best suited, brick being suitable for light ornamental work.

(5) Bricks when exposed are liable to get damp which may ultimately lead to the disintegration of the masonry. Stonework on the other hand suffers from no such danger.

(6) Certain salts present in the sewage, react chemically with exposed brick and as such when brick-work happens to come in contact with urine or sewage it is always plastered. Stone on the other hand can be used in such places without providing any protective coat.

(7) On account of the high cost of stone masonry, its usage is generally restricted to hilly areas or stone districts ; bricks on the other hand are easily available and the masonry constructed with bricks costs much less.

(8) First class bricks prossess all such qualities which are required for a good construction and hence brick masonry has now practically replaced stone masonry.

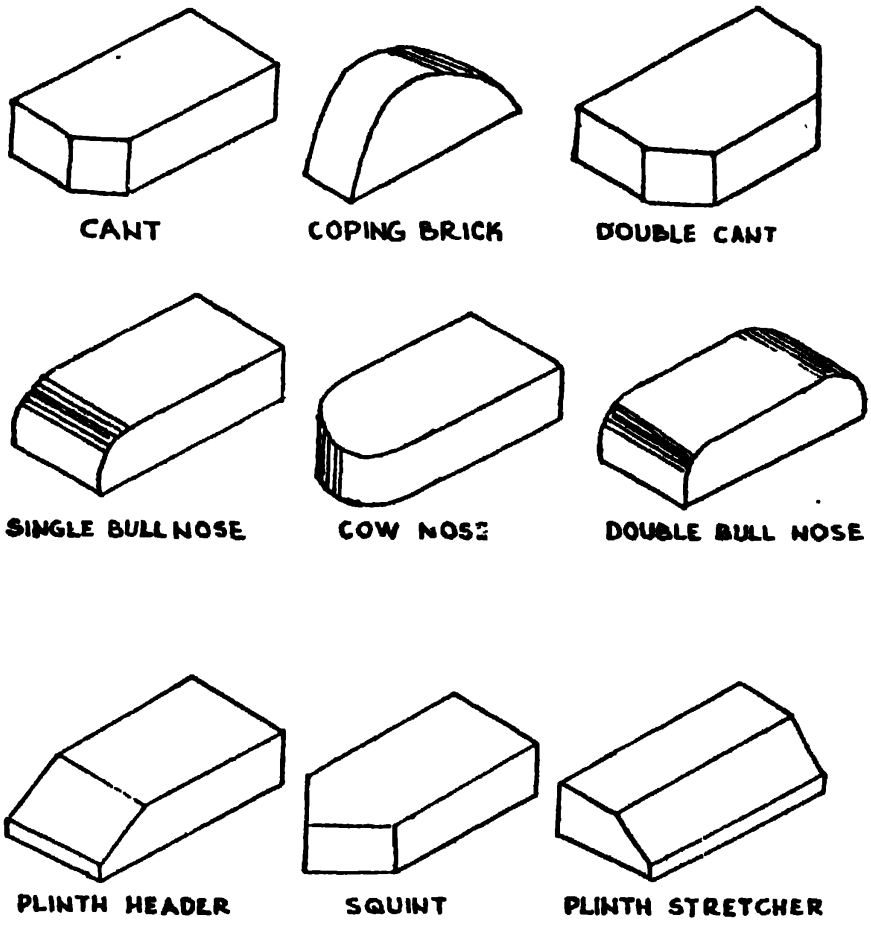


Fig. 7·1—Fig. 7·8

Bricks moulded in different shapes

(9) On account of their regular shape and size, bricks afford great facility in maintaining proper bond in the masonry. It also results in quick construction. On the other hand, in stone masonry, the process of dressing and placing stones requires a great deal of time and extra labour.

(10) For the construction of jambs of doors and window and for the walls meeting at obtuse or acute angle, bricks offer greater facility than stone.

(11) Bricks can be conveniently moulded into any desired shape at reasonable cost while the expense of the moulding of stone work is far more than that of brick.

(12) Skilled labour is required for a good stone masonry construction because the defects left by a careless mason cannot be rectified easily, while in brick masonry the defects of a careless bricklayer can be concealed by plastering.

(13) On account of their convenient size and light weight, bricks require no lifting tackle while in stone masonry the large blocks of stone have to be kept in position with the aid of some lifting device.

(14) Brick walls can be easily built in small thickness of 10 cm. and 20 cm. while the minimum thickness of a stone wall is generally restricted to 38 cm.

(15) Brickwork is more fire-resisting than stone work.

Both the brick masonry and the stone masonry are further subdivided into a series of categories. Before dealing with them in detail it is considered desirable to get acquainted with the technical terms used in masonry.

7·3 Technical terms used in masonry. The terms which are in common use in masonry have been defined below :

(1) *Header* : It is a full brick or stone which is laid with its length perpendicular to the face of the wall. Thus the brick laid as header will show its face measuring 10 cm. × 10 cm. on the face of wall. In stone masonry header is sometimes termed as through stone.

(2) *Stretcher* : It is a full brick or stone which is laid with its length parallel to the face of the wall. Thus a brick laid as stretcher will show its face measuring 10 cm. × 20 cm. on the face of the wall.

(3) *Bond* : It is a term applied to the over-lapping of bricks or stones in a wall in alternate courses, to bind the whole wall together. Bonding is essential to eliminate continuous vertical joints both in the body as well as on the face of wall.

(4) *Course* : An horizontal layer of bricks or stones is termed as a course. Thus in brick masonry the thickness of a course will generally be equal to 10 cm. plus thickness of one mortar joint.

(5) *Header course* : It is a course of brickwork entirely composed of headers.

(6) *Stretcher course* : It is a course of brickwork in which all the bricks are laid as stretchers.

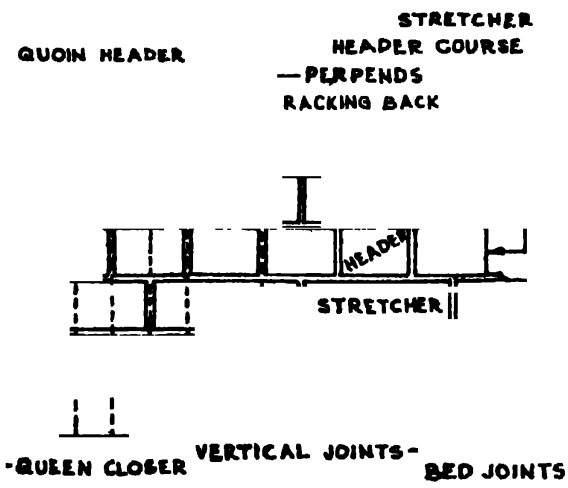


Fig. 7·9

(7) *Bed* : It is a term used to indicate the lower surface of bricks or stones in each course. It may also be termed as the surface of bricks on which it rests.

(8) *Face* : The surface of a wall exposed to weather is termed as face.

(9) *Facing* : The material used in the face of the wall is known as facing.

(10) *Back* : The inner surface of wall which is not exposed to wheather is termed as back.

(11) *Backing* : The material used in forming the back of the wall is known as backing.

(12) *Hearting* : The portion of a wall between facing and backing is termed as hearting.

(13) *Joint* : The junction of two or more bricks or stones is called joint. Joints may be of cement mortar or of lime mortar. Joints parallel to the bed of bricks or stone in a course are termed as *bed joints*. Thus the pressure always acts normal to the bed joints. The joints which are perpendicular to the bed joints are termed as *vertical joints* or simply joints.

(14) *Raking back* : The process of stopping the unfinished end of a wall in stepped fashion.

(15) *Bat* : It is the portion of a brick cut across the width or a brick cut by some fraction of its length.

(16) *Closer* : It is a portion of a brick cut in such a manner that its one long face remains uncut.

(17) *King closer* : It is a brick which is cut in such a way that the width of one of its end is half that of a full brick. It is formed by cutting off the triangular piece between the centre of one end and the centre of one side.

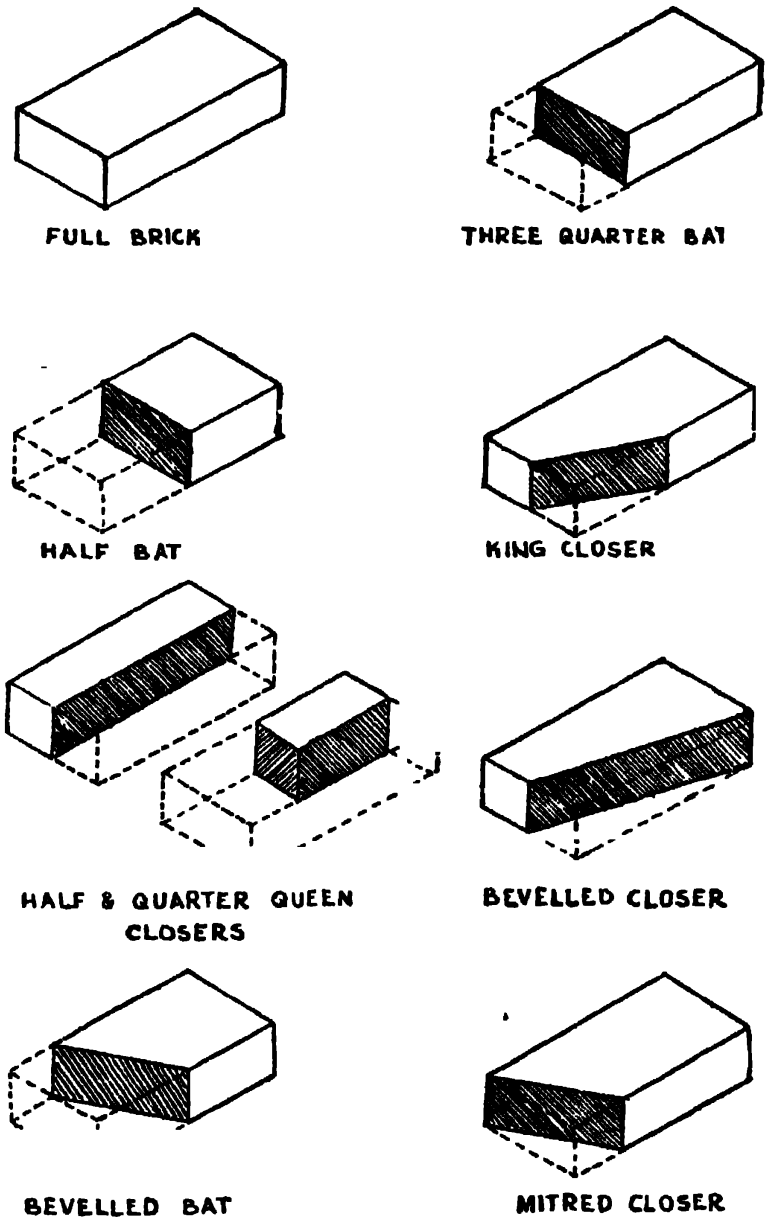


Fig. 7·10—7·17

(18) *Queen closer* : It is a term applied to a brick which is half as wide as a full brick. Queen closer is made by cutting a brick lengthwise into two portions.

(19) *Bevelled closer* : It is similar to king closer with the only difference that the whole length of the brick is bevelled for maintaining half width at one end and full width at the other.

(20) *Mitred closer* : It is a brick whose one end is cut splayed or mitred for the full width.

(21) *Perpend* : It is a vertical joint on the face of a wall directly over vertical joints in alternate courses.

(22) *Frog* : It is a depression on the top face of a brick. Frog provides a recess for the mortar which on setting forms a key and prevents the displacement of the brick above.

(23) *Quoin* : The exterior angle or corner of a wall is termed as quoin. The brick or wedge shaped stone used for the corner of walls is also known as quoin.

(24) *Plinth* : The horizontal projecting course of stone or brick provided at the base of the wall above ground level is known as plinth. It raises the level of the ground floor of the building above the natural ground level and incidentally protects the building from rain and other weather effects.

(25) *Plinth course* : It is the topmost course of plinth and is finished flush with the ground floor surface.

(26) *Sill* : It is a horizontal member of brick, stone, concrete or wood provided to give support for the vertical members of a wooden window. It is also employed for the purposes of shedding off rain water from the face of wall immediately below the window opening.

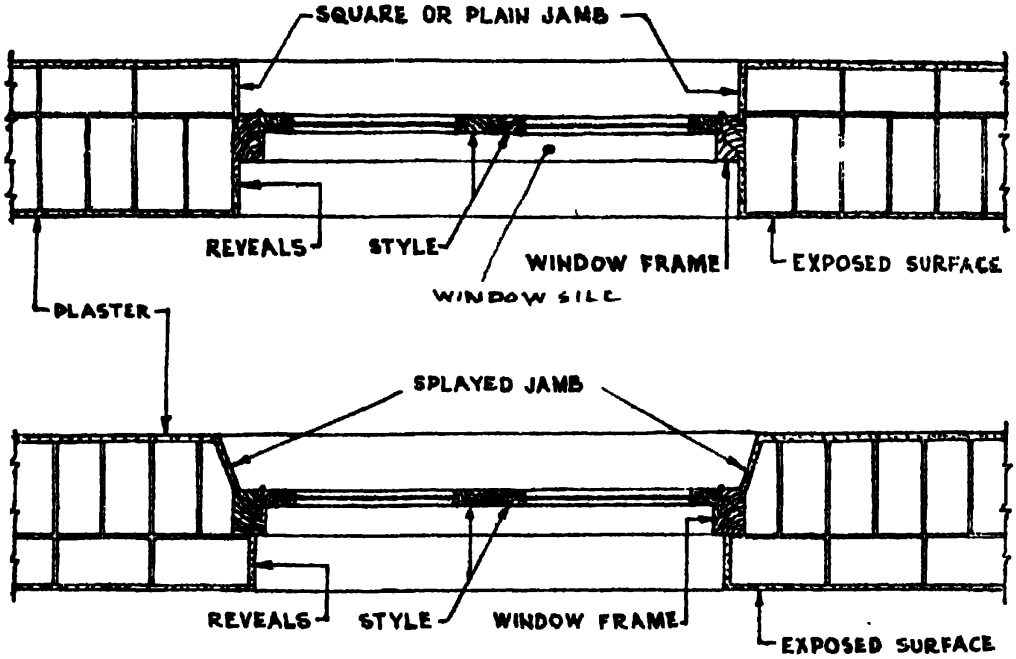
(27) *Jambs* : The vertical sides of a finished opening for door, window or fire-place etc. are termed as jambs. Jambs may be plain or rebated or splayed.

(28) *Reveals* : Reveals are the exposed vertical surfaces left on the sides of an opening after the door or window frame has been fitted in position.

(29) *Lintel* : A horizontal member of stone, brick, wood, iron of R.C.C., used to support the masonry or load above an opening.

(30) *Arch* : A mechanical arrangement of wedge-shaped blocks of stone or brick arranged in the form of a curve supporting the masonry or load above an opening.

(31) *String course* : It is a horizontal course of masonry projecting from the face of the wall and is generally at every floor or sill level throughout the length of the wall. It is intended to improve the elevation of the structure.



Figs. 7·18—7·19

Plain and splayed jambs

(32) *Cornice* : It is a horizontal moulded projection provided near the top of a building or at the junction of a wall and ceiling. It not only increases the architectural beauty of the structure, but also serves as a barrier for shedding the rain water off the face of the wall.

(33) *Frieze* : It is a course of stone provided immediately below a cornice. This may be flushed with the wall or may be moulded. It is intended to add to its appearance.

(34) *Blocking course* : It is a course of stone masonry provided immediately above the cornice to check the tendency of the cornice to overturn and incidentally adds to its appearance.

(35) *Parapet* : It is a term applied to a low wall built round a flat roof to act as a protective solid balustrade for the users of the terrace (flat roof). In pitched roof parapet wall is provided to conceal the gutter at eaves level and for imparting an architectural effect to the structure.

(36) *Coping* : Coping is a covering placed on the exposed top of an external wall. It is essentially provided to prevent the seepage of water through the joints of the topmost course of wall. It may be of concrete, stone, brick or terracotta.

(37) *Toothing* : Bricks left projecting in alternate courses for the purposes of bonding future masonry work.

(38) *Weathering and throating* : Weathering is the term applied to the bevelled top surface of a stone. Bevelling or sloping of the

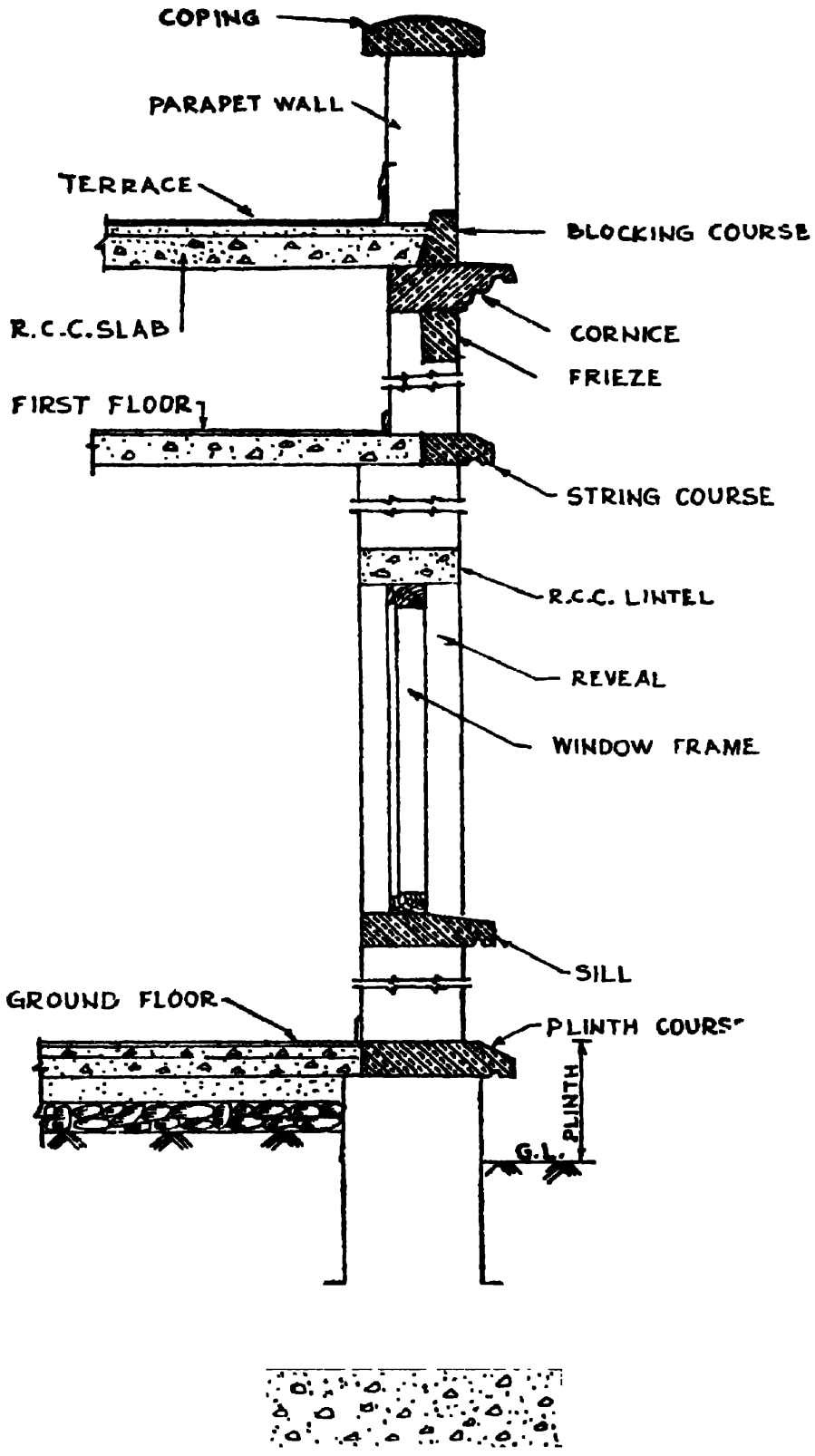

COPING
PARAPET WALL
TERRACE
BLOCKING COURSE
R.C.C.SLAB
CORNICE
FRIEZE
FIRST FLOOR
STRING COURSE
R.C.C. LINTEL
REVEAL
WINDOW FRAME
SILL
GROUND FLOOR
PLINTH COURSE
PLINTH
G.L.

Fig. 7·20

surface is necessary to enable the rain water to flow off the surface. *Throating* is the term applied to the groove cut on the underside of

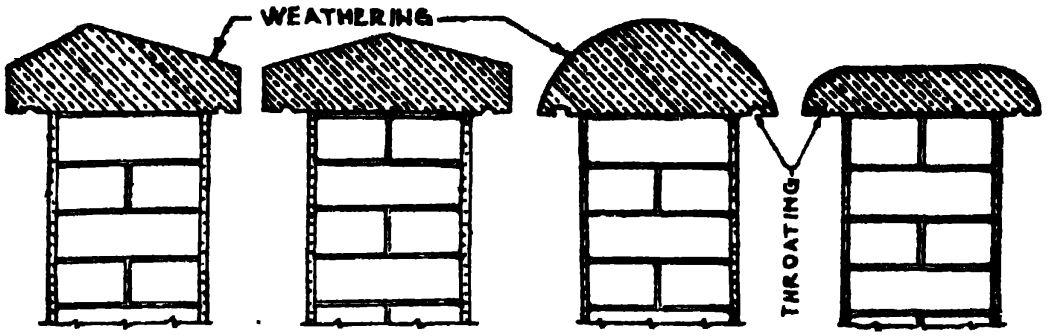


Fig. 7·21
Different forms of stone copings

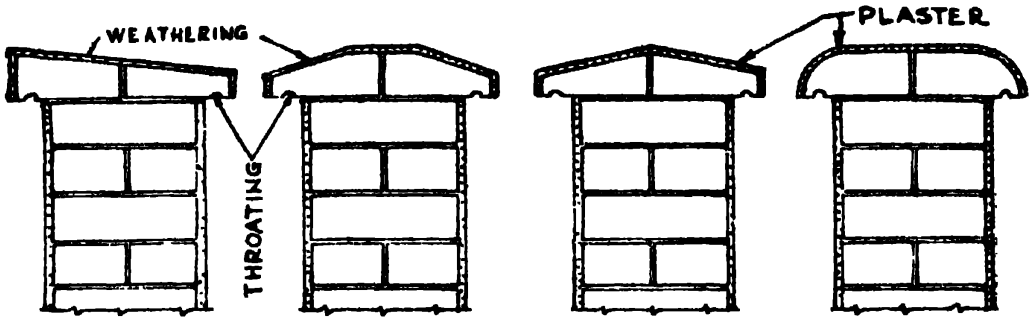


Fig. 7·22
Different forms of brick copings

a projecting course of masonry in order to check the creepage of rain water on the underside of projected portion. If the rain water is not intercepted by such groove, it will spread across the bottom of the projected surface and will finally start flowing along the vertical surface of the wall, making it damp.

(39) *Gable* : It is a triangular shaped portion of masonry at the end of a sloped roof.

(40) *Through stone* : A stone passing through a wall from front to back face and acting as a blinder for the two faces of the wall is termed as through stone.

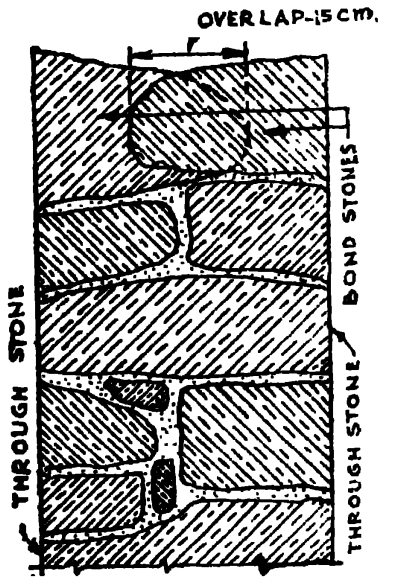


Fig. 7·23
Section of a stone wall showing through stone

(41) *Indenting* : The process of leaving recesses in masonry into which future work can be bonded.

(42) *Template or bed block* : Block of stone of designed dimensions used under a beam or grider to distribute the concentrated load at the end of the beam or grider over a greater area of bearing surface.

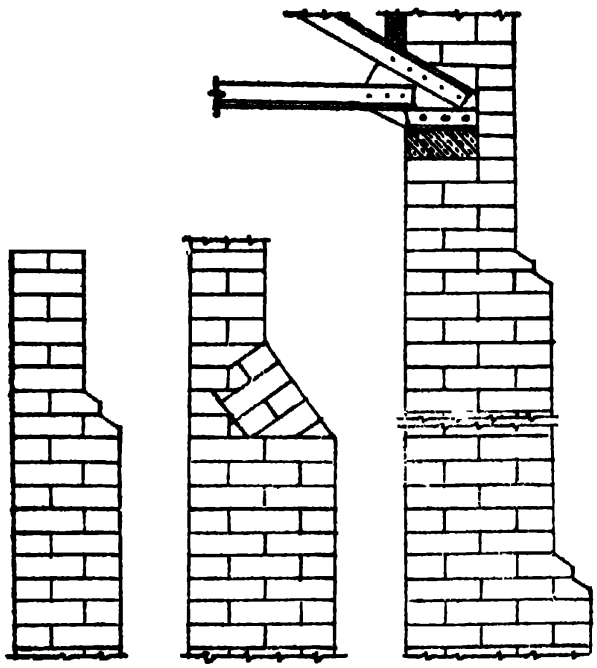
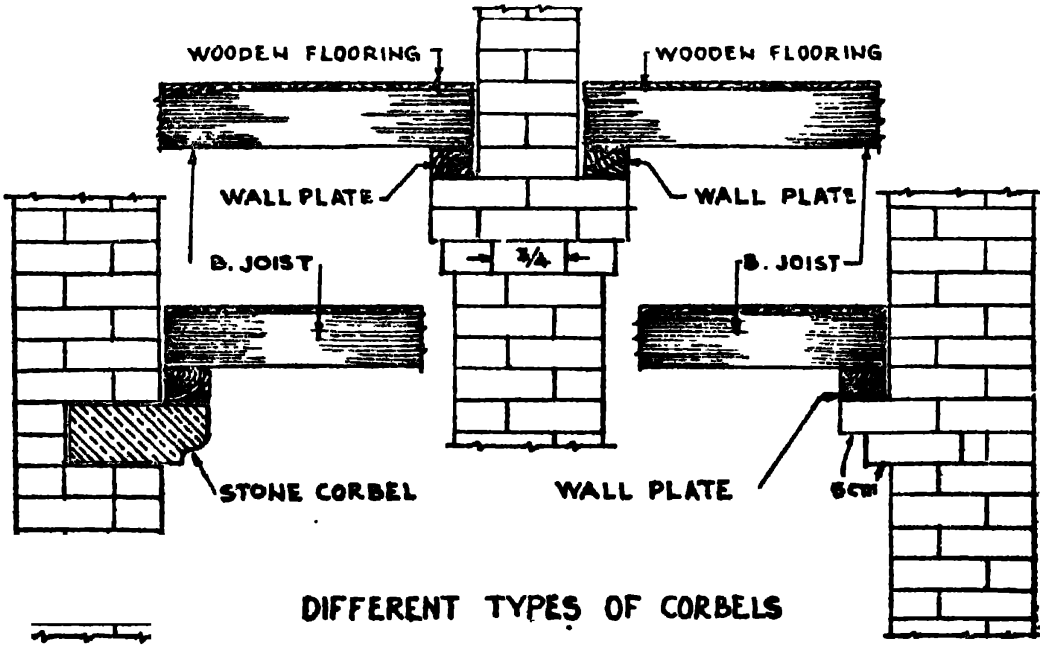


Fig. 7·24
Different forms of buttresses

(43) *Spalls* : Chips or small pieces of stone broken off a large block are termed as spalls. They are used in filling the interstices in stone masonry.

(44) *Column* : It is an isolated vertical load bearing member whose width does not exceed four times its thickness.

(45) *Pier or pilaster* : It is a vertical member of stone or brick masonry constructed to support an arch, beam, or lintel etc., the width of which exceeds four times its thickness. Generally they are made monolithic with the walls for the purpose of



DIFFERENT TYPES OF CORBELS

Fig. 7·25

increasing the stability and stiffness of the wall to carry more vertical concentrated loads.

(46) *Buttress* : It is similar to a pier built in the wall to increase its stability. It need not always extend to full height of the wall.

(47) *Corbel* : It is the extension of one or more courses of brick or stone from the face of a wall. The projection of courses which is generally ornamental in shape serves as a support for wall plates etc.

STONE MASONRY

7·4 Dressing of stone. Building stone has to be quarried out

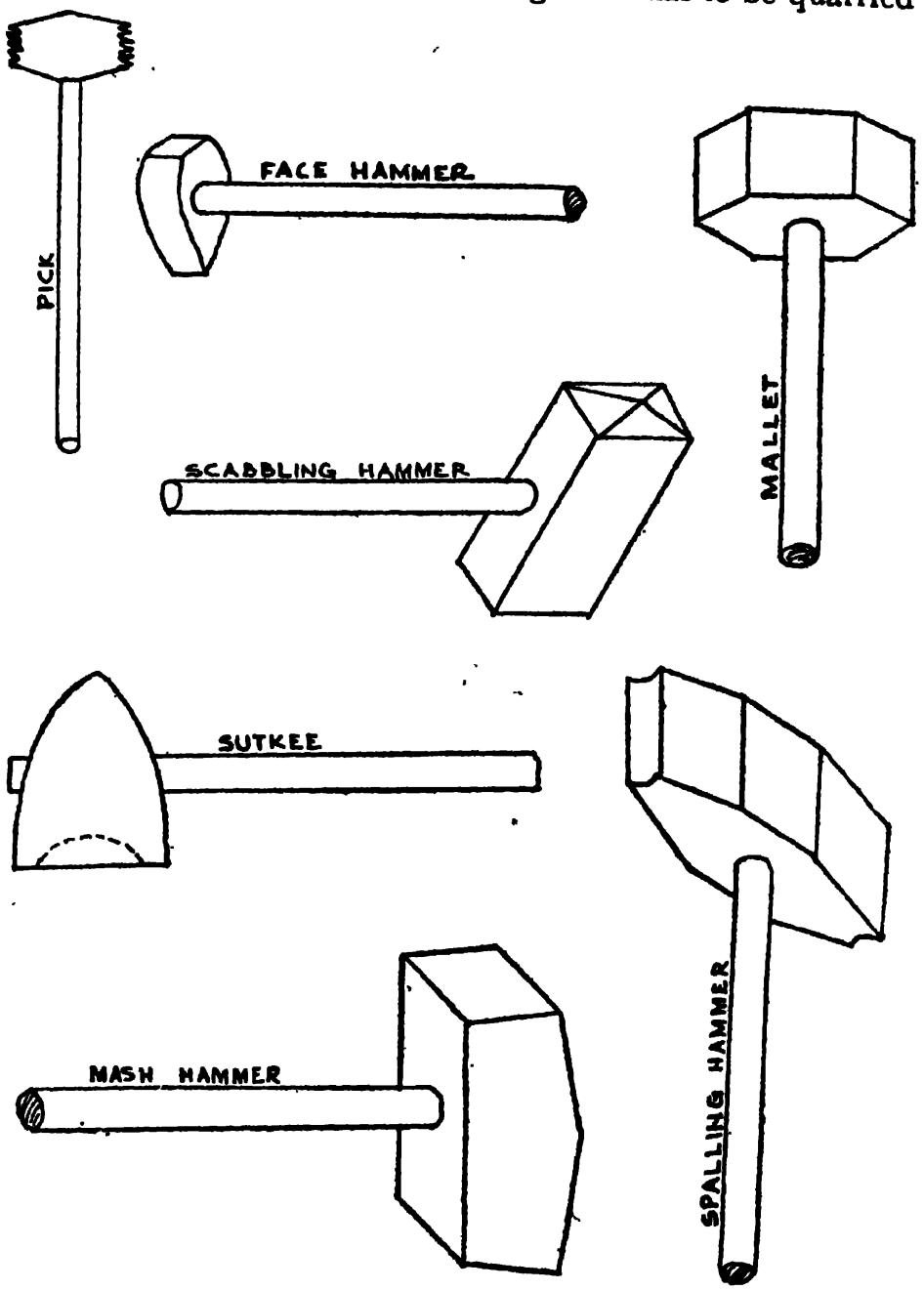


Fig. 7·26 Tools and implements used in dressing of stone

from the rock formation before it can be put to use. The quarry of stone may be done either by hand tools or with the help of explosives. In large quarries, machines have to be used for the purpose. Rough blocks of stone, as obtained from quarry, are irregular in shape and non-uniform in size and as such they cannot be used in masonry without proper dressing and cutting. The dressing of stone is done at the quarry itself, because stones when freshly quarried contain some moisture called "*quarry sap*" and in this state they are softer and can be easily worked.

Moreover, the local workmen are well experienced in the art of dressing.

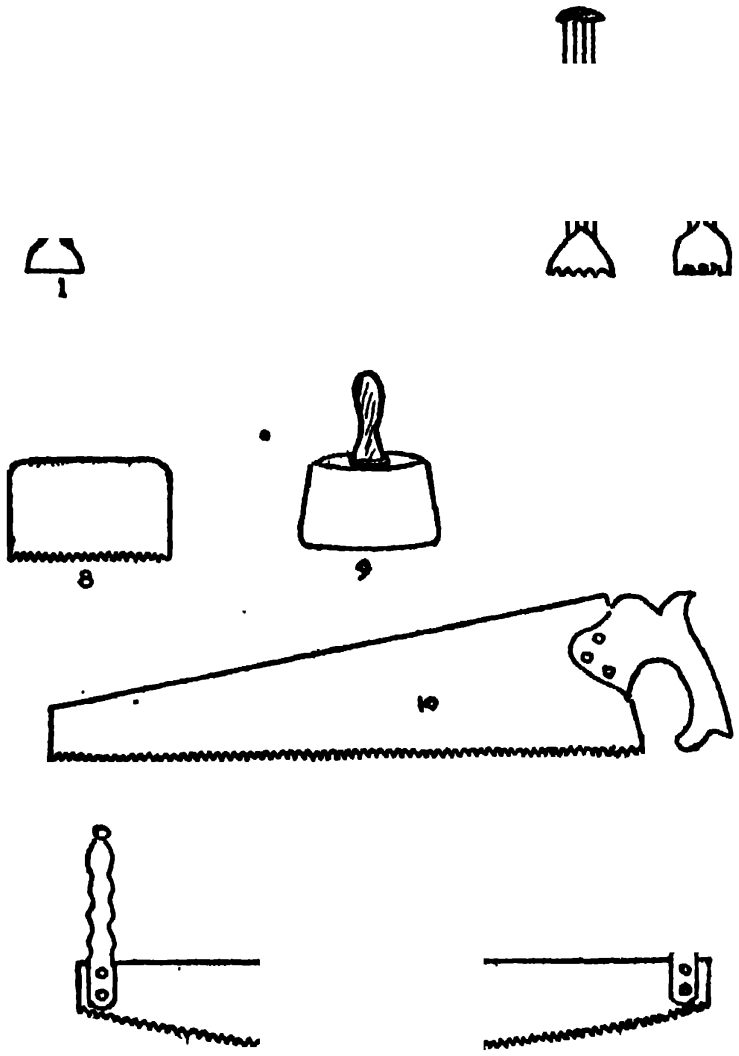


Fig. 7·27

(1) Pitching tool ; (2) Punch ; (3) Chisel ; (4) Chisel (5) Toothed chisel ; (6) Claw chisel ; (7) Jumper ; (8) Drag ; (9) Mallet ; (13) Saw for soft stone ; (11) Cross-cut saw.

Quarry dressed stones are thus economical and the reduced weight of the dressed blocks result in still further economy in transportation and handling costs.

The commonly used tools and implements for the cutting and dressing of stone blocks are shown in Figs. 7.26-7.27. The stones are dressed in a variety of finishes which depend upon the types of masonry and the kind of stone. The different types of surface finishes are described below.

(1) **Hammer dressed or Quarry-faced surface.** This is the roughest form of surface finish. Stone as removed from the quarry has large projections which are knocked off with the quarry hammer and it is finally broken up into blocks of suitable size and shape such as khandki, quoin, or rectangular blocks. The faces of the blocks are roughly planned and the stone is rendered suitable to be used in masonry. When used in a wall, the roughly finished surfaces are further modified by forming a 2 cm. to 5 cm. wide margin about the edges of the exposed face.

(2) **Rough tooled surface.** In this type of surface finish the projections of the stone block are removed by means of chisels and the surface is nearly dressed true. The corners and the edges are made accurate, chisel-draughted margins sunk and the side and bed joints roughly treated to ensure proper bonding.

(3) **Tooled surface.** In this type of surface finish continuous parallel chisel marks are produced throughout the width of the stone. The parallel corrugations or chisel marks are made at closer intervals rendering the surface truly planned. Different types of tooled finishes are obtained by use of different chisel and marking patterns. The various forms of tooled surface finishes as shown in Fig. 7·28.

(4) **Cut stone surface.** In this type of surface finish, the surface is dressed by using a sharp chisel so that the chisel marks are practically imperceptible. It is considered superior to tooled surface.

(5) **Rubbed surface.** This type of surface finish is obtained by grinding or rubbing a cut stone surface by hand or machine until it gets perfectly smooth.

(6) **Polished surface.** The rubbed surface of granite, marble or lime-stones are polished to enhance their texture. Polishing may be done by manual labour using sand and water, pumice stone etc. or by rubbing machine.

7 5 Selection of surface finish. The important factors influencing the selection of a particular type of surface finish are : The position of the stone and its function in the structure ; the architectual effects ; the type of stone ; the atmospheric consideration

and the finance available. Hammer-dressed and quarry-faced surface finish is best suitable for random rubble and coursed rubble masonry. Rough tooled surface and tooled surface are suitable for exposed surface. Polished finishes are used where absolute cleanliness is desired *i.e.* for hospitals, bath-rooms, etc.

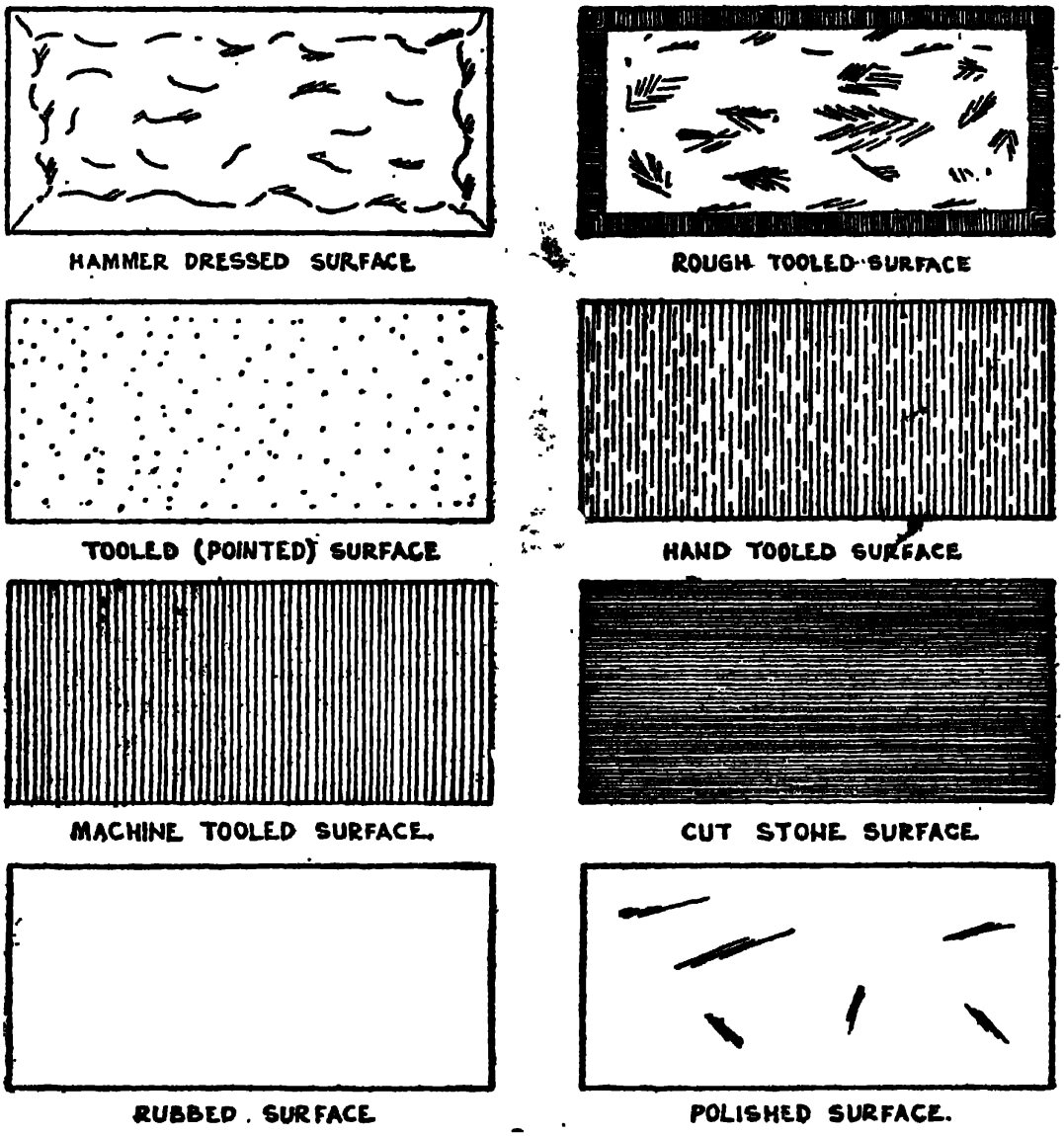


Fig. 7·28

Different types of surface finishes

7·6 Setting of stone work (*Lifting appliances*). The process of placing a stone in its position in masonry construction is termed as "*Setting*". On account of its weight and size, lifting appliances are necessary for the setting of stone. The stone block is held by suitable means and is hoisted in position. For bigger block of stones

a derrick or a gantry is used for its lifting and placing purposes. The various appliances used for lifting stone blocks are described below

(1) **Lewis.** There are many kinds of Lewis, the most commonly used are pin lewis, chain lewis and three legged-lewis.

Pin lewis : It consists of a pair of steel pieces put into the inclined hole made in the stone block. The steel pieces are attached to a chain or rope. When the stone is hoisted the attached chain or rope gets stretched and the steel pieces get jam in the hole and are then prevented from coming out.

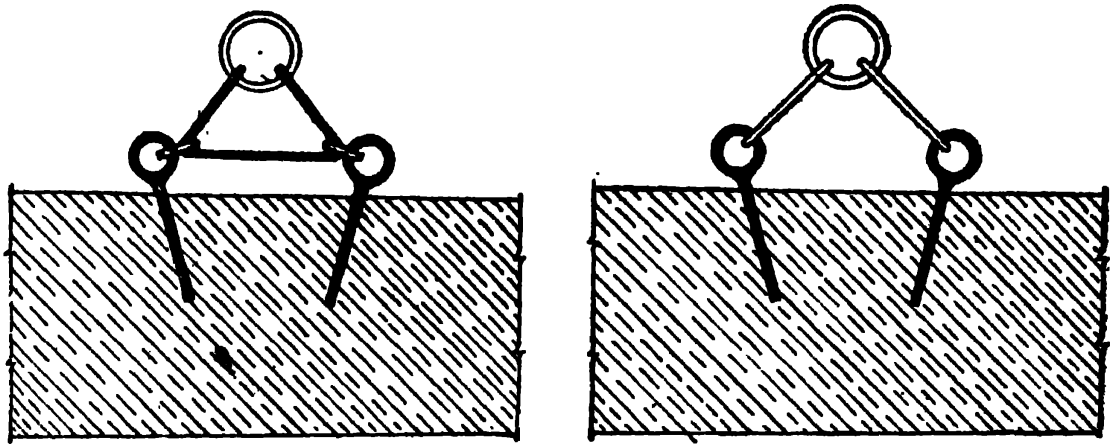


Fig. 7.29—7·30
Pin lewis

Chain dog ; chain lewis : In this type of lifting tackle, hooked pieces called dogs are used for lifting stone. The hooked end

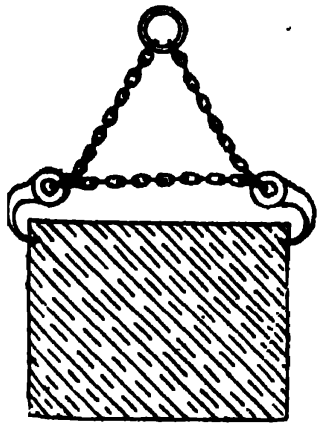


Fig. 7·31
Chain dog

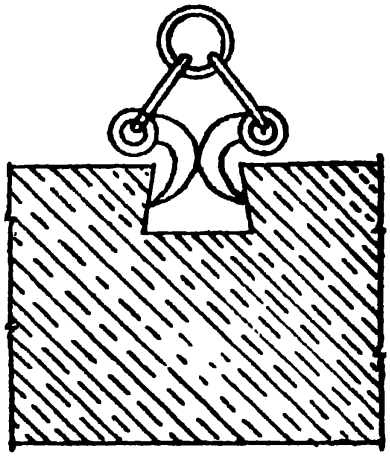


Fig. 7.32
Chain lewis

of the dogs are fitted into the 18 mm. deep hole punched in the centre of each side 7·6 to 10 cm. below the top face of the stone. The dogs are connected to the hoisting chain which enables the stones to be raised. When the chain is raised, the dogs get tightened and permit the lifting of stone. In another from of chain lewis a dovetailed hole is made in the centre of the top surface of stone. The curved steel legs are inserted in the hole and are inter-connected be means of three steel rings, Hoisting chain is attached to the topmost ring while lifting the stone.

Three-legged lewis : This lewis consists of a system of a rectangular piece of steel with two dovetailed steel pieces on either side of it, a shackle at the top and a round steel pin connecting these components together. A dovetailed hole is made in the stone first. The dovetail steel pieces are inserted in the hole and the rectangular

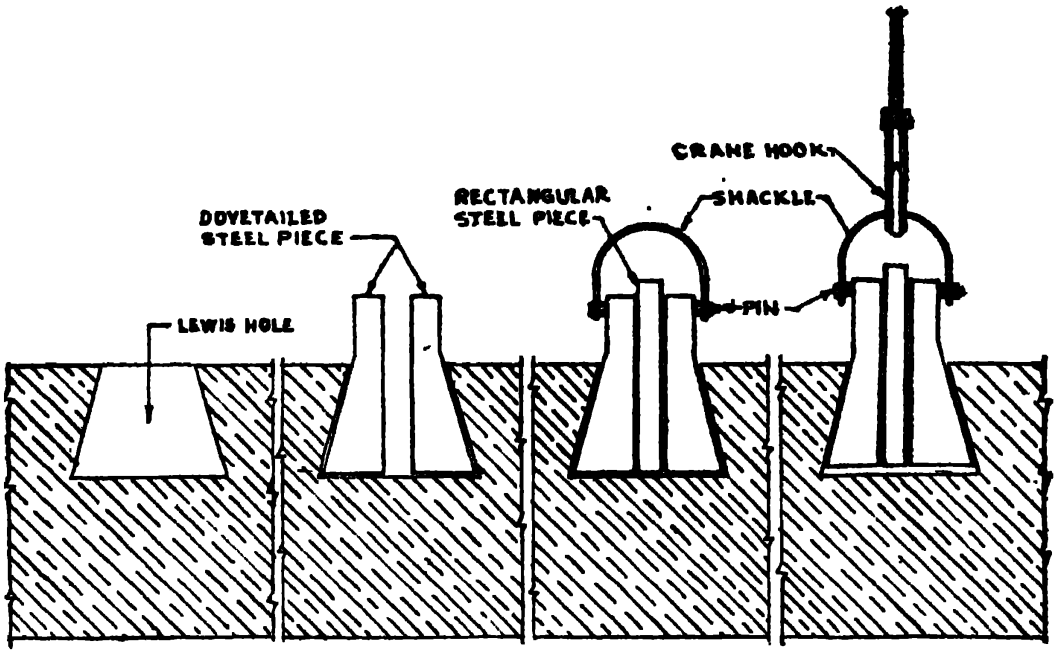


Fig. 7·33—7·36

Figures showing different stages in fixing the three-legged lewis in a stone block

steel piece is then driven between them. The shackle is held in its position and it is secured to the three pieces by means of the round steel pin. When the stone is lifted, the lewis gets tightly fitted in the stone permitting the stone to be raised.

Modified form of three logged lewis : A modified form of the above lewis consists of a wedge-shaped block which can freely slide between two steel plates placed against the tapering sides of the wedge-shaped hole made in the centre of the stone top. The steel plates are connected to each other through two pieces placed on

either side of the plates on the stone top and hinged to them. The wedge-shaped block has an eye for fixing the hook of the hoisting chain. When the stone is raised, the lewis on account of its shape does not allow the stone to slide down.

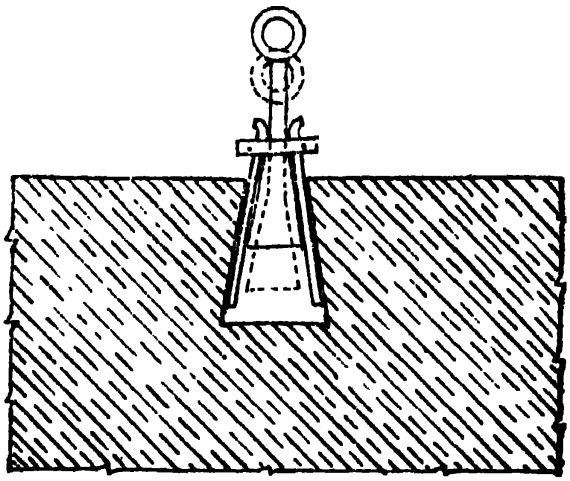


Fig. 7·37

Modified form of three-legged lewis

Fig. 7 38 illustrates a lewis, which is commonly used for lowering and setting stone under water. The wedge-shaped steel piece is inserted first and the rectangular straight piece is placed next in the hole made in the centre of the stone top. It is obvious from the shape of the lewis that when it is lowered down, the slant side of the dovetailed piece will prevent the slant side of the whole from permitting the lewis to get loosened.

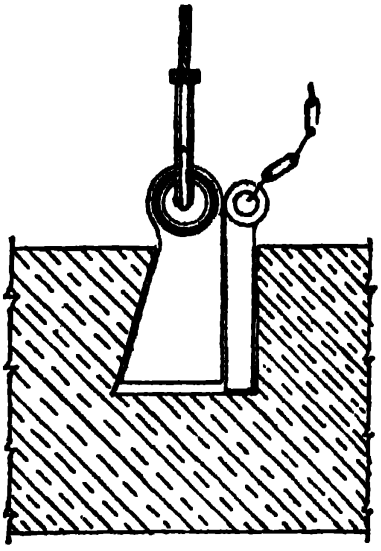


Fig. 7·38

Form of lewis used for lowering stone block

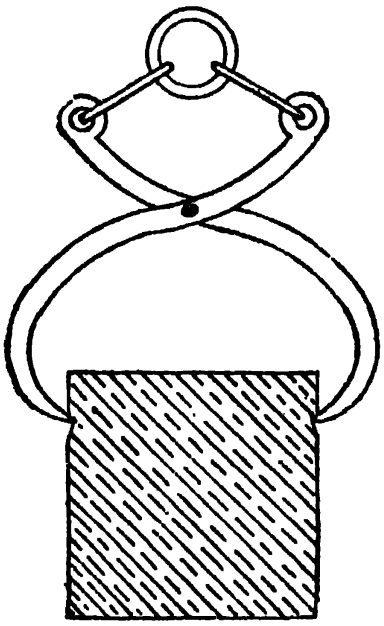


Fig. 7·39

Nippers

(2) **Nippers.** This is another device for lifting stones. The pointed ends of the nippers are inserted in the holes made a little

below the stone top face and on account of the fixing arrangement of nippers, they permit the raising of stone.

7·6 Joints in Stone Masonry. The various types of joints commonly used in stone work are described below :

(1) *Butt joint* This joint is formed by placing two stones side by side.

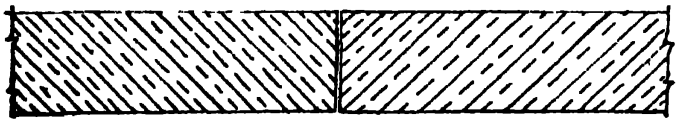


Fig. 7·40

Butt joint

(2) *Rebated or lapped joint* : This joint is usually provided for stone laid on slopes to prevent the movement of one stone over the other by sliding.

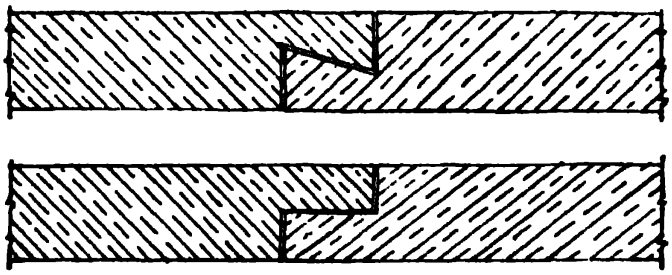


Fig. 7·41

Different forms of rebated joints

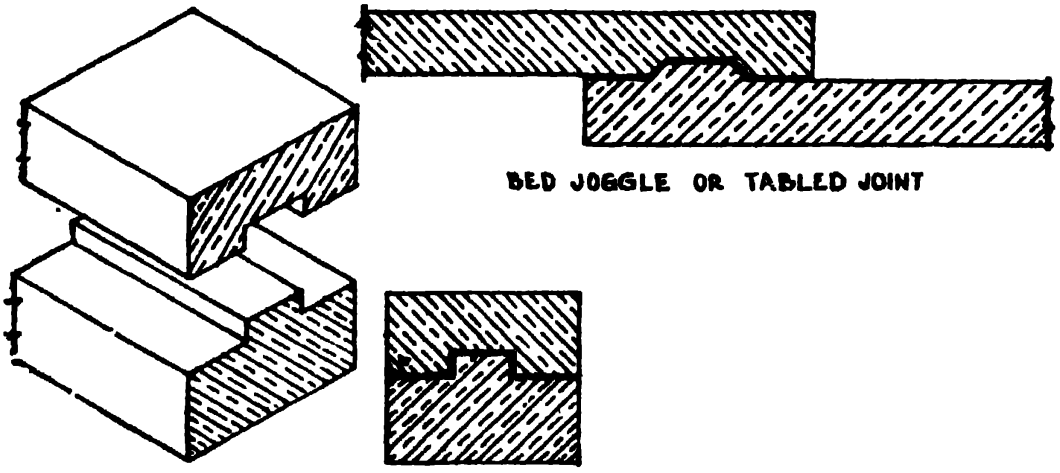


Fig. 7·42

Bed joggle or tabled joints

(3) *Table joint* : Its function is similar to that of rebated or lapped joint.

(4) *Cramped joint* : The function of cramp which may be of slate or any metal, is to prevent the tendency of the joint to be pulled apart.

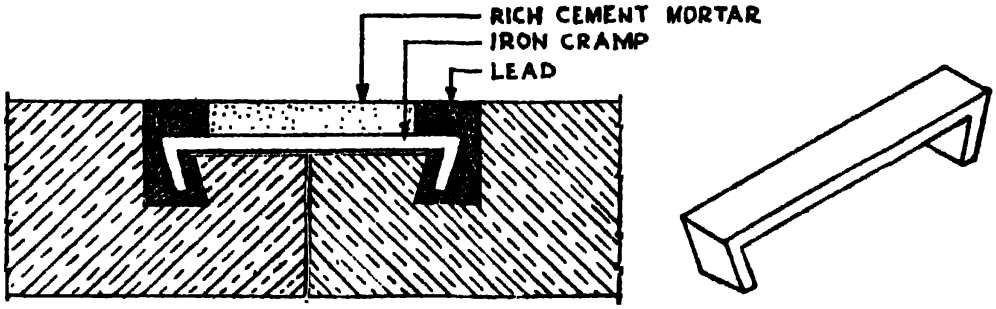


Fig. 7·43

Cramp joint

Wrought iron cramps may also be used, but they must be dipped in oil while hot or galvanized to prevent them from corrosion. The cramp, it may be of any metal, should be completely encased with lead, cement or asphalt.

Plug joint : Plug joint is an alternative of cramp joint and consists of plug holes, made dovetail-shaped in plan, and cut below the top surface of stones. The stones are jointed by fitting the holes with cement or lead.

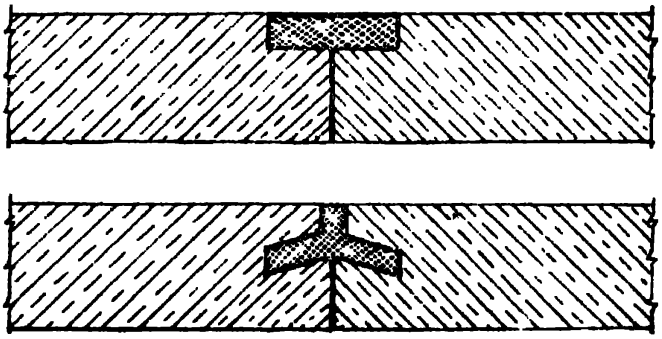


Fig. 7·44—7·45

Different forms of plug joint

Dowel joint : This type of joint ensures stability of the components against displacement or sliding. The dowels may be of slate, gun metal, copper or brass. They are generally set in cement mortar.

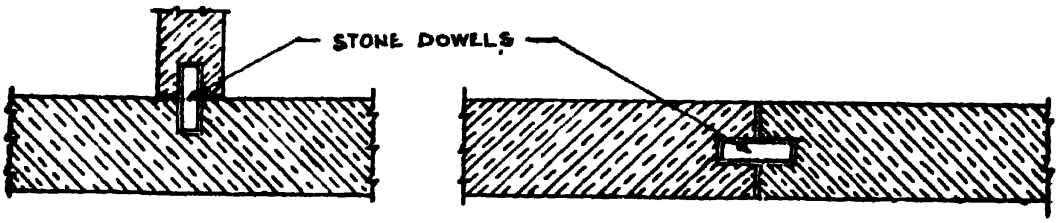


Fig. 7·46—7·47
Dowel joint

Joggle joint: To prevent sliding along the side joints, joggle made up of metal or slate is placed in between the groove between the two adjacent stones.

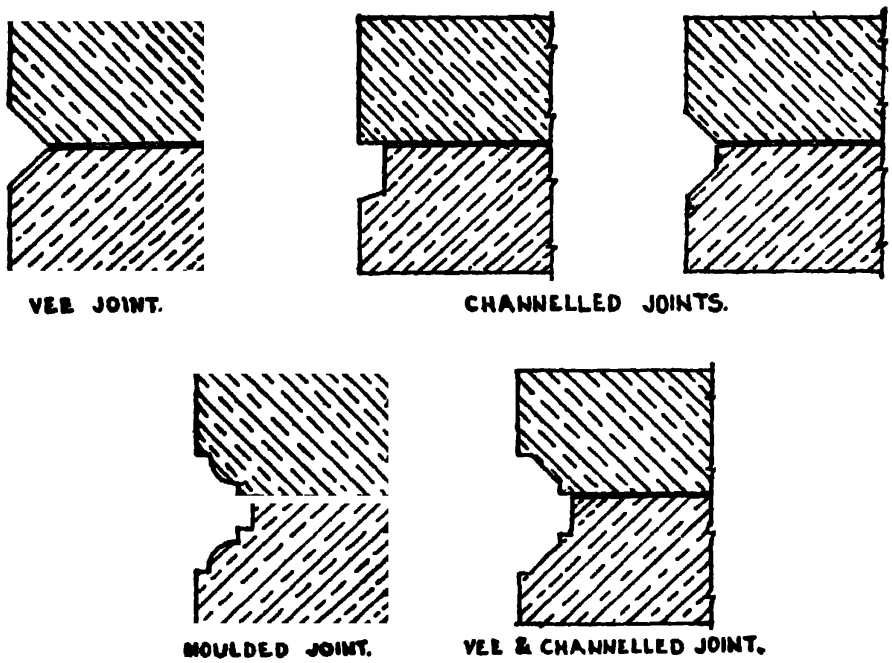


Fig. 7·48—7·52
Rusticated or rebated joints

Rusticated or rebated joint. This type of joint is frequently used in plinths or masonry in lower storeys of buildings to give the structure massive appearance.

7·8 General Principles to be Observed in Stone Masonry Construction

(1) Stone used in a good masonry should be well seasoned, hard, tough, compact grained and uniform in texture.

(2) Stone masonry may be constructed in mud, lime or cement mortar above plinth level, but in damp-proof construction, on

water-logged site or in basements, hydraulic lime or cement mortar with surkhi should be used in foundation and upto plinth level.

(3) In stone masonry construction all stones should be laid upon their natural bed (construction of corbels, and other such projecting course are exceptions), so that pressure on each stone is at right angles to its laminations. Natural bed of stone is the term applied to the original position occupied by the stone during its formation. Corbels, cornice, string courses and other projecting courses are built by so placing the stones that their natural bed is parallel to the face of the supporting wall.

(4) Proper bond should be maintained throughout the masonry. The construction should be well supervised.

(5) The facing and the backing of the wall should be well bound by through stones. They should be laid staggered in the successive courses and kept apart with their centre to centre distance not exceeding 1·5 m.

(6) Quoins used to form the jambs for door or window openings should be of the full height of the course. The breadth of the quoin should be at least $1\frac{1}{3}$ times the depth of the course and its length should be at least twice its depth.

(7) As far as practicable, the whole of the masonry in any structure should be carried up to the same uniform level throughout, but where breaks are unavoidable, the joint should be left in good long steps so as to allow a proper connection between the old work and the new work.

(8) The hearting of the masonry should be properly packed with chips (spalls) and mortar to avoid hollows being left.

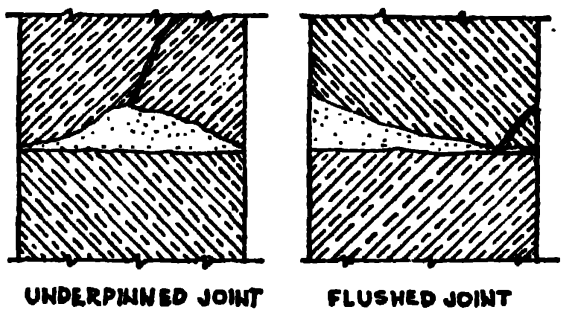


Fig. 7·53—7·54

(9) The joints should not be too smooth to loose friction. The bed joints should not be dressed hollow. Such joints may

concentrate the uniform loading at certain points and finally result in cracks in stone work. Refer Figs. 7·53—7·54 for explanation.

(10) The verical surfaces should be constructed truly vertical and checked with plumb rule. Similarly, the battered surfaces should be checked with a wooden template and a plumb for the correctness of the slope.

(11) Stones to be used in the work should be well-wetted before use.

(12) The masonry should not be subjected to tensile stresses.

(13) When it is desired to construct over old or dry surface, it should be well cleaned and wetted before starting construction.

(14) The exposed joints in stone masonry should be properly pointed. This is done by raking the exposed joints to a depth of 2·5 cm. and filling them with cement or lime mortar.

(15) The entire work should be well cured, *i.e.* it should be kept well-wetted for at least two weeks.

7·9 Classification of Stone Masonry. Depending upon the degree of refinement used in shaping the stone, the finishing adopted and the arrangement of the stone in the construction, stone masonry can be broadly classified in the following two types:

(1) *Rubble masonry*

(2) *Ashlar masonry*

7·10 Rubble Masonry. It is further sub-divided in the following categories :

(*a*) *Uncoursed rubble masonry*

(*b*) *Random rubble masonry*

(*c*) *Coursed rubble masonry*

(*d*) *Dry rubble masonry.*

(*a*) **Uncoursed rubble masonry.** This is the poorest form of stone masonry. The stones to be used for the work are directly obtained from the quarry, after merely knocking off weak corners and edges with the mason's hammer. The stones are carefully laid so as to break joints as much as possible. To avoid thick joints, chips of stone or spals are wedged into the hearting. The face stones

selected from the heap should have uniform colour, good beds and greater size. One-fourth of the face stones should tail back in the



Fig. 7·55

Random rubble masonry (uncoursed)

hearting in the form of headers. Bond stones provided to interlock the two faces should extend up to the full thickness of wall if the wall is less than 60 cm. in thickness. For wall thicker than 60 cm. a line of headers overlapping each other for a length of at least 15 cm. are laid right through the wall. The quoins are chisel or hammer dressed and are laid as header and stretcher alternately. In this work the thickness of joints should not exceed 13 mm.

(*b*) **Random rubble masonry.** This form is slightly superior to uncoursed rubble masonry. In this form the stones used in the

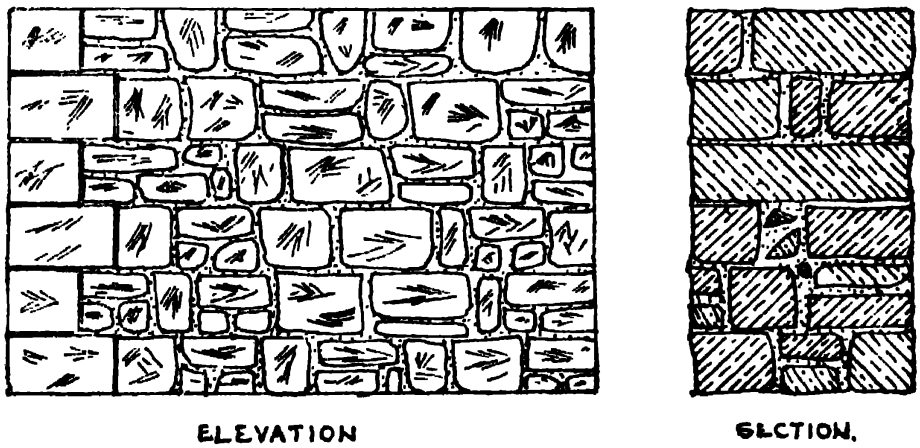


Fig. 7·56

Random rubble masonry

work are hammer or chisel-dressed. The stones are not suitably shaped or finished and as such the elevation of this type of masonry shows irregular shaped stones with non-uniform joints. In a good work the face stones are of uniform colour and approximately equal in size. The height of stones should not be greater than their breadth or length of tail into the work.

At least one fourth of the face stones should tail back into the hearting for ensuring proper strength to the work. The quoins and the through stones are provided in a similar manner as described above. The thickness of joints should not exceed 13 mm.

(*c*) **Coursed rubble masonry**. This is the form which is commonly adopted in the construction of residential buildings,

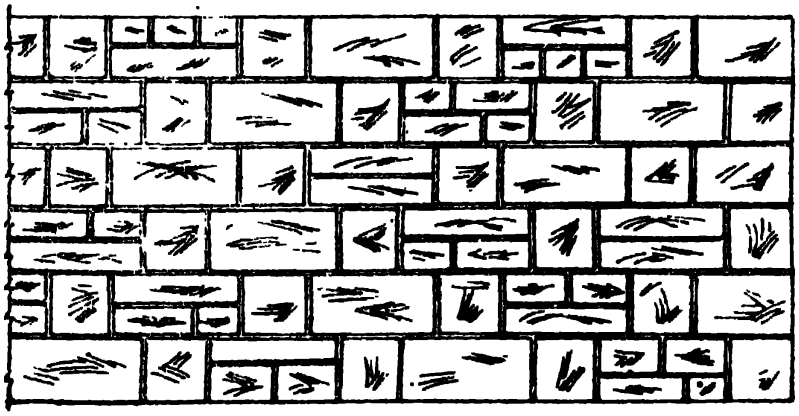


Fig. 7·57

Coursed rubble second class

public buildings, piers and abutments for ordinary bridges. Considering the dressing and finishing of the stones, it is further

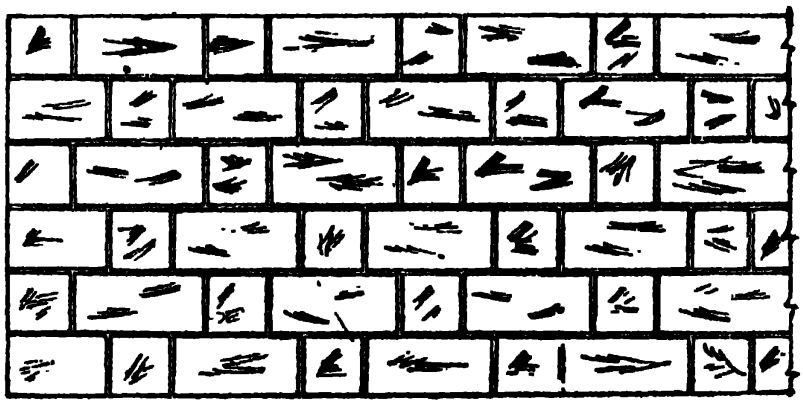


Fig. 7·58

Coursed rubble first class

sub-divided into first class, second class and third class masonry. In first class masonry, generally all the courses are of the same height and the minimum height of the course is limited to 15 cm. The face stones are hammer dressed and the projection of the rock-faced surface does not exceed 38 mm. beyond the side or bed joints. The beds of the face stone are hammer or chiesel dressed and rendered true and square. In good work at least one-third of the face stones tail back into the hearting for a distance equal to two times their height normally, and three times their height for thicker walls. The through stones provided to bind the two faces together are spaced at 1·8 m. apart and the quoins are of the same height as the height of the course. The length of the quoin is generally kept 45cm. The thickness of joints in this type should not exceed 10 mm.

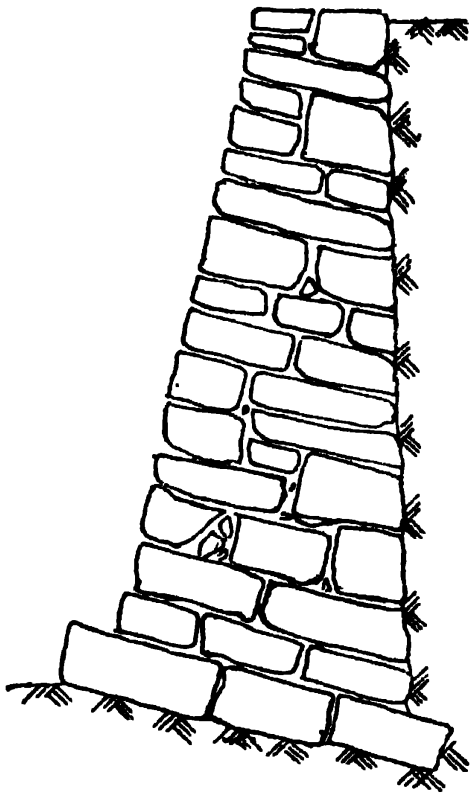


Fig. 7·59
Dry stone retaining wa'l

(*d*) **Dry rubble masonry.** The construction of this form is similar to that of ordinary rubble masonry without mortar.

7·11 Ashlar Masonry. The work built from carefully dressed stones with accurate bedding and jointing is termed as ashlar masonry. This construction is further sub-divided into various divisions. The different types of ashlar masonry are given below :

(1) *Ashlar fine*

(2) *Ashlar rough tooled*

(3) *Ashlar rock, rustic or quarry faced*

(4) *Ashlar chamfered*

(5) *Ashlar facing*

(1) **Ashlar fine.** In this type of masonry, all the stones are fine tooled, on all bed and side joints, and the faces are rendered perfectly true to the pattern desired. The height of the courses is never less than 30 cm. and generally all the courses are kept of the same height throughout the work. The height of the stones used is

never less than their breadth and their length is never less than twice their height. The face stones are generally laid as header and stretcher alternately. For wall below 75 cm. thick, the through stones

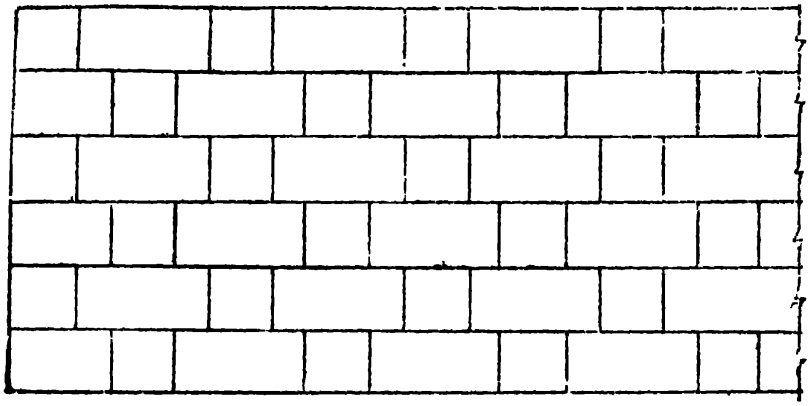


Fig. 7·60

Ashlar fine

extend to the full thickness of wall. The bed and the side joint in this type of work should never exceed 3 mm. in thickness.

(2) **Ashlar rough tooled.** In this type of masonry, the exposed faces of stone generally have a fine dressed chisel drafting all round the edges. The portion of face stone enclosed by the chisel draft is rough tooled. The thickness of joints in this type of work should never exceed 6 mm. In all other respects it conforms to the specifications of Ashlar fine masonry.

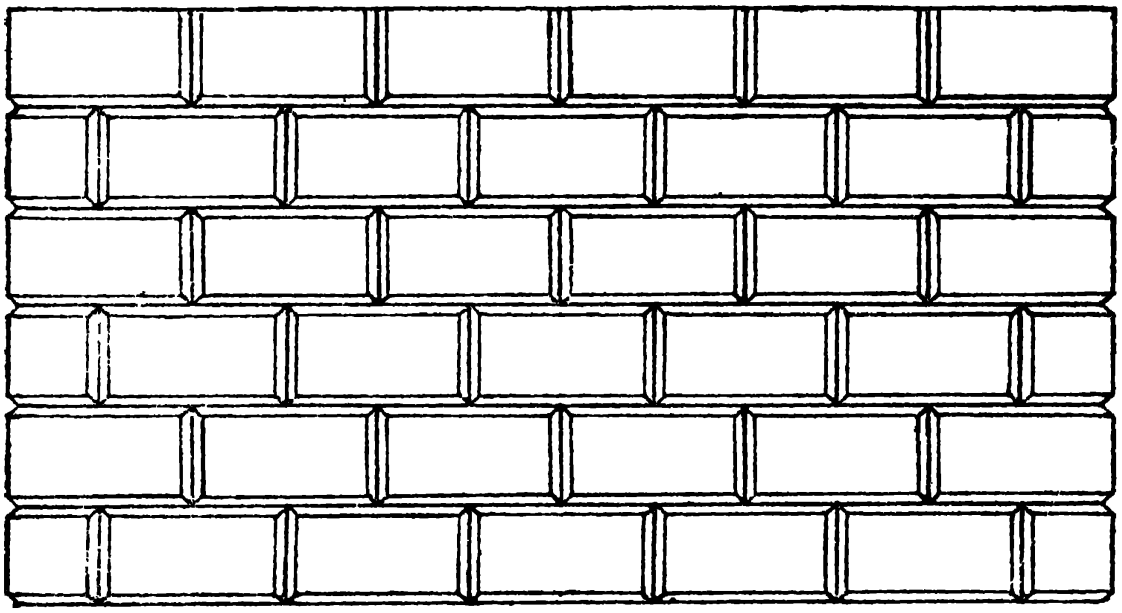


Fig. 7·61

Ashlar Chamfered

(3) **Ashlar rock, rustic or quarry faced.** This type of construction is similar to ashlar rough tooled except that the exposed faces of face stones between the chisel draftings are left rough. The projections in the space enclosed by chisel drafts are restricted to 7·6 cm. only.

(4) **Ashlar Chamfered.** This type of masonry is similar to the one described above with the only difference that the edges around the expose face of each stone are bevelled-off at an angle of 45° for a depth of 25 mm. or more.

(5) **Ashlar facing.** In this type of masonry the faces of stones are rough tooled are chamfered and are provided in face work only. The backing may be made in brick, concrete, or rubble as desired. The composite construction appreciably reduces the cost of work. The height of the course is never kept less than 20 cm. and the width of each stone is about $1\frac{1}{2}$ times its height. The bed joints of all the stones are dressed perfectly true and square. For wall upto 75 cm. in thickness the bond stones should extend for the full thickness of the wall and for thicker wall, the bond stones should overlap each other by 15 cm.

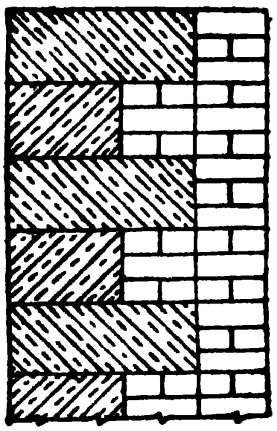


Fig. 7·62
Ashlar facing (stone facing with brick backing)

SPECIFICATION 7·1

Random Rubble Masonry

1. *Quality of stone* : The stone used shall be hard, sound and free from defects of any kind. It should be of specified type and of approved quality and colour.

2. *Dressing* : The stone shall be roughly hammer dressed. The 'Bushing' in the exposed face of the stone shall not project more than 3·8 cm. In case of the stone face to be plastered, the Bushing' shall not exceed 13 mm.

4. *Laying* : As far as possible the stones selected for the face work shall be of pretty equal in size. The stone shall be laid so as to tail back and bond well into the backing. The height of face stones shall not be greater than either the breadth of face or the length of tail into the work. The stones used for hearting shall not be less than 13 cm. in size and shall be solidly bedded in the mortar. Chips and spawls of stones shall be wedged into the work

wherever necessary to avoid thick mortar beds on joints. No hollow space shall be left in the masonry.

4. *Joints* : Every stone shall be carefully laid so as to break joints as much as possible and to avoid long vertical line of joints. The face joints shall be neat and close and shall not exceed 25 mm. in thickness.

5. *Bond stones* : Headers, bond stones or through stones running right through the full thickness of the wall, shall be provided in walls upto 60 cm. in thickness. For walls more than 60 cm. in thickness, two or more headers (bond stones) overlapping each other by about 15 cm. shall be laid in a line from face to back. At least one bond stone or a set of bond stones (for thicker wall) shall be inserted in every 0·5 sq. m. of the wall face.

6. *Quoins* : The quoins shall be neatly dressed to form the required angle at the corner. The quoins shall be laid as header and stretcher alternately. The length of the quoins shall be at least 45 cm. and its volume shall not be less than 0·028 cu. m.

7. *Curing* : In case the masonry is in cement mortar the curing shall start just after 24 hours of the laying of masonry and shall be continued for at least seven days. In case of masonry in fat lime mortar, curing shall start two days after the laying of masonry and shall be continued for at least seven days.

SPECIFICATION 7·2

Coursed Rubble Masonry

1. *Quality of stone* : Same as for random rubble mosonry.

2. *Dressing* : The face stones shall be hammer or chiesel dressed to an approximate rectangular block shape on all joints and beds. The bed joints and the side joints shall be dressed true and square for a depth of at least 7·6 cm. and 3·8 cm. respectively from the face. The 'Brushing' on the exposed face of stones shall not project more than 3·8 cm. In case of the stone face to be plastered the 'Brushings' shall not exceed 13 mm.

3. *Height of courses* : The stones shall be laid in horizontal courses not less than 15 cm. in height. The stones in each course shall be of equal height so as to get all the courses truly horizontal and all joints truly vertical.

4. *Size of stones* : The height of the face stones shall not be less than their breadth and they shall tail back into the work for a length not less than their height.

5. *Laying* : The face stones shall be laid alternate headers and stretchers. Stones shall break joint at least half the height of course. At least $\frac{1}{3}$rd of the stones shall tail back into the work for a distance not less than twice their height. The interior filling of the wall shall consist of flat bedded stones carefully laid on their proper beds and solidly bedded in mortar. Chips and spawls shall be wedged into the work, wherever necessary, to avoid thick joints. No hallow space shall be left in the masonry.

6. *Joints* : No pinnings shall be allowed on the face. All side joints shall be vertical and bed joints horizontal. The mortar joints in the face work shall not exceed 23 mm. in thickness.

7. *Bond stones* : Bond stonnes ruining right through the full thickness of the wall shall be provided in walls upto 60 cm. in thickness. For walls more than 60 cm. in thickness, two or more headers overlapping each other by at least 15 cm. shall be laid in a line from face to back. Bond stones or a set of bond stones shall be inserted 1·5 to 1·8 m. apart clear in every course.

8. *Quoins* : The height of quoins shall be the same as that of the course in which they occur. The quoins shall be laid as stretchers and headers alternately and shall be formed of stones at least 45 m. in length. They shall be laid square on their bed, which shall be fair dressed to a depth of at least 10 cm.

9. *Curing* : Same as for random rubble masonry.

Questions for Revision

1. What general principles would you keep in mind while supervising a (*i*) Stone work and (*ii*) Brick work under construction ? What guiding principles would you apply to ensure a structurally sound, aesthetically pleasant and a comfort-cum-service type construction ? Give only a general review.

2. (*a*) What is the most common type of building construction that you see being practised in Bombay and what are its advantages over any other type ?

(*b*) Explain with neat sketches the following :

(*i*) Coursed rubble masonry construction indicatiog clearly the position of through stones. What is the quality of mortar used ?

(*ii*) The difference devices are used for lifting heavy and moulded stone.

(*iii*) Method of finishing pointing in stone masonry construction.

3. Give detailed specification for the following items of work :

(*a*) First class brick work in cement mortar.

(*b*) Ashlar stone masonry in cement mortar.

4. Sketch a section of a wall showing all the details starting from the foundation concrete bed block to the coping. The section should indicate two-storeyed building with a flat roof. The section line should pass through a door at ground floor and a window at the first floor.

5. Describe with sketches the difference between uncoursed rubble masonry and random rubble masonry.

6. What are the types of joints used in stone masonry ? Describe each joint with neat sketch.

7. What is the purpose of dressing stone ? Discuss the different types of surface finishes employed in stone masonry construction.

8. Write short notes on :

(*i*) Lewis

(*ii*) Cramp joint

(*iii*) Joggie joint

(*iv*) String course

(*v*) Chain dog

(*vi*) Rusticated joints.

9. Define the following terms with sketches where necessary :

(*i*) Perpend

(*ii*) Plinth course

(*iii*) String course

(*iv*) Blocking course

(*v*) Copings

(*vi*) Weathering and throating

(*vii*) Through stone.

10. Describe in brief the comparision between stone masonry and brick masonry.

11. Explain with neat sketches and proper reasoning where you would adopt the following :

(*i*) Fine ashlar construction

(*ii*) Coursed random rubble

(*iii*) Dry stone revetment

(*iv*) Artificial stones

(*v*) Headers quoins ; copings.

12. Explain the following with sketches wherever necessary :

(*i*) Corbelling

(*ii*) Template

(*iii*) Composite masonry

(*iv*) Buttress.

13. Give detailed specifications for coursed rubble masonry in cement mortar for a wall 45 cm. thick. Illustrate the same with sketches.

14. Name the different sorts of Rubble masonry. What are the important points which have to be kept in view in the construction of rubble masonry ?

15. What do you mean by masonry work ? Name various kind of masonry. Give general specifications for masonry work.

16. State the different, classifications of stone mcsonry. State also the general principles to be observed and the preautions to be taken in constructing stone masonry.

17. (*a*) What do you understand by dressing of stones ? Describe various methods of dressing. Explain with sketches.

(*b*) What are the general principles to be observed in the construction of masonry ?

18. (*a*) State the comparative merits and demerits of stone masonry and brick masonry.

(*b*) Give a section of a wall from ground level to roof and show clearly the plinth course, string course, Cornice, blocking course and coping. There are two floors supported by wall.

19. (*a*) What are the objects of dressing of stones ?

(*b*) Write a short note on block-in-course masonry and draw a neat sketch of the same.

(*c*) What types of stone masonry will you use for (*i*) boundry wall, (*ii*) parapet wall, (*ii*) pier of a bridge, (*iv*) monument and (*v*) market-place ?

8

Brkic Masonry

8·1 Definition. Construction of brick units bonded together with mortar is termed as brick masonry. The strength of brick-work primarily depend upon quality and strength of the bricks, the type of mortar and the method of bonding, adopted in construction. Mortar not only acts as a cementing material but also imparts strength to the work by holding the individual bricks together to act as a homogeneous mass. Mortar is usually a mixture of cement and sand or lime and sand or a mixture of the three. For works of temporary nature, mud is generally used as mortar and the construction is termed as kuccha pukka masonry. Cement mortar is used for works of permanent character, where strength of work is of vital importance. Lime mortar is used for all types of construction.

8·2 General Principles to be Observed in Brick Masonry Construction. The brick masonry in classified as first class or second class according to the type of bricks used (wheather first class or second class) and according to the method of laying. The strength of masonry work, however, depends very much upon the types of material used, nature of workmanship and supervision. Bad workmanship assisted by lack of supervision may lead to unsound construction inspite of the materials used being of the best possible type. The general principles which should be observed for a sound brick masonry are given below. (The technical terms used in this chapter have already been described in the chapter on Stone Masonry).

(1) The bricks used in a good work should be sound, hard and well burnt with uniform size, shape and colour. They should have no cracks or flaws and a fractured surface should be free from holes, grit or lumps of lime etc. The surface of the bricks should be such that no mark should be made when scratched by the finger nail. The bricks when struck together should produce metallic ringing sound and they should not break when dropped from a height of 90 to 120 cm. on the ground. The bricks should not as a rule absorb water more than 20% of their weight when dry when immersed in water for twenty-four hours.

(2) The bricks should be thoroughly soaked in clear water for at least one hour before use. This not only helps in removing the dirt or dust from them but also prevents suction of water from the wet mortar.

(3) All the courses should be laid truly horizontal and all vertical joints should be truly vertical.

(4) No brick-bats should be used in the work except when it is absolutely necessary for obtaining the specified bond.

(5) Brick work is generally laid in the English bond. In all cases, it should be ensured that a proper bond is maintained throughout the work.

(6) Only specified mortar of a good quality should be used in the work, taking great care that uniform mortar joint is obtained throughout the construction. The thickness of joints should not exceed 13 mm in any case.

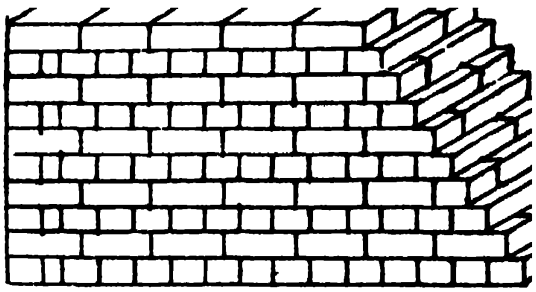


Fig. 8·1
Raking back of a brick wall

(7) Unless brick-on-edge is specified, all the bricks must be laid on their proper beds with their frogs pointing upwards.

(8) The progress of work in raising masonry should be such that all the connected brick work should be carried up in uniform layers at one level. It should be ensured that no part of the wall should preferably rise more than 100 cm. than the rest of it. When it is not possible, the work should be racked back according to the bond. The walls should be raised up truly vertical.

(9) The buttresses, counterforts etc. should be built up course by course, maintaining proper bond with the main wall and should not be added or joggled afterwards.

(10) Iron fixtures like pipes, hold-fasts of doors and windows etc., which are to be fixed in the brick wall should be embedded in cement mortar or in cement concrete.

(11) The face joints are generally raked to a minimum depth of 10 to 15 mm. when the mortar in the joints is still green. This is done to provide proper key for the plastering or pointing.

(12) In works where plastering or pointing is not desired, the mortar joints should be struck flush and finished at the time of laying.

(13) All the finished masonry work should be kept wet for at least seven days.

(14) When an existing wall has to be strengthened by making it thicker, 20 cm × 20 cm. × 10 cm. (dimensions of one brick) recesses are cut in the existing wall. The recesses are staggered taking care that one recess is made in every sq. metre of the wall. This enables the new work to be properly bonded to the old one. This operation is termed as *back-bonding.*

(15) When it is desired to increase the length of the wall under construction at a future date, the wall is stopped with a toothed end. This is necessary to ensure continuous bonding between the old and the new work.

(16) It is found that with an average winter-summer temperature differences of about 100°F a brick masonry wall expands by about 10 mm. in every 30 m. length of wall. Hence it is desirable to provide 18 mm. wide expansion joints after every 30 to 45 m. length of wall.

(17) When timber floor or roof is required to be supported on masonry walls the ends of timber joists (supporting the floor or roof) should as far as possible rest on corbels or bracket. In cases where the ends of timber joists have to be built into the wall itself, it is necessary to apply suitable preservative treatment to the embedded portion of the joists and in addition some space should be left around them to ensure free circulation of air.

(18) Bed blocks of stone, concrete or reinforced concrete should be provided at the ends of beam (it may be of timber, steel or R.C.C.) carrying heavy loads.

(19) The bearing of R.C.C. floor or roof slab resting on brick masonry walls should not be less than the effective depth of slab or 10 cm which ever is more.

(20) The courses of bricks, at the plinth, window sill, floor/roof and at the top of parapet walls should be laid with bricks on edge.

(21) As a general practice, quoin brick should be headers and strethers laid in alternate courses and the bond is developed by placing a quoin choser next to the queen header.

(22) Half brick partition walls should be reinforced with suitable reinforcement placed at every third or fourth course of the brickwork. The reinforcement may be in form of mild steel bars, flat bars, hoops iron, expanded mesh, or fabric etc.

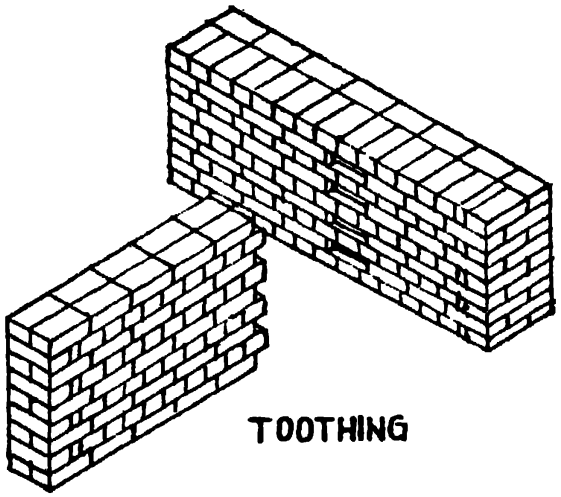


Fig. 8·2

8·3 **Bonds in Brick-work.** On account of their uniform size and shape, the bricks can be arranged in a variety of patterns giving rise to different types of bonds. Bonding is essential to eliminate continuous vertical joints both in the body as well as in the face of wall thereby importing strength to masonry. A wall having defective arrangement of bricks, reduces the strength and stability of the structure. A wall having continuous vertical joint does not act as a homegeneous mass to distribute the superimposed load. On the other hand, it may be assumed to be consisting of small columns and when a particular column of this wall comes under the load, it fails, on account of its inability to distribute the load to the wall on either side of it. The different types of bond commonly adopted are given below :

1. **English bond.** This bond consists of alternate course of headers and stretchers. In this arrangement, vertical joints in the header courses come over each other and the vertical joints in the stretcher course are also in the same line. For the breaking of vertical joints in the successive course it is essential to place queen closer, after the first header in each heading course. The following additional points should be noted in English bond construction :

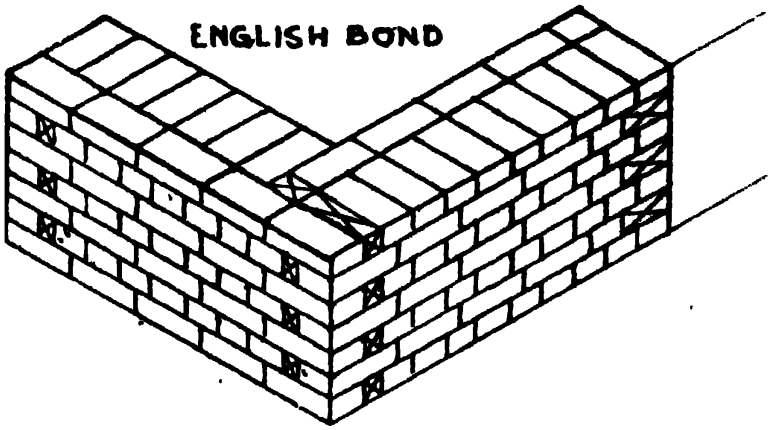


Fig. 8·3
Isometric view of 1½ brick thick wall in English bond

(1) A heading course should never start with a queen closer as it is liable to get displaced in this position.

(2) In the stretcher course, the stretchers should have a minimum lap of ¼th their length over the header.

(3) Walls having their thicknesses equal to an even number of half bricks, *i.e.* one brick thick wall, 2 brick thick wall ; 3 brick thick wall and so on, present the same appearance on both the faces, *i.e.* a course consisting of headers on front face will show headers on the back face also.

(4) In walls having their thicknesses equal to an odd number of half bricks, *i e.* 1½ brick thick walls or 2½ brick thick walls and so on, the same course will show stretchers on one face and headers on the other.

(5) In thick walls the middle portion is entirely filled with headers to prevent the formation of vertical joints in the body of the wall.

(6) Since the number of vertical joints in the header course is twice the number of joints in the stretcher course, the joints in the header course are made thinner than those in the stretcher course.

Alternate courses of even and odd number of half brick thick walls are shown in Figs. 8·4—8·8.

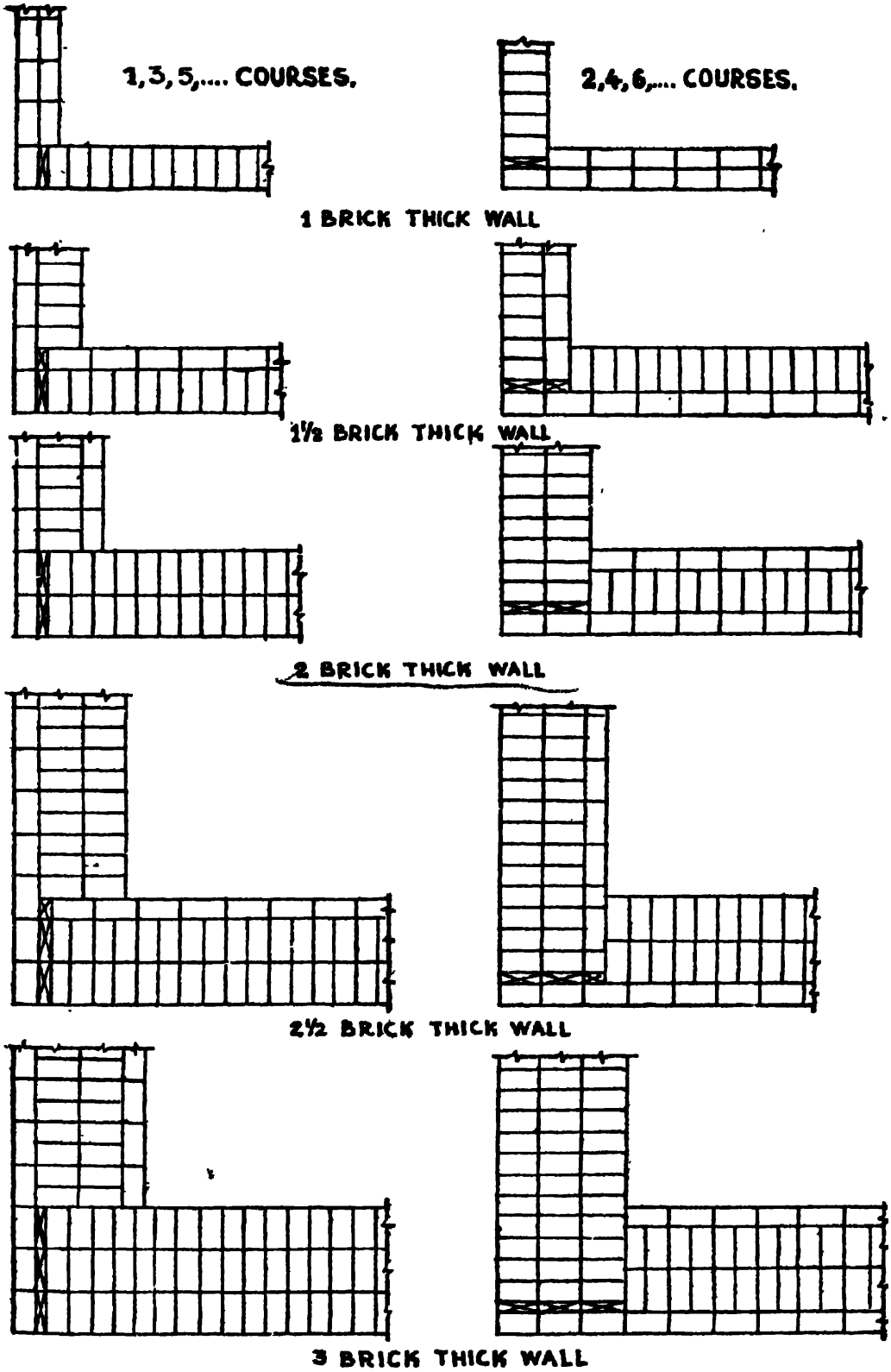


Fig. 8·4—8·8

Plans showing alternates of varius thickness of brick walls in English bond

(2) **Flemish Bond.** In this arrangement of bonding brick work, each course consists of alternate headers and stretchers. The alternate headers of each course are centred over the stretchers in the course below. Every alternate course starts with a header at the corner. For the breaking of vertical joints in the successive courses, closers are inserted in alternate courses next to the quoin header. In walls having their thickness equal to odd number of half bricks, bats are necessary to be used.

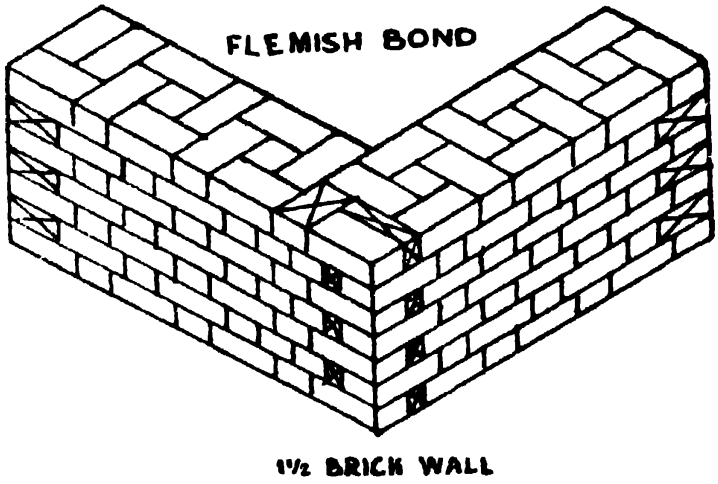


Fig. 8·9
Isometric view showing 1½ brick thick wall in Flemish Bond

Flemish bond is further divided into two different types *viz.* Single Flemish bond and Double Flemish bond.

Single Flemish bond : This bond is a combination of English and Flemish bond. In this work the facing of the wall consists of flemish bond and the backing consists of English bond in each course. This type of bonding cannot be adopted in walls less than one and a half brick in thickness. This bond is adopted to present the attractive appearance of Flemish bond with an effort to ensure full strength in the brick work. The alternate courses of brick walls of various thicknesses in Single Flemish bond are shown in Figs. 8·10—8·12.

Double Flemish bond : In this system of bonding brick work, each course presents the same appearance both in the front and back elevations. Every course consists of headers and stretchers laid alternately. This type of bond is best suited from considerations of economy and appearance. It enables the one brick wall to have flush and uniform faces on both the sides. This type of bonding is comparatively weaker than English bond. The alternative courses of the walls of various thicknesses in Double Flemish bond are shown in Figs. 8·13—8·17.

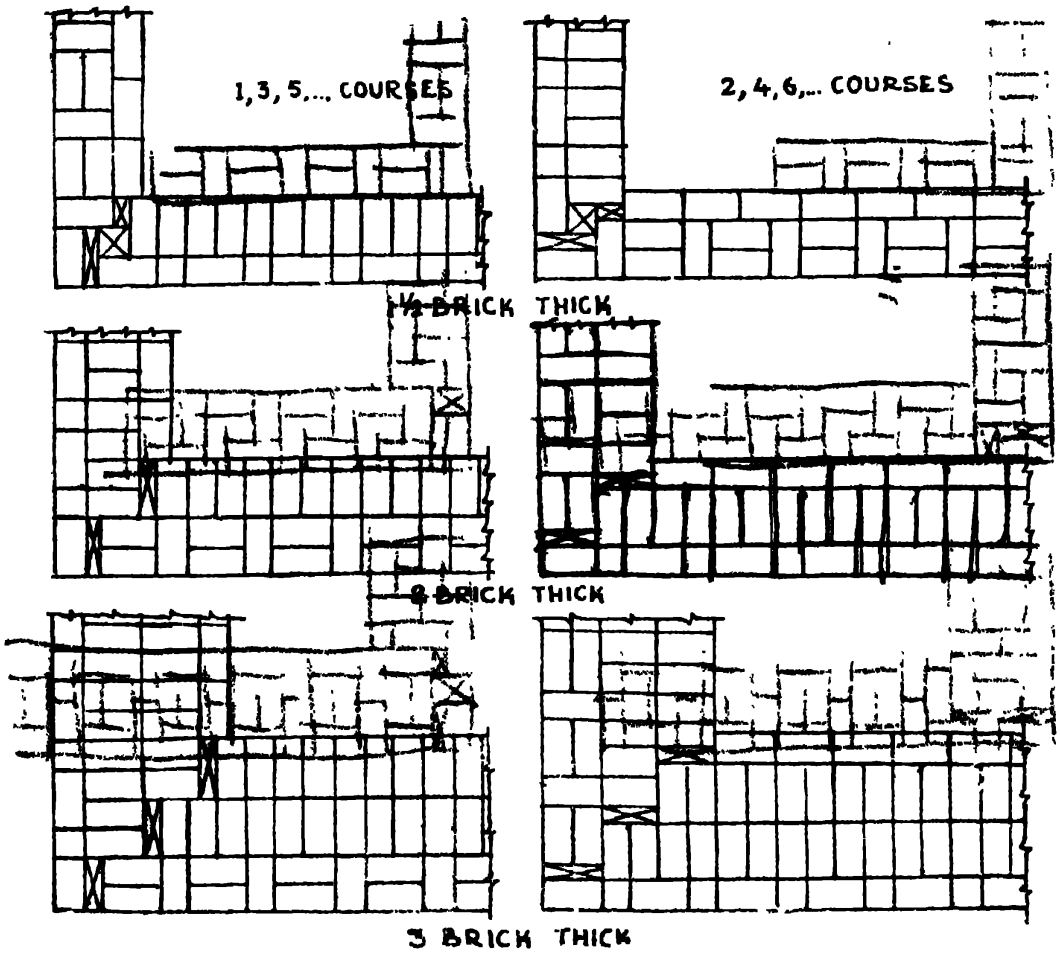


Fig. 8·10—8·12

Plans showing alternate course of various thicknesses of brick walls in single Flemish bond

8·4 Comparative merits and demerits of English and Flemish Bond

(1) For walls thicker than $1\frac{1}{2}$ brick, English bond is stronger than Flemish bond.

(2) Flemish bond renders the appearance of the face work more attractive and pleasing.

(3) Flemish bond is slightly economical as a number of bats can be used. This renders the use of broken bricks possible, but requires more mortar for additional joints.

(4) The appearance of Flemish bond requires good workmanship and careful supervision. Thus extra attention is necessary to keep the vertical joints in alternate course one above the other.

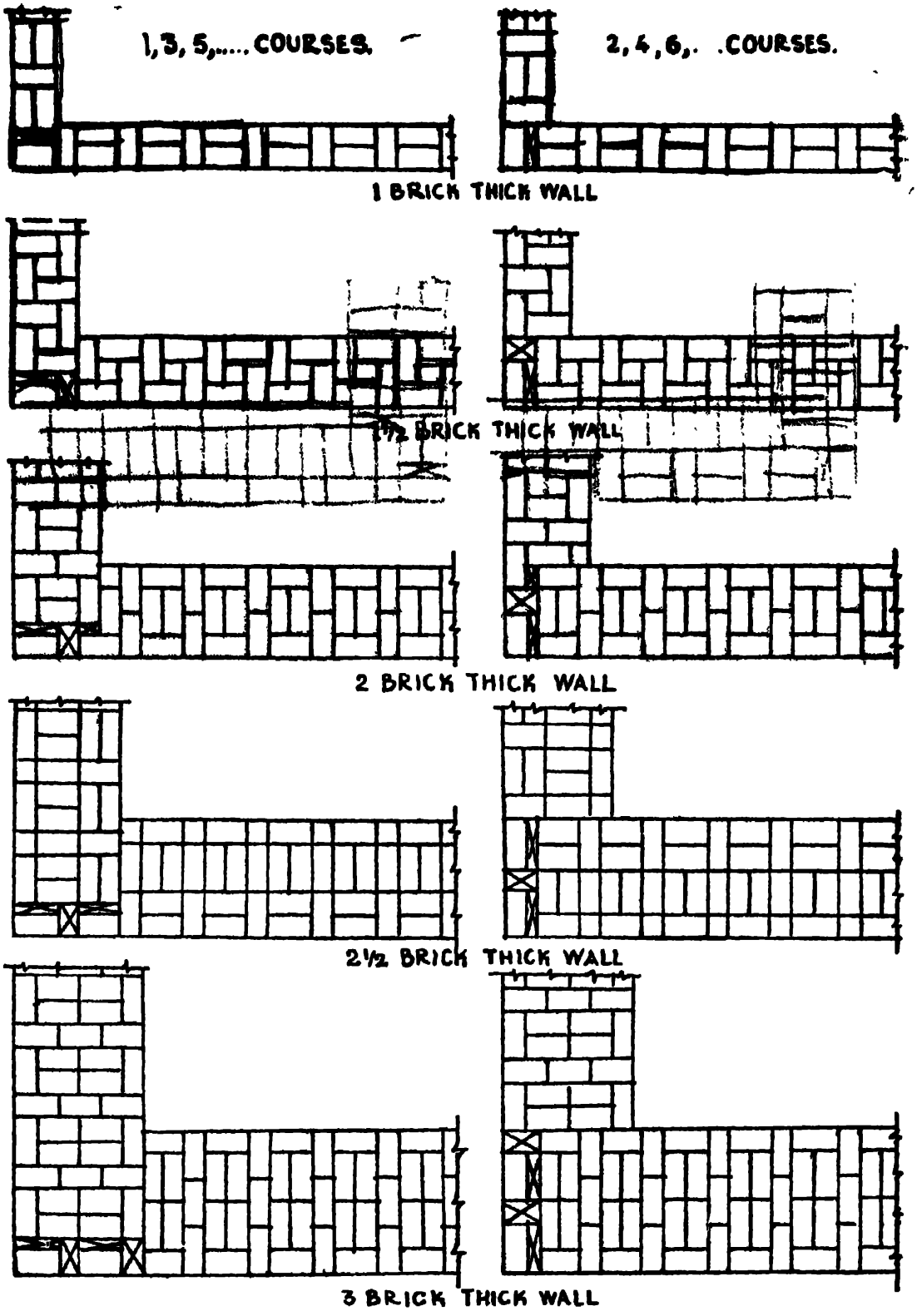


Fig. 8·13—8·17

Plans showing alternate courses of various thicknesses of brick walls in Double Flemish bond

8·5 Other Types of Bonds. The bonds described below are not very common in use. Their use is restricted to special types of construction.

(*i*) **Stretching bond.** In this arrangement of bonding brickwork all the bricks are laid as stretchers. The overlap, which is usually of half brick, is obtained by commencing each alternate course with a half brick bat. It is used for half brick wall only. This bond is also termed as running bond and is commonly adopted in the construction of half brick thick leaves of cavity walls, partition walls, etc. Since there are no headers suitable, reinforcement should be used for structural bond.

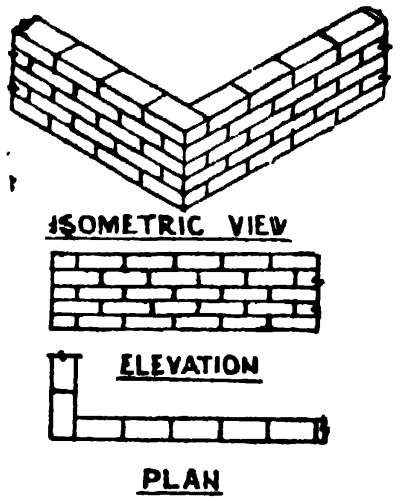


Fig. 8·18
Stretching bond

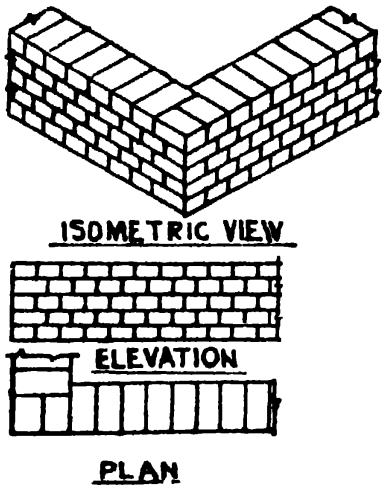


Fig. 8·19
Heading bond

(*ii*) **Heading bond.** In this type of bonding all the bricks are laid as headers on the faces. The overlap, which in usually of half the width of the brick is obtained by introducing a three-quarter bat in each alternate course at quoins. This bond is chiefly used for footings in foundations for better transverse distribution of load.

(*iii*) **Garden wall bond.** This type of bond is suitably adopted for one brick thick wall which may act as a garden wall or boundary wall. In garden wall bond, it is possible to build uniform faces for a wall without much labour or expense. This type of bond is not so strong as English bond, that is why its use is only restricted to the construction of such dwarf walls as are not subjected to large stresses. On account of its good appearance, this bond is sometimes used for the construction of the outer leaves of cavity walls.

There are two varieties of garden wall bond.

(*a*) *English garden wall bond*

(*b*) *Flemish garden wall bond*

(*a*) *English garden wall bond.* The general arrangement of bricks in this type of bonding is similar to that of English bond except that the heading courses are only inserted at every fourth or sixt course. Usually the arrangement consists of one course of headers to three courses of stretchers. A queen closer is placed next to the quoin header of the heading course to give the necessary lap.

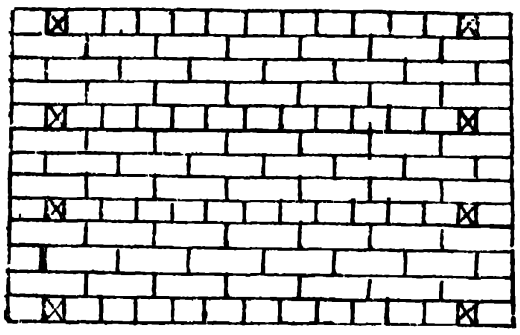


Fig. 8·20
Elevation of a wall in English garden wall bond

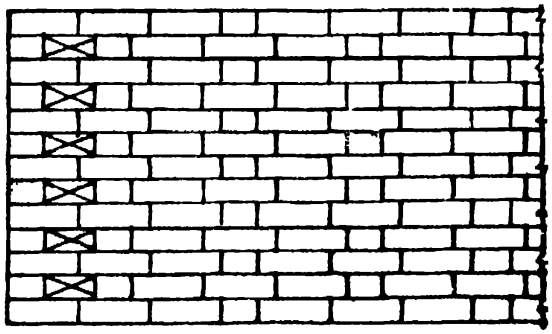


Fig. 8·21
Elevation of a wall in Flemish garden wall bond

(*b*) *Flemish garden wall bond.* This consists of alternate courses composed of one header to three or sometimes even five stretchers in series throughout the length of the courses. Each alternating course contains a three quarter bat placed next to the quoin header and a header is laid over the middle of each central stretcher.

(*iv*) **Facing bond.** This arrangement of bricks is adopted for thick walls, where the facing and backing are desired to be constructed with bricks of different thicknesses. This bond consists of heading and stretching courses so arranged that one heading course comes after several stretching courses. Since the number of joints in the backing and the facing differ greatly, the load distribution is not uniform. This may sometimes lead to unequal settlement of the two thicknesses of the wall.

(*v*) **Raking bond.** It is a bond in brick work in which the bonding bricks are laid at any angle other than zero or ninety degrees. This is necessary to be constructed to increase the longitudinal stability of thick walls built in English bond, In this arrangement of bonding, the space between the external stretchers of a wall is filled with bricks inclined to the face of the wall. This bond is introduced at certain intervals along the height of a wall. There are two common forms of raking bond : (*a*) Herring-bone bond (*b*) Diagonal bond.

(*a*) *Herring-bone bond.* This type of bond is best suited for very thick walls usually not less than four bricks thick. In this arrangement of brick work, bricks are laid in courses inclined at 45° in two directions from the centre This bond is also commonly used for brick pavings.

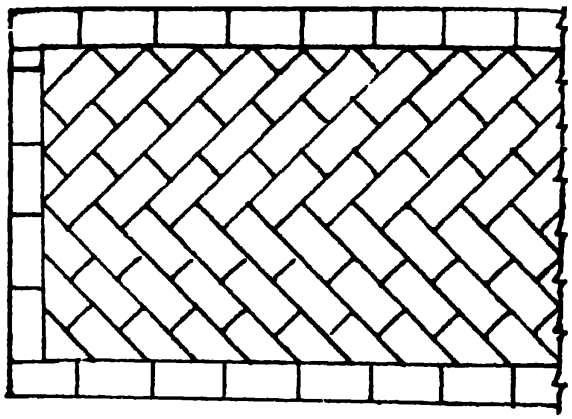


Fig. 8·22
Plan showing arrangement of bricks in Herring-bone bond

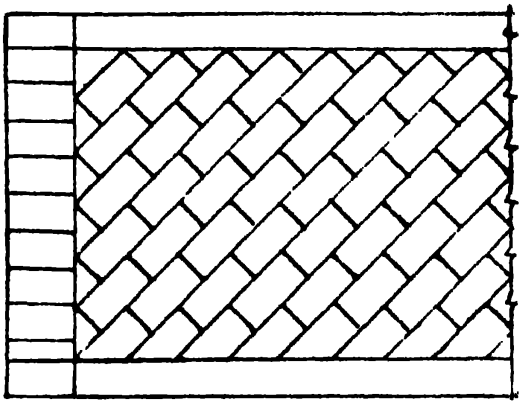


Fig. 8·23
Plan showing arrangement of bricks in Diagonal bond

(*b*) *Diagonal bond.* This bond is best suited for walls which are 2 to 4 brick thick. This bond is usually introduced at every fifth or seventh course along the height of the wall. In this bond, the bricks are placed end to end in such a way that extreme corners of the series remain in contact with the stretchers.

(*vi*) **Dutch bond.** This bond is a modification of old English cross bond and consists of alternate courses of headers and stretchers. In this arrangement of brick work, each stretching course starts at the quoin with a three-quarter bat and every alternate stretching course has a header placed next to the three-quarter brick bat provided at the quoin.

(*vii*) **English cross-bond.** This is similar to English bond and consists of alternate course of headers and stretchers. However,

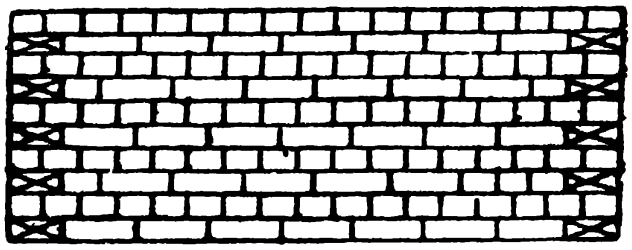


Fig. 8·24
Elevation of a wall in Dutch bond

in this bond, queen closers are introduced next to quoin headers and each alternate stretching course has header placed next to quoin stretcher. The bond is strong and bears a good elevation.

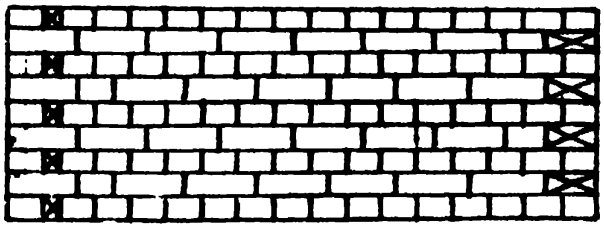


Fig. 8·25.
Elevation of a wall in English cross-bond

(*viii*) **Zig-Zag bond.** This is similar to herring-bone bond with the only difference that in this case the bricks are laid in a zig-zag fashion. This is commonly adopted in brick paved flooring.

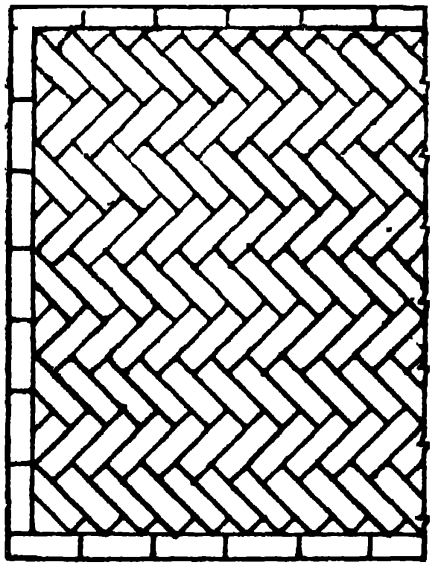


Fig. 8·26

Plan showing the arrangement of bricks in Zig-Zag bond

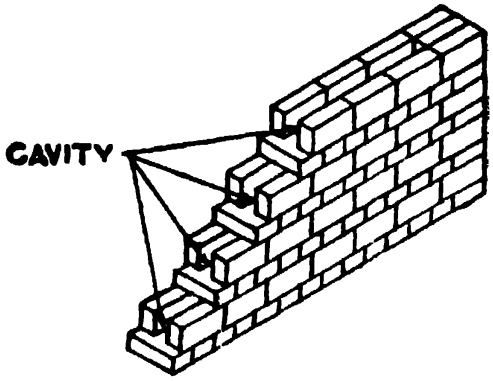


Fig. 8·27

View showing a wall in Silverlock's bond

(*ix*) **Silverlock's bond.** It is a form of bonding brick-work in which bricks are laid on edge. It is economical but weak in strength and hence it is only recommended for garden walls or partition walls. In this bond, the bricks are laid as headers and stretchers in alternate courses in such a way that headers are laid on bed and the stretchers are laid on edge forming a continuous cavity as shown in Fig. 8·27.

8·6 Tee-junctions. A Tee-junction is formed when two

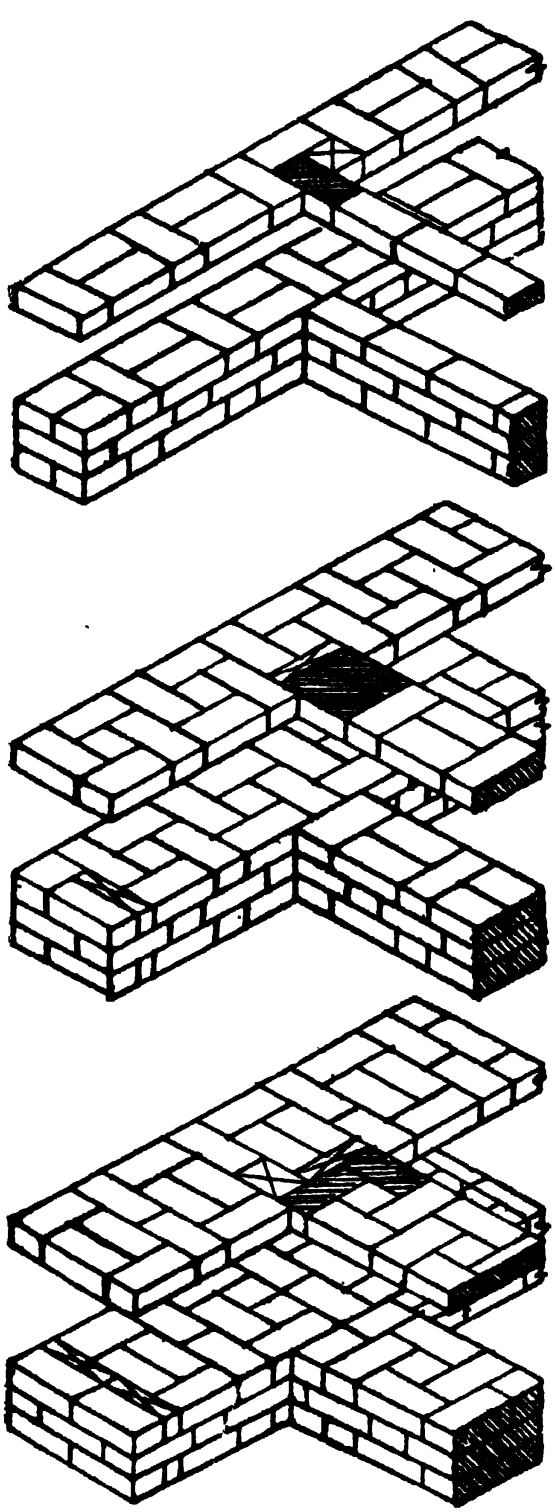


Fig. 8·28—8·30

Isometric view of T-junctions in English bond

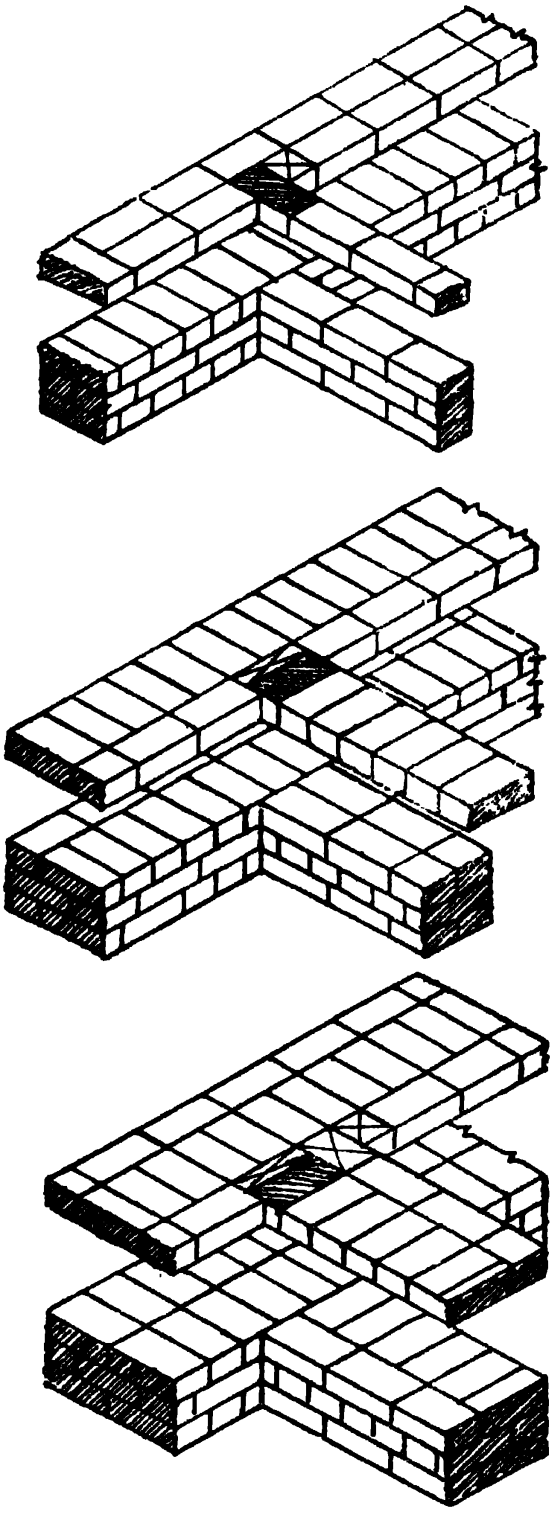


Fig. 8·31—8·33

Isometric view of T-junctions in Flemish bond

walls meet each other at right angles forming the letter 'T' in plan. T-junction may be formed in a number of different bonds described

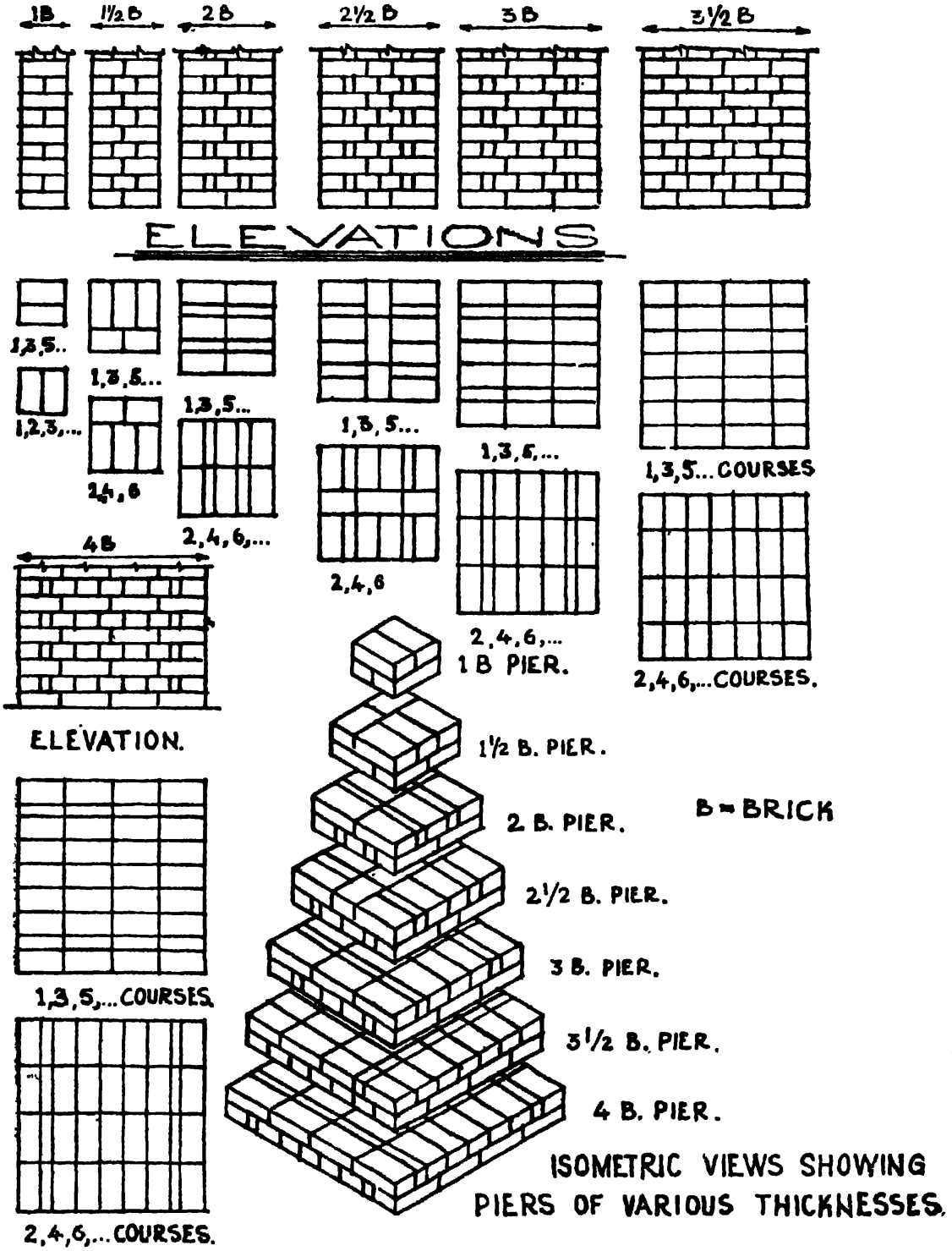


Fig. 8·34
Piers in English bond

earlier. Figs. 8·28—8·33 show the isometric views of T-junction between walls of various thicknesses. Fig. 8·28] shows T-junction

between half brick and one and a half brick thick wall in English bond. Fig. (8·29) shows T-junction between one brick and one and a half brick thick wall in English bond. Fig. (8·30) shows T-junction between one and a half and two brick walls in English bond. Figs. (8·31—8·33) show T-junctions with similiar combination of wall thicknesses, in Flemish bond.

8·7 Bonds in Piers. Piers may be constructed in a variety

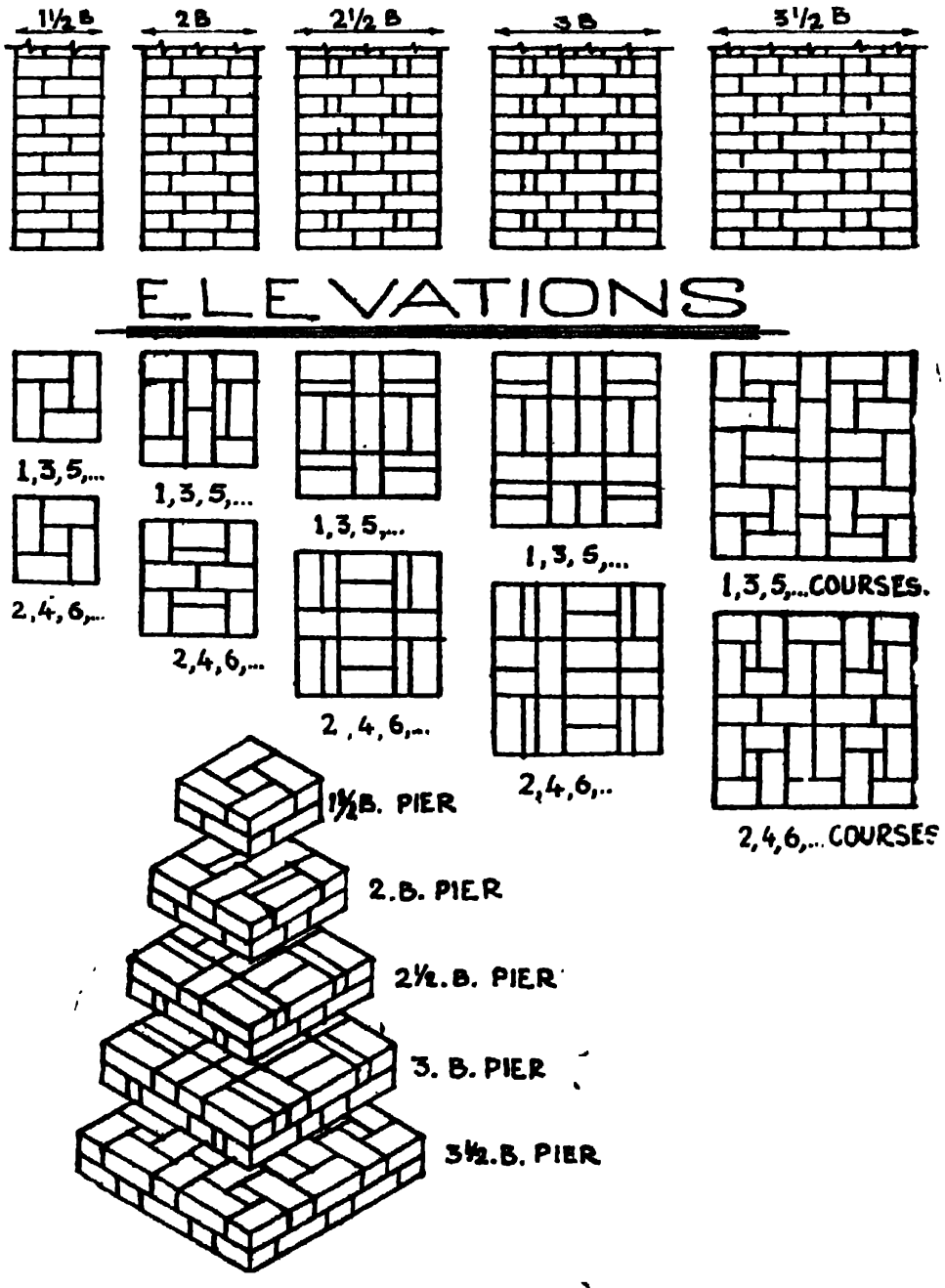


Fig. 8·35
Piers in Double Flemish bond

of bonds already described. The selection of the type of bond depends much upon shape of the pier as well as choice of the indi-

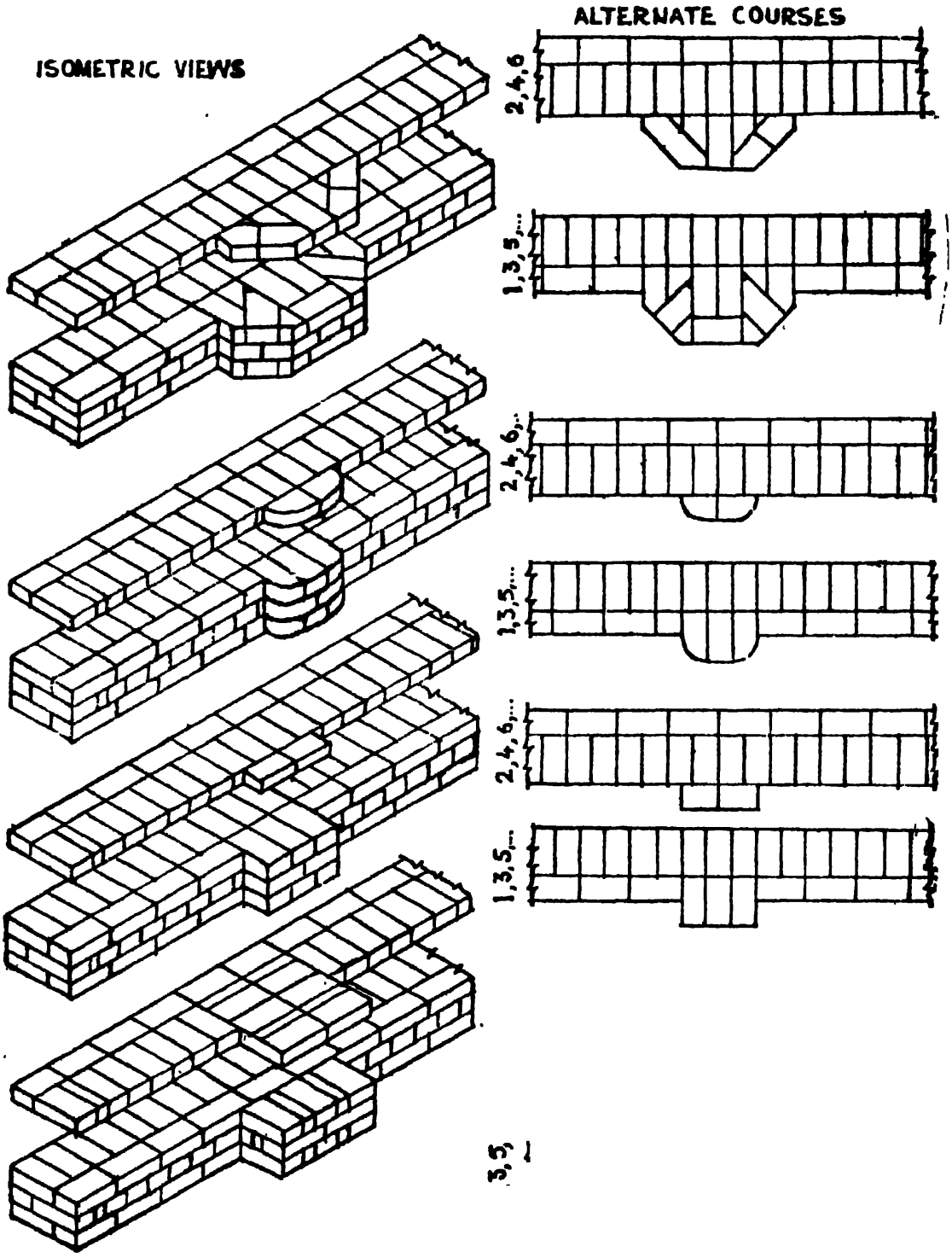
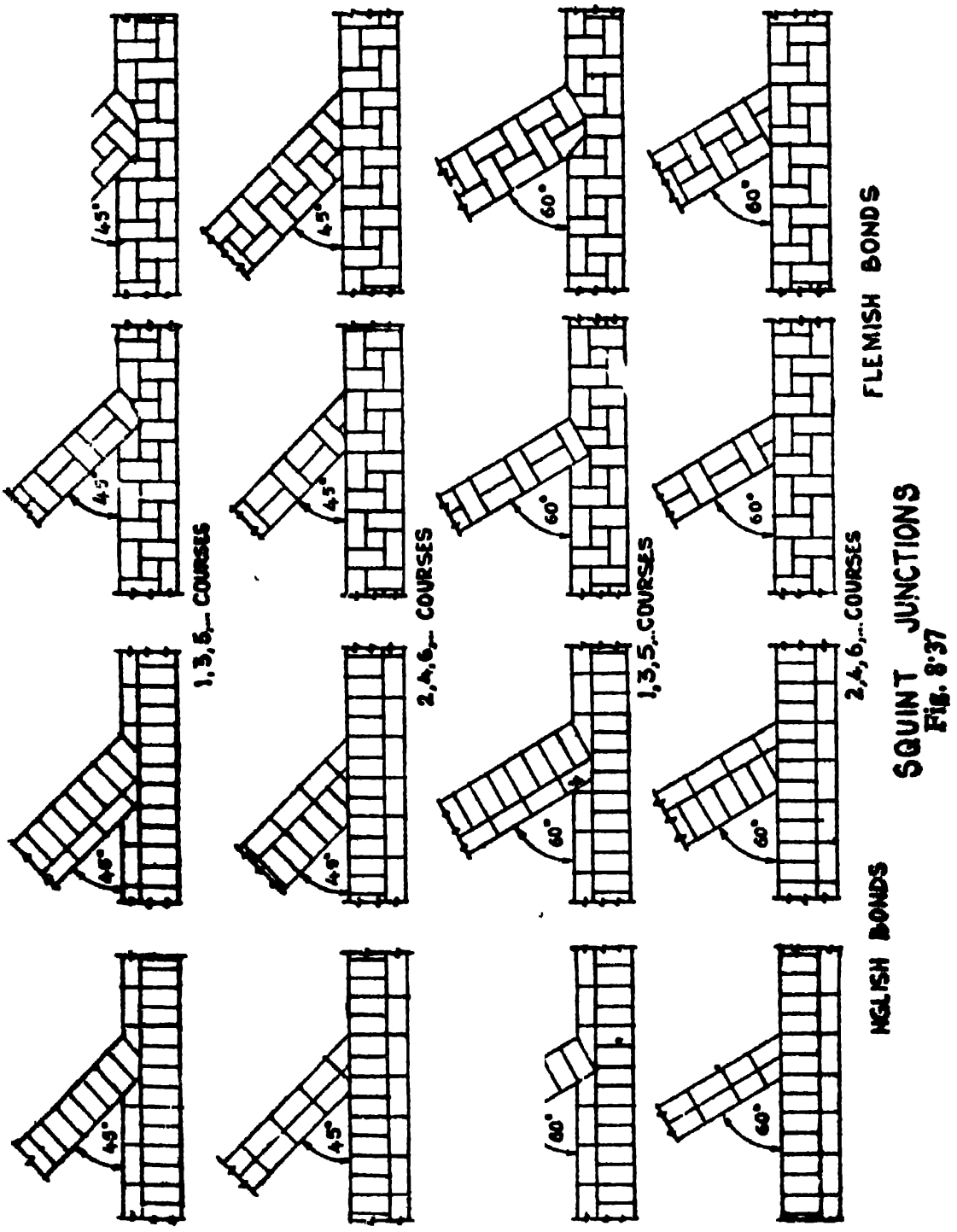


Fig. 8·36

Attached piers

vidual. In common practice brick piers are built in English bond or Double Flemish bond.

8·8 Piers attached to Main Walls. Fig. 8·36 shows plans of alternate course of various shapes of piers attached to 1½ brick thick wall. On the left hand side of the plans is given the isometric view of the described shape of attached pier. The function of the piers is to provide a large bearing area for giving support to the roof.



walls meet each other at right angles forming the letter 'T' in plan. T-junction may be formed in a number of different bonds described

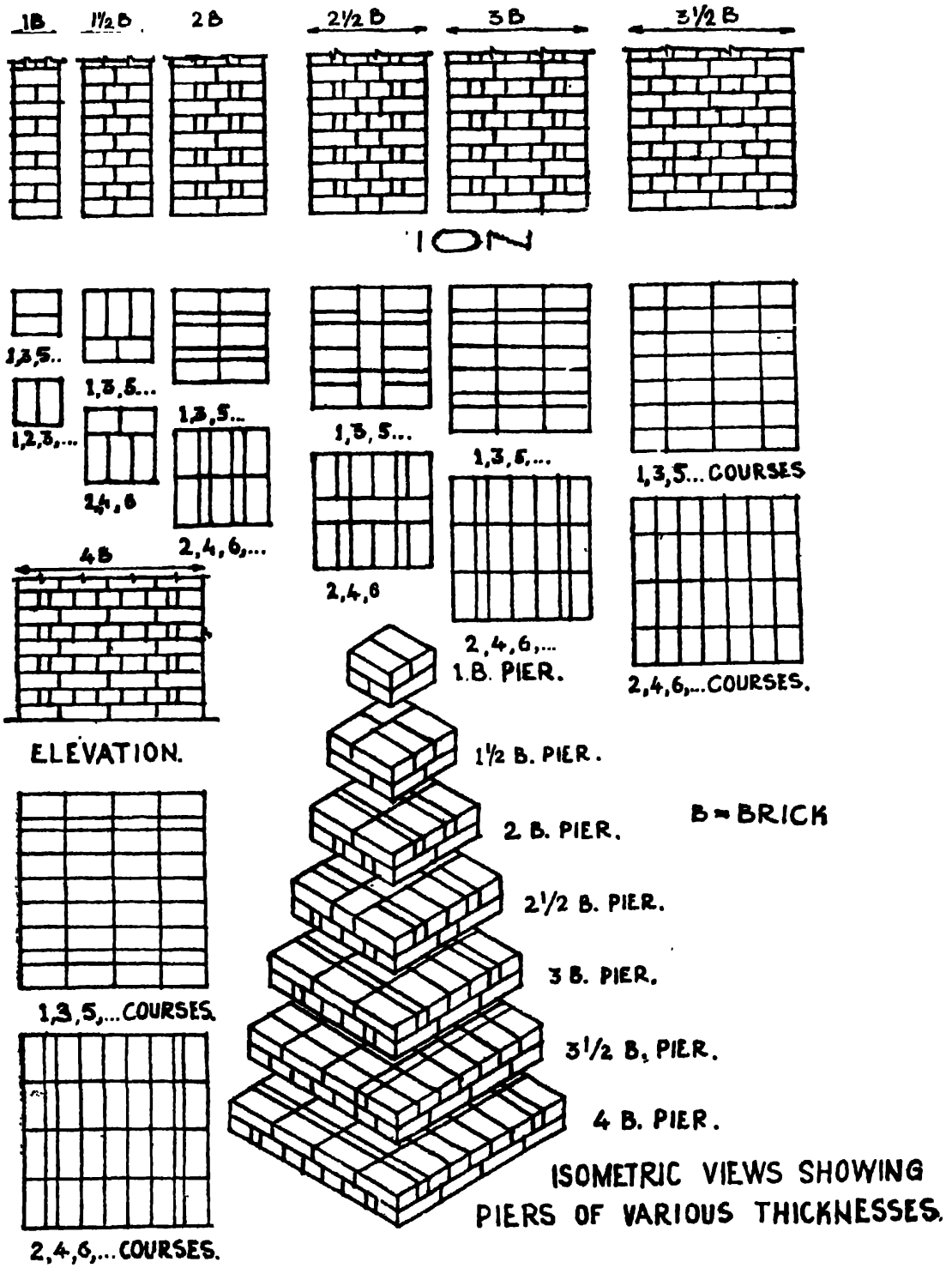


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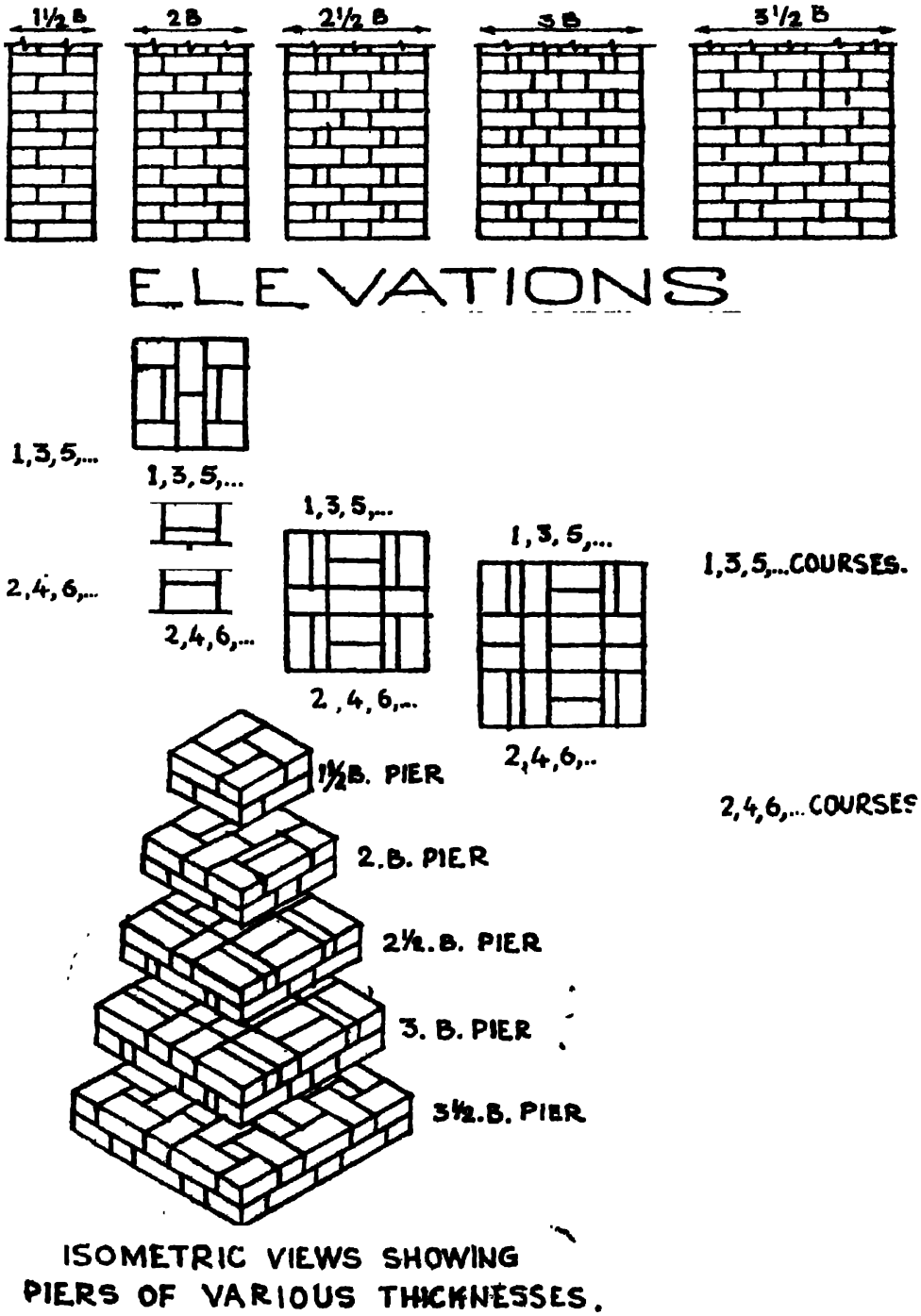


Fig. 8·35
Piers in Double Flemish bond

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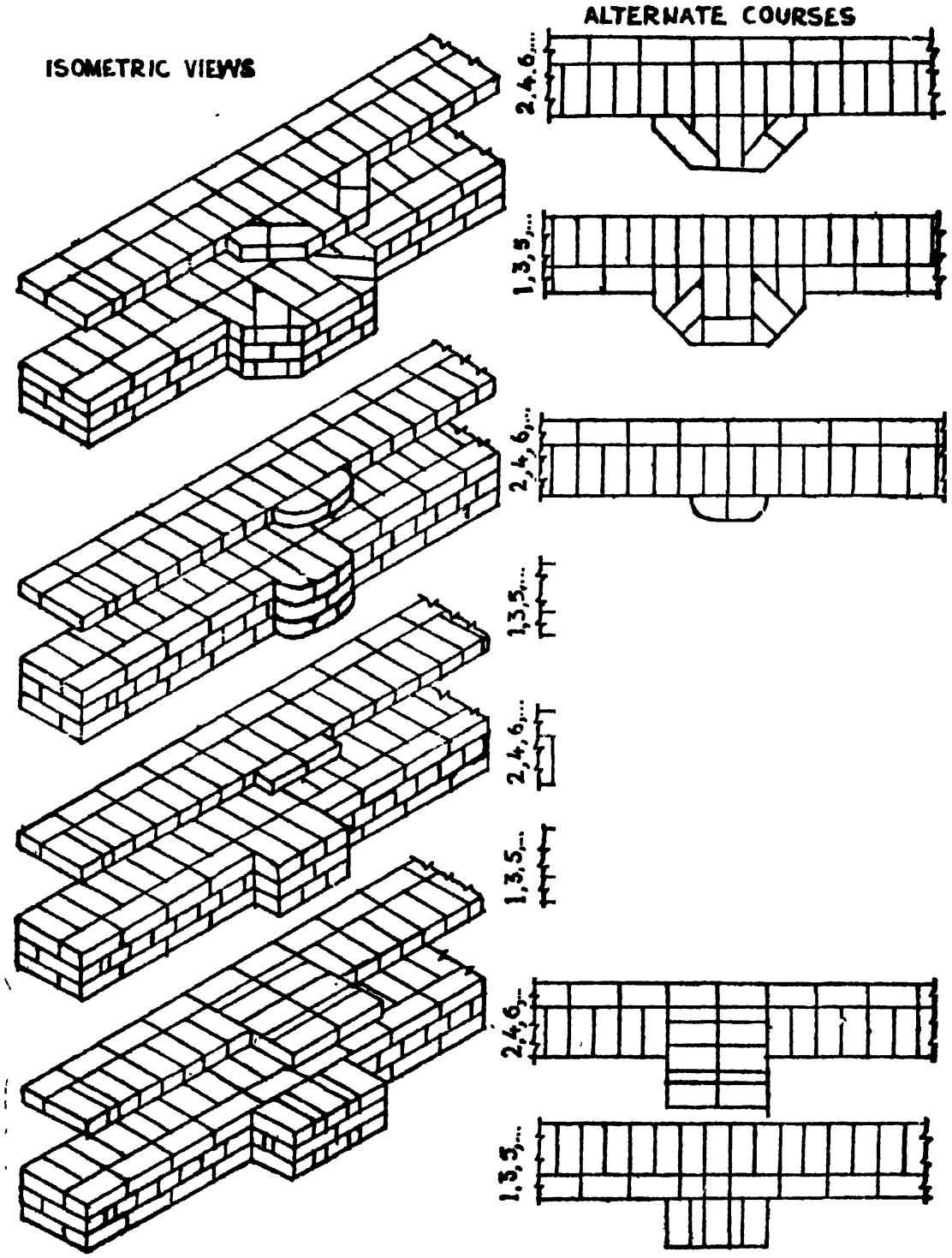
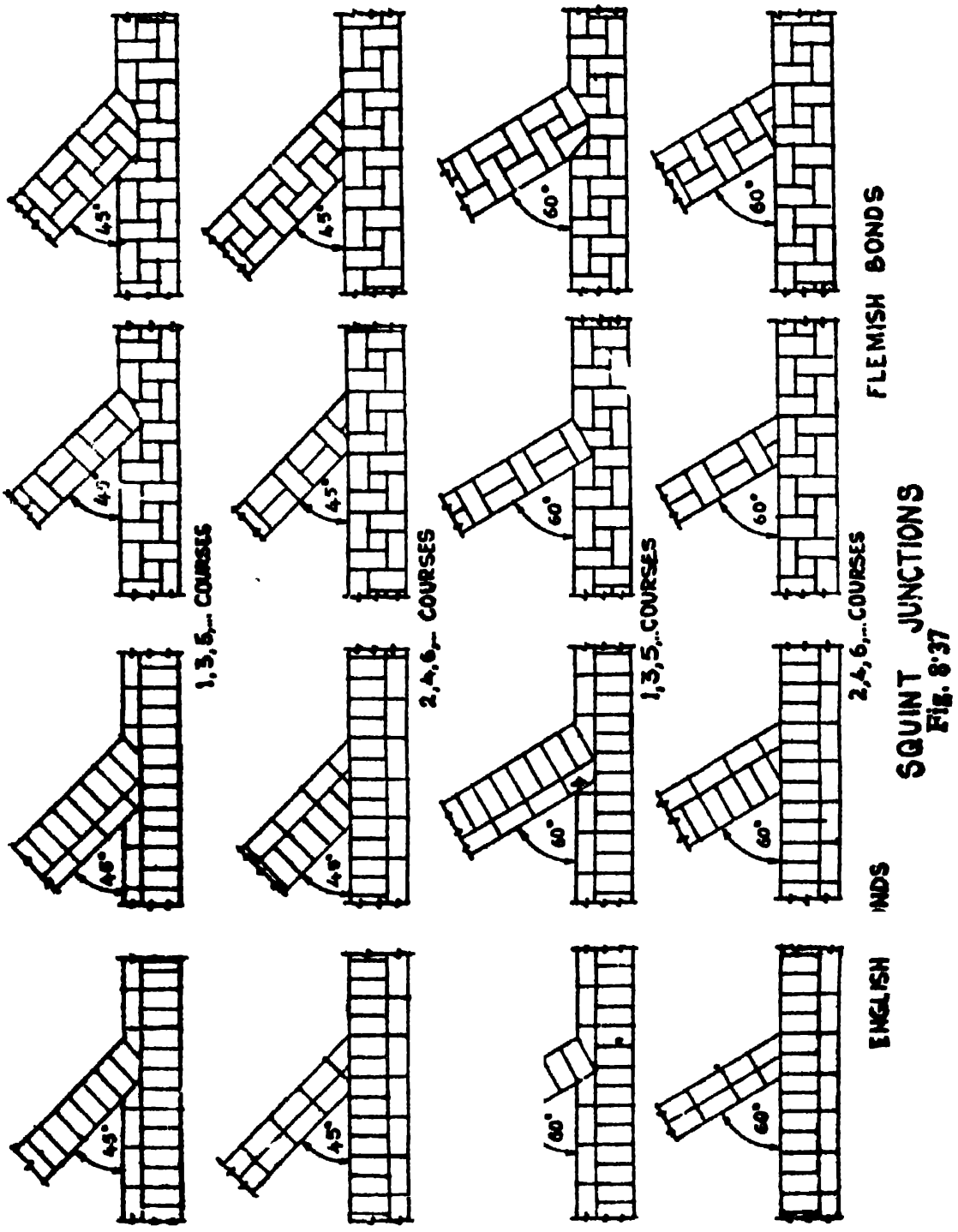


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SQUINT JUNCTIONS
Fig. 8·37

It also helps in increasing the stability of the wall by stiffening it at various points.

8·9 Squint Junctions. A squint junction is formed when two walls meet each other at an angle other than a right angle without forming a quoin. The junctions may be in English or Flemish bond. Great difficulty is experienced in forming the junctions accurately and that is why they are rarely adopted. Squint junctions between walls of various thicknesses have been shown in Fig. 8·37.

8·10 Squint Quoins. When two walls meet at an angle other than a right angle, the junction or quoin thus formed is termed as squint. The squint quoins may be divided into the following two categories :

(*i*) *Obtuse squint quoins*

(*ii*) *Acute squint quoins.*

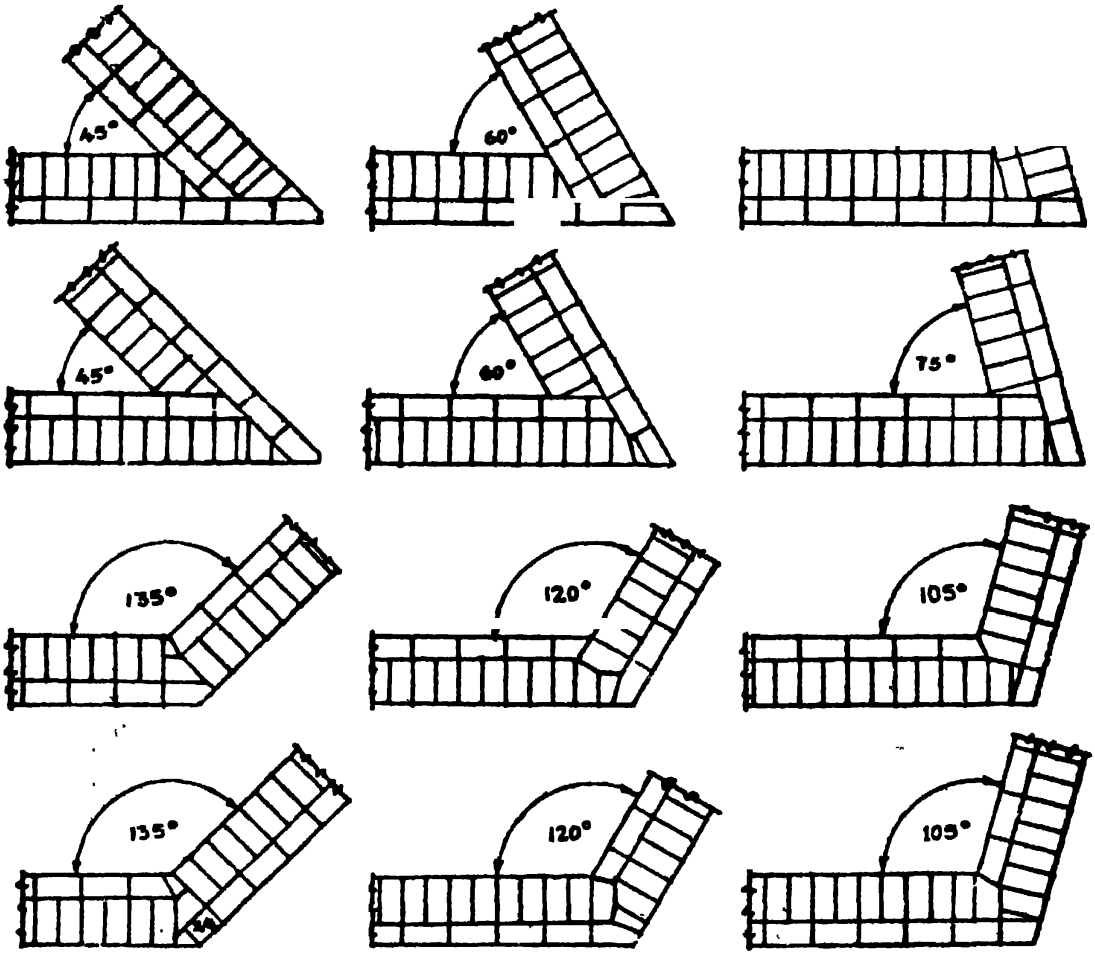


Fig. 8·38

Acute and obtuse squint quoins in English bond

The principle of bonding of brick work is the same as described earlier. In forming the required angle at the junction, standard bricks have to be cut to the desired shape so as to achieve facility in obtaining the maximum lap with minimum cutting.

Fig. 8·38 shows acute and obtuse squint quoins in English Bond.

Fig. 8·39 shows acute and obtuse squint quoins in Double Flemish bond.

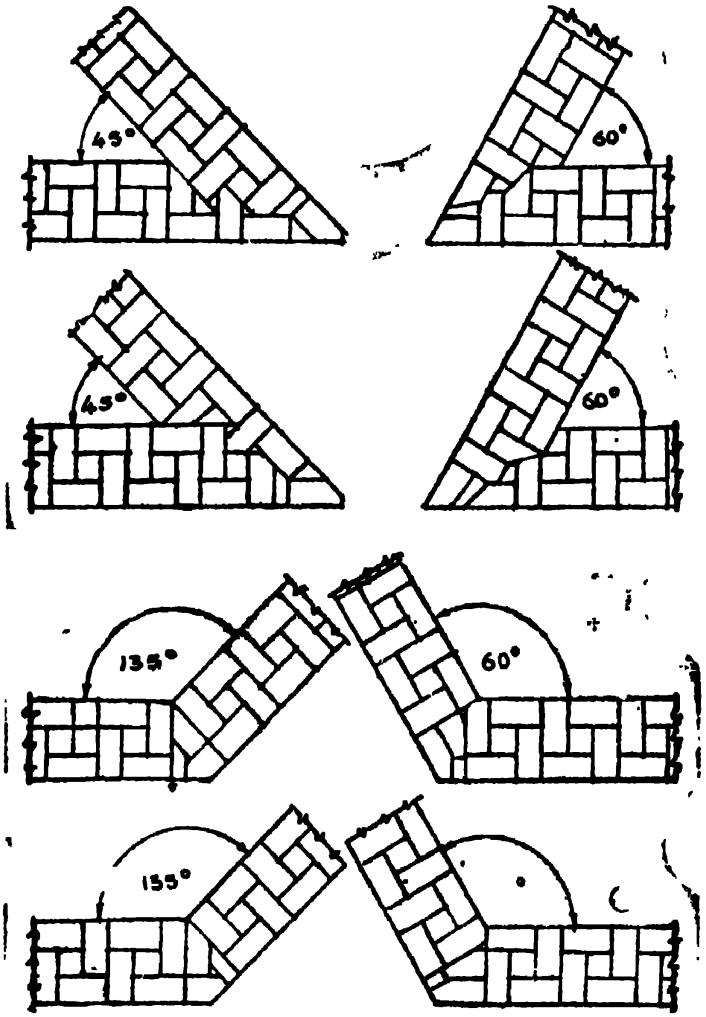


Fig. 8·39

Acute and obtuse squint quoins in Flemish bond

8·11 Tools of Brick-layer. Tools used for brick masonry construction have been shown in Fig. 8·40.

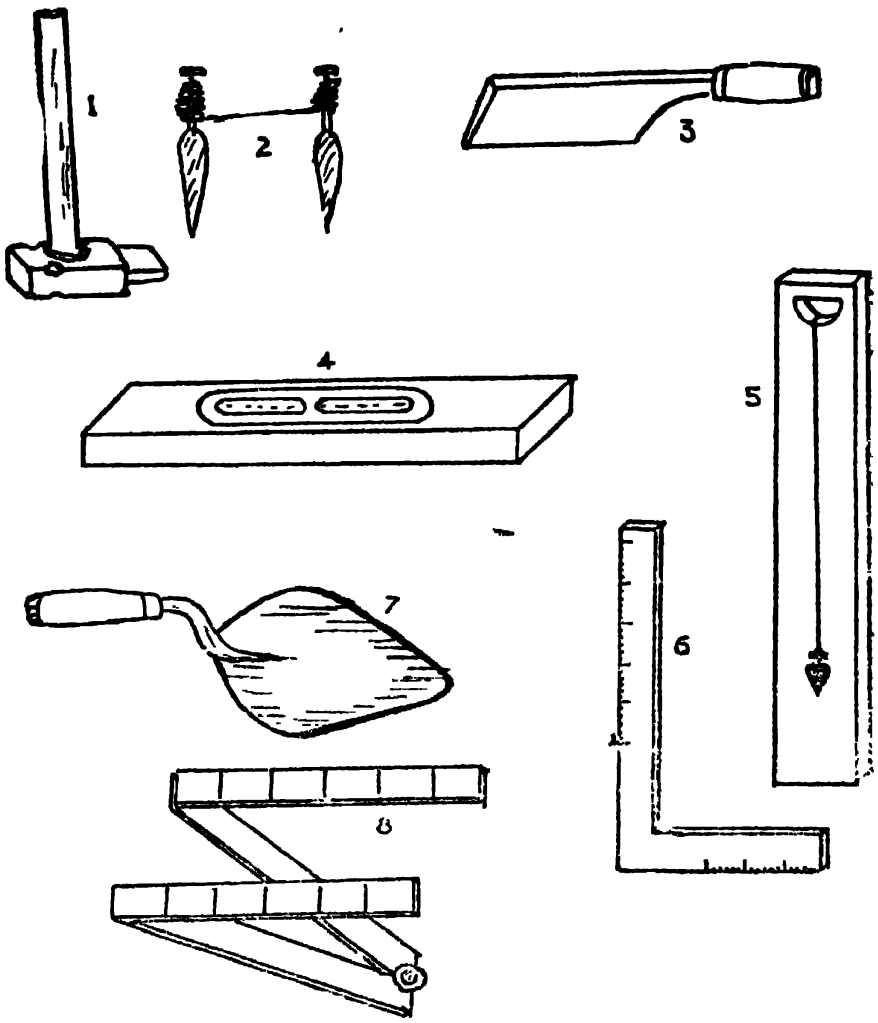


Fig. 8·40

Tools of Brick-layer

(1) Hammer ; (2) Line and pins ; (3) Brick axe ; (4) Spirit level ; (5) Plumb rule ; (6) Mason's square ; (7) Trowel ; (8) Two-foot four fold rule.

8·12 Retaining wall. It may be defined as a wall built to resist the pressure of earth filling, sand, or other similar filling deposited behind it after it is built. It is commonly required in the construction of hill roads, masonry dams, abutments and wing walls of bridges and so on. Depending upon the site conditions, type of material to be retained and the height of the wall to be constructed, retaining wall may be built in dry stone masonry, stone masonry, plain cement concrete and reinforced cement concrete.

Dry stone retaining wall : This is the simplest form of retaining wall. The stability of such walls depends upon the arrangement

of stones in the wall and the friction between the individual stones. The stones used in the wall should be of large size and roughly hammer-dressed so as to secure maximum bedding area. The wall should have a minimum top width of 60 cm. and the front face should have a batter varying from 1 in 4 to 1 in 3. The batter of 1 in 4 is adopted for walls lesser than 4·5 m. in height. In principle, the height of dry stone masonry wall should be restricted to 6 m. For walls above 4·5 m. in height, the upper 4·5 m. of the wall is usually built of dry rubble stone masonry and the portion below this height is built in mortar. The stones used in the wall construction are laid at right angle to the face batter. A proper bond is maintained and the front and the rear faces of the wall are nicely bonded with the hearting. The filling immediately behind the wall should usually consist of stone chips and not earth. Weep-holes should be provided in the wall at suitable distances apart to drain off the water from the filling behind. The wall has already been shown in figure on page (198).

Dry stone pitching or revetment : It is generally provided to protect the sloping face of an earthen cutting or embankment from erosion. Stones used, should be perfectly sound and roughly cut to fit in the shape of the pitching. In case of channels and dams, pitching should be carried at least 90 cm. above the high flood level and to secure its stability, the toe should be prevented from slipping by suitable constructions. The slopes of embankment should not be steeper than 1 : 1, a slope of $1\frac{1}{2}$: 1 being usually adopted. The thickness of pitching varies from 30 cm. to 75 cm. Selected stones are tightly handpacked and all the intersties are filled up with smaller pieces of stone and wedged up tight. Every stone in pitching is laid flat and no projecting stones are allowed.

Breast walls : These are stone walls provided to protect the

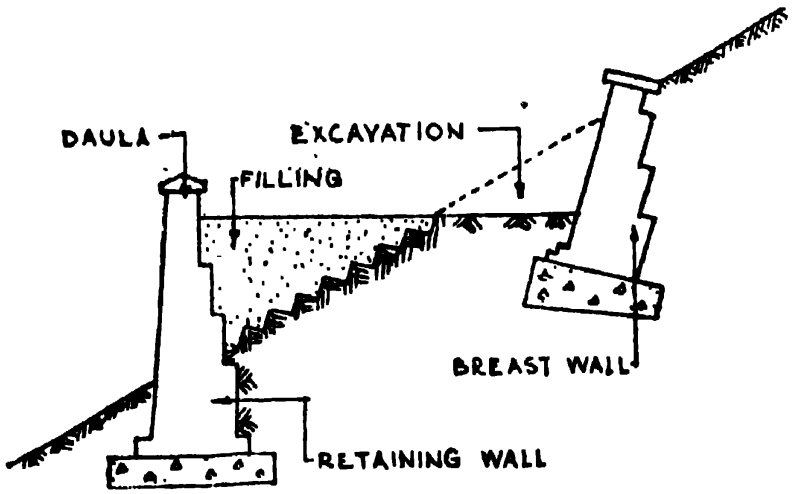


Fig. 8·41

Breast wall and retaining wall in their respective positions.

slopes of cutting in natural ground from the action of weather. The section of wall to be adopted depends upon the height of wall, the nature of the backing and the slope of cutting. The front and back batters of the wall vary from 1 in 4 to 1 in 2 (1 in horizontal : 4 or 2 vertical), with the minimum top width of 60 cm.

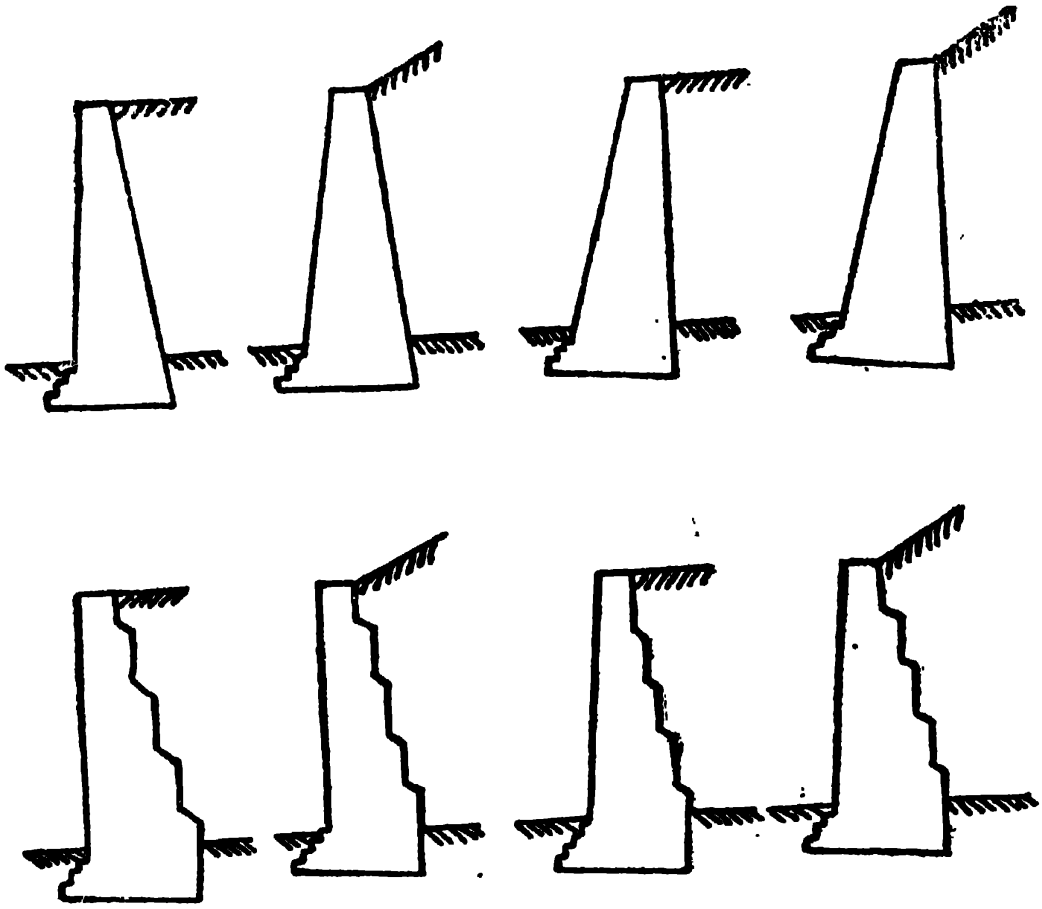


Fig. 8·42

Stone masonry and plain concrete retaining walls : These walls are also provided to support earth, loose stone, coal etc. The wall acts as one mass to resist the thrust from the backing and is much more stronger than dry stone masonry wall. The stability of the walls depend entirely upon its dead weight. They are designed on the assumption that masonry or concrete is not subjected to any tensile stresses. In order that the walls may be stable they have to be very thick in section and as such they are seldom constructed for heights beyond 6 m. The top width of masonry walls and concrete walls should not be less than 60 cm. and 45 cm. respectively. The bottom width of the walls vary with the height. The backing material is suitably drained through the weep holes provided in the wall at 1·8 to 3 m. apart.

8·13 Design of retaining walls. The thrust from the backing which tends to overturn the wall or causes it to slide, is the

deciding factor in the selection of the section and type of the wall. There are many conditions upon which the thrust exerted by the backing depends, such as cohesion of the soil, dryness of the backing material, the manner in which the material is filled against the wall and so on. There are various theories by the help of which the value of thrust under different conditions can be easily worked out. Having known the thrust, the section of the wall is so designed that its self-weight is sufficient to resist the tendency of the thrust to slide the wall and the bottom width of the wall is such that the resultant force (resultant of the weight of wall and pressure of filling behind) lies within the middle third of the base. This condition is necessary to prevent the tendency of the thrust to overturn the wall and to ensure that there is no tension at the wall base. It is equally essential to ascertain that the maximum stress at the toe of the wall does not exceed the safe bearing capacity of the soil.

Calculation of earth pressure. The thrust due to the back filling, which may be assumed to be earth, is generally calculated by Rankine's Theory. The theory is based on the assumption that the backing material or earth consists of cohesionless granular particles. The formulae derived from this theory under different conditions of back filling are given below :

Case 1 : *Walls with earth levelled with the top of wall.*

(*a*) Horizontal pressure per sq. m. (ph) at a depth of metre below the levelled top is given by the formula :

$$ph = w \times h \times \frac{1-\sin\phi}{1+\sin\phi}$$

where w = weight of filling in kg/m^3.

and ϕ = angle of repose of the soil.

(*b*) Total horizontal pressure (P) at a depth of (h) metre per metre length of wall is given by the formula :

$$P = \frac{wh}{2} \times \frac{1-\sin\phi}{1+\sin\phi}$$

Acting at $\frac{h}{3}$ metre from the base.

Case 2 : *In case of surcharged retaining wall* or wall retaining earth filled at slope of $\alpha°$ to the horizontal, the formula giving lateral earth pressure (ph) is given by :

$$ph = wh\cos\alpha \frac{\cos\alpha - \sqrt{\cos^2\alpha - \cos^2\phi}}{\cos\alpha + \sqrt{\cos^2\alpha - \cos^2\phi}}$$

acting parallel to the surcharge slope of the filling.

Total pressure (P) at depth of h metre per metre length of wall is given by the formula :

$$P = \frac{wh^2}{2} \cos \alpha \frac{\cos \alpha - \sqrt{\cos^2 \alpha - \cos^2 \phi}}{\cos \alpha + \sqrt{\cos^2 \alpha - \cos^2 \phi}}.$$

8·14 Conditions of Stability of Retaining Walls. A satisfactory retaining wall must meet the following requirements for earth its stability :

(1) The wall should be structurally capable of resisting the pressure applied to it.

(2) The section of the wall should be so proportioned that it will not overturn by the lateral pressure.

(3) The wall should be safe from consideration of sliding, *i.e.*, the wall should not be pushed out by the lateral pressure.

(4) The weigh of wall together with the force resulting from the earth pressure acting on it, should not stress its foundation to a value greater than safe bearing capacity of the soil on which it is founded.

(5) It is important to prevent accumulation of water behind a retaining wall. The boding material should be suitably drained by providing 10 cm. diameter, weep holes located at 1·8 to 3m apart. In order to prevent chokage of weep holes, some filter media, consisting of gravel or crushed stone, should be provided around the intake of each weep hole, the back faces of the retaining walls should in addition, be provided with suitable water-proofing treatment in areas of heavy rainfall, when backfill material is relatively impermeable or when this wall is made out of porous masonry blocks.

(6) As far as possible, long masonry retaining should be provided with expansion joints located at 6 to 9 metre apart.

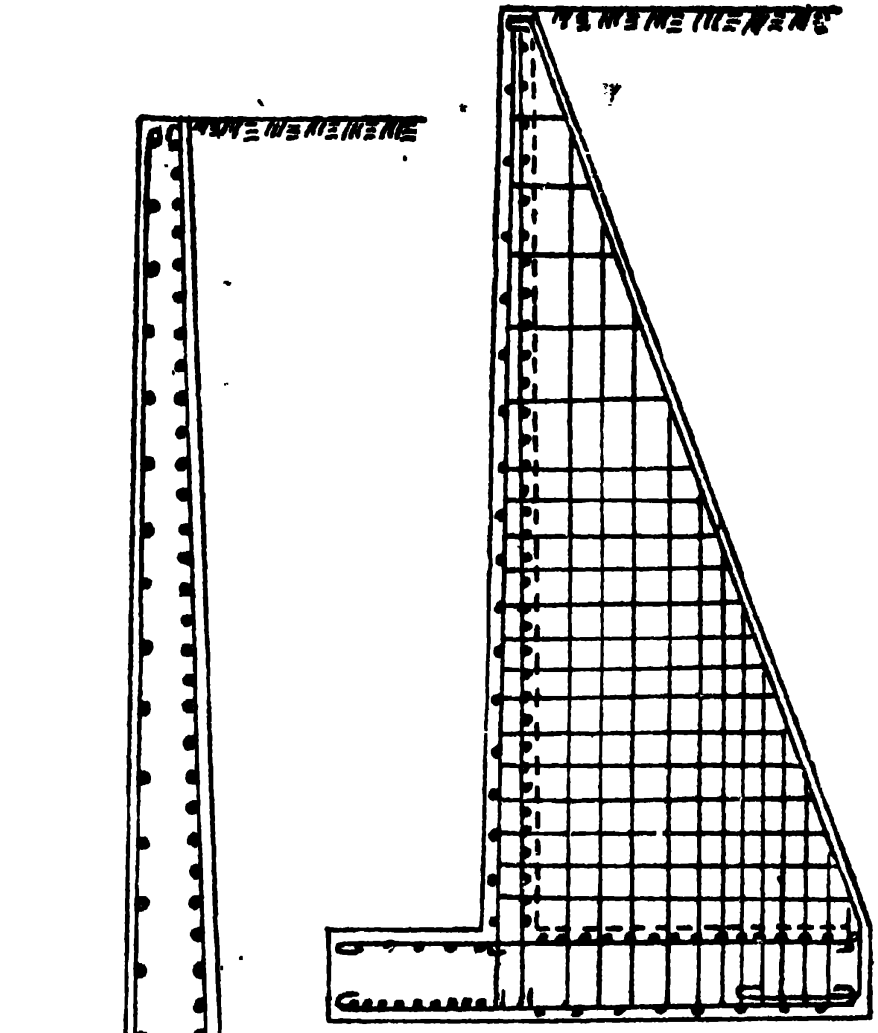
8·15 R.C.C. Retaining Walls. Plain concrete walls, on account of their thick section, render the solution of retaining materials an uneconomical choice. The thickness of plain concrete wall is greatly reduced by inserting mild steel reinforcements in places where the wall is likely to be subjected to tensile stresses. Thus the reinforced concrete retaining walls can be economically constructed for greater heights. They are usually constructed in two different shapes :

(1) *Cantilever type*

(2) *Counterfort type*

Cantilever type retaining wall : It consists of a vertical stem rigidly fixed to a horizontal base slab. The base slab is further

divided into two components *viz.* heel slab and toe slab. The stem, toe and heel slabs are designed as cantilever beams for moment, shear and bond. The stem is also reinforced to withstand the adverse effect of temperature variations. This type of wall is economical for moderate heights upto 6 m.



Figs. 8·43–8·44

Counterfort retaining wall : For walls above 6 m. in height, the cantilever type of retaining wall requires great stem thickness to make the wall self supporting. Great economy is made in high walls

by placing counterforts at suitable intervals along the wall length. The steam behaves as a vertical slab continuous over the counterforts and loaded by the horizontal thrust due to back filling. The action of counterfort is to tie the vertical wall slab to the base of wall. As in case of cantilever type of retaining wall, the base slab is divided in two parts *viz.* toe slab and heel slab. The heel is designed as horizontal slab supporting the counterforts aud subjected to bending stresses induced by back fill and the sub-soil reaction of the loading. The toe is designed similar to cantilever type of retaining wall.

Questions for Revision

1. Draw neat sketches, in plans of successive courses and elevation, to illustrate the construction of a brick-wall, 2½ brick thick in English bond at a right-angled corner.

How does English Bond differ from Flemish bond ?

2. Explain the difference between brick masonry and stone masonry with reference to their suitability, cost and method of construction.

Sketch two consecutive courses of a square pier in English bond 2½ brick thick.

3. (*a*) Name the various bonds used in brick-work.

Draw neat sketches of the following in English bond (adopting usual brick size).

(*i*) Two consecutive courses of right-angle corner of a brick wall 1½ brick thick.

(*ii*) Two consecutive courses of a brick pillar 1½ brick square.

4. Write short notes on :

(*i*) Flemish bond

(*ii*) Garden wall bond

(*iii*) Heading bond

(*iv*) Facing bond

(*v*) Raking bond

(*vi*) Dutch bond

(*vii*) Silverlock's bond.

5. Supposing you are supervising the construction of a residential building in a good locality, write the general principles you would expect the brick-layer to observe during the progress of the brick masonry.

6. Define a bond. Distinguish with the help of sketches between a wall in English bond and a wall in Flemish bond.

7. Sketch free-hand to a suitable scale the following :

(*a*) Un-coursed and coursed rubble masonry in elevation.

(*b*) Corner of 2 brick thick brick wall.

8. Sketch free hand to a suitable scale the following :

(*a*) Ashlar, random and coursed rubbled masonry in elevation.

(*b*) Isometric view of the corner of one and half brick wall.

9. Answer briefly the following :

(*a*) Of what and how are bricks made ?

(*b*) Mention all the equipments required by the brick-layer and his assistant for erecting a brick wall in lime mortar.

(*c*) Where are the following joints used :

Mortise, tennon, tongue and groove, and dovetailed joint.

10. What are retaining walls ? Underline the design procedure adopted in deciding the section of a retaining wall.

11. Define the following :

(*i*) Header

(*ii*) Stretcher

(*iii*) King closer

(*iv*) Queen closer

(*v*) Perpend

(*vi*) Bat.

12. Write short notes on any three of the following :

(*a*) Damp-proof courses.

(*b*) Tests conducted on bricks.

(*c*) The English and Flemish bond in brick work.

(*d*) Joints in stone work.

(*e*) Composite masonry construction.

13. Give detailed specifications for the following item of work :

First class brick work in cement mortar.

14. How many kinds of brick bonds are there ? Compare the two main kinds. In what respect is one superior to the other ? Show two courses of a small length of wall of one and a half brick in thickness in English bond.

15. Draw neat sketches of the following in English bond (adopting usual brick size).

(*i*) Two consecutive courses of the right-angled corner of a $1\frac{1}{2}$ brick wall.

(*ii*) Two consecutive courses of a $1\frac{1}{2} \times 2$ brick pillar.

(*iii*) Two consecutive courses of a junction of $1\frac{1}{2}$ brick wall with that of a 2 brick wall.

16. Draw a plan and elevation of two consecutive courses in English bond for :

(*a*) $1\frac{1}{2}$ brick wall meeting a 2 brick wall at a right-angled corner of a building.

(*b*) Single brick cross wall meeting a $1\frac{1}{2}$ brick main wall at any intermediate point.

17. Describe with neat sketches the different types of bonds used in brick work.

Give sketches for any two of the following showing the alternate courses in English bond.

(*i*) 2 brick wall at a corner of a rectangular building,

(*ii*) $2 \times 3\frac{1}{2}$ brick pillar.

(*iii*) 2 brick wall crossing with $3\frac{1}{2}$ brick brick wall.

18. What is the difference between English bond and Flemish bond in brick masonry construction ?

19. (*a*) What are the general principles observed in brick masonry ?

(*b*) Name the different bonds used in brick masonry. Show by sketches any two.

(*c*) Describe with sketches a dry stone retaining wall.

20. In which cases would you prefer brick masonry to stone masonry ?

State the general principles to be observed and the precautions taken in constructing brick masonry as well as stone masonry.

21. What do you mean by Bond in brick work ? Distinguish between English and Flemish bond. What are the various precautions to be taken in brick masonry construction ?

22. (*a*) State the general principles to be observed during the construction of brick masonry work.

(*b*) Draw plans of

(*i*) two consentive courses of a right angled quoin between two walls, each 1½ brick thick, in English bond and

(*ii*) two consecutive courses of the junction of two 1½ brick walls in English bond.

23. (*a*) What is meant by efflorescence on brickwork ? List the sources which give rise to dampness and efflorescence on buildings constructed near the sea coast.

(*b*) Show by free hand well-proportioned sketches plan and elevations of two successive courses of a brick pier 2½ brick thick × 3 brick wide.

24. Draw a sketch to illustrate the various elements of a brick layer's scaffold and state the difference between this type of scaffolding and that used by masons.

9

Composite Masonry

9·1 Definition. Walls constructed from two or more building materials are termed as composite walls. The combination may be stone slab in the face work and brick masonry at the backing, or superior stones in the facing with rubble stone masonry at the backing and so on. Composite masonry may be essential to improve the appearance of a structure by concealing the inferior work by use of superior quality of material in the desired positions. This results in great saving in cost and, if properly constructed, the structure remains equally strong and durable. Stones, bricks, concrete and tiles are the materials commonly used in such constructions.

9·2 Composite Masonry in Stone and Brick. This is the construction in which stone slabs are used in the face work and

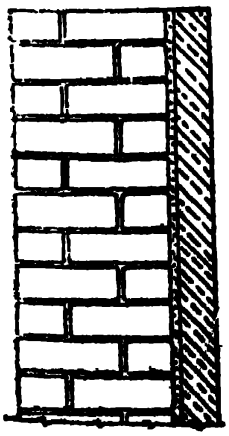


Fig. 9·1
Stone facing with brick backing

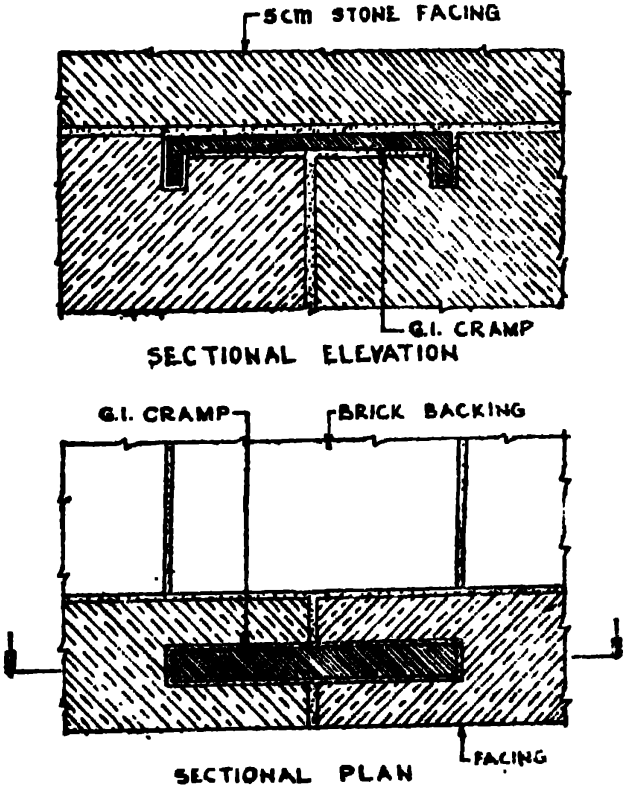


Fig. 9·2
Method of securing facing to the backing by means of G. I. cramp

brick masonry is used as backing. Stones used may be natural or artificial. The stones are secured to the backing either by means of metal cramps, or by projecting the headers in the face work well inside the backing. It is obvious that the number of joints in the backing will be much more than the joints in the facing and as such

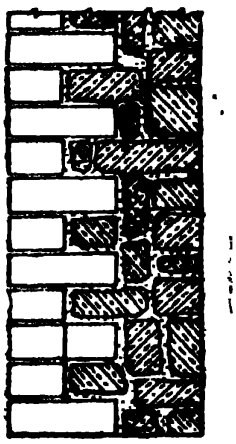


Fig. 9·3
Brick facing and stone backing

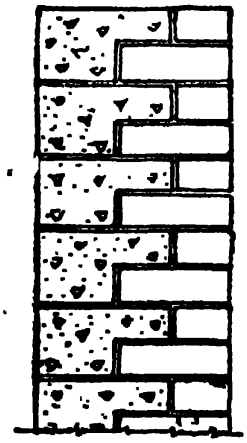


Fig. 9·4
Brick facing and concrete backing

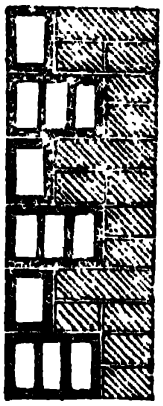


Fig. 9·5
Tile facing and brick backing

the bonding between the two faces should be perfect to avoid unequal settlement of the two leaves. The different types of composite masonry are described below :

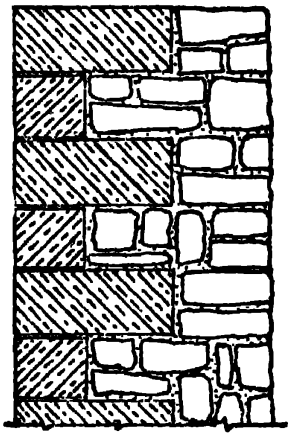


Fig. 9·6
Stone facing and rubble backing

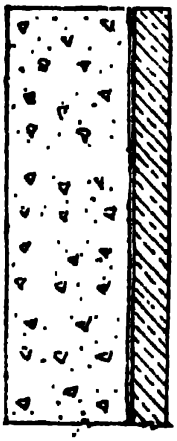


Fig. 9·7
Stone facing and concrete backing

(1) **Brick backed Ashler.** This has been described in the chapter on Stone Masonry.

(2) **Brick facing with rubble or concrete backing.** In this type of construction, special types of glazed tiles or bricks are used as facing material and rubble or concrete or brick is used as

backing. Terra-cotta tiles and other such glazed tiles are commonly used in lavoratory blocks and other such sanitary structures.

(3) **Stone facing with brick, rubble or concrete backing :** The purpose of this type of masonry is to make a wall constructed in brick to appear as if constructed in stone. It is adopted to improve

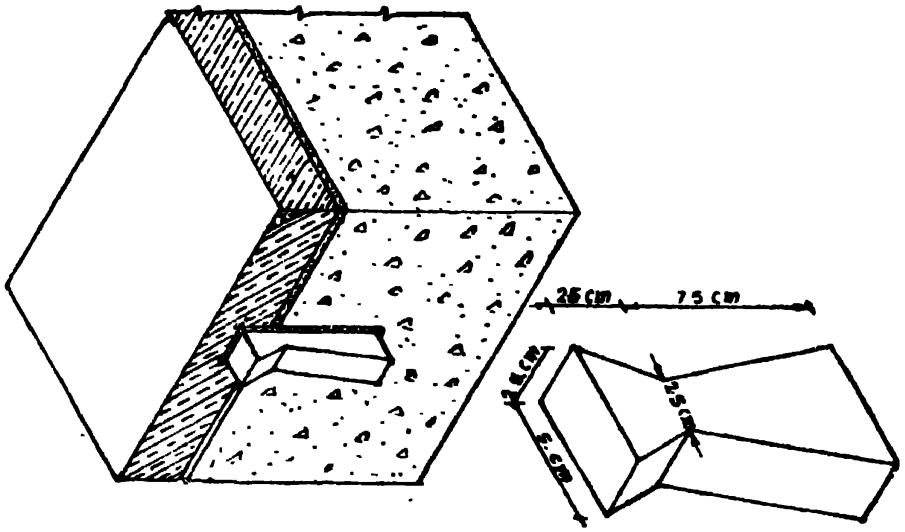


Fig. 9·8
Method of fixing stone facing with concrete backing

the appearance of the structure at a lesser cost. The stone slabs seldom exceed 5 to 10 cm. in thickness and are properly secured to the backing.

9·3. Cement Concrete Masonry. Cement concrete is largely used for constructional purposes on account of its numerous advantages over the other building materials. Cement concrete may be used in the form of pre-cast hollow concrete blocks, plain concrete slabs or reinforced concrete slabs. Hollow units may be defined as those units having core-void areas greater than 25% of their gross area. The blocks may have one or multi-core design to suit the choice of manufacturer. The various advantages of concrete block masonry are described below :

(1) On account of their regular and uniform size, concrete blocks afford great facility in masonry construction which ultimately results in rapid execution of work.

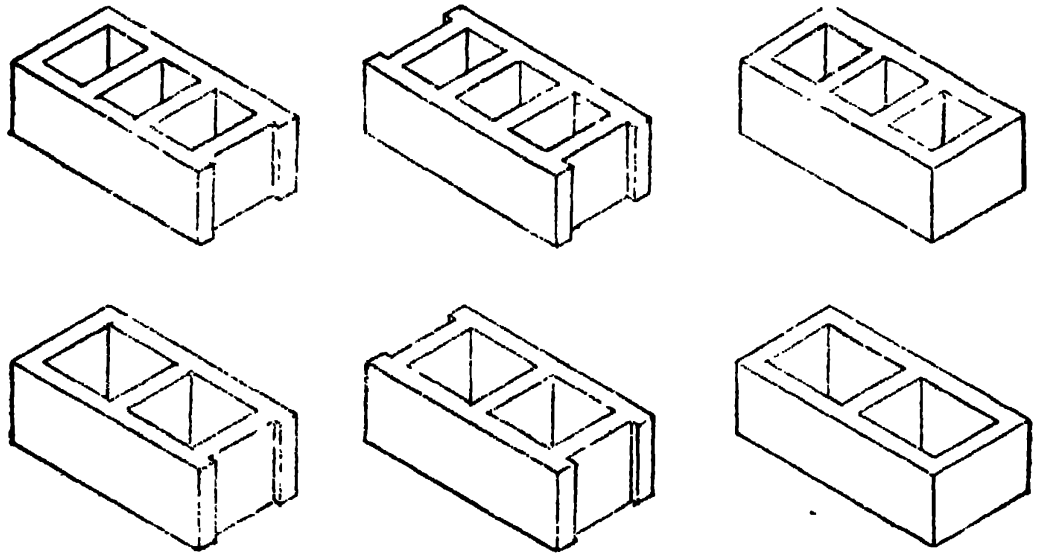
(2) Hollow blocks of concrete are stronger than stone or brick and as such thinner walls can be used to carry the superimposed load. This gives an increased floor area and hence there is a saving of space.

(3) There is a great saving of material on account of the blocks being hollow from inside. The air space (hollow space) in concrete blocks varies from 20 to 40 per cent of their volume.

(4) On account of the large size of concrete blocks, the number of joints in a work are lesser and hence there is saving of mortar in this type of masonry.

(5) The hollow space in the blocks enables the masonry to have good insulating properties against sound, heat and dampness.

(6) On account of good properties of concrete, hollow concrete blocks masonry can safely withstand the atmospheric action and it requires no protective covering as is necessary in case of brick work.



Figs. 9·9—9·14
Different forms of hollow concrete blocks

(7) Unskilled labour can be employed in this type of work and on account of the light weight of the blocks, the speedy construction results in economy in labour, cost and in time.

(8) The rough surface of the concrete block renders facility in plastering (if needed).

The hollow concrete blocks are manufactured in various shapes and sizes. The blocks are moulded in machine and can be obtained in the following standard sizes :

(1) Standard size hollow concrete block...40 cm. × 19 cm. × 20 cm.

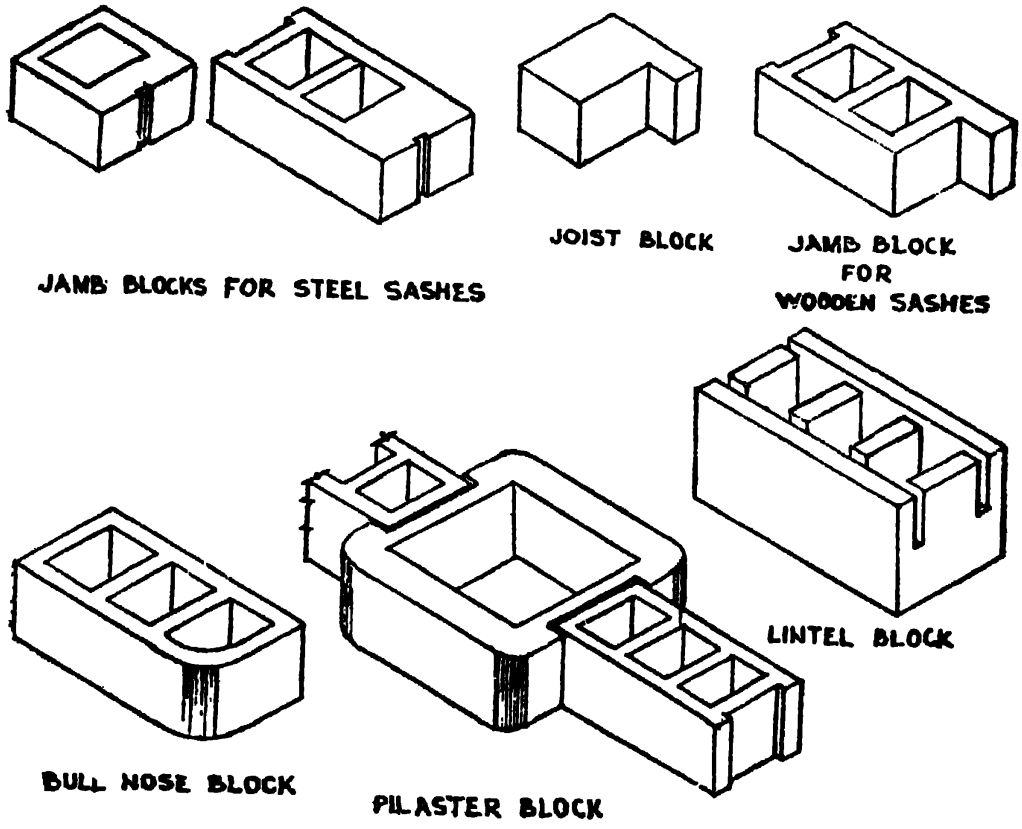
(2) Hollow building tiles ... 40 cm. × 10 cm. × 20 cm.

(3) Hollow concrete blocks for partitions...20 cm × 19 cm × 11 cm

The various shapes of hollow concrete blocks are shown in Figs. (9·9—9·14).

Specially shaped blocks are manufactured for corners, sills, lintels and jambs, wall closures, piers between doors and windows etc. to fit in the job suitably.

In order to ensure maximum economy in construction the overall length and height of walls should be so fixed as to make maximum use of full and half length blocks. The width and height of door and window openings and the wall area between them should be planned keeping in view the size of block available. This is essential to minimise cutting the blocks and avoid wastage of material and time.



Figs. 9·15—9·21
Specially shaped hollow concrete blocks for jambs, lintels, corners, etc.

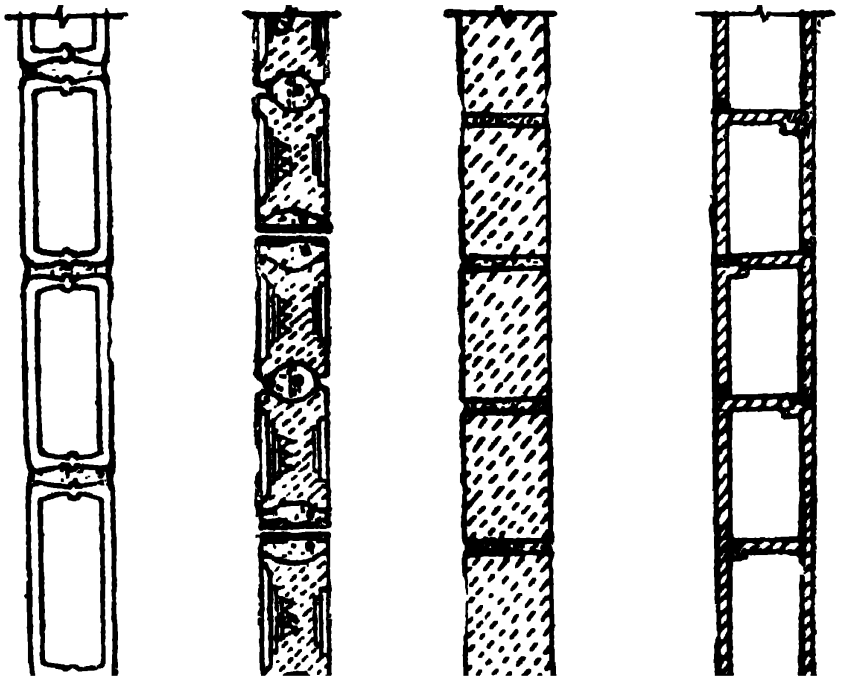
9·4 Load Bearing Wall Tiles. There are a variety of shapes



Figs. 9·22—9·23
Sectional elevation of different thicknesses of load bearing tile walls

for load bearing clay tiles. The tiles may be used for either interior or exterior load bearing walls. As in the case of hollow concrete blocks, the surface of the tiles is rough and can be easily plastered if desired. The tiles may be used with or withont any backing or facing. The tiles are designed to carry the superimposed load plus the weight of the facing material such as plaster etc.

9·5 Glass Block Masonry. There are various shapes and sizes of glass blocks available these days. The blocks are made from structural glass annealed to withstand rigorous use of the material. In addition, the glass used is such that it is impervious to grease, chemicals, moisture and does not change its colour with age. The blocks may be made hollow or solid. Glass block panels should never be used to carry loads other than their own weight. They are



Figs. 9·24–9·27
Sections of different types of glass block masonry

generally laid in cement-lime mortar (1 : 1 : 4). In glass b lock masonry with blocks more than 30 cm. high, every horizonta ljoin t should be reinforced with galvanized expanded metal strips. The construction is so executed that there is complete freedom of movement of the panel within the enframing members. Provision for expansion is made along the jambs and the head of each panel and there is proper anchorage of panel at head, sill and jambs.

Advantages of glass-block masonry :

(1) It is attractive in appearance.

(2) On account of the dead air space within, the glass block masonry has great heat insulating value.

(3) It is non-porous, non-absorbent and impervious to moisture.

(4) It can be easily cleaned and as such it is considered more sanitary.

(5) It diffuses the light which passes through and with proper selection of suitable patterns, a wide range of light and decorative effects can be produced.

(6) It has a good sound.proofing property and thus the room with glass block masonry walls has improved acoustical effects.

(7) Glass block masonry is best suited in places where window openings cannot be provided and clear glass is objectionable from consideration of visibility.

Questions for Revision

1. Explain, what do you understand by the term 'composite masonry.' Draw neat sketches wherever necessary to support your answer.

2. What do you understand by hollow block ? What are the advantages of hollow concrete block masonry over the stone masonry construction ?

3. Write an essay on glass walls.

4. Write short notes on :
   (*i*) Method of securing stone slabs to concrete or brick backing.
   (*ii*) Composite masonry.
   (*iii*) Hollow concrete block masonry.
   (*iv*) Glass block masonry.

10

Partition Walls

10·1 Definition. A partition wall may be defined as a wall or division built of brick, studding, glass or other such material provided for the purpose of dividing one room or portion of a room from another. Generally, partition walls are designed as non-load bearing walls. It may be of folding, collapsible or fixed type. So far as the functional use of partition walls is concerned, they are employed to provide privacy from considera tion of sight or sound or both. A good non-load bearing partition wall should be cheap, light, thin, fire-resistant and easy in construction.

10·2. Types of Partition Walls. Depending upon the material used, partition walls may be divided into the following different types :

(1) *Brick partitions*

(2) *Hollow brick partitions of clay, terra-cotta or concrete*

(3) *Glass partitions*

(4) *Concrete partitions—plain or reinforced*

(5) *Metal lath and plaster partitions*

(6) *A.C. sheet or G.I. sheet partitions*

(7) *Timber partit ions.*

(1) **Brick partitions.** They may be constructed with plain bricks, reinforced bricks or brick nogged.

Plain brick partition : The type of wall is constructed by laying bricks as stretchers in cement mortar. Thus the wall is generally 10 cm. (half brick) thick and plastered on both the faces. If properly constructed, it is considerably strong and fire-resistant.

Reinforced brick partition wall : This type of wall is similar to plain brick partition wall except that at every fourth or fifth course the bricks are reinforced with iron straps 25 to 38 mm. wide, 1 and 1·6 mm. thick. 6 mm. mild steel bars spaced at every fourth course of wall may be used as a substitute for iron straps.

Brick nogging type of partition wall : It consists of brick work built within a framework of wooden members. The frame work consists of vertical posts called studs spaced at 60 cm. to 1·5 m. apart

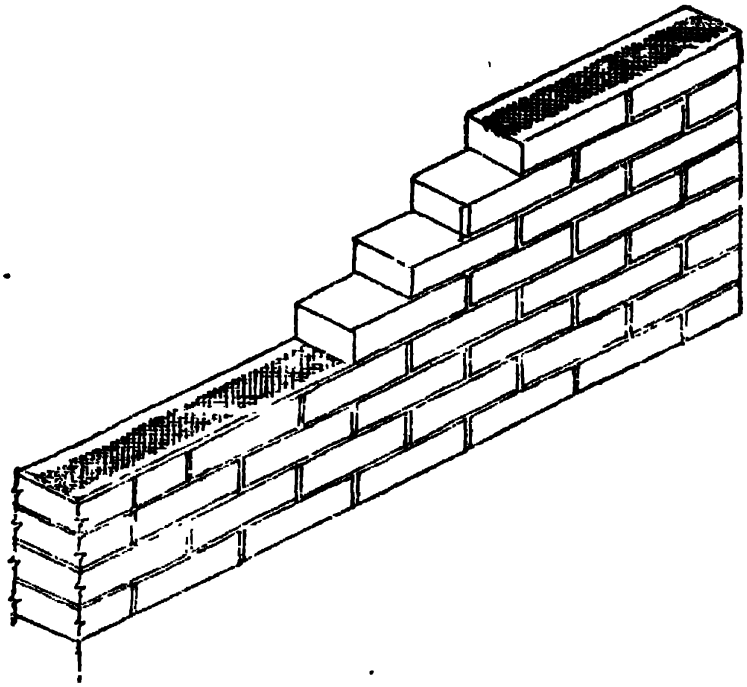


Fig. 10·1
Reinforced brick partition wall

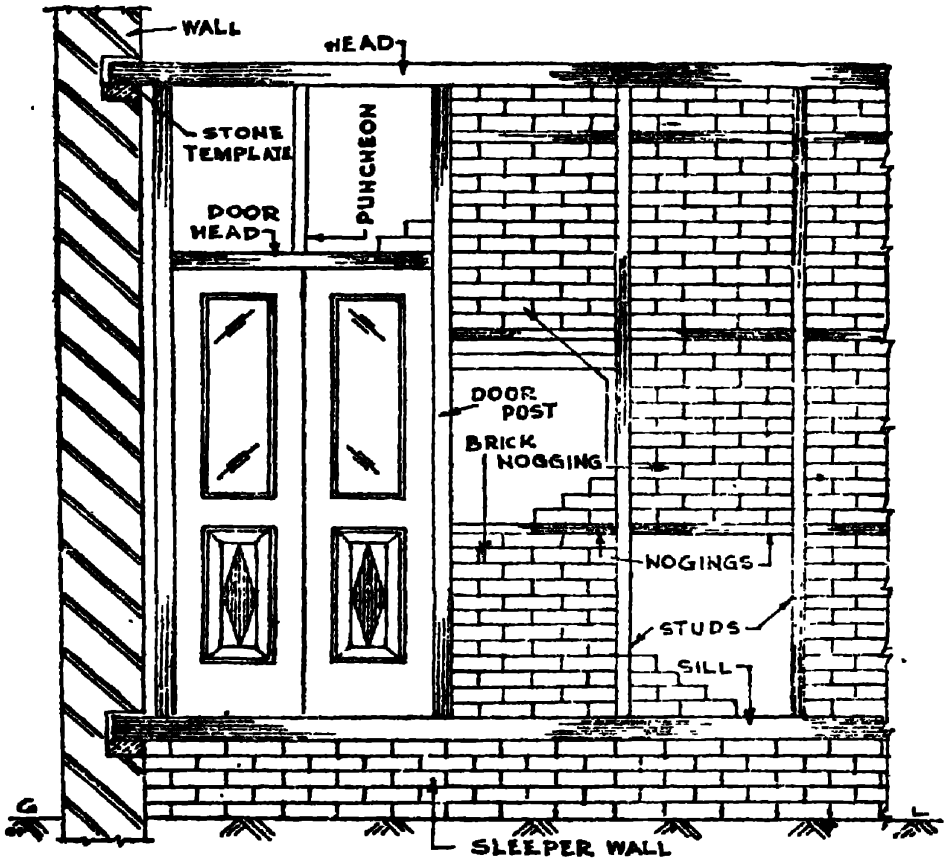
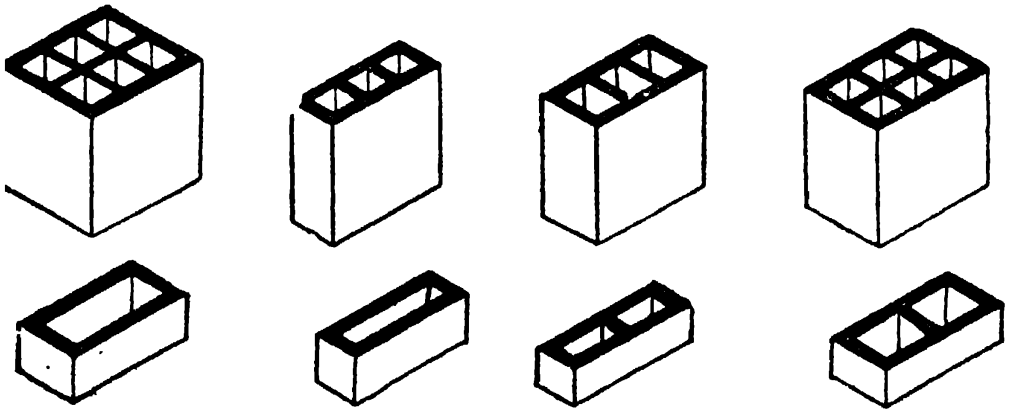


Fig. 10·2
Brick-nogged partition wall

and held in position by horizontal members called *nogging* pieces. The nogging pieces are housed into the studs at 60 cm. to 90 cm. apart vertically. The object of the wooden frame work is to increase the stability of the wall both along the length and height and to make it more rigid to withstand vibrational effect produced on account of careless opening or closing of the window or door leaves. The brick work is built by laying the brick flat or on edge and the surface is plastered from both the faces. Thus the size of the studs and nogging depends upon the thickness of partition wall. For a 10 cm. (half brick) thick partition wall, the studs and nogging should be 15 cm. wide so that after the brick-work is plastered from both the faces, the timber frame work may finish flush with the wall face. This wall has the serious disadvantage of the timber getting decayed. Moreover, the mortar used may not stick well to the timber members and thus the brick work is likely to become loose after some time.



Figs. 10·3—10·10
Different types of hollow clay blocks for partition wall

(2) **Hollow block partitions of clay, Terra-cotta or Concrete.** Hollow blocks moulded from clay, terra-cotta or concrete are now commonly used for the construction of partition walls. Such walls are light, rigid, economical, strong and fire-resistant. They have good sound insulating properties The size of the block differs with the nature of material and the thickness of wall varies between 6 to 15 cm. The partition walls are constructed in similar manner as structural load bearing walls.

(3) **Glass Partitions.** These may be made from sheet glass or hollow glass blocks. The hollow glass block construction has already been described in chapter on "*Composite Walls*". In case of sheet glass partitions, sheets of glass are fixed in the frame work of wooden members dividing the entire area in a number of penals. The panels may be square or rectangular in shape and their size varies with the choice of the individual. Glass partitions are cheap, light, easy in construction and provide reasonable privacy and sound insulation. The cost of maintenance of such partitions is much more as glass is liable to break when struck hard by any thing. With

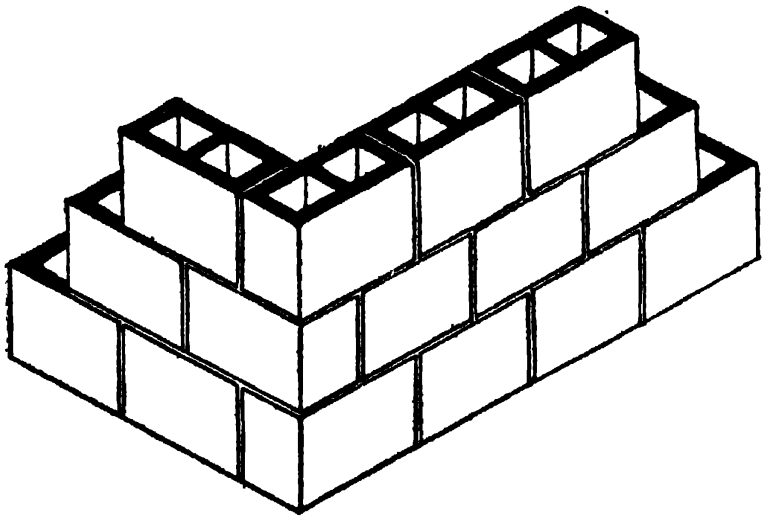
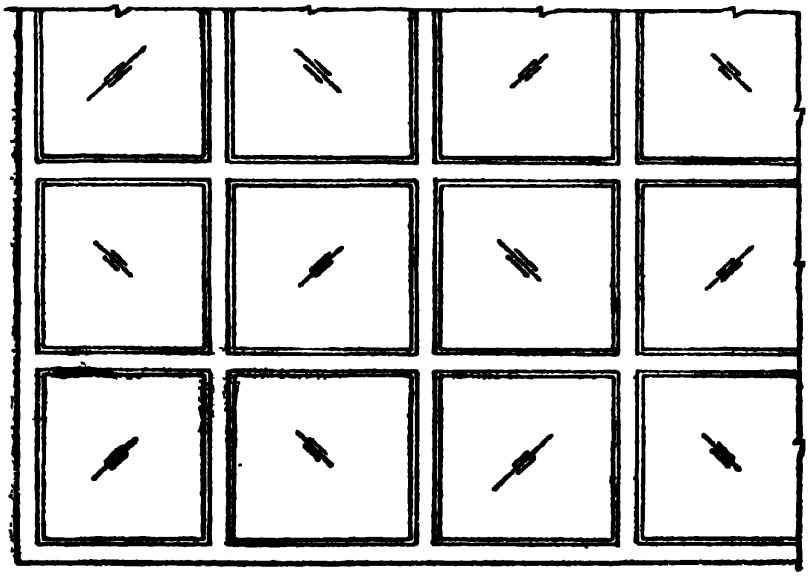
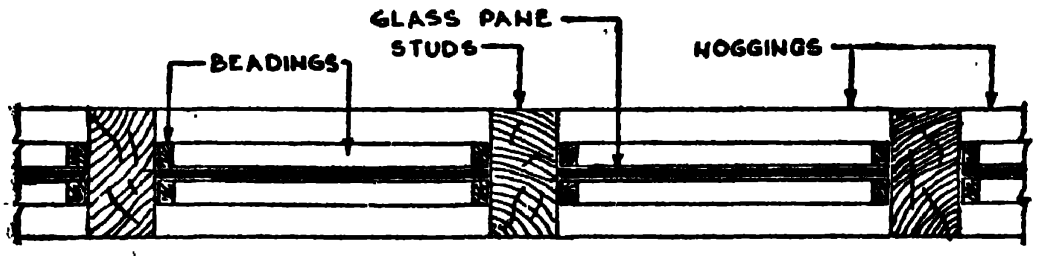


Fig. 10·11
View showing hollow block partition wall



ELEVATION



DETAILED PLAN
(ENLAGED)

Fig. 10·12
Elevation and sectional plan of glass partition

the introduction of reinforced glass sheets, this danger is greatly minimised. Three-ply glass and armour plate glass are some of the varieties of sheet glass which possess good shock-resisting properties

(4) **Concrete Partitions.**—*Plain or reinforced*: Partition walls constructed in concrete plain or reinforced, may be cast-in-situ or built from panels or blocks precast well in advance of the commencement of work. Generally for cast-in situ walls, 10 cm. thick and below, the reinforcement consisting of mild steel bars or R.R.C. fabric is placed in the centre of the wall thickness. Concrete mix. usually adopted in the work is M 150 (1 : 2 : 4). The wall is cast monolithically with the intermediate columns so as to be rigid and stable both along its length and height.

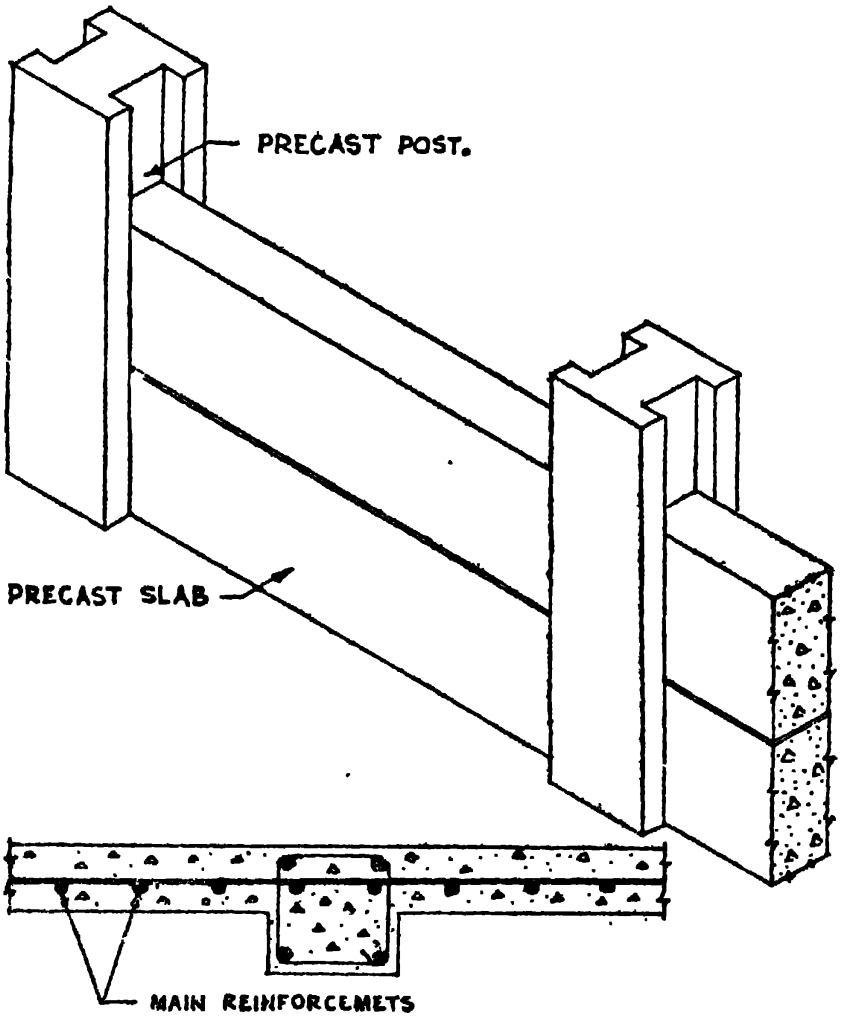
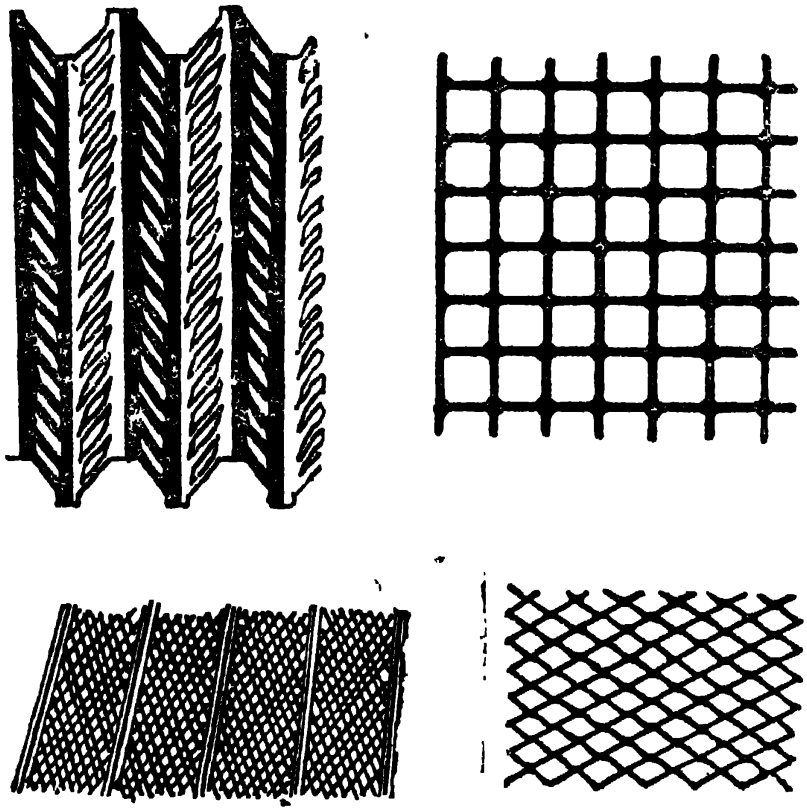


Fig. 10·13—View of a pre-cast concrete partition wall

Fig. 10·14—Sectional plan showing arrangement of reinforcement in a cast-in-situ partition wall

In case of precast concrete partition wall, concrete slabs and special shaped concrete posts are used. The slabs are generally 32 mm. thick and are inserted in the grooves of the precast post and the joints filled with cement mortar.



Figs. 10·15–10·18

Different forms of metal laths

(5) **Metal lath and plaster partitions.** Metal lath and plaster when properly laid form a reinforced partition wall which is thin, strong, durable and is considerably fire-resistant. The metal lath is available in a variety of patterns and it generally require a frame-work of steel or wood for the purposes of fixing in position. Lath is generally tied by galvanized iron wire to mild steel bars or channels spaced at 15 to 30 cm. apart. The latter is fixed on one side and the plaster is applied on both the sides of the lath. Such partition walls may be 5 to 7·6 cm. thick.

In order to achieve improved insulation against heat and sound, metal lath and plaster partition walls can also be made with a cavity between the wall thickness. The type of hollow partition wall is constructed by fixing metal lath on both sides of specially shaped steel channels spaced at 30 to 45 cm. apart. Depending upon the width of cavity desired, the channels are generally 5 to 10 cm. deep.

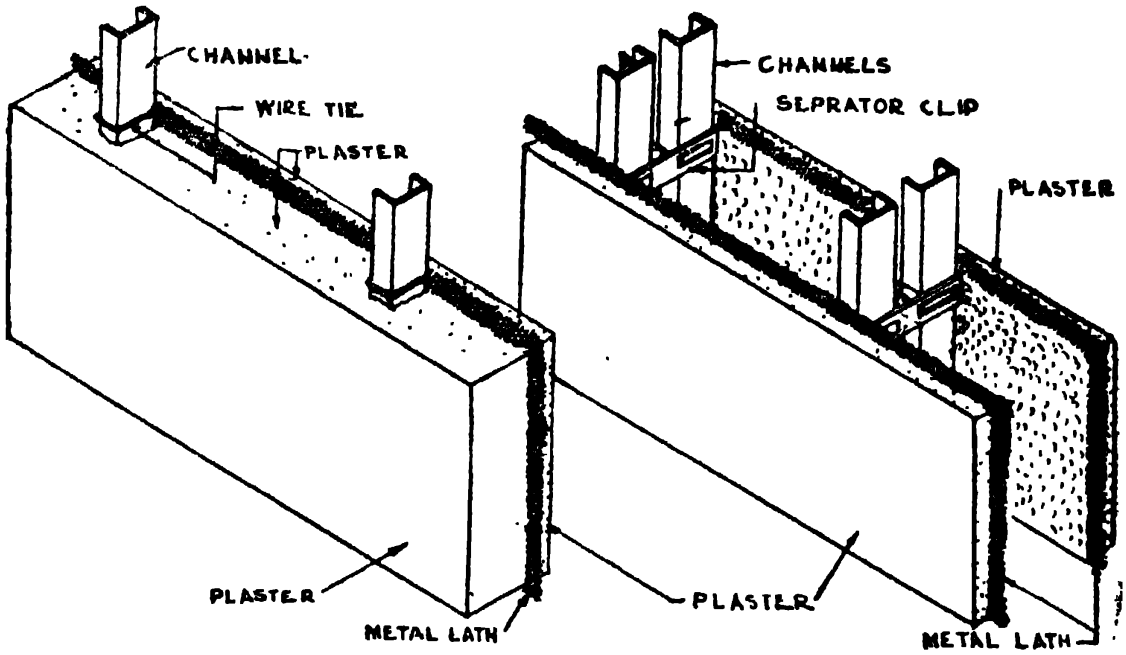


Fig. 10·19—Metal lath and plaster partition wall

Fig. 10·20—Metal lath and plaster wall with a cavity in between

(6) **A.C. Sheet or G.I. Sheet Partitions.** Partition walls constructed from asbestos cement sheeting or galvanised sheeting fixed to wooden or steel members are mostly adopted in works of temporary character. These walls are economical, light, thin and fairly rigid if constructed properly.

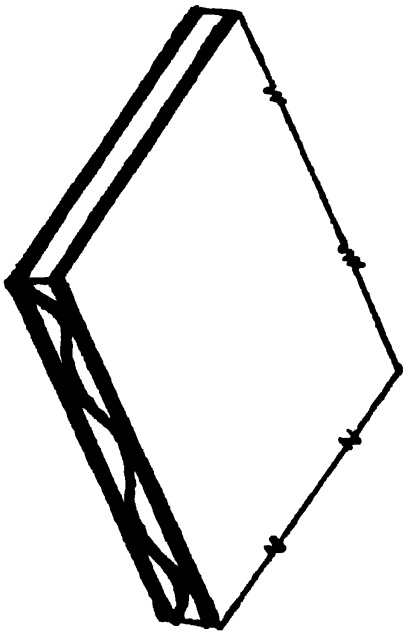


Fig. 10·21

For superior type of asbestos cement sheet partition walls, specially manufactured slab of the said material are used. Each slab consists of core of corrugated asbestos cement sheet with the plain asbestos cement sheet attached to it on either side. The use of such slabs renders the partition wall more fire-resistant and makes it have good heat and sound insulation properties.

(7) **Timber Partitions.** They consist of a wooden framework either supported on the floor below or by side walls. The frame work consists of a rigid arrangement of timber members which may be plastered or covered with boarding etc. from both the sides. Such partitions are not fire-resistant and the timber forming the partition is likely to decay

or eaten away by white ants. With the introduction of new building materials timber partitions are rarely employed these days. Broadly speaking, timber partitions may be divided into two different types :

(*a*) *Stud or common partition.*

(*b*) *Trussed or braced partition.*

(*a*) *Stud or Common partition* : It consists of a wooden frame comprising of light vertical upright members called studs which are fixed between two horizontal members. The horizontal member at the foot of stud is called sill and the one at its top is called the head. The studs are stiffened by horizontal timber piece called nogging. The studs are generally 10 cm. × 5 cm. in section and are spaced at an average distance of 30 to 45 cm. apart. Head and sill are members of varying size which are rigidly secured to the ceiling

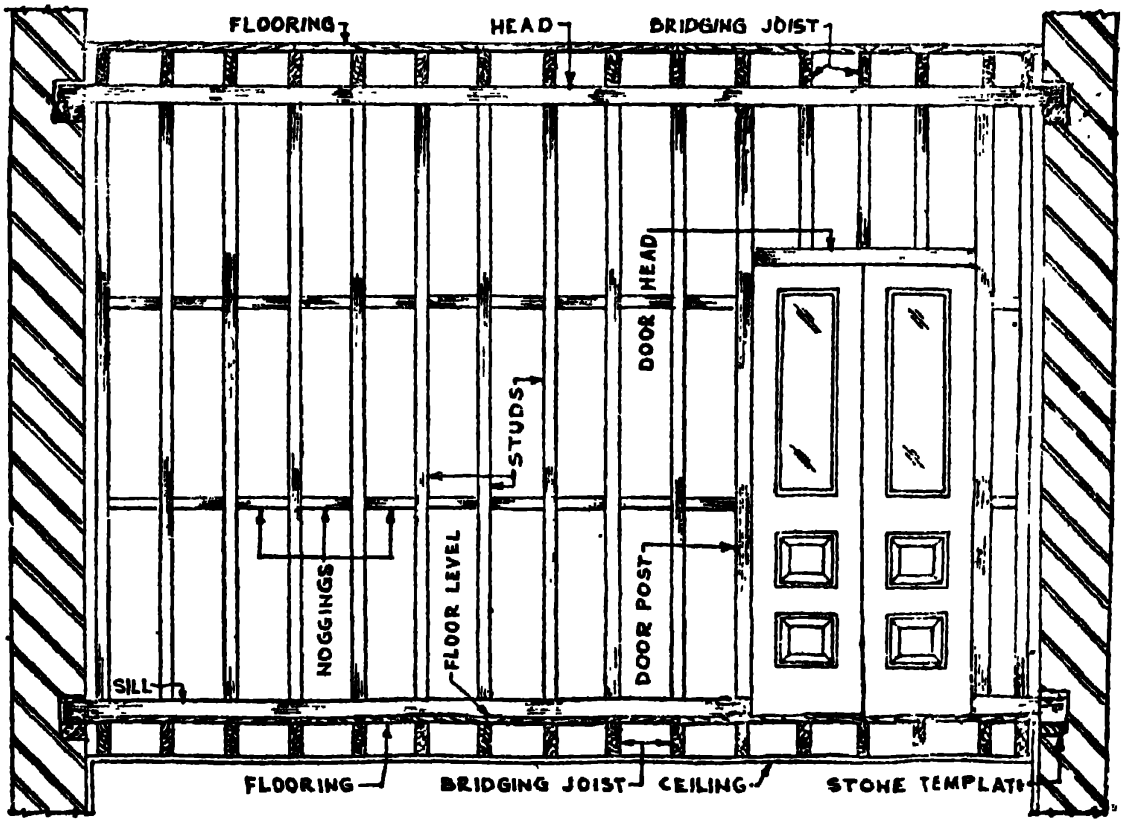


Fig. 10·22

Studs or common partition

joists and floor joists respectively. The door posts are sufficiently strong studs, capable of withstanding the impact due to the usage of the opening. The studs or short length verticals provided between the door head and the partition wall head are termed as puncheons. To increase the stability of the partition, the ends of head and sill

are usually embedded in the side walls for a short distance. The entire weight of the partition is borne by the floor and as such solid support for the sill member must be ensured. The support may be a solid wall or girder or a beam below the floor.

Trussed partitions : In places where the provision of solid support below the sill is not possible, the wooden trussed partitions have to be employed. The weight from the trussed partition walls is borne by the side of walls and thus it may be constructed quite independent of the floor. Trussed partition wall structure consists

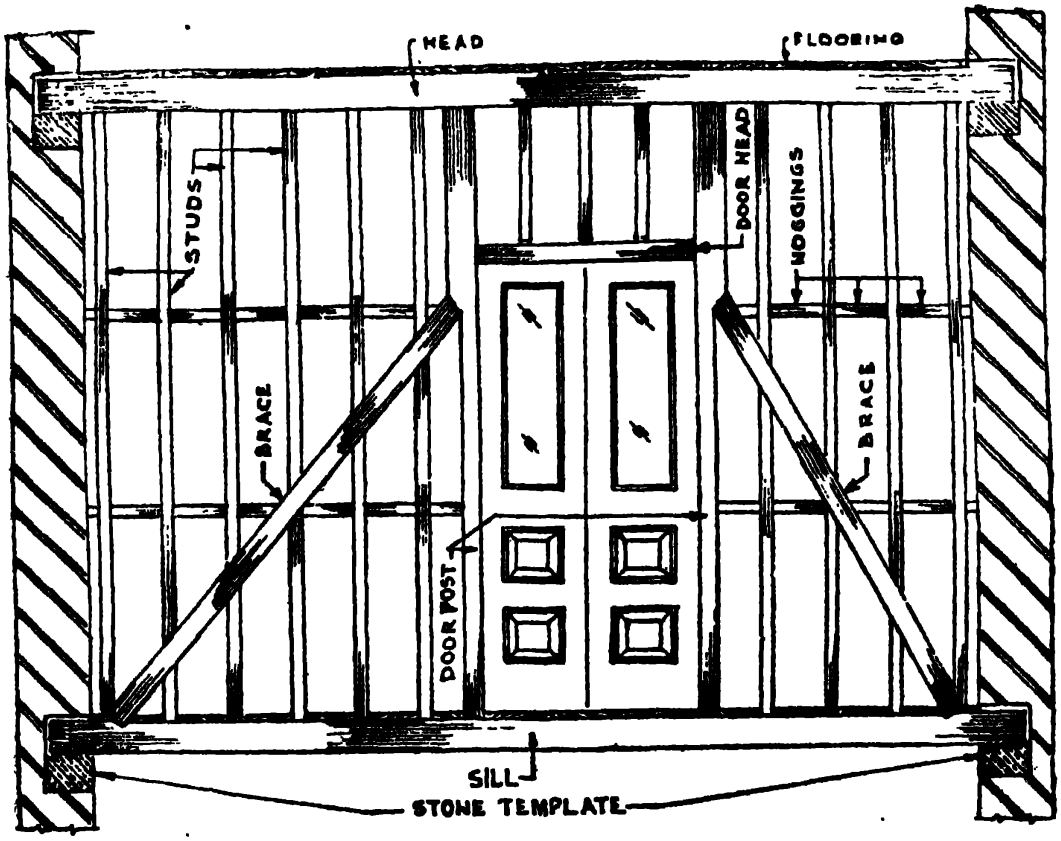


Fig. 10·23

Trussed partition

of a triangulated frame-work of horizontal, vertical and inclined wooden members. Suitable means are employed to make the combination of the members as rigid and stable. Trussed partition comprises vertical upright members called studs and horizontal members at top and bottom termed as head and sill respectively. In addition there are inclined members called braces and horizontal members stiffening the studs known as nogging. The ends of head and sill are made to rest on stone template embedded in wall at ends. The joints are further strengthened by mild steel straps and bolts.

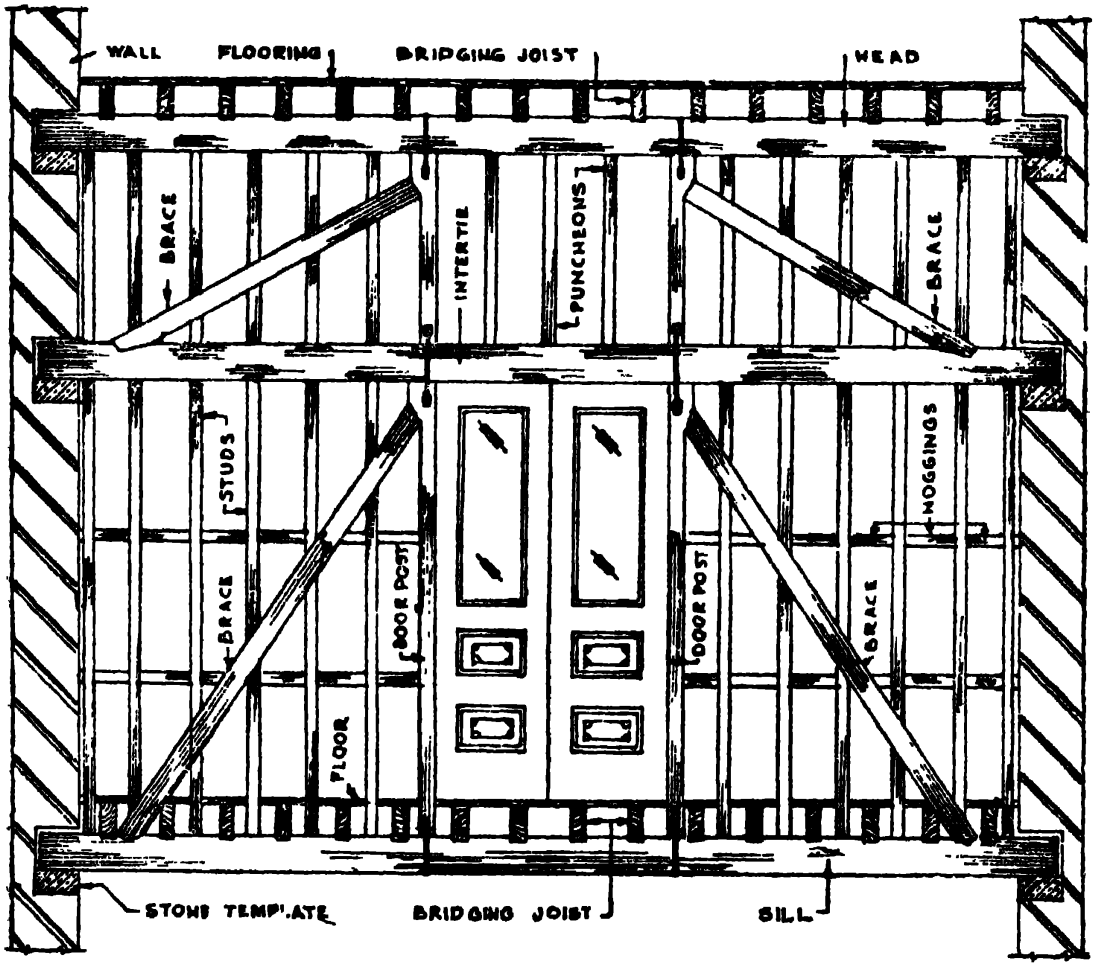


Fig. 10·24

Trussed partition supporting floor loads

Questions for Revision

1. Sketch the details of wooden partition 2·44 m. high with a door 120 cm. × 214 cm. in the middle, to be provided half way in a room of 12 m. × 6 m.

2. Describe the various types of partitions, giving the merits and demerits of each.

3. (*a*) Write a brief essay on the employment of different types of partition walls in modern construction. Illustrate your essay with sketches and give a critical note about each type in respect of efficiency, durability, economy and constructional aspect.

4. Write short notes on :

   (*i*) Metal lath and plaster partitions.

   (*ii*) Pre-cast concrete partitions.

   (*iii*) Asbestos cement partitions.

   (*iv*) Glass partitions.

5. Draw to a suitable scale, sketch showing the elevation of a trussed timber partition. Indicate on the sketch the names of the different members of the partition giving a brief note for their function,

7. What is the difference between a load bearing and a non-load bearing wall ? What is the purpose of providing partition wall ? Suggest the type of partition you would recommend in a modern office building.

7. Describe briefly the different types of brick partitions. What is the function of nogging in a brick partition ? Draw a neat sketch to illustrate your statement.

11

Ground Floors

11·1 General. The floor of a building immediately above ground is known as ground floor. In case, part of the building is constructed below ground level or the building has basement, the floor is termed as basement floor.

There are various types of floors which are commonly adopted in residential or public buildings these days. Each type of floor has its own merits and there is not a single type that could be suitably provided under all circumstances. The different types of floors which are commonly used for ground floor construction are given below :

(1) *Mud flooring*

(2) *Muram flooring*

(3) *Brick flooring*

(4) *Flag stone flooring*

(5) *Tiled flooring*

(6) *Cement concrete flooring*

(7) *Granolithic flooring*

(8) *Terrazzo flooring*

(9) *Mosaic flooring*

(10) *Timber flooring*

(11) *Asphalt flooring*

(12) *Rubber flooring*

(13) *Linoleum flooring*.

The selection of the types of floor often pose a problem and as such the following points are carefully considered before making final selection :

(*a*) It should be durable.

(*b*) It should be sanitary.

(*c*) As far as possible it should be noiseless.

(*d*) It should have a good appearance.

(*e*) It should be free from dampness.

(*f*) It should be fire-resistive.

(*g*) It should have low maintenance cost.

(*h*) It should not be very costly.

The description of various types of floors is given below :

11·2 Mud flooring. In a tropical country like India, mud floors are commonly constructed in villages. They are cheap, hard, fairly impervious, easy in construction and easy in maintenance. They remain warm in winter and cold in summer and hence are most suitable for places where the temperature is extreme during these seasons. The method of its construction is very simple. Upon the prepared bed, a 25 cm. thick layer of selected moist earth is evenly spread out and is rammed well so as to get a consolidated thickness of about 15 cm.

It is important to note that no water is used during the process of ramming. In order to prevent the formation of cracks after drying, chopped straw in small quantity is mixed with the moist earth before ramming. The floor is maintained by giving a thin cement cow-dung wash (1 : 2 to 1 : 3) once or twice a week.

11·3 Muram flooring. Any disintegrated rock is called muram. Muram floors are also constructed in villages in India and have the same advantages as that of mud-floors. Unlike mud floors, they are constructed with great care. First of all a hard-bed or sub-grade is prepared by laying about 25 cm. thick layer of hand-packed rubble boulders or broken hard brick-bats and rammed hard. Water in sufficient quantity being used during the process of ramming. Upon the sub-grade thus prepared, a 15 cm. thick layer of muram is laid. A 25 mm. thick layer of powdery muram is spread over the already laid muram layer and water is sprinkled over the entire surface. The surface is then rammed well. After ramming, the surface is saturated with water, so that a thin layer is formed on the top of the rammed surface. Then the surface is trampled well till the cream of muram rises to the top. The surface is left in this state for about a day and then it is rammed again with wooden rammer called thapies for about three days. The dry hard surface thus formed is then smeared with a thick coat of cow-dung and rammed once again for two days in the morning. Finally the surface is finished with a cement cow-dung plaster 1 : 4 (1 cement : 4 cow-dung). To maintain the floor in good condition, it is given a wash of cement cow-dung plaster once a week and the surface is wiped clean immediately.

The merits and demerits of mud or muram flooring may be summarised below :

Merits :

(*i*) It is cheap.

(*ii*) It has smooth, hard and fairly impervious surface.

(*iii*) It is easy in construction.

(*iv*) It has sufficiently long life if properly maintained.

(*v*) It maintains equable temperature in all seasons.

Demerits : For perfect maintenance of the surface it has to be given cement cow-dung wash once or twice a week. This may be objectionable from sanitary consideration.

11 4 Brick-flooring. This type of flooring is commonly provided in warehouses, stores and godowns or in places where heavy articles are stored. The flooring may be done with brick laid flat or on edge arranged in herrying bone fashion or set at right angle to the walls.

Excavation is made to the required depth, depending upon the nature of the soil and the type of structure.

The sub-grade may be made with a 25 cm layer of hand-packed rubble boulder or over-burnt brick bats well rammed and watered. This is further covered with 10 to 15 cm. thick layer of lime concrete or lean cement concrete. Upon the prepared sub-grade the bricks are laid in desired shape and set in cement or lime mortar. The joints should preferably be 1·5 mm. in thickness. To get thin joints it may sometimes be necessary to rub the sides of the bricks to obtain smooth surface. In places where the joints are required to be pointed, the thickness of joints should not be less than 6 mm.

Merits :

(*i*) It is durable and sufficiently hard.

(*ii*) It is cheaper than cement concrete, wooden or mosaic flooring.

(*iii*) It is non-slippery.

(*iv*) It is easily repairable.

Demerits :

It is absorbent.

11·5 Flag-stone flooring. Any laminiscated sandstone available in uniform thickness of 4 to 10 cm., is called flag stone. The stone slab may be square or rectangular with width not less than 38 cm. and thickness 4 cm. The sub-grade is prepared by

laying a 10 to 15 cm. thick layer of lime concrete over hard bed. On this sub-grade well-wetted flag stones are laid on 20 to 25 mm. thick mortar. When the stone slabs are properly set, mortar in the joints is raked out to a depth of about 20 mm. and flush pointed with cement motar (1 : 3). A slope of 1 to 40 is necessary to be given in flag stone flooring for proper drainage.

Merits :

(*i*) It is hard, durable and resistance to wear and tear and as such is used in workshops, motor-sheds and godowns.

(*ii*) It is easily repairable.

(*iii*) It is easy in construction.

(*iv*) In stone districts, it can be used with economy.

Demerits :

(*i*) It does not give a pleasing appearance and hence it is not suitable to be provided in places like residential building or important public buildings.

(*ii*) Its usage is not comfortable.

11·6 Tiled flooring. Pottery, cement concrete and terrazzo tiles are manufactured in square, polygonal and various other shapes, sizes and thicknesses these days. The tiles are laid on a reasonably hard subgrade, which may be of concrete or R.C.C. Over the sub-grade 12 to 24 mm. thick layer of lime mortar is laid which serves as the bedding mortar. The bedding mortar is allowed to harden for some hours and then spread over by neat cement slurry. The ready made tiles are laid on this surface with a thin paste of cement applied on their sides. The joints in tiles flooring construction are kept as thin as possible. After placing the tiles in position, they are slightly tapped and the extra cement that oozes out through the joints is immediately wiped clean with saw dust. After two or three days, all the joints are rubbed with carborundum stone so that slight projections rising above the surface are levelled. The surface is then rubbed with soft carborundum stone which again follows rubbing with pumice stone. The rubbing of surface may be done by rubbing machine or by hand. The process of rubbing is also called polishing of the surface. The polished surface is finally washed with a soft soap solution. This type of floor is provided in modern W.cs, battery rooms and other artistocratic buildings.

Merits :

(*i*) It is non-absorbent.

(*ii*) It is easily repairable in patches.

(*iii*) It offers pleasant appearance.

(*iv*) It is durable.

(*v*) It permits quick laying of floor.

(*vi*) It is durable, resistant to wear and has fairly good strength.

Demerits :

(*i*) This type of construction is very costly both in initial cost and in maintenance.

(*ii*) It becomes slippery when wet.

11·7 Cement concrete flooring. This type of flooring is commonly used both in residential as well as public buildings.

The method of laying cement concrete flooring on ground floor of a building can be broadly divided in the following steps.

(*i*) *Preparation of sub-base.* The earth filling in plinthis consolidated thoroughly so as to ensure that no loose pockets are left in the whole area. A 10 to 15 cm. thick layer of clean coarse sand is then spread over the whole area. The sand layer a consolidated and dressed to the required level and slope.

(*ii*) *Laying of base concrete.* The base concrete used under floors may be of cement concrete on lime concrete laid to a thickness varying from 7·5 to 10 cm. In case of cement concrete the mix commonly used is 1 : 5 : 10 (1 cement : 5 sand : 10 stone or over burnt brick aggregates 40 mm nominal size). Lime concrete, if used, should be made up out of 40 mm nominal size stone/over burnt brick aggregate and 40% mortar comprising of 1 lime : 2 sand/surkhi or 1 lime : 1 surkhi/ash : 1 sand.

The base concrete layer is deposited over the whole area, thoroughly tamped and levelled to a rough surface.

(*iii*) *Laying the topping.* When the base concrete layer has fully set and hardened its surface is thoroughly cleaned and the entire area is divided into rectangular or square panels by use of screed strips (narrow strips of timber or steel). The size of panel is basically governed by the location of floor (exposed or indoor), temperature and other climatic conditions, thickness of topping and the proportions of ingredients in concrete mix. etc. In general the area of one such panel should not preferably be more than 3·5 sq. m. The surface of base concrete should be made damp and applied with in a coat of neat cement slurry prior to laying the topping. The rough finished surface of base concrete coated with cement slurry ensures adequate bond between the base and the topping. The cement concrete topping normally consisting of 1 : 2 : 4 (1 cement 2 sand : 4 stone aggregate) is then laid in required thickness in alternate panels. The concrete is spread evenly by using a straight edge and the surface is thoroughly tamped, and floated with wooden floats till the cream of the mortar comes at top. The surface is then smoothened and finally finished by means of steel trowels.

In case the cement concrete flooring is to be laid over R.C.C. slab, it is usual to allow the slab concrete to harden and then lay the flooring. Prior to laying the slab top is cleaned of all dirt, dust, loose, particles mortar droppings and debris etc. and the flooring laid as described under the sub-head "*laying of topping*" above.

In order to prevent this tendency of separation of the cement concrete flooring from the R.C.C. slab, a 20 mm thick cushioning layer of lime mortar (1 lime : 2 sand/surkhi or 1 lime : 1 surkhi/sand) or 50 to 75 mm thick lime concrete is sometimes provided between the R.C.C. slab and the cement concrete flooring.

If the working conditions permit, the flooring can also be laid monolithically over the R.C.C. slab while, the slab concrete is still green. In this case the slab concrete is roughened with wire brushes so as to ensure a good bond between the base and the flooring layer. Prior to laying of flooring, the slab surface is cleaned and a coat of cement slurry is applied over it. In this case any slope required for the floor is given in structural concrete itself.

Merits :

(*i*) It is non-absorbent and thus it is very useful for water stores.

(*ii*) It is durable and hence it is commonly used in kitchens, bathrooms, schools, hospitals, drawing rooms, etc.

(*iii*) It is smooth and pleasing in appearance.

(*iv*) It is economical and has the advantages of costlier types of floors.

(*v*) It possesses good wearing properties and can be easily maintained clean.

Demerits :

(*i*) Defects in carelessly made floors cannot be rectified, and as such, it requires proper attention.

(*ii*) It cannot be satisfactorily repaired by patch work.

11·8 Granolithic flooring. It is a finishing coat provided over the concrete surface to form a hard, resistant to abrasion and durable flooring. Granolithic concrete is composed of cement, sand and specially selected aggregate. The grading of aggregates is very important. Coarse aggregates from basalt or limestone or quartzite are suitably graded from 13 mm. to I.S. Sieve No. 240. The concrete mix. is usually of 1 : 1 : 2 or 1 : 1 : 3. In order to get monolithic construction, the granolithic concrete should be laid before the base concrete has set. The minimum thickness of finishing should be 13 mm. After laying, the surface is tamped and floated with wooden floats and finally smoothened by means of steel trowel.

11·9. Terrazzo flooring. On account of its decorative and good wearing properties this type of flooring is becoming very popular these days and is being commonly provided in offices, schools, hospitals, residential buildings, banks etc. Terrazzo is a concrete surface with special aggregate of marble chips (or other decorative material) mixed with white and coloured cement in proportion of 3 : 1 (three marble chips : one cement). The aggregates are exposed by grinding the surface mechanically or manually. The flooring may be laid in different thicknesses. The construction of 40 mm. thick flooring is described below.

The operations of the preparation of sub-base and laying of base concrete are carried out in similar manner as described earlier in case of cement concrete flooring. The 40 mm thick flooring will consist of a 6 mm thick layer of terrazzo topping and 34 mm thick under layer of cement concrete 1 : 2 : 4. Prior to laying flooring, the whole area is divided into suitable panels by use of dividing strips (made from copper, brass, aluminium or glass) of thickness not less than 1·5 mm and width not less than 25 mm. In order to reduce the risk of cracking the area of one panel should not exceed two square metre.

The surface of base concrete should be cleaned of all dirt, mortar dropping debris etc. and then wetted with water. Prior to laying the cement concrete under layer, the wet surface of base concrete is smeared with a coat of neat cement slurry to ensure proper bond between the base concrete and flooring.

The concrete under layer is then spread, consolidated, levelled and finished to a slightly rough surface. When the under layer has hardened sufficiently, already prepared plastic terrazzo mixture is laid over the treated under-layer of concrete and compacted thoroughly by tamping or rolling. The terrazzo mixture consists of one part of cement (white or coloured or a mixture of the two) mixed with two to three parts of marble chips with water just sufficient to make it a workable mix. During tamping or rolling, it should be ensured that at least 80% of the finished surface should show exposed marble chips aggregate and if necessary additional marble chips may be added during the process of tamping or rolling to satisfy this condition.

After tamping or rolling. the surface is floated and troweled and left to dry out for 12 to 18 hours. After this period the surface is cured under standing water for 2 to 4 days.

Thereafter surface is subjected to first grinding by use of carborundum stones of 60 grit size. The whole surface is then scrabbed using plenty of water. All pores and holes (if any) are then filled with cement grout (using the sand coloured cement as in the original mix for terrazzo topping) and the surface coated with

neat cement grout of creamlike consistency. The surface is again cured for four days and second grinding is carried out by using carborundum stones of 80 grit size. In the similer manner the surface is subjected to third and fourth grinding by using carborundum stones of 120 to 180 grit size and 320 to 400 grit size respectively

The finished surface is finally worked with dilute oxalic acid solution. The floor is finally polished by floor polishing machine fitted with felt or hessian bobs, till it shines.

11·10 Mosaic flooring. Over the hard base concrete bed, a 5 cm. to 6 cm. thick layer of lime surkhi mortar is spread in a small area. The area taken is such that the flooring can be easily completed in that portion without the mortar getting dry. On this a layer of paste consisting of two parts of sifted slaked lime, one part of powdered marble and one part of puzzolana is laid in thickness not exceeding 3 mm. This surface is left to get dry for four hours. Tiles or marble pieces, cut to the desired shapes, are then hammered on this surface in the desired pattern. The surface is gently rolled by light stone roller about 30 cm. in diameter and 45 to 60 cm. in length. Rolling is done till the tile or marble pieces form an even surface and are cemented together properly. The surface is allowed to dry for a day and then polished by rubbing it with pumice stone fitted with long wooden handle. The polished surface is finally allowed to dry for some weeks before use.

11·11 Timber flooring. In hilly areas where the climate is damp and wood is easily available, wooden floors prove economical and as such are commonly used. Its use is not extensive in other places. However, they are used for dancing halls, capentry halls, auditoriums etc. In this type of floor, prevention of dampness is of great importance and hence every precaution is taken to check the dampness from rising above. The entire area of ground below the floor is covered with a 15 cm. layer of cement concrete. This layer is called *"site or oversite concrete."* Timber floors essentially consist of boarding supported on timber joists called bridging joists or floor joists which are nailed to wall plates at their ends and supported by intermediate walls, called sleeper or dwarf walls, along their length. The sleeper walls are generally 10 cm. thick and are honey-combed. They are intended to reduce the span for the floor joists. The sleeper walls are seldom spaced more than 1·8 m. apart and are honey-combed to enable free circulation of air in the space below the floor. Longitudinal timber members called 'sleeper plates' are fixed on the top of sleeper walls. The floor joists are secured to the sleeper walls by being nailed to the sleeper wall plates. A damp-proof course layer is laid immediately below the wall plates to prevent the rising of dampness. The hollow space between the flooring and the oversite concrete is kept dry and fully ventilated.

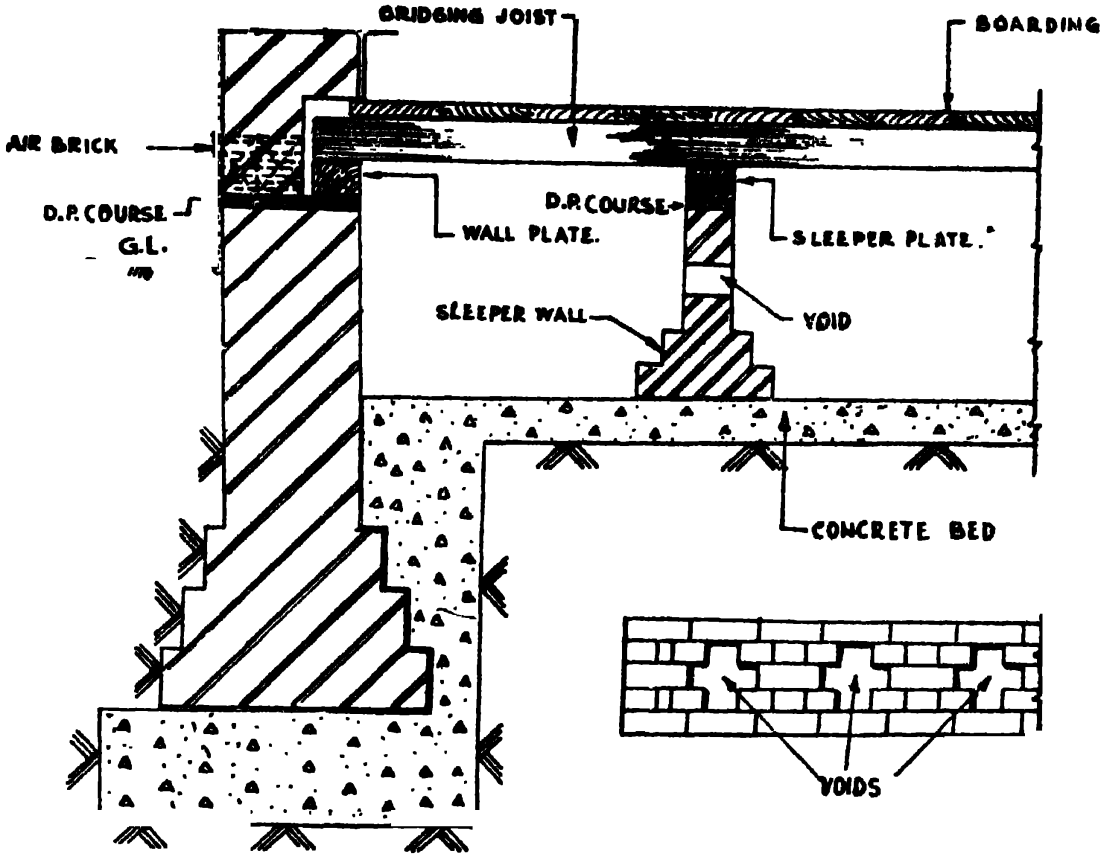


Fig. 11.1 Section through a timber floor

Fig. 11.2 Detail showing position of voids in the honey-combed sleeper wall

11·12 Asphalt flooring. On account of its being dustless, elastic, durable, waterproof, acidproof and attractive in appearance, mastic asphalt flooring is becoming very popular these days. This type of flooring is non-slippery and noiseless too, as such it is recommended for use in factories, loading platforms, swimming pools, and terrace floors etc. The construction of floor involves the following operations :

(*i*) Preparation of mastic asphalt.

(*ii*) Laying of the prepared compost (mastic asphalt).

(*i*) *Preparation of mastic asphalt.* Asphalt, which is generally sold in drums, is broken into pieces and is put into an iron pot known as "Cauldron" and is heated with the fire lighted under it. During the process of heating when melting of asphalt starts, the whole mass is stirred in such a manner that the pieces at the bottom are constantly brought to the surface. When the whole quantity has melted, clean sharp sand or grit is then gently added to the molten mass in the proportion of 2 : 1. (Two parts of sand or grit :

one asphalt). The mixture is constantly stirred till it emits jets of light-brown smoke. At this stage the mixture or compost is of such a consisteney that it drops freely from the stirrrer and is considered to be fit for use. The cauldron is then taken off the fire to prevent the compost getting over-burnt and is used immediately.

(*ii*) *Laying of the prepared compost* (*mastic asphalt*) : The compost is poured on the previously prepared concrete bed by means of iron ladle. This is brought to a uniform thickness varying from 13 mm. to 25 mm. by means of trowels. Before the compost becomes hard, very fine sand in small quantity is sifted over it and the surface is well rubbed with a hand float or trowel. In case it is necessary to have a second layer of asphalt, it should be laid before the bottom layer solidifies (no sand being sifted over the bottom layer in that case). The top layer is then finished in the same manner as described above.

11·13 Rubber flooring. This type of flooring is not common in India but in foreign countries it is used in residential buildings as well as public buildings like offices, hospitals, schools. etc. It is noiseless. comfortable, sanitry and durable. Like linoleum, this type of flooring is manufactured in the form of sheets or tiles in a variety of colours. Its thickness seldom exceeds 10 mm. Rubber sheets or tiles are made by combining at very high temperature pure rubber with cotton fibre, granulated cork, asbestos fibre, other glues and colour pigments to get the designed colour. The rubber tiles are laid by glueing them to a smooth and thoroughly clean and dry base by use of a special adhesive. The base may be of concrete, R C C. or wood. It is expensive in its initial cost but it is a most durable wearing surface. Oil or grease render the floor slippery and it is difficult to restore it in good condition.

11·14 Linoleum flooring. Linoleum is a covering laid over wooden or concrete floors in order to hide the defects of flooring or to enhance its appearance. It is a material manufactured by mixing oxidised linseed oil with powdered cork, wood flour, various types of gums and suitable colouring pigments. The plastic mass thus obtained is pressed in the designed form and dried in ovens. It is finally cured and seasoned. It is available in varieties of colours both in plain and printed form. It is mostly sold in rolls which are 1·8 to 3·66 m. in width and the thickness of the felt seldom exceeds 6 mm.

Linoleum can be laid in the following three ways :

(*i*) By spreading the covering loose on dry and smooth floor.

(*ii*) By pinning down the ends of the loosely laid linoleum covering to the floor below.

(*iii*) By fixing the linoleum covering to the floor by use of a special adhesive.

Merits :

Linoleum floor covering has the following advantages :

(*i*) It is washable, dustproof and can be easily cleaned with just a swab of damp cloth.

(*ii*) It has cushioning effect which gives comfort to the users.

(*iii*) It reduces noise effectively.

(*iv*) It forms a long-wearing and durable surface if laid and maintained properly.

(*v*) It gives a decorative floor finish which looks very attractive.

(*vi*) It is economical.

Linoleum floor covering is largely used in residential buildings, offices, schools, hospitals, libraries, restaurants, railway carriages, and buses etc. It is, however, not recommended in basement floors.

11·15 Acid-Proof Flooring. In places like chemical laboratories, and plants, storage battery buildings etc., where acids are used or manufactured, it is necessary that the floor topping should be acidprof. Asphalt blocks, made by moulding under high pressure a mixture of inert crushed rock aggregate and an acid.proof asphalt, successfully meet the requirements of an acid-proof flooring. The asphalt blocks are first laid on the hard base and then acid-proof asphalt is uniformly spread over the surface of the blocks. Before the liquid asphalt hardens, fine sand in small quantity is uniformly spread over it and surface is finished smooth and levelled.

Questions for Revision

1. Describe briefly the type of floor used for different types of buildings and state the reasons for their choice. Give a detailed specification for a coloured Terrazzo flooring.

2. Describe in brief the types or floors that are normally adopted in modern buildings. Explain the advantages and disadvantages of each type. Suggest the type of floor you would recommend for a hospital ward measuring 12 m. × 12 m.

3. How are the flooring materials used in construction of floor ? Give an idea of the cost of each type of flooring in U.P.

(*a*) Linoleum.

(*b*) Cork.

(*c*) Rubber.

(*d*) Clay tiles.

(*e*) Marble.

(*f*) Stone.

(*g*) State.

4. Give the specifications for flooring of a grain storage godown where trucks of 5 tonne capacity would come in and where the sub-soil water-level is within 1·5 m. of the prevailing ground level.

5. Describe briefly with sketches the type of flooring you would adopt for the following : Justify the selection.

(*i*) Operation theatre in a modern hospital.

(*ii*) Recreation hall of a high-class hotel.

(*iii*) Public laterine.

(*iv*) Warehouses.

(*v*) Dancing halls.

6. What type of flooring you adopt for the following :

(*a*) Grain store.

(*b*) Factory hall.

(*c*) Recreation hall of a high-class hotel.

(*d*) Dancing hall.

(*e*) Materials testing laboratory.

7. Write short notes on :

(*a*) Granolithic flooring.

(*b*) Mosaic flooring.

(*c*) Terrazzo flooring.

(*d*) Asphalt flooring.

(*e*) Rubber flooring

(*f*) Tiled flooring

8. Under what circumstances, cement concrete flooring is recommended ? What treatment would you suggest if the cement concrete flooring is to be provided in the following situations.

(*a*) Basement of a building to be situated in a waterlogged ground.

(*b*) Children ward of a modern hospital.

(*c*) Bath room.

9. What type of flooring would you recommend for the following :

(*i*) Lecture halls of a modern college.

(*ii*) Drawing halls.

(*iii*) Laboratories.

(*iv*) Hostels.

(*v*) Workshops,

10. A wooden floor is to be provided in the ground floor room. Draw neat sketches showing the various parts.

11. What factors affect the design and specifications of a floor finish ?

Describe the types of floor you would recommend for any four of the following, assuming that they are to be built on hard moorum soil :

(*i*) A large school hall.

(*ii*) A warehouse.

(*iii*) A drawing room of a spacious residential bungalow.

(*iv*) Floor of a R.C.C. reservoir at ground level.

(*v*) A garage.

12. What kind of floor finishing will be required for :

(*a*) Warehouse.

(*b*) Walkways.

(*c*) Hospitals.

(*d*) Library.

(*e*) Dance hall.

Briefly describe the method of construction in each case.

12

Stairs

12·1 Definition. A stair may be defined as a series of steps suitably arranged for the purpose of connecting different floors of a building. It may also be defined as an arrangement of treads, risers, stringers, newel posts, hand rails and balusters so designed and constructed as to provide an easy and quick access to the different floors rendering comfort and safety to the users. The enclosure containing the complete stairway is termed as stair-case.

Stairs may be made from various materials like timber, stones, bricks, steel, plain concrete or reinforced concrete. The selection of the type of material to be used depends upon the aesthetical importance, funds available, durability desired and fire-resisting qualities expected.

12·2 Location of Stairs. The location of stairs in a building requires a careful consideration. In the advent of fire or any such calamity, stairs provide the only means of communication and as such they are so located as to serve the purpose for which they are

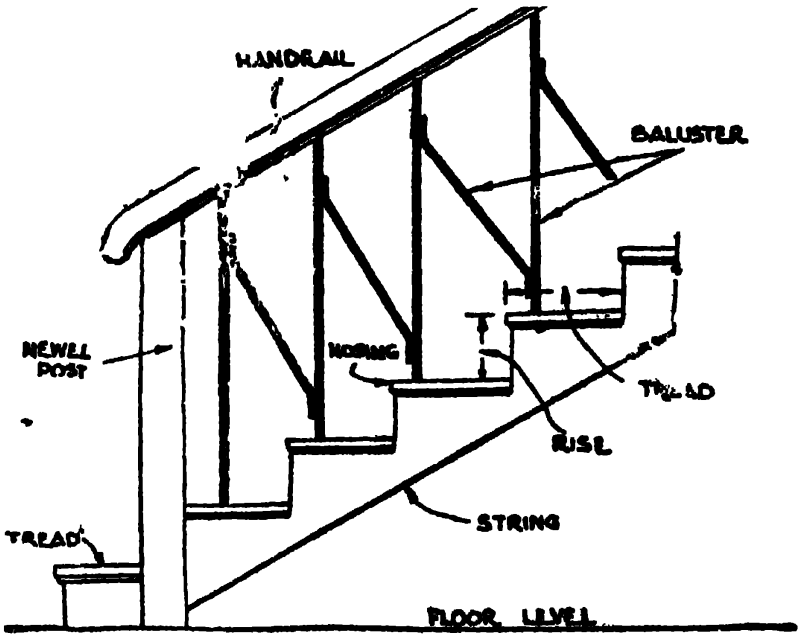


Fig. 12·1
Part section of stair showing its various components

provided. In public building it should be located near the main entrance and in residential building it should be placed centrally so as to provide easy access from all the rooms and maintain privacy at the same time.

12·3 Technical Terms. The common technical terms used in stair construction are briefly discussed below :

(1) *Steps* : A portion of a stairway comprising the tread and riser which permits ascent or descent from one floor to another.

(2) *Tread* : The horizontal upper part of a step on which foot is placed in ascending or descending a stairway.

(3) *Riser* : The vertical portion of a step providing a support to the tread.

(4) *Flight* : A series of steps without any platform, break or landing in their direction.

(5) *Landing* : A platform or resting place provided between two flights. A landing extending right across a stair-case is termed as half space landing and the one extending only half across a stair case is called a quarter-space landing.

(6) *Nosing* : The outer projecting edge of a tread is termed as nosing. Nosing is usually rounded to give good architectural effect to the treads and makes the stair-case easy to negotiate.

(7) *Scotia* : It is a moulding provided under nosing to beautify the elevation of the step.

(8) *Line of nosing*. It is an imaginary line touching the nosing of each tread and is parallel to the slope of the stair.

(9) *Flier* : It is a straight step having a parallel width of tread.

(10) *Winders* : These are tapering steps which are provided for changing the direction of a stair.

(11) *Going of step* : The run of a step in a stair or the width of the tread between two successive treads.

(12) *Rise of step* : It is the vertical distance between the upper surface of the successive treads.

(13) *Soffit* : It is the under-surface of a stair.

(14) *Pitch or slope* : It is the angle which the line of nosing of the stair makes with the horizontal.

(15) *String or stringers* : These are the sloping wooden members providing support for the steps. For stairs of average width, the stringers are usually provided one outside and the other adjacent to the wall. In case of wider stairs, a third stringer is also provided in the middle to the two. Stringers have been described in detail in "wooden stairs".

(16) *Hand rails* : They are provided to render assistance in negotiating a stair-way. They are supported on balustrades and usually run parallel to the slope of the stair.

(17) *Baluster* : It is a wooden, metal or masonry vertical member supporting a hand rail.

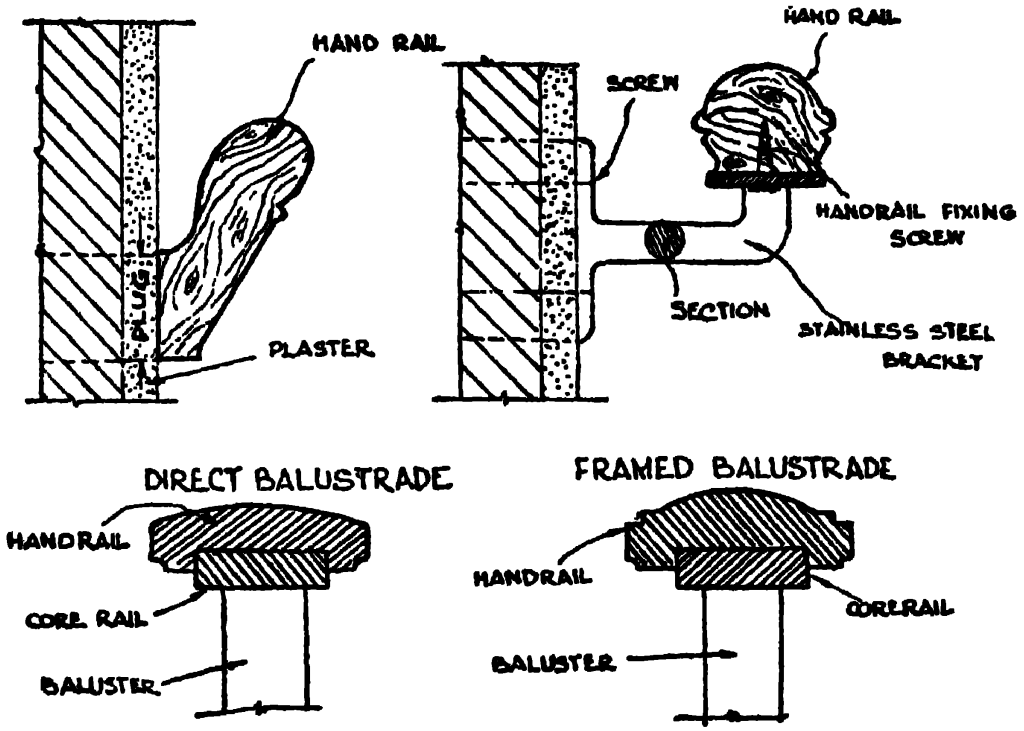


Fig. 12·2

Various types of handrails

(18) *Balustrade* : It usually consists of a row of balusters surmounted by a rail and is provided to perform the function of a fence or guard for the users of the stair-way.

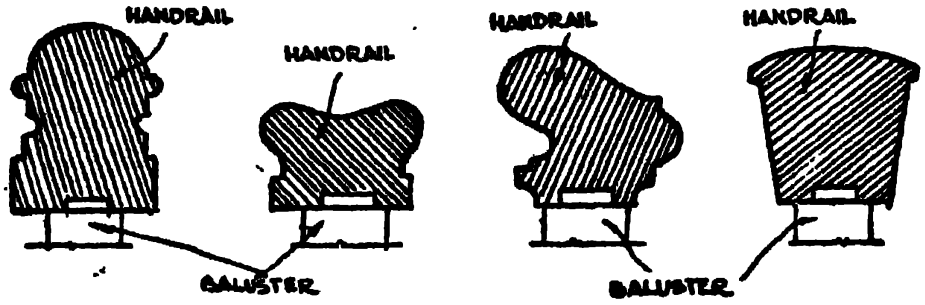


Fig. 12·3

Different types of wooden handrails

(19) *Newel*: It is a wooden or metallic post supporting the hand rail and is usually provided at the head, foot or at point where the balustrade changes its direction.

(20) *Head room or head way* : It is the clear vertical distance between the tread of a step and the soffit of the flight or the ceiling of a landing immediately above it.

(21) *Spandrel* : It is the triangular framing under the outside string of an open string stair.

12·4 Requirements of a Good Stair. A well-planned and designed stair should provide an easy, quick and safe mode of communication between the various floors. The general requirement of a good stair may be divided into the different heads, described below :

(1) *Location* : It should be so located that sufficient light and ventilation is ensured in the stairway. If possible it should be located centrally so as to be easily accessible from the different corners of the building.

(2) *Width of a stair* : Width of a stair varies with the situation and the purpose for which it is provided. Obviously in public building where there is a regular traffic of people using the stair-way its width should be sufficient while in a residential building it may be just the minimum. The usually adopted average value of the stair width for public and residential building is 1·37 m. and 90 cm. respectively.

(3) *Length of flight* : For the comfortable ascent of stair-way the number of steps in a flight should be restricted to a maximum of 12 and a minimum of 3.

(4) *Pitch of stair* : The pitch of long stairs should be made flatter by introducing landings to make the ascent less tiresome and less dangerous. In general the slope of stair should never exceed 40° and should not be flatter than 25°.

(5) *Head room* : The head room or the clear distance between the tread and the soffit of the flight immediately above it should not be less than 2·14 m.

(6) *Materials* : The stair should preferably be constructed of materials which possess fire-resisting qualities.

(7) *Balustrade* : The open well stairs should be provided with balustrade so as to minimise the danger of accidents.

(8) *Landing*: The width of landing should not be less than the width of stair.

(9) *Winders* : The introduction of winder in stairs should be avoided as far as possible. They are liable to be dangerous and

involve extra expense in construction. They are difficult to carpet and are especially unsuitable for public buildings. However, where the winders cannot be dispensed with, they should preferably be provided near the lower end of the flight. Thus instead of quarter-space landing three winders may be used and for a half-space landing five winders or four radiating risers may be adopted.

(10) *Step proportions* : The rise and tread of each step in a stair should be of uniform dimensions througout The ratio of the (going) and the (rise). of a step should be so proportioned as to ensure a comfortable access of the stairway.

12·5 Fixing the "Going" and "Rise" of a Step. The size of a tread and riser vary with the situation of the stair and the purpose for which it has to be provided. In general, the following rules are used as a guide to obtain a satisfactory result :

(1) (Going in cm.)+(2×Rise in cm.)=60

(2) (Going in cm.)×(Rise in cm.)=400 to 410 approx.

(3) Adopt the standard size of going and rise as 30 cm. and 14 cm. respectively and for each 25 mm. deducted from going add 12 to 13 mm. to the rise.

In addition to empirical rules described above, the following rules must be kept in view while deciding the step size. The results given below are the ones which are practically adopted in the stair construction :

(1) For residential buildings the size of step commonly adopted is 25 cm. × 16 cm.

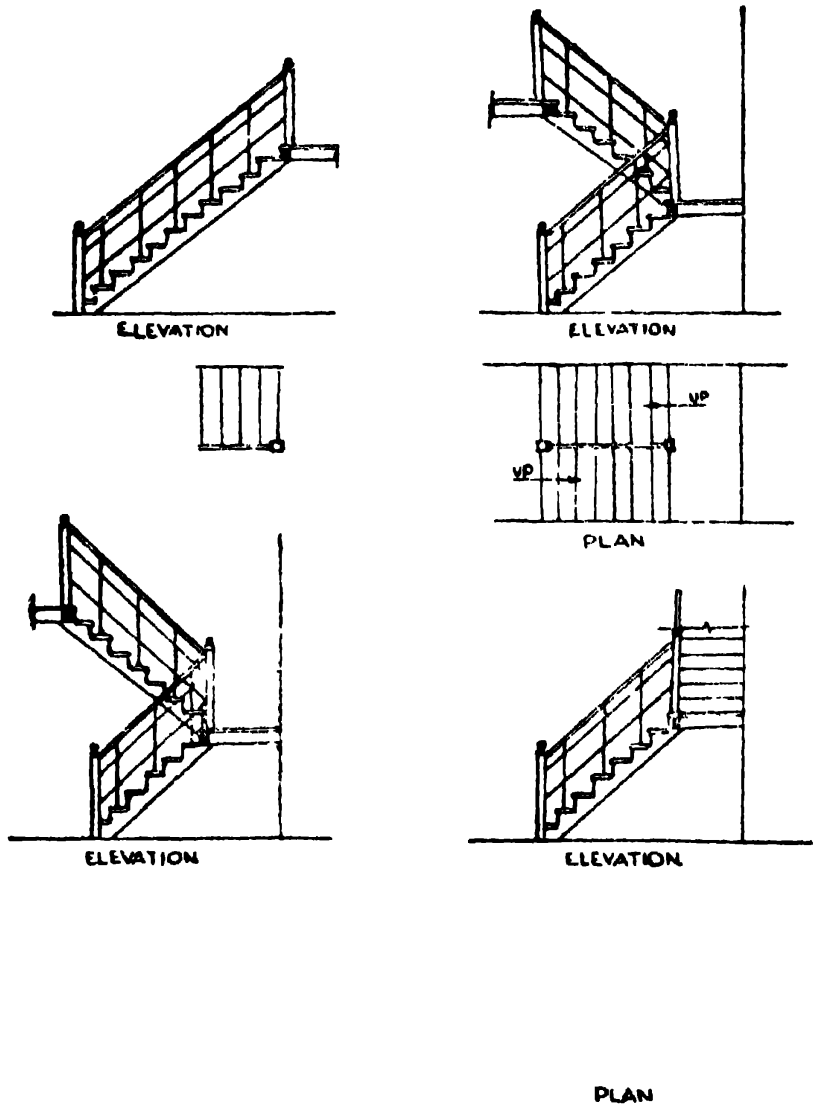
(2) For public buildings the adopted sizes of steps vary from 27 cm. × 15 cm. to 30 cm. × 13 cm.

12·6 Classification of Stairs. The different forms of stairs may be classified under the following main heads :

(*i*) *Straight stairs*
(*ii*) *Dog-legged stairs*
(*iii*) *Open-newel stairs*
(*iv*) *Geometrical stairs*
(*v*) *Circular stairs*
(*vi*) *Bifurcated stairs*

(*i*) *Straight stair* : The most obvious use of the straight stair is to form an access to entrance, porch or portico. Straight stairs cannot be avoided in places where the stair-case hall is long and narrow and the possibility of any other form of stair may not be practically possible. In this form of stair, all the steps rise in the same direction. If the ascent is steep, the straight flight may be broken at an intermediate landing.

(*ii*) *Dog-legged stair* : It consists of two straight flights of steps with abrupt turn between them. Usually, a level landing is placed



Figs. 12·4—12·7

Fig. 12·4 Elevation and plan of a straight stair

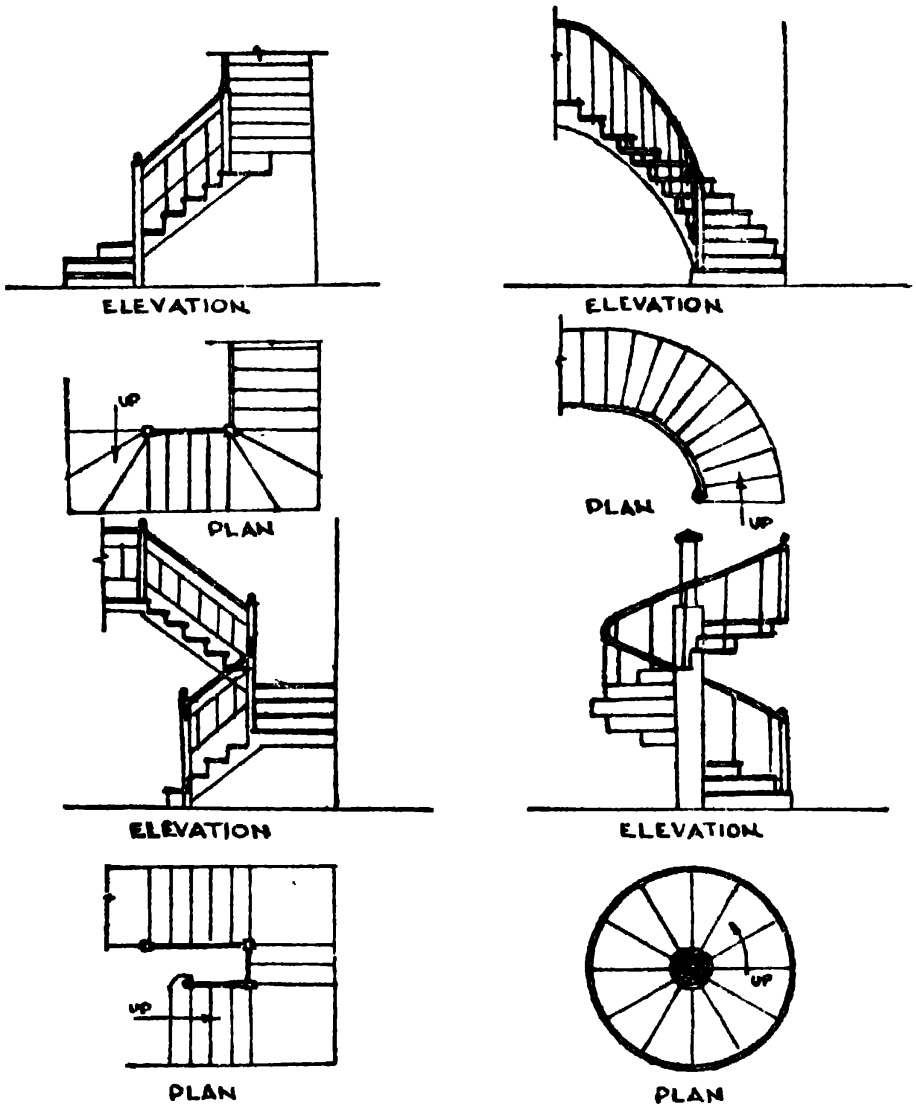
Fig. 12·5 Elevation and plan of a open-well stair

Fig. 12·6 Elevation and plan of a dog-legged stair

Fig. 12·7 Elevation and plan of a quarter turn newel

across the two flights at the change of direction. This type of stair is useful where the width of the stair-case hall is just sufficient to accommodate two widths of the stair.

(*iii*) *Open-newel stair* : It consists of two or more straight flights arranged in such a manner that a clear space called a "well" occurs between the backward and the forward flights. If the width of the stair case hall is such that it becomes difficult to accommodate the number of steps in the two flights without exceeding the maximum allowable limit of steps in each flight, a short flight of 3 to 6 steps may be provided along the width of the hall. In this state the intermediate short flight will have quarter-space landing on its either side.



Figs. 12·8—12·11

Ffg. 12·8 Elevation and plan of a quarter-turn newel stair

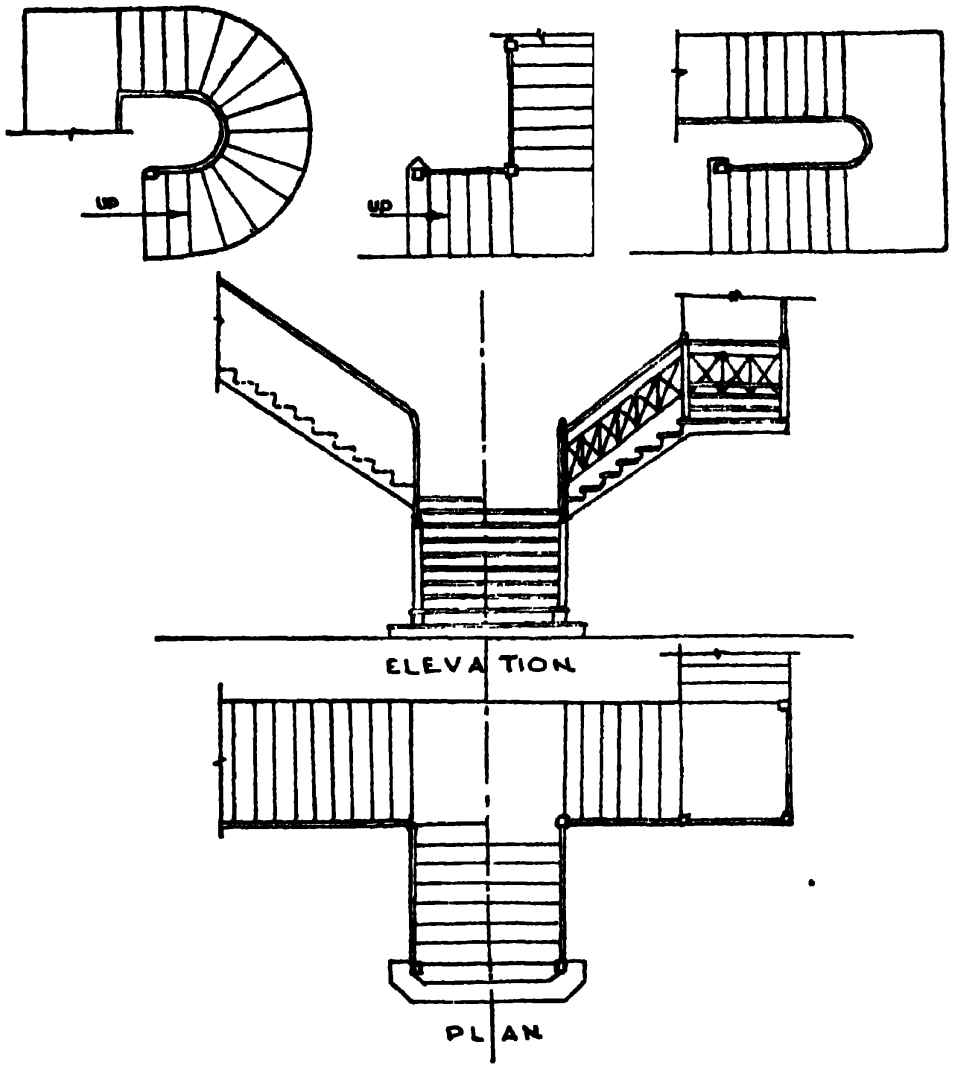
Fig. 12·9 Elevation and plan of an open-newel stair with quarter-space landing

Fig. 12·10 Elevation and plan of a circular stair

Fig. 12·11 Elevation and plan of a spiral stair

(*iv*) *Geometrical stair* : This is similar to the open-newel stair with the difference that the open well between the forward and the backward flight is curved. In this form of stair, the change in direction is obtained through winders.

(*v*) *Circular stair* : Circular stair is commonly provided at the backside of a building for rendering access to its various floors for service purposes. The circular stairs are commonly constructed in R.C.C iron or stone. In this form of stair all the steps radiate from a newel post or well hole, in the form of winders.



Figs. 12·12—12·15

Fig. 12·12 Plan showing half-turn geometrical stair

Fig. 12·13 Plan showing quarter-turn stair with quarter-space landing

Fig. 12·14 Plan showing open-well geometrical stair

Fig. 12·15 Elevation and plan of a bifurcated stair

(*vi*) *Bifurcated stair* : This type of stair is suitably provided in modern aristocratic public buildings. In this type of stair the flights are so arranged that there is a wide flight at the start which is sub-divided into narrow flights at the mid-landing. The two narrow flights start from either side of the mid-landing.

12·7 Stair of Different Materials. The commonly adopted materials in the construction of stairs are wood, stone steel, cast, iron, plain concrete or reinforced concrete, brick work or reinforced brick work. The stair of different materials have been described below.

12·8 Wooden Stairs. Timber is mainly used for stair construction where fire-resistance is not of much importanee. Timber stairs are cheap, easy in construction and maintenance and light in weight. Timber stairs constructed from fire-resisting hard wood, like oak, teak, mahogany etc., using a minimum thickness of various members as 5 cm. is found to serve the requirement of a fire-resisting stair to a great extent. The various components of timber stairs are described below :

Steps : The thickness of tread should not be less than 32 mm. and that of the risers as 25 mm. It is a common practice to adopt the thickness of tread as 38 mm. The riser and the treads are connected by tongue and grooved joints and the joints are nailed or screwed. The nosing of the step should not project beyond the riser for a distance more than the thickness of the tread. The nosing may be suitably finished by scotia piece.

Stringers : As described earlier, stringers are employed to provide support for the steps. Strings are inclined wooden members 32 to 51 mm. thick and 25 to 38 cm. deep. They are supported on newels, timming joists or pitching pieces. Strings may be broadly classified into four main types :

(*i*) *Cut string*

(*ii*) *Housed and closed string*

(*iii*) *Rough string*

(*iv*) *Wreathed string*

(*i*) *Cut string* : It is a stringer with its upper surface having carriages or houses accurately cut to receive the treads and risers and the lower edge being parallel to the pitch of the stair. It is considered that the appearance of stair is improved by use of cut-string but it has the disadvantage of weakening the string as deep cuts have to be made in it.

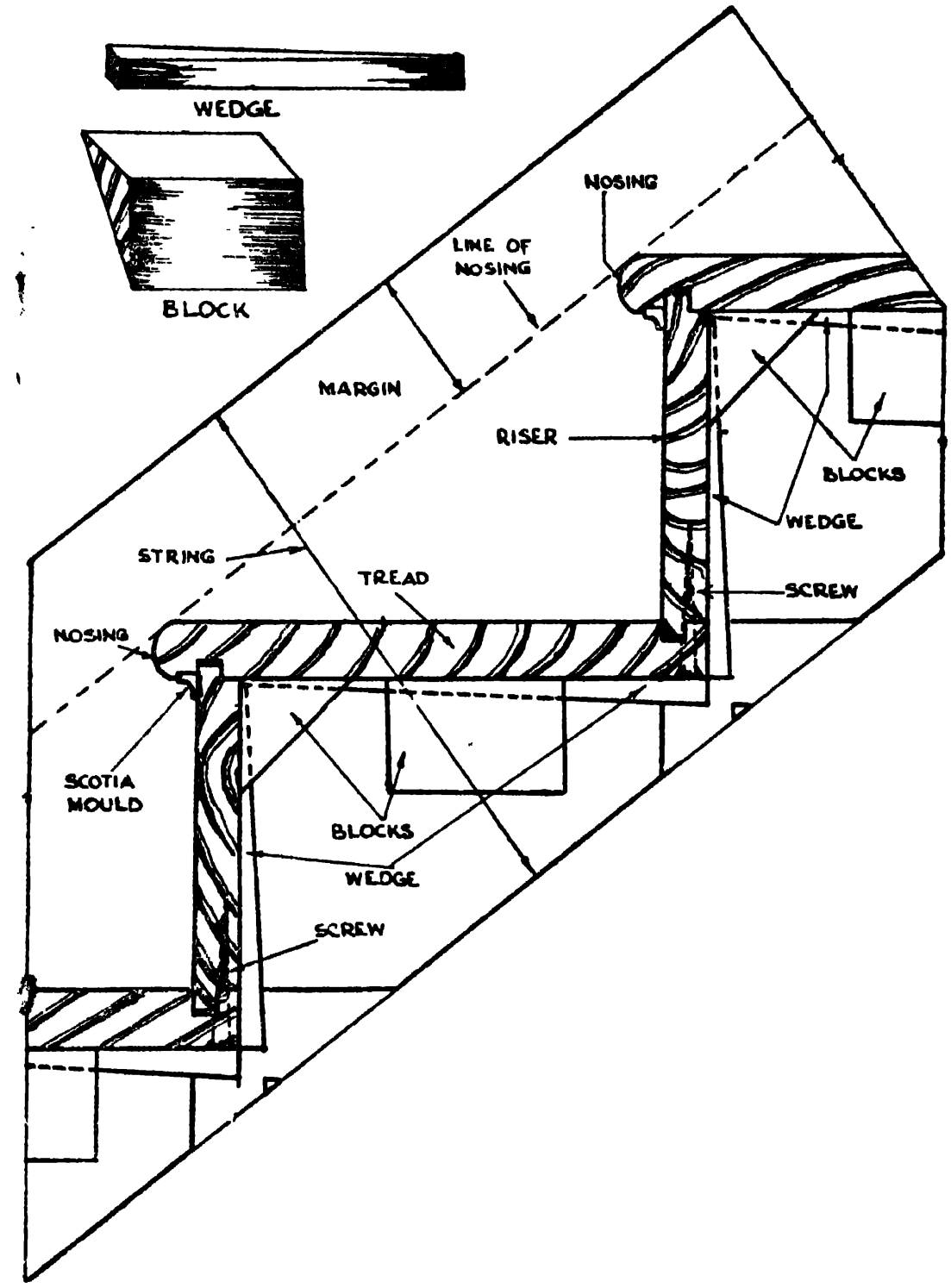


Fig. 12·16

Wooden stair

(*ii*) *Housed or closed string* : It is a stringer having its top and bottom edges parallel to the slope of the stair. It has grooves cut on its inside to receive the treads and risers of the steps. The treads and risers are usually nailed, glued and wedged to the stringer.

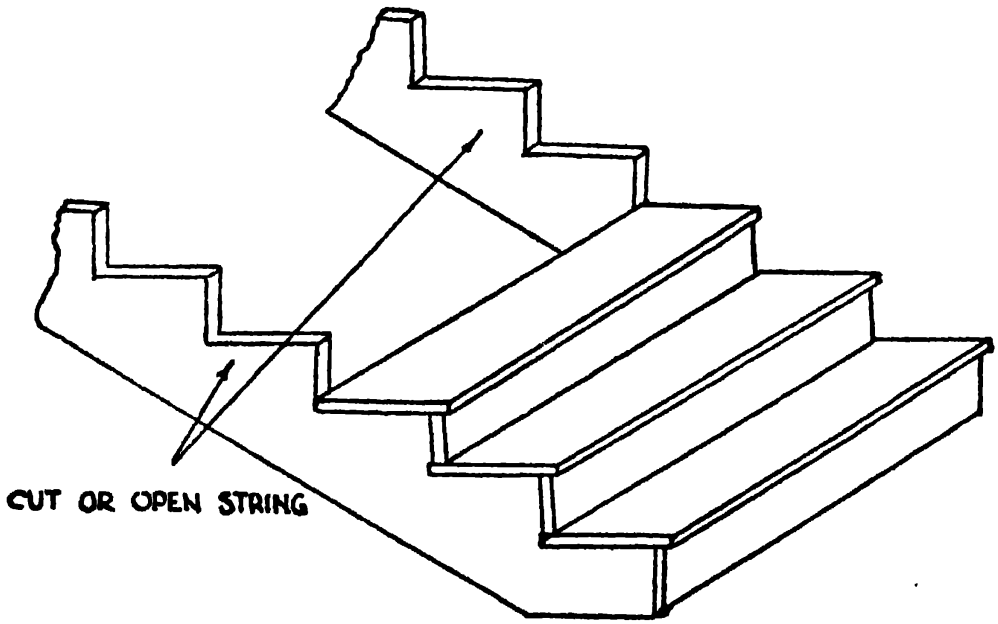


Fig. 12·17

(*iii*) *Rough string* : Rough strings are introduced in wider stairs for the purpose of rendering intermediate support to the steps.

(*iv*) *Wreathed string* : It is curved or geometrical stair string. It may be of cut or closed type.

Winders : In narrow stairs, the treads of winder steps are supported on risers which act as cantilever beams fixed in the staircase wall. In such cases, the riser should be of sufficient thickness to perform the function of a cantilever beam. At its free end, the cantilever riser beam is housed into the newel post. For wider stairs the winders are supported by means of bearers built into the wall at one end and framed and housed into the newels at the other. The back of the bearer is rendered flush with that of the riser immediately over it.

Landings : These may be constructed of tongued and grooved boarding on joists. The arrangement for supporting landing boarding differs with the type of landing.

In case of straight stairs, newels are carried down to the ground floor and bearers are provided from the newel to the staircase wall. These landing joists are usually provided between the bearers.

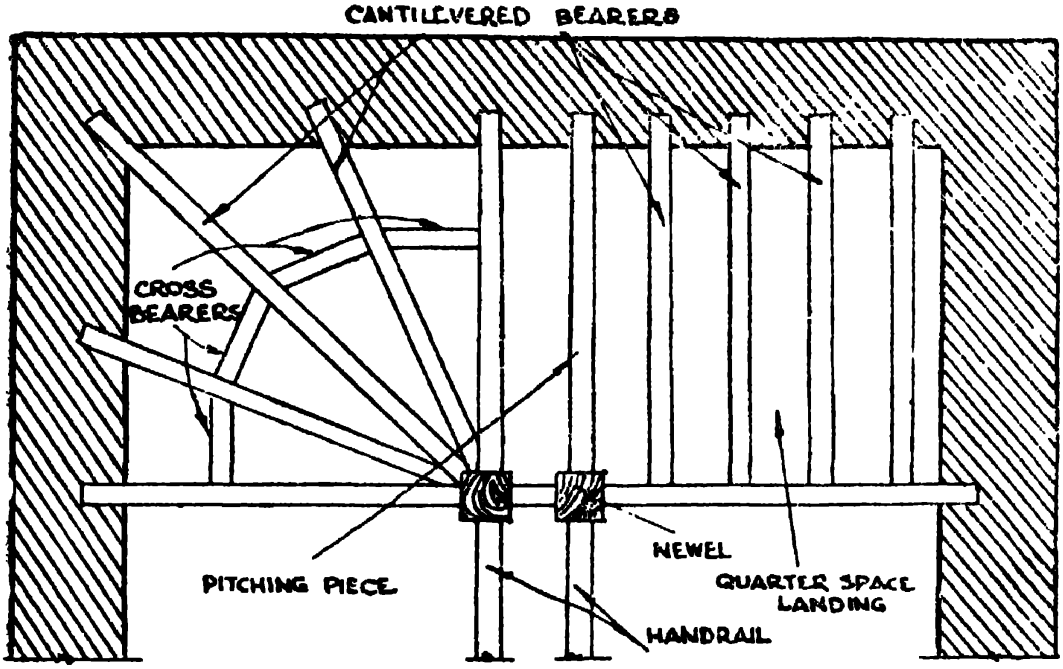


Fig. 12·18
Plan on left hand side shows arrangement of bears for supporting winders and the plan on right hand side shows the frame work for quarter space landing

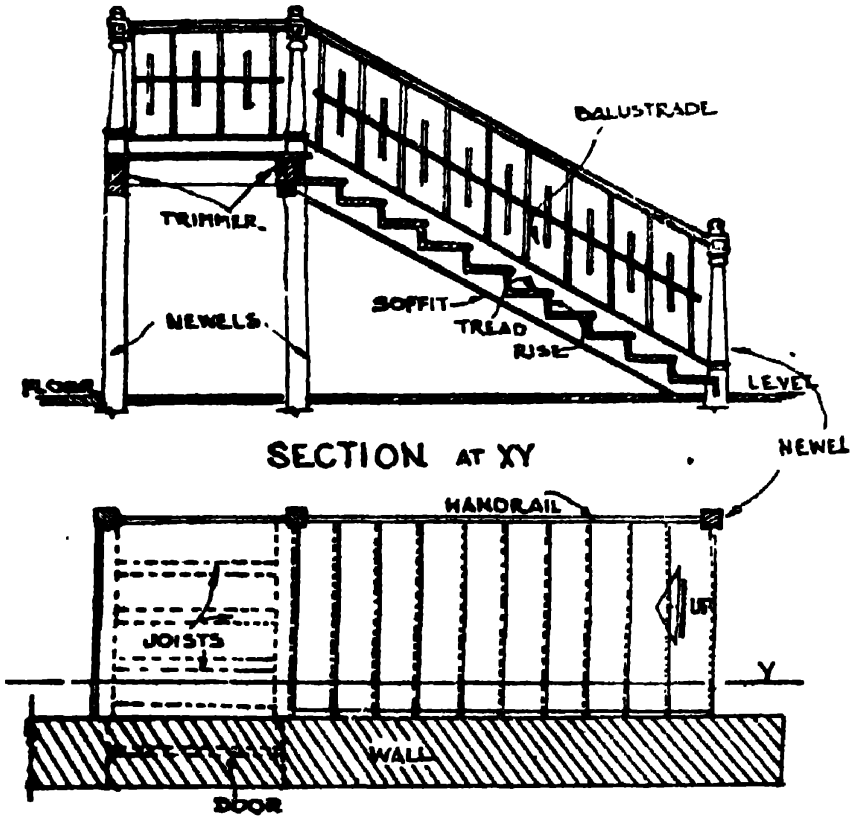


Fig. 12·19
Straight flight stairs

In forming quarter-space, landing a timber joist, termed as "pitching piece", is built with in the wall at one end and housed with the newel at the other. Depending upon the type of newel, the pitching piece may be supported as a beam or act as a cantilever beam fixed in the staircase wall. In case where the pitching piece acts as a cantilever beam, it should be strengthened by means of a bracket below it. Pitching pieces support the ridging joist to which the landing boarding is fixed.

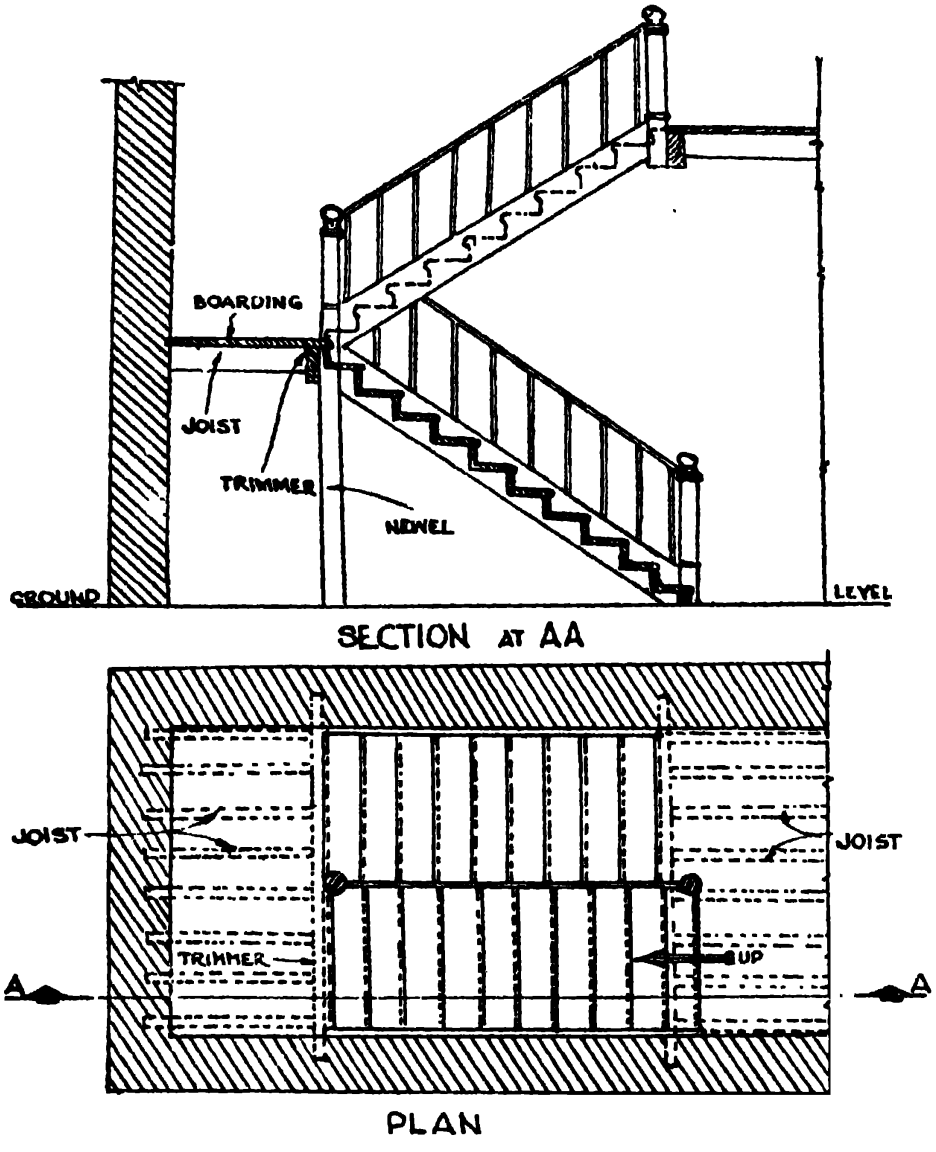


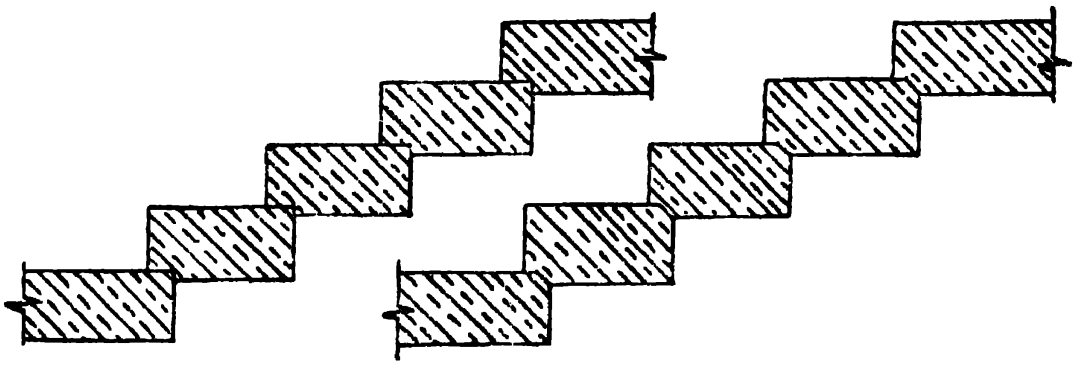
Fig. 12·20

Dog-legged stair

For forming a half-space landing wooden joist termed as trimmer is fixed across the width of the staircase. Landing joists

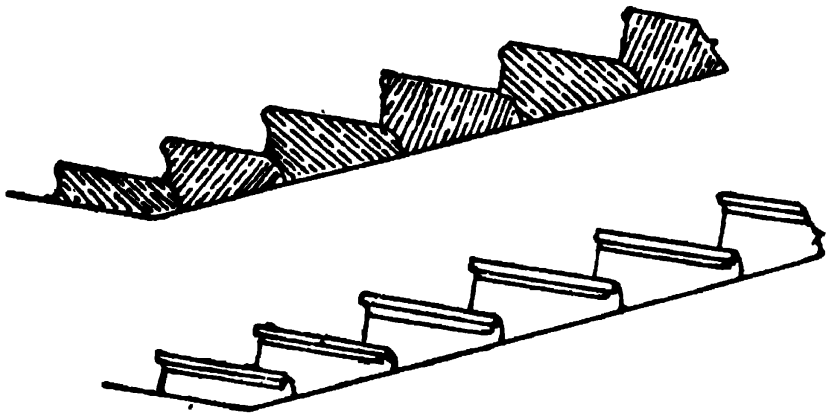
or bridging joists are tennoned into the trimmer at one end and are supported on the staircase wall at the other end.

12·9 Stone Stairs. Stair made out of hard, strong, resistant to wear stones are found to be durable and fire resisting. They are commonly constructed in workshops, warehouses and other public buildings. Their usage in residential building is generally restricted to outside stairs. Being heavy in weight, stone stairs require stable support to avoid the danger of damage due to settlement of supporting walls. The stone steps derive their name from their shape and form of construction. The main type of stone are steps described below :



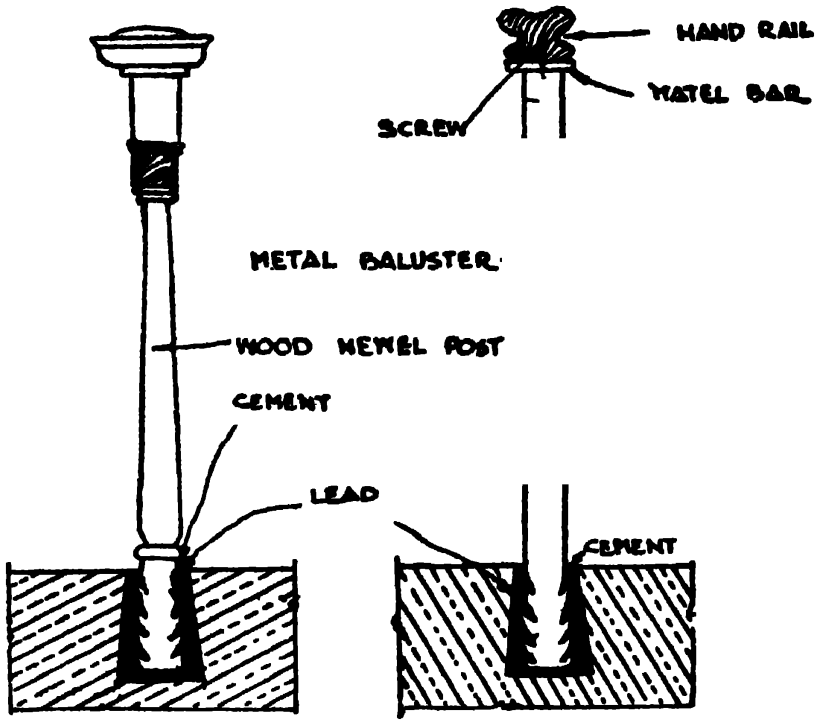
Figs. 12·21—12·22
Rectangular steps

(*i*) *Rectangular steps* : They are cut from solid stone into square or rectangular blocks of uniform size. In its simplest form the steps are arranged with the front edge of one step resting on the upper back edge of the step below. The defect in this type of construction is that the joint is not covered and may be exposed when the bedding or pointing mortar gets defective. This defect is overcome by cutting rebate at the front lower edge of step each to lap over the back edge of lower step.



Figs. 12·23—12·24
Spandril steps

(*ii*) *Built up steps* : They consist of treads and risers formed of thin swan stone slabs. They are often used as facing for concrete or brick steps. The minimum thickness of tread if supported at end is restricted to 5 cm.



Figs. 12·25—12·26

Methods of fixing balusters in stone steps

(*iii*) *Spandril step* : A spandril step, excepting the ends which are built into the wall, approximates to a triangle in cross--section. The under-side of the steps or the soffit usually exhibits a plain surface. This gives a greater head-room. The steps are rebated to fit on the one's below.

12·10 Metal Stairs. They are usually fabricated from steel and cast iron and their use is generally restricted to factories, godowns etc. In its simplest form, a metal stair consists of steel stringers to which steel angles are riveted or welded and metal treads are provided over them. Sometimes concrete is filled in steel grating to form the treads. The details of metal stair are shown in figure 12·27.

12·11 Rainforced Concrete Stairs. Reinforced concrete stairs predominate the stairs made from wood, stone or metal. This is because of the various advantages R.C.C. has over other materials. Reinforced concrete is perhaps the most suitable of all the said materials for the construction of stairs. R.C.C. stairs can be moulded in any desired form to suit the requirements of the architect.

The various advantages of reinforced concrete stairs are given below :

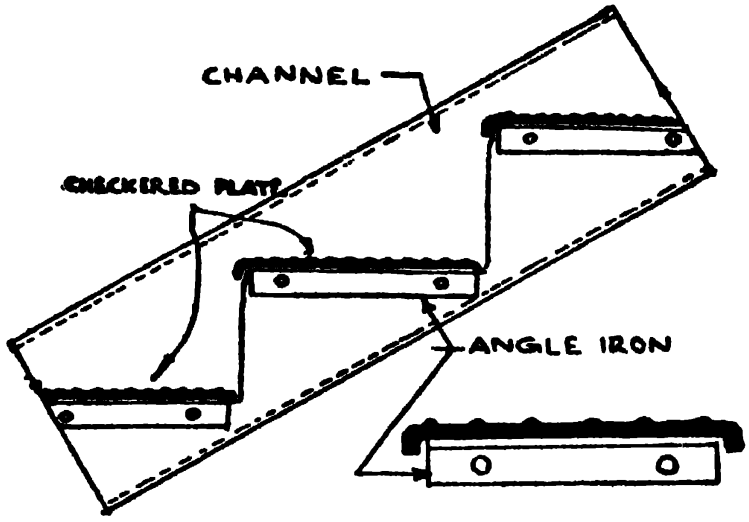


Fig. 12·27

Metal stair

(*i*) They have requisite fire-resisting qualities to a great extent.

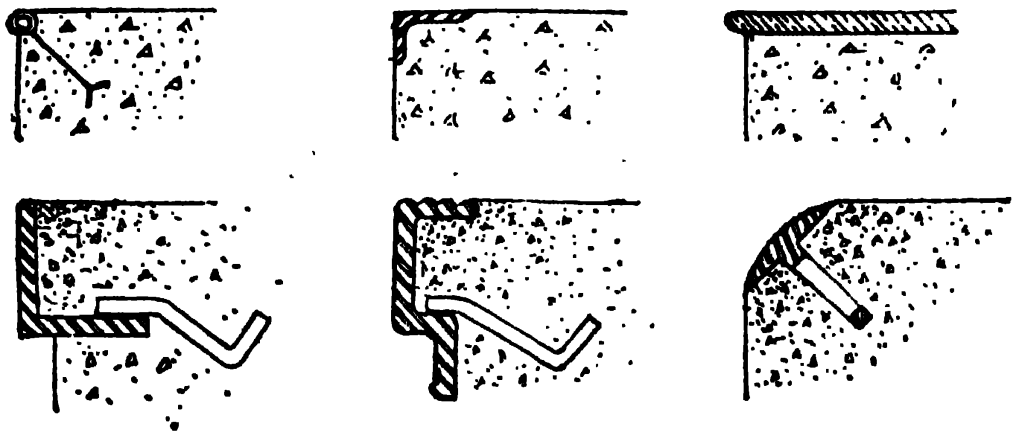
(*ii*) They are durable, strong, pleasing in appearance and can bc easily rendered non-slippery.

(*iii*) They can be designed for greater widths and longer spans.

(*iv*) They can be easily cleaned.

(*v*) The cost of maintenance is almost nil, if used properly.

(*vi*) In a framed structure of reinforced concrete, R.C.C. stair. is perhaps the only choice.



Figs. 12·28—12·33

Different methods of protecting the nosing of concrete steps

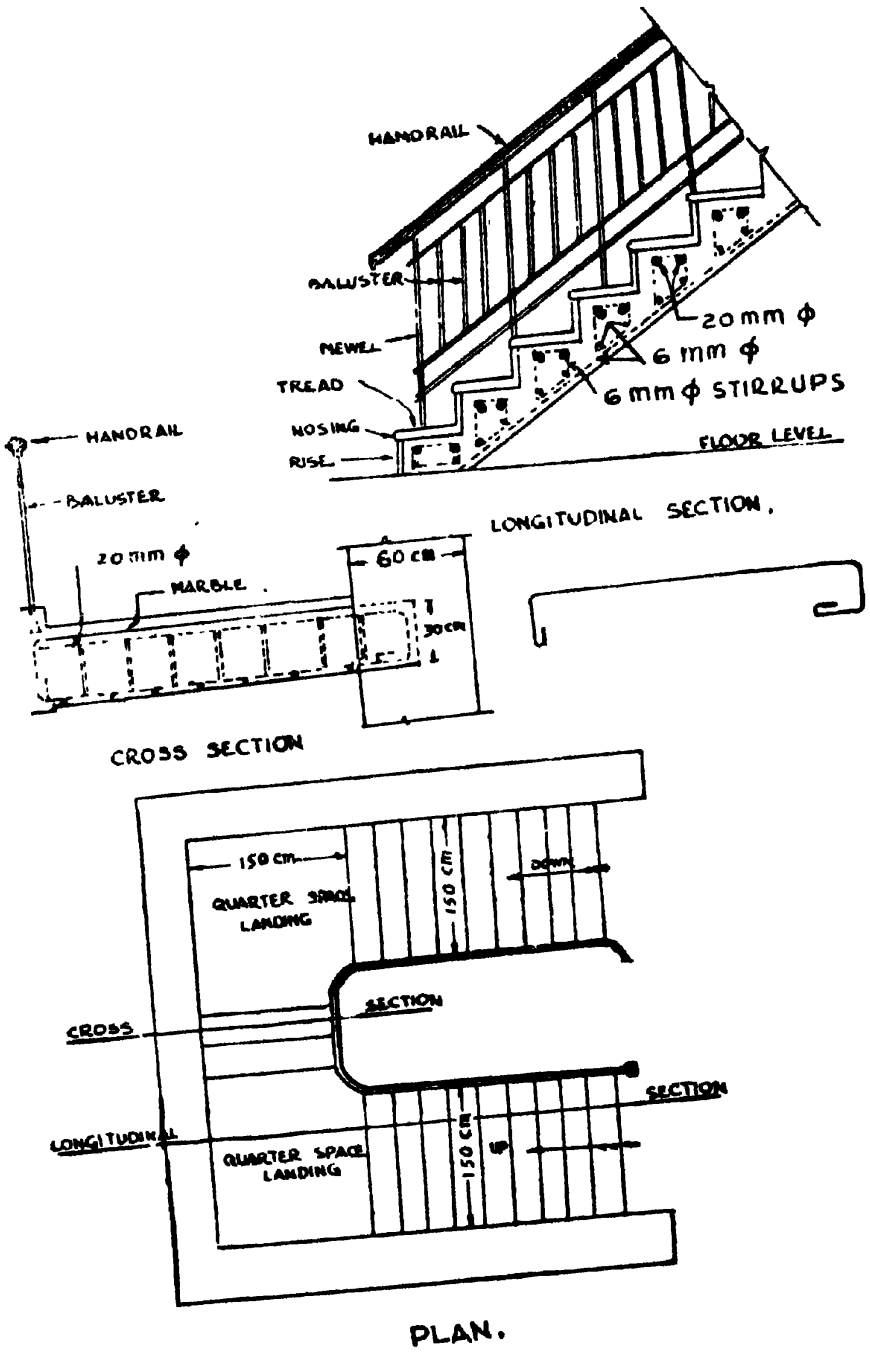


Fig. 12·34

Details of an R.C.C. stair

Reinforced concrete stairs can be pre-cast or cast-in-situ. To change their appearance, R.C.C. stairs are often covered with thin slabs of marble tiles or with terrazzo finish. In order to prevent the

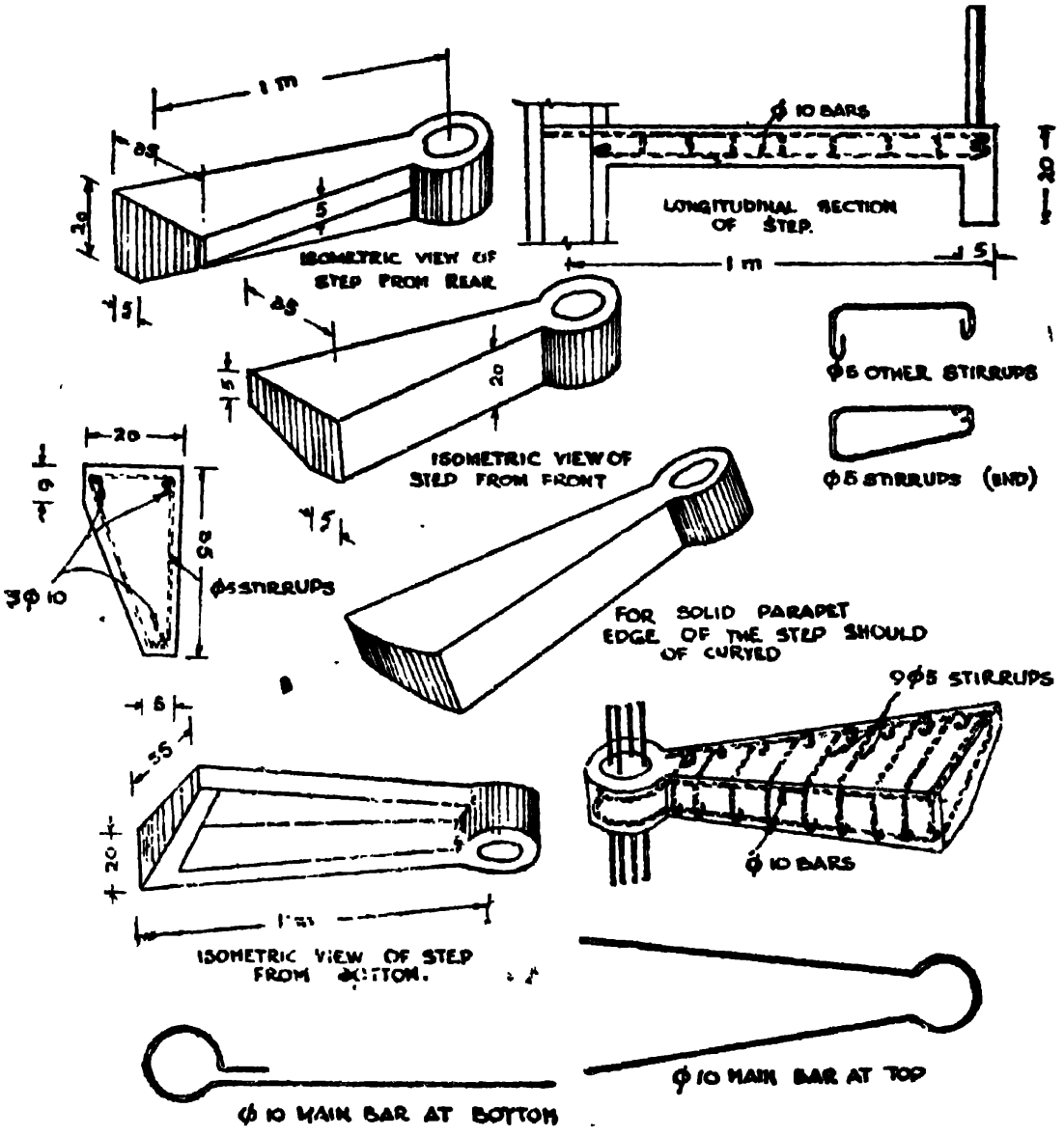


Fig. 12·35 Structural details of a pre-cast R.C.C. spiral stair

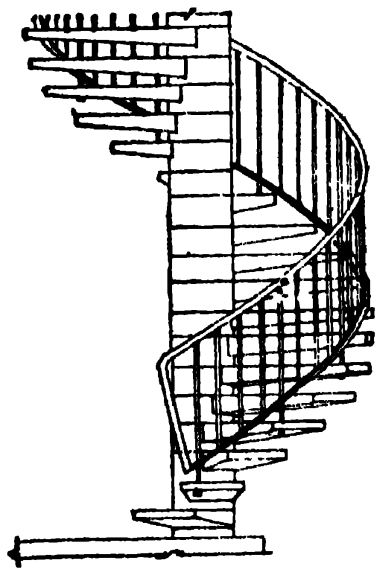


Fig. 12·36 Elevation of a spiral stair

nosing of the step getting cracks or knocking off, it should preferably be protected by metallic strips or angles as shown in Figs. 12·28—12·33.

12·12. Design Principle. The choice of the type of stair to be adopted depends very much upon the size of the staircase hall and the loading conditions. In short the design of the reinforced concrete stairs may be summarised in the following few steps :

(*i*) R.C.C. steps cantilever out from the stair-case wall and act both as supporting beam and stair.

(*ii*) R.C.C. steps spanning between two inclined R.C.C. beams.

(*iii*) An inclined slab of the full width of the stair and supported between beams or landing slabs at either end and the steps cast monolithic with the inclined slab.

The various details of R.C.C. stairs are shown in figure I2 34.

Questions for Revision

1. A suitable stair has to be located in a stair-case 7·62 m. long, 4·57 m. wide and 4·57 m. high, with a door 1·22 m. wide in each of the longitudinal wall. The doors face each other and are located with their centres at a distance of 1·07 m. from the respective corners of the stair-case. Assuming that it is in a public building, design the stair and draw a dimensional sketch plan and a dimensional sketch section to illustrate your proposals.

2. Write short notes on the following :
   (*i*) Geometrical stairs.
   (*ii*) Dog-legged stairs.
   (*iii*) Open-newel stairs.

3. Write the requirement of a well-designed stair. Describe the type of stair you would recommend for connecting two wooden floors in a high-class hotel.

4. Draw complete details of an R.C.C. stair-case for an office building leading from the ground to the first floor. Height of the floor is to be 4·27 m. and the width of the steps is to be 1·22 m. State reasons for the size of the risers and treads adopted by you. Provide a lift well 1·22 m. × 1·83 m.

5. What do you understand by the following ? Draw rough sketches to support your answers wherever necessary :
   (*a*) Landing
   (*b*) Nosing
   (*c*) Stringer
   (*d*) Winders
   (*e*) Balustrade
   (*f*) Spandril.

6. (*a*) State briefly the requirements of a good stair-case.
   (*b*) How are treads and risers proportioned ?
   (*c*) Where do you use :

(*i*) Dog-legged stair.

(*ii*) Open newel stair.

(*iii*) Geometrical stair.

7. Sketch neatly large view to show details of the following :

(*i*) Treads with rounded nosings.

(*ii*) Tongued risers.

(*iii*) Wall or outer string.

(*iv*) Newel, hand rail and balusters.

8. A two-storeyed building is to have a R.C. stair-case from ground to first floor roof. The size of the stair case is 4·27 m. × 3 m. and there is one door opening in the short wall and a window opening on the opposite wall.

Design the stair-case, give the details of foundations, R.C. slab, arrangment of building, risers and treads with their top finishings with suitable sketches. The width of the stair is 1·22 m. and the height of each story is 3·36 m.

9, Write short notes on the following :

(*i*) Metal stairs.

(*ii*) Stone stairs.

(*iii*) R.C.C. stairs.

(*iv*) Spiral stairs.

10. A straight flight stair has to be provided for connecting two floors. The vertical distance between the floors is 3 m. and the width of stair has to be restricted to 75 cm. for want of space. Draw sectional plan and elevation of the designed stair, showing clearly the constructional details.

11. What are the different types of stair cases used in buildings ? Which of them will be most suitable for a public building ? Describe in details the construction of a helicoidal stair case and state where this is commonly used.
(*A.M.I.E., Nov. 1969*)

12, What are the limitations on different types of stair cases in regard to their rise and tread. How would you choose them for :

(*a*) House ; (*b*) School ;

(*c*) Hospital (*d*) Railway station.
(*A.M.I.E. May 1970*)

13. Discuss the considerations in planning of stair-cases for buildings.

Illustrate the different types generally used, indicating their suitabiilty for specific uses. (*A.M.I.E. May 1971*)

13

Structural Design of Stairs

13·1 Design of Stairs. As per Indian Standard Code of Practice, stairs, landings and cantilever access balconies may be designed for the super-imposed or live load of 300 kg. per square metre for residential or office buildings and 500 kg. per square metre for other public buildings and warehouses etc.

The slab portion under the steps called the waist is considered to take the hole load and is designed as an ordinary slab.

Depending upon the method of support provided R.C. stairs slab may be divided into two types :

(*i*) *Stair slab spanning horizontally*

(*ii*) *Stair slab spanning longitudinally.*

13·2 Stairs Spanning Horizontally. In such types of stairs, the slab is supported on each side. The supports may be provided by the walls on either side ; stringer or wall beam, on one side and beam on the other. Stairs may also be designed to span horizontally when there is a newel between the backward and forward flights. Each stair is supported at one end by the newel wall and at the other end by a side wall. In such a case the waist slab is designed for a bending moment $= \frac{wl^2}{8}$, where l is the horizontal distance from the centre to centre of the sup ports.

13·3 Stairs Spanning Longitudinally. In this type, the waist slab is supported at bottom and top of the flight and is unsupported at the sides. The flight of the stair is continuous having beams both at top and bottom. The waist slab may be designed as a horizontal slab spanning over horizontal distance equal to the centre to centre distance of the supported beam. The waist slab is designed for a bending moment of $\frac{wl^2}{10}$. Where the flights or landings are built into wall, the landing slab is assumed to span in the same direction as the stairs. They should be considered as acting together to form a single slab. The effective span for each flight

shall be taken as the clear horizontal distance covered by the flight including the whole of landing plus 8 cm. at either end for end bearing. The formula for bending moment is given by $\frac{wl^2}{8}$.

Sometimes the landing slab may span at right angles to the direction of the stairs. In such a case the landing slab may be supposed to be acting as a beam supporting the flights. The effective span in such a case should be taken as a distance equal to the going of the stairs plus at each end either half the width of the landing or one metre whichever is smaller.

13·4 Distribution of Loading on Stairs. As per Indian Standard Code of Practice, in the case of stairs with open wells, where spans partly crossing at right angles occur, the load on areas common to any two such spans may be taken as one half in each direction and 15 cm. wide strip of the landing near the wall should be considered as not subjected to any live load.

To obtain the weight on plan, of the inclined waist slab, its weight at right angles to the slope, must be increased in the ratio of

$$\frac{\sqrt{R^2+T^2}}{T}.$$

For computing the weight of the steps, weight of slab equal to half the rise may be taken and this value may be treated as the weight of the step on plan.

13·5 Design of a Dog-legged Stair

Example. *The main stair of an office building is to be located in a stair-case measuring 3 cm.×5 m. If the vertical distance between the floors is 3·5 m. draw a dimensional plan and section of the proposed R.C.C. stair showing details of construction, i.e. position of reinforcements in the different portions of the stairway. Assume the weight of R.C.C.=2300 kg./m³.*

Solution

It is proposed to provide a Dog-legged stair and keeping in view the utility of the stair, its width will be kept 1·4 m. and as such the width of the landing will also be restricted to 1·4 m. Assuming two flights, height of each flight $=\frac{3·5}{2}=1·75$ m.

$=175$ cm.

Assuming 16 cm. riser ; no. of risers required $= \frac{175}{16} = 10{\cdot}94$

$= 11$ numbers, say

$\therefore$ Exact size of each riser $= \frac{175}{11}$

$= 15{\cdot}8$ cm.

No. of treads to be provided in each flight

$T = R - 1$

$= 11 - 1 = 10$

It is proposed to keep the width of the tread

$= 27$ cm.

$\therefore$ Space occupied by 10 treads

$= 27 \times 10 = 270$ cm.

Space left for passage

$= 5 - (1{\cdot}4 + 2{\cdot}7)$

$= 0{\cdot}9$ m.

$= 90$ cm.

Structural Calculations

Total horizontal projection of the waist slab

$= 1{\cdot}4 + 2{\cdot}7$

$= 4{\cdot}1$ m.

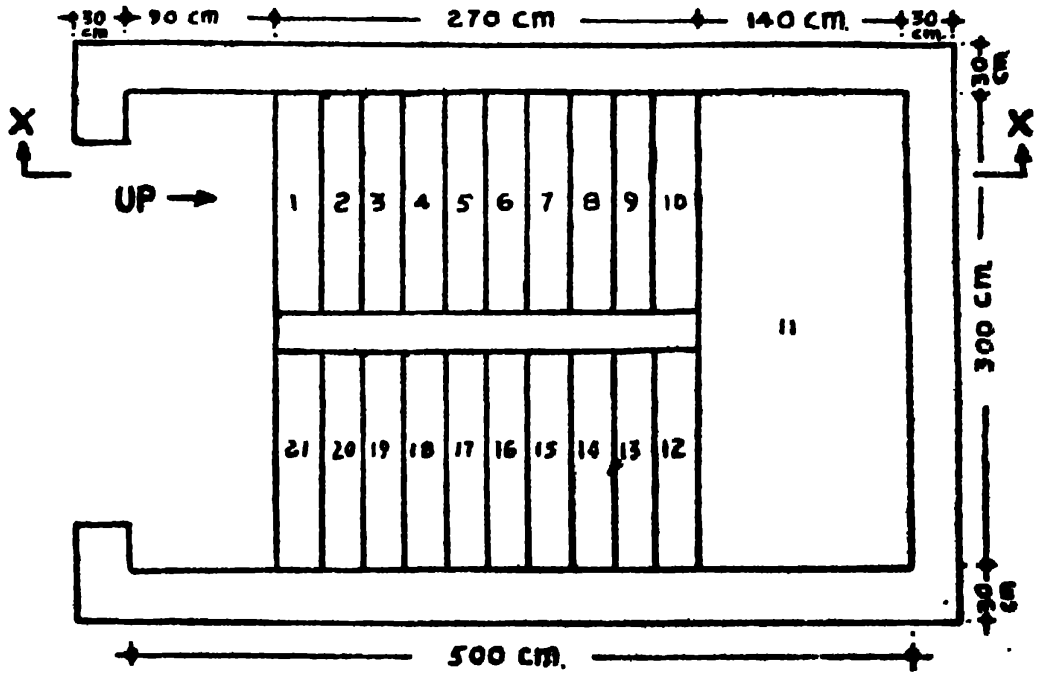


Fig. 13·1

Assuming the thickness of the waist slab to be 18 cm., its weight on slope

$$= 0{\cdot}8 \times 2300$$

$$= 414 \text{ kg.}$$

$$\text{Its weight on plan} = \frac{418\sqrt{R^2+T^2}}{T}$$

$$= \frac{414\sqrt{15{\cdot}8^2+27^2}}{27}$$

$$= 414 \times 1{\cdot}16$$

$$= 480 \text{ kg.}$$

Consider a strip of slab 1 m. wide.

Load per metre run :

(1) Weight due to waist slab = 480 kg.

(2) Weight due to step $\left(\frac{15{\cdot}8}{2} \text{ cm., thick}\right)$ = 182 kg.

(5) Weight due to finishing etc. (assumed) = 6 kg.

(4) Live load = 400 kg.

Total Load (w) = 1068 kg./m.

Effective span $= 4{\cdot}1 + (0{\cdot}18 - 0{\cdot}02)$

$$l = 4{\cdot}26 \text{ m.}$$

$$M = \frac{w.l^2}{8}$$

$$= \frac{1068 \times 4{\cdot}26^2}{8}$$

$$= 2420 \text{ kg. m.}$$

$$= 242000 \text{ kg. cm.}$$

Required effective depth of slab

$$d = \sqrt{\frac{M}{Q.b}}$$

$$= \sqrt{\frac{242000}{8{\cdot}48 \times 100}}$$

$$= 16{\cdot}91 \text{ cm.}$$

Adopt an overall depth of the slab = 18 cm. and effective depth 18 − 2 = 16 cm.

Area of steel required :

$$At = \frac{M}{a_1.d.t}$$

$$= \frac{242000}{0{\cdot}87 \times 16 \times 1400}$$

$$= 12{\cdot}42 \text{ sq. cm.}$$

Pitch of 14 mm. ϕ bars (area of 14 mm. ϕ bar = 1·54 sq. cm.)

$$= \frac{100 \times 1{\cdot}54}{12{\cdot}42}$$

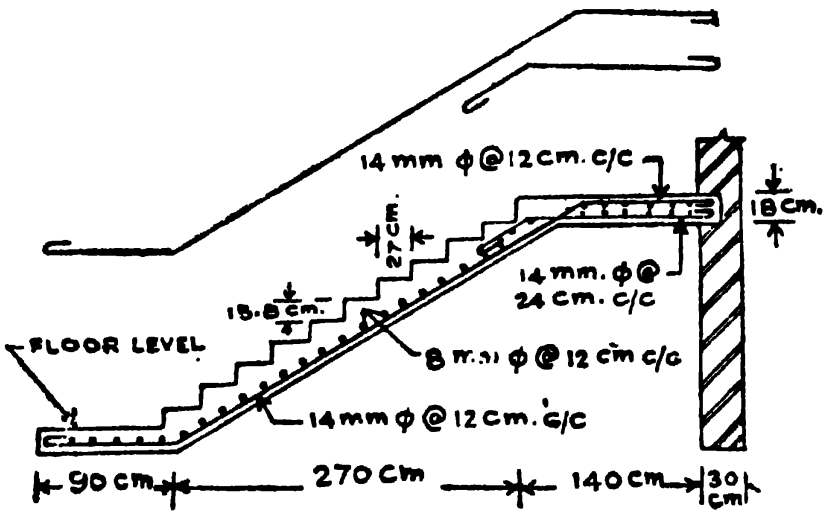
$$= 12{\cdot}4 \text{ cm.}$$

$$= 12 \text{ cm. c/c. say.}$$

Distribution bars @ 0·2% of the area of concrete

$$= \frac{0{\cdot}2 \times 18 \times 100}{100}$$

$$= 3{\cdot}6 \text{ sq. cm.}$$



Section XX

Fig. 13·2

Pitch of 8 mm. ϕ distribution bars (area of one 8 mm. ϕ bar = 0·5 sq. cm.).

$$= \frac{100 \times 0{\cdot}5}{3{\cdot}6} = 13{\cdot}9 \text{ cm. c/c}$$

$$= 14 \text{ cm. c/c., say.}$$

13·6 Design of an Open Well-type Stair

Example. *A suitable stair has to be located in a stair-case 6 m. long, 3·6 m. and 3·6 m. high with a door 1·15 m. wide in each of the longitudinal walls. The doors face each other and are located with their centres at a distance of 108 cm. from the repective corners of the stair-case. Assuming that it is in a public building, design the stair and draw a dimensioned sketch plan and a dimensioned sketch section to illustrate your proposals. Adopt the weight of R.C.C.=2300 kg./m³.*

Solution

Assuming the width of the stair to be 1·25 m., the space available in the centre of the stair case $= 3·6 - 2 \times 1·25$

$= 1·1$ m.

Hence, an open well type of stair shall be provided.

Assuming 15 cm. riser ; no. of risers required

$$\frac{3·6 \times 100}{15} = 24 \text{ Nos.}$$

If we provide two flights, no. of risers in each flight $= \frac{24}{2} = 12$

Since it is a public building, 12 risers in one flight appear to be more.

Hence provide 4 treads, in the landing portion and make the stair of quarter space landing type.

Provide 9 treads each, in the remaining two fiights.

Total no. of risers required to accommodate 22 treads in three flights = 25.

Hence height of each riser

$$= \frac{3·6 \times 100}{25}$$

$= 14·4$ cm.

Adopt the width of the tread = 27 cm.

Space occupied by 9 treads $= 9 \times 27$ cm.

$= 243$ cm.

Fig. 13·3 shows the final arrangement of steps.

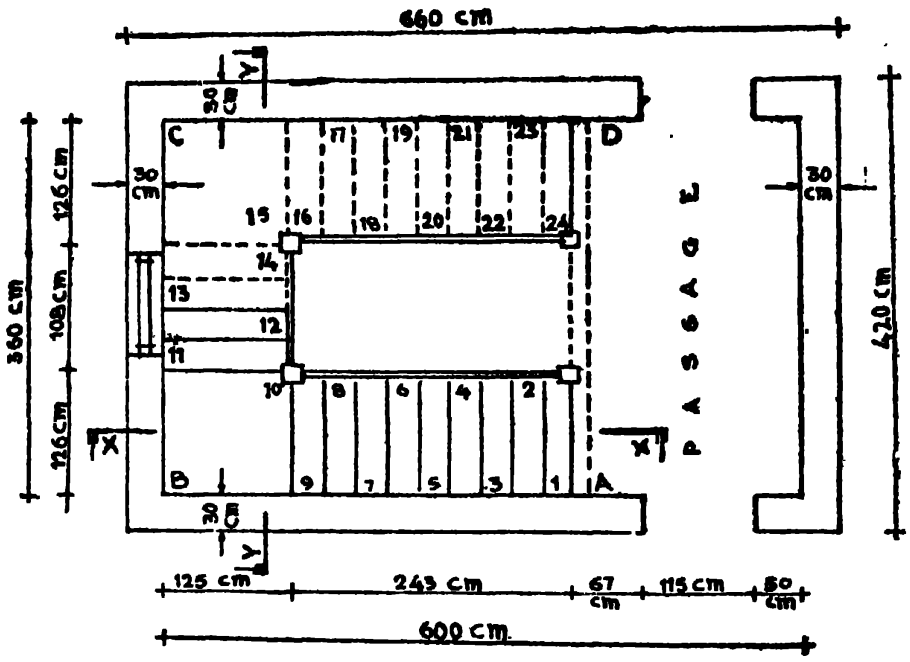


Fig. 13·3

Structural calculations

Loads :

Dead load : Assuming the thickness of the waist slab to be 18 cm., measured at right angles to the slope :

$$\text{Its weight on plan} = \frac{0{\cdot}18 \times 2300\sqrt{R^2+T^2}}{T}$$

$$= \frac{1414\sqrt{14{\cdot}4^2+27^2}}{27}$$

$$= 414 \times 1{\cdot}133$$

$$= 469 \text{ kg.}$$

It is assumed that the landing slab is also 18 cm. thick.

Loading conditions in landing portion and in the inclined flight will be different and as such, the loads for the two will be calculated separately. Consider a strip of slab one metre wide.

Loading in inclined flight slab :

(1) Dead load due to waist slab = 469 kg/m.

(2) Wt. due to steps (7·2 cm. average thickness) = 166 kg/m.

(3) Wt. due to finishing etc. = 6 kg/m.

(4) Live load = 400 kg/m.

Total = 1041 kg/m.

= 1040 kg/m. (say)

Loading in the landing portion :

(1)	Dead load due to landing slab (18 cm. thick assumed)	$= 0{\cdot}18 \times 2300 = 414$ kg/m.
(2)	Wt. due to finishing etc.	$= 6$ kg/m.
(3)	Live load	$= 400$ kg/m.
	Total	$= 820$ kg/m.

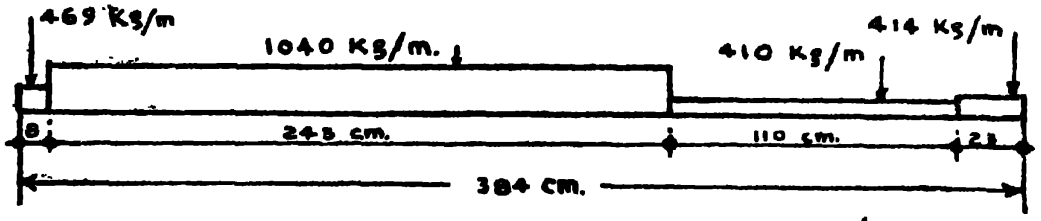
Load distribution and effective span :

As per rules the load on landing common to two flights shall be taken as equally divided between the two flights, and 15 cm. wide strip of the landing near the face of bearing wall shall be considered as not subjected to any live load.

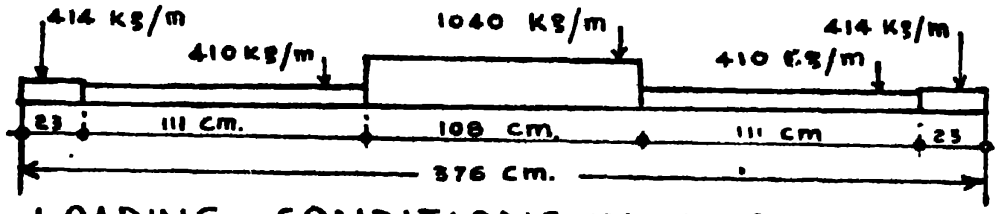
$\therefore$ Design load for landing portion in each direction

$$= \frac{820}{2} = 410 \text{ kg/m.}$$

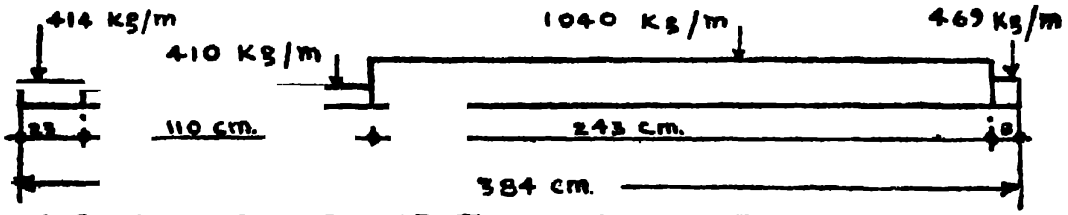
The effective span for all the flight shall be taken as the clear horizontal distance covered by the flight including whole of landing plus 8 cm. at either end of flight for end bearing.



LOADING CONDITIONS IN FLIGHT AB



LOADING CONDITIONS IN FLIGHT BC



LOADING CONDITIONS IN FLIGHT CD

Figs. 13·4—13·6

Since the loading conditions in the flight AB and CD are just identical, only flight AB will be designed and the same design will hold good for the flight CD also.

To calculate Max. Bending Moment for the flight AB.

Taking moments about A, we have

$$R_B \times 3{\cdot}84 = 469 \times 0{\cdot}08 \times \frac{0{\cdot}80}{2} + 1040 \times 2{\cdot}43 \times 1{\cdot}295 + 410 \times 1{\cdot}1 \times 3{\cdot}06 + 414 \times 0{\cdot}23 \times 3{\cdot}725$$

$$\therefore \quad R_B = 1303 \text{ kg.}$$

$$R_A = (469 \times 0{\cdot}08 + 1040 \times 2{\cdot}43 + 410 \times 1{\cdot}10 + 414 \times 0\ 23) - 1303$$

$$= 3113 \text{ kg.} - 1303 \text{ kg.}$$

$$= 1810 \text{ kg.}$$

Max. B.M. will occur where the shear force is zero. Let the shear force be zero at any distance x from A.

$\therefore$ At the point of zero shear force

$$0{\cdot}08 \times 469 + 1040(x - 0{\cdot}08) = R_A = 1810 \text{ kg.}$$

or $1040\,x = 1855{\cdot}68$

$$\therefore \quad x = \frac{1855{\cdot}68}{1040}$$

$$= 1{\cdot}784 \text{ m.}$$

Max. B.M. at 1·784 m. from A

$$= 1810 \times 1{\cdot}784 - 469 \times {\cdot}08 \times 1{\cdot}744 - 1040 \times 1{\cdot}704 \times 0.85$$

$$= 1649\ 5 \text{ kg. m.}$$

$$= 164950 \text{ kg. cm.}$$

Max. B.M. in flight BC :

The loading on the flight being symmetrical :

$$R_B = R_C = \tfrac{1}{2}(2 \times 414 \times 0{\cdot}23 + 2 \times 410 \times 1{\cdot}11 + 1040 \times 1{\cdot}08)$$

$$= 1112{\cdot}2 \text{ kg.}$$

Max. B,M. will occur at the centre of the flight, its valu

$$= 1112{\cdot}2 \times \frac{3{\cdot}76}{2} - 414 \times 0{\cdot}23 \times 1{\cdot}765$$

$$- 410 \times 1{\cdot}11 \times 1\,095 - 1040 \times \frac{1{\cdot}08}{2} \times \frac{1{\cdot}08}{4}$$

$$= 1277{\cdot}2 \text{ kg. m.}$$

$$= 127720 \text{ kg. cm.}$$

Required effective depth of the inclined waist slab, to resist max. bending moment in the flight AB or CD.

$$d = \sqrt{\frac{M}{Qb}}$$

$$= \sqrt{\frac{164950}{8\,48 \times 100}}$$

$$= 13{\cdot}08 \text{ cm.}$$

Adopt overall depth of slab = 15 cm.

and effective depth = 15 − 2 = 13 cm.

Although the depth of the landing slab will work out to be slightly lesser but it is proposed to maintain the same depth of 15 cm. for the landing slab also.

Area of steel required for the flight AB or CD

$$A_t = \frac{M}{a_1.d.t}$$

$$= \frac{164950}{0{\cdot}87 \times 13 \times 1400}$$

$$= 10{\cdot}41 \text{ sq. cm.}$$

Using 14 mm. ϕ bar (area of one 14 mm. ϕ bar = 1·54 sq. cm.) pitch of the bars required :

$$= \frac{100 \times 1{\cdot}54}{10{\cdot}41}$$

$$= 14{\cdot}8 \text{ cm. c/c.}$$

$$= 14 \text{ cm. c/c say.}$$

Area of steel required for the landing slab BC,

$$A_t = \frac{M}{a_1.d\,t}$$

$$= \frac{127720}{0{\cdot}87 \times 13 \times 1400}$$

$$= 8\,07 \text{ sq. cm.}$$

Using 12 mm. ϕ bars (area of one 12 mm. ϕ bar = 1·13 sq. cm.), pitch of the bar required :

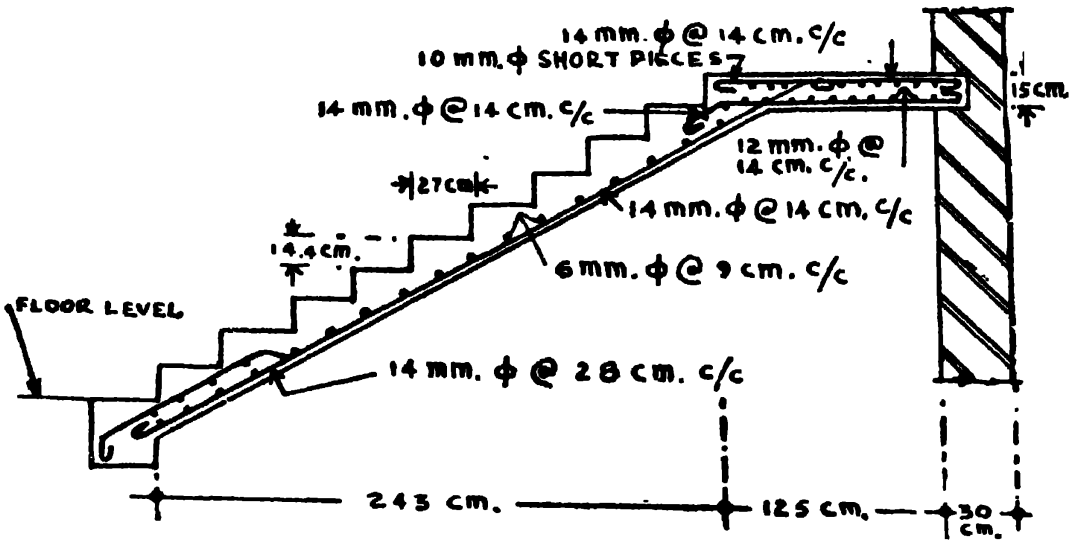
$$= \frac{100 \times 1 \cdot 13}{8 \cdot 07}$$

$$= 14 \text{ cm. c/c.}$$

Distribution bars @ 2% of the area of concrete :

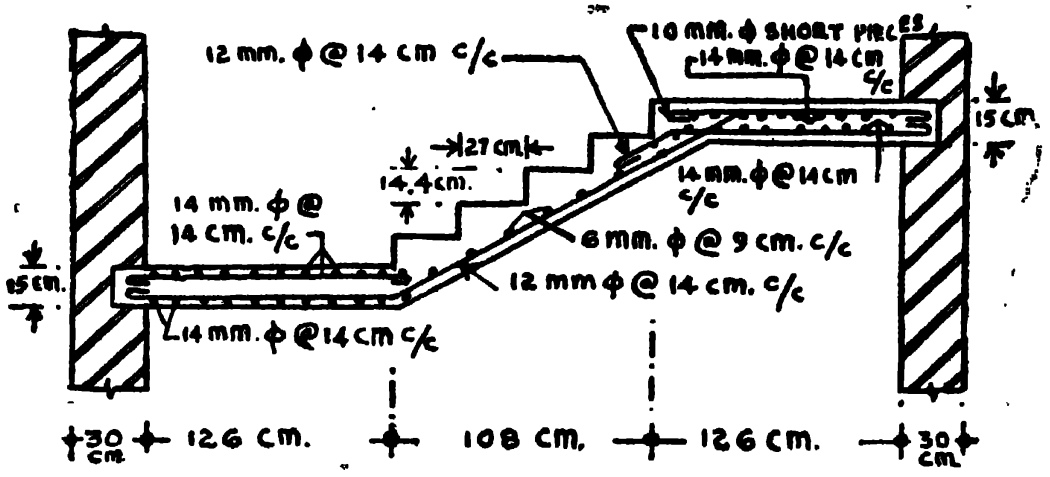
$$= \frac{0 \cdot 2 \times 15 \times 100}{100}$$

$$= 3 \text{ sq. cm.}$$



SECTION-XX

Fig. 13·7



SECTION-YY

Fig. 13·8

Using 6 mm. ϕ distribution bars (area of one 6 mm. ϕ bar 0·28 sq. cm.), pitch of the bars required

$$= \frac{100 \times 0{\cdot}28}{3}$$

$$= 9{\cdot}33 \text{ cm. c/c.}$$

$$= 9 \text{ cm. c/c. say.}$$

Questions for Revision

1. Design an R.C.C. stair located in a stair-case hall measuring 2·5 m. × 5·5 m. The vertical distance between the floors is 4 m. Draw a section showing details of reinforcements.

2. (*a*) Design and draw sketch showing details of a reinforced concrete staircase 1·22 m. wide to connect two floor 4·12 m. apart. The stair case room fs 5·49 m. × 4·88 m. with three side walls, one side being open to the halls in each floor.

(*b*) Give short specifications regarding the material and workmanship for the above construction to ensure satisfactory work.

3. Design from emperical rules a suitable stair-case to connect the ground floor of a public building with its first floor. The stair hall is 6 m. long by 4·5 m. wide, and the height of the first floor above the ground floor is 4 m. Windows are to be provided to light up the stairs.

Draw neat sketches of the plan and sectional elevation of the stairs with dimensions. (*A.M.I.E. Nov. 1967*)

14

Upper Floors

14·1 General. Depending upon the arrangement of beams and girders or the frame work for supporting the flooring and the materials used in the construction of the entire system, the upper floors may be broadly classified into the following different types :

(1) Timber floors.
(2) Timber floors supported on rolled steel joists.
(3) Flag stone floors, resting on steel joists.
(4) Jack arch floors.
(5) Reinforced cement concrete floors.
(6) Ribbed floors.
(7) Pre-cast concrete floors.

14·2 Timber floors. There are three main types of timber floors :

(1) *Single floors*
(2) *Double floors*
(3) *Framed floors*

(1) **Single floors.** They are the cheapest form of wooden floors. They are easy in construction and are frequently used in domestic buildings. These floors are constructed by fixing 25 to 30 mm. thick planking or boarding to wooden joists known as "bridging joists" spaced at 30 to 40 cm. apart. The bridging joists are placed along the short span of the room and are nailed to timber wall plates fixed in the wall on either end. The span for single floor is limited to 3 66 m. as for greater span, the joists become very deep and consequently this system proves uneconomical. The depth of joists depend upon the loading condition of the flooring. The joists are designed both for strength and rigidity. In other words the joists provided should be such that they may safely carry the floor loads without deflection. The joists should not be allowed to come in contact with green mortar or masonry as this would cause the woodwork to rot and decay. Thus a gap is left between the end of the joists and the wall so that there may be free circulation of air round the joists ends. If by any chance there is slight sag in the joists, there is every possibility of the ceiling (if any) fixed to joists to crack.

Strutting of bridging joists : When the span of the room is more than 2·44 m. the bridging joists have a tendency to buckle. In deep joists this tendency of tilting or buckling sideways in prominent. To

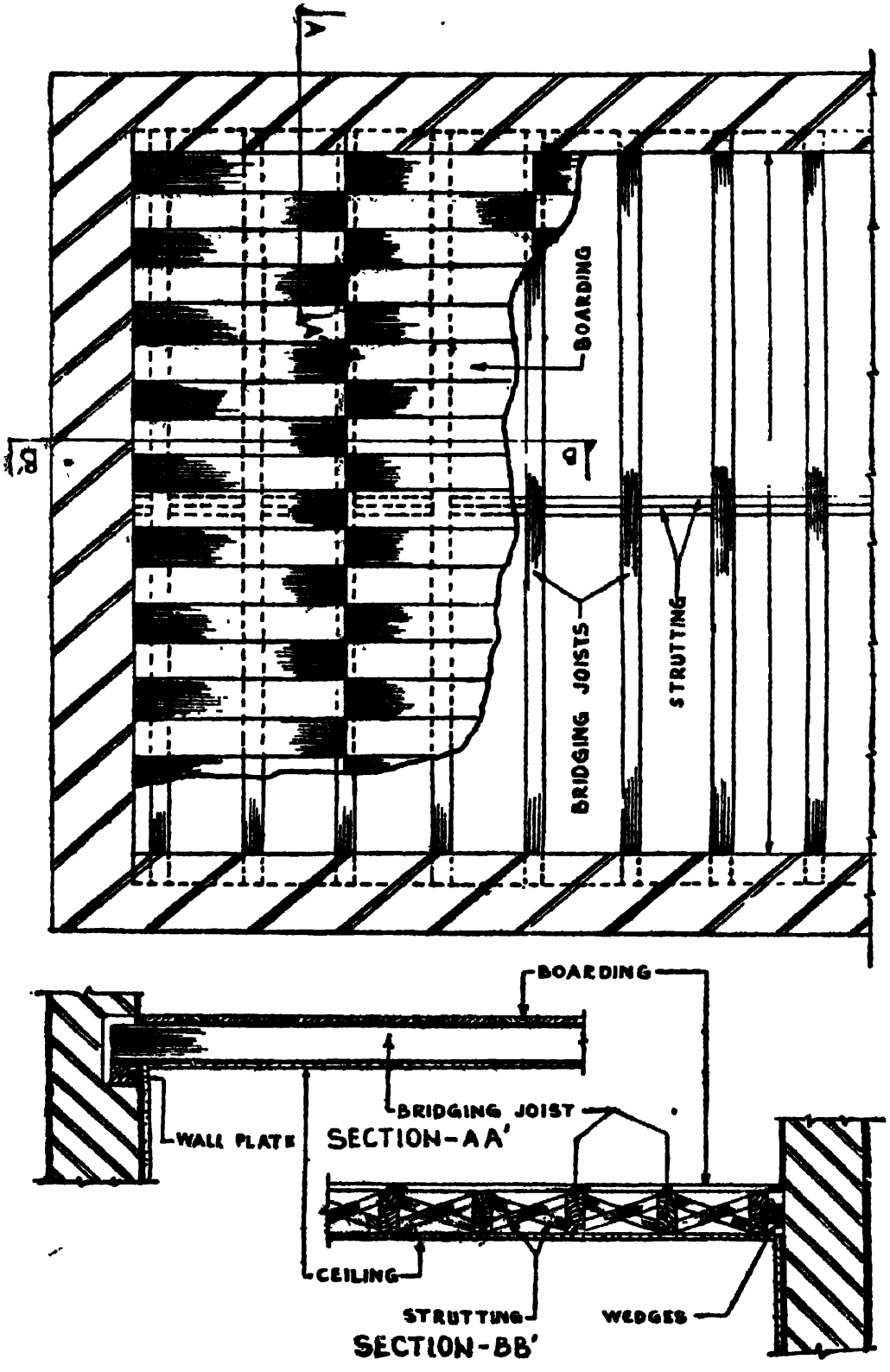


Fig. 14·1

Plan and sections of wooden single floor

prevent this the joists are strutted apart in the midspan all along the length of floor. There are two different types of struttings, namely :

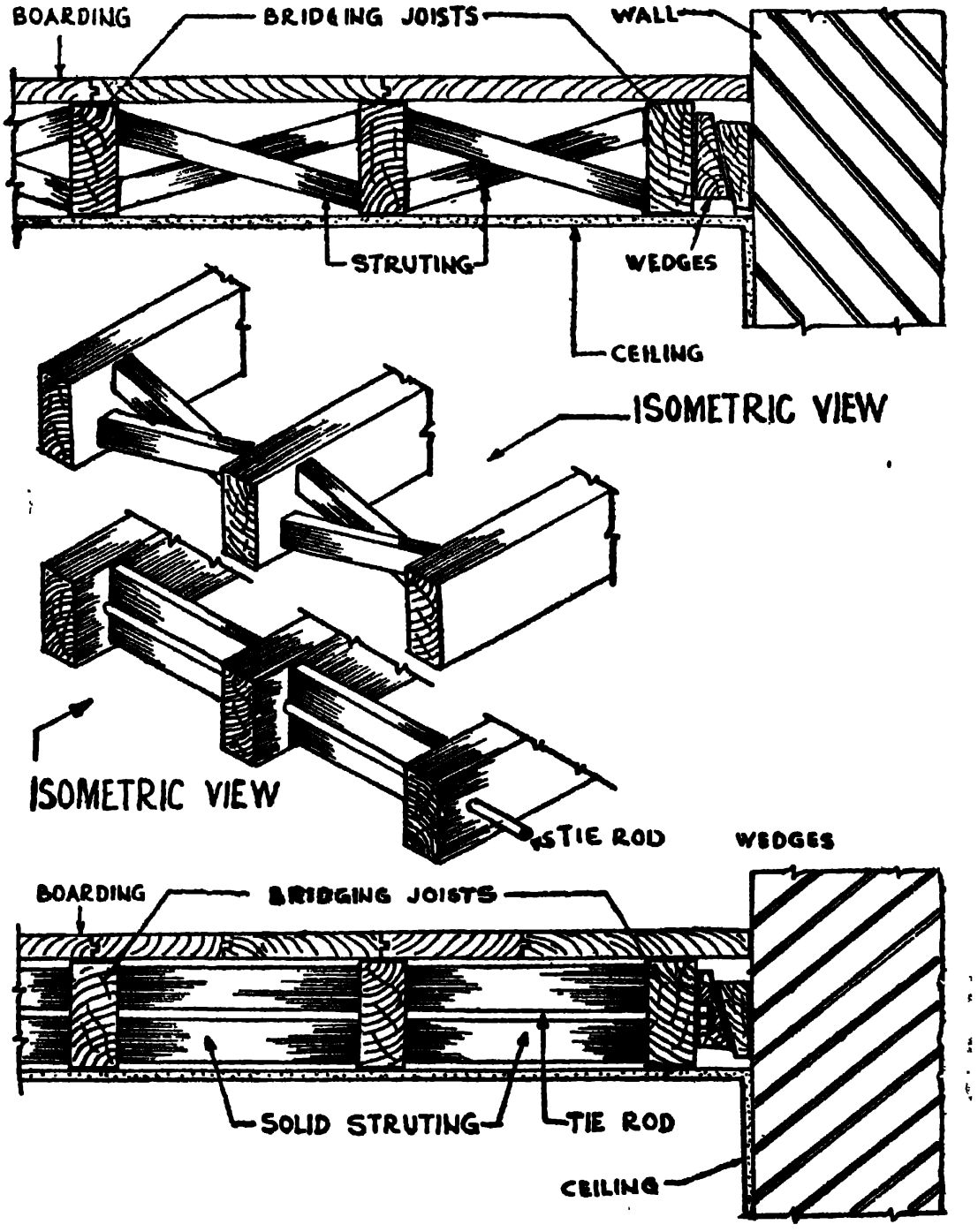


Fig. 14·2

Sectional details and isometric views of Herring bone and solid strutting.

To

(*i*) Herring bone strutting

(*ii*) Solid strutting

Herring bone strutting consists of a system of inclined pieces of timber 2·5 to 3·8 cm. thick and 5 cm. wide fitted diagonally between the bridging joists in such a manner that they cross each other in the middle of the joist. At their ends, the timber pieces are splayed and are secured to the joist by nailing. To give additional strength to the strutting joist, wedges are inserted between the walls and the end joists of the strutting.

Solid strutting is not so strong as herring bone strutting. This consists of short pieces of timber board, 2·5 to 3·8 cm. thick, fixed between the joists in continuous row. The length of each piece being equal to the centre to centre spacing of the bridging joists and breadth being about 20 to 25 mm. less than the depth of the bridging joists. To strengthen the strutting, a 13 to 25 mm. ϕ steel rod, placed by the side of strutting is passed through the mid-depth of all the joists and is tightened at its ends.

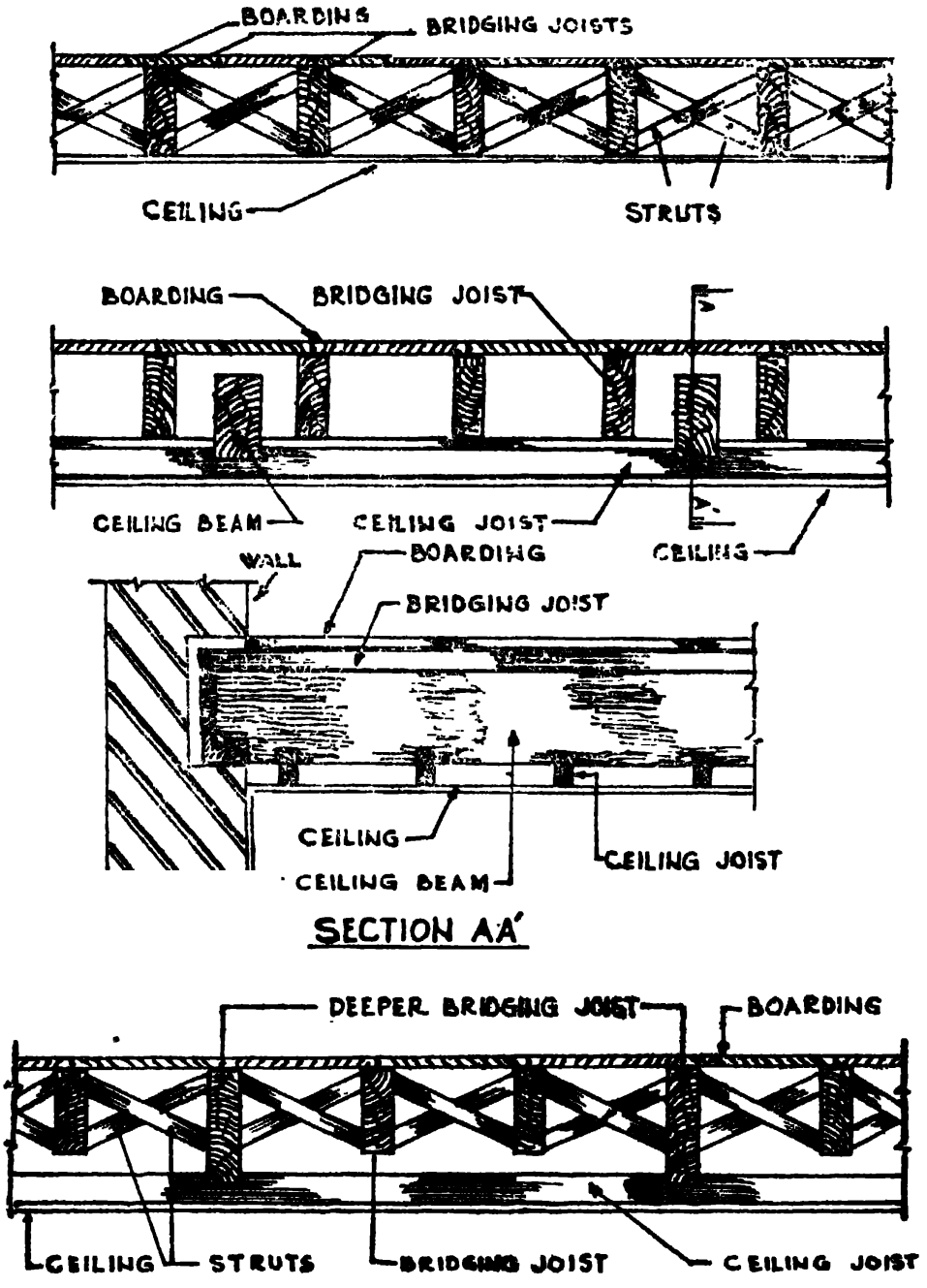
Methods of fixing ceiling : The underside of the floor does not provide a good appearance for the users of ground floor. In order to have the pleasing effect of plain ceiling, the bridging joists must be connected. Ceilings of wood, jack board, floor board, etc. are fitted to the bottom of joists for this purpose. Metal lathe and plastered ceiling are also commonly provided. The various methods of fixing ceiling to the joists are described below.

(*i*) The ceiling boards which may be of wood, jack-board, fibre board or other similar material are directly nailed to the underside of the bridging joists. This is the simplest and cheapest from of ceiling. Due to the vibrations arising in the floor joists on account of the floor usage, this ceiling is liable to crack or open at joints. This type of ceiling is not sound-proof unless specially treated.

(*ii*) In the second method every third or fourth joist is made deeper and the ceiling is nailed to the ceiling joist fixed to the deeper joists. Although this type of ceiling renders the floor more sound-proof, but the increased depth of bridging joists (which is not necessary from structural considerations) required for fixing ceiling, makes the floor deeper and ceiling costly.

(*iii*) In the third method the ceiling is supported entirely independent of the flooring. Separate beams called "ceiling beams" are laid parallel to the bridging joists at suitable distance apart. The ceiling, strong and rigid enough to carry ceiling loads, is fixed in the wall plates in the end walls and is kept about 20 to 25 mm. below the bottom face of the boarding. Ceiling joists are fixed at

right angles to the ceiling beams. Ceiling of required material is then fixed to the ceiling joists as shown.



Figs. 14·3—14·6

Methods of fixing ceiling to wooden floors

Method of Sound-proofing of Timber floors. In its simple form, the method of sound-proofing of timber floors consists in dividing the space between the bottom of the boarding and the ceiling by

Top

means of insulating-material. This insulating material obstructs the sound waves and does not allow them to travel from floor to the ceiling. The base for storing the insulating material is made by fixing small timber piece (fillets) on either side of each bridging joist which supports the insulating boards. Upon these boards insulating material which may be sand, dust, asbestos, cork, slag wool, etc. is filled as shown in the figure below.

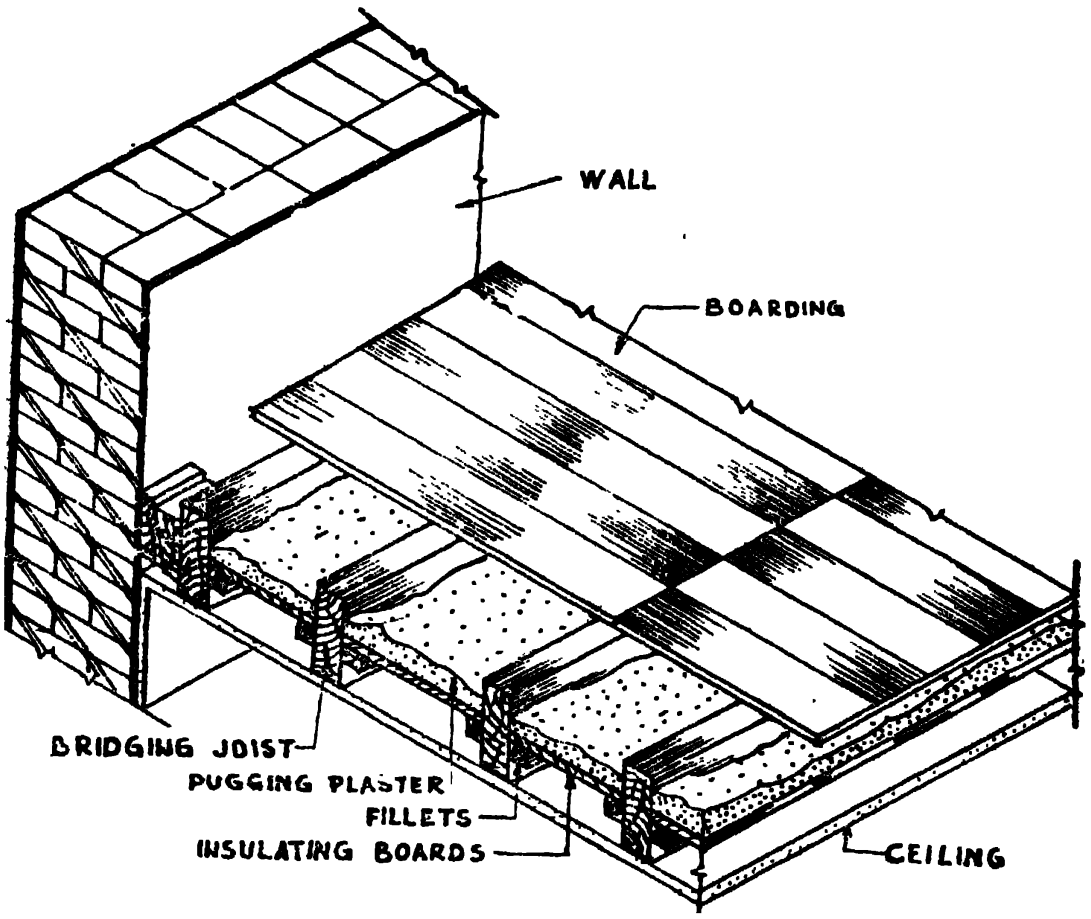


Fig. 14·7

Section of a wooden floor showing method of making it sound proof

(2) **Double floors.** In case, the shortest span of the room is more than 3·66 m. and it is desired to provide a timber floor, double type of timber floor may be constructed. The span of double floors is restricted to 7·32 m. beyond which framed floors have to be adopted. In double floors the bridging joists do not span the whole room, but rest on other joists placed at right angles to them. These joists are called binding joists or binders and are placed across the short span. Thus in double floor, the bridging joists support the boarding and the binders support the floor load through bridging joists. The centre to centre spacing of the binder varies from 1·8 to 2·4 m. At their ends, the binders rest on stone or concrete templates embedded in

the walls. If possible, the binders should not be placed immediately over door or window opening, but if this cannot be avoided, they should rest on lintel or beams (of stone or R.C.C.) which may span over piasters between the openings. There are two different ways

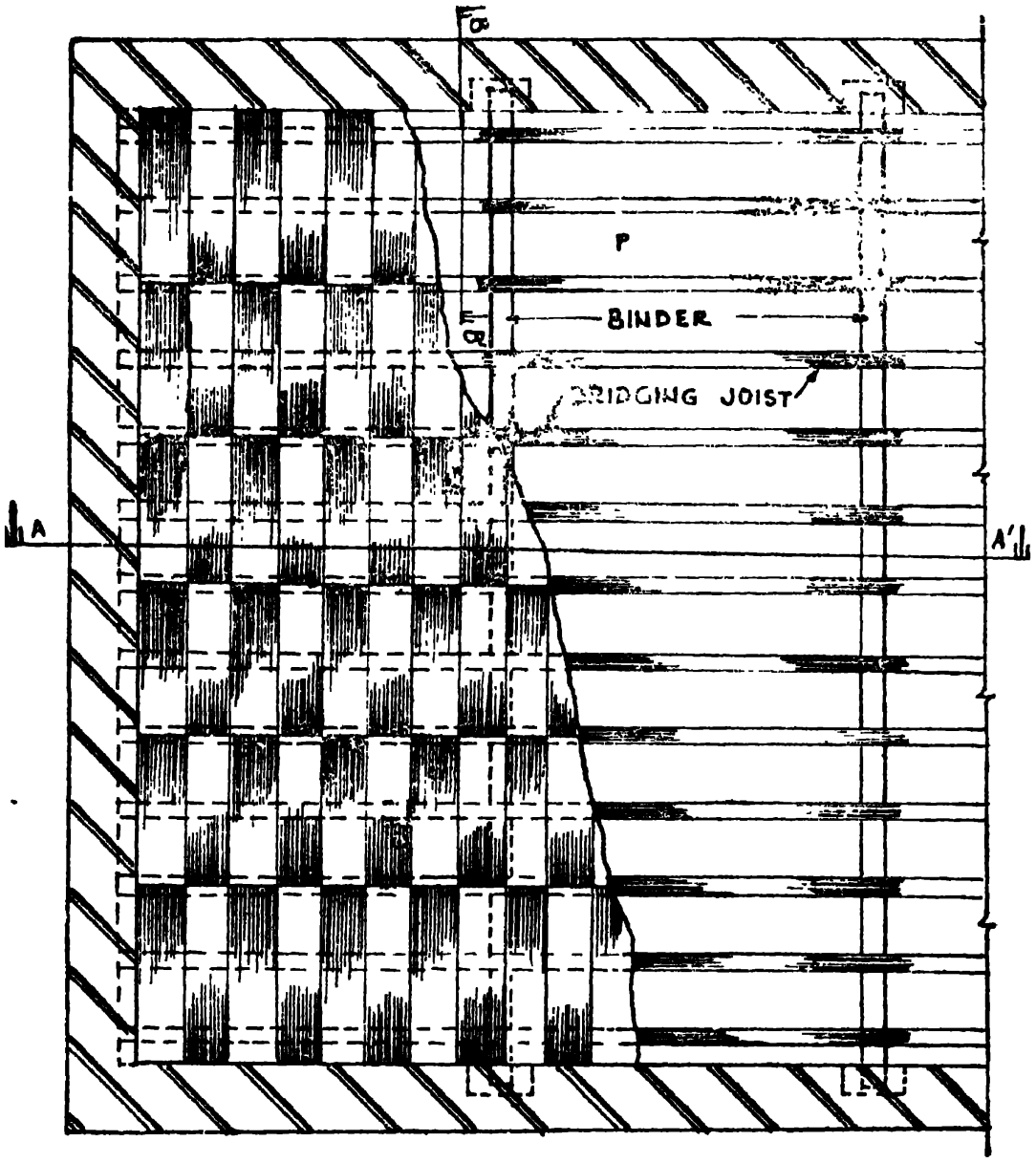


Fig. 14·8

Plan showing arrangement of supporting boarding in a wooden double floor

of fixing the bridging joists to the binders. In one, the bridging joists are cogged to the binders (*i.e.* notches are cut on the top of binders and the bridging joists are fixed on them). The depth of

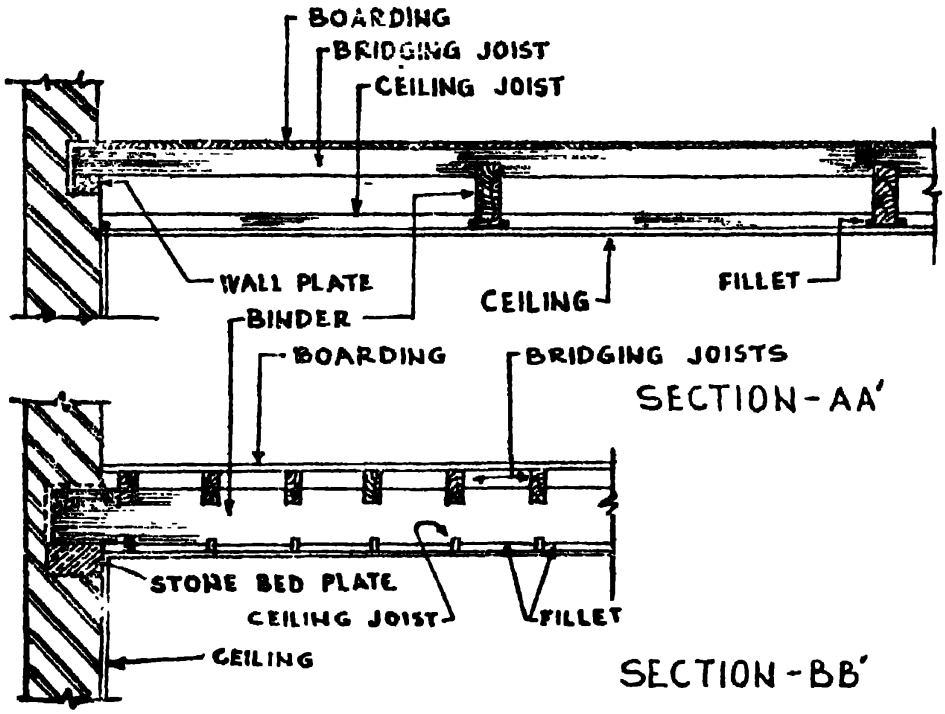
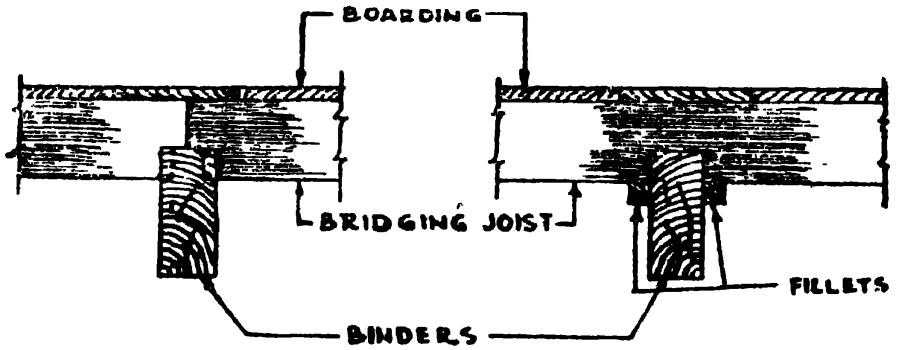
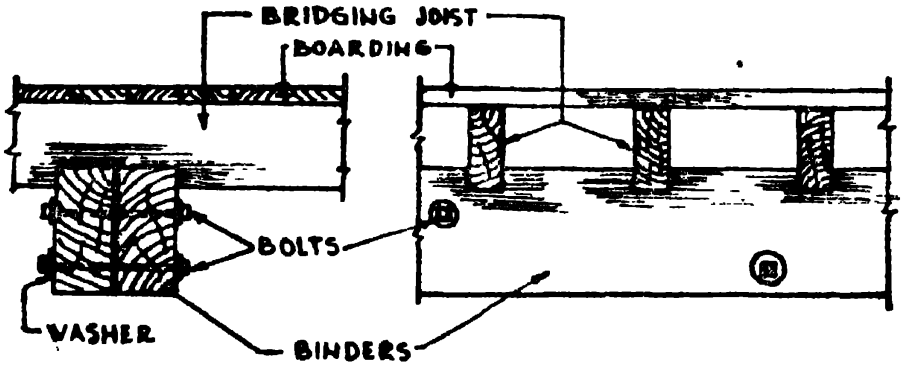


Fig. 14·9





Figs. 14·10—14·13

Details showing the different methods of supporting bridging joists

notch should not be more than $\frac{2}{3}$rd depth of the bridging joists and width of notch may be 25 mm. The disadvantage of this method is that the cutting of the notches on the compression side of the binders render them weak in strength. In the second method, timber pieces or fillets are fixed on either side of each binder and the bridging joists are cut as shown, so as to rest on fillets. This method of fixing is better than the first one. This type of floor is stronger and more rigid than single floor construction and has better sound insulating property. The plastered ceiling fixed to the binders through the formwork of fillets and ceiling joists, is not liable to crack in this floor. Double floors are costlier than single floors and have increased depth of floor which reduces the head room. In some places where the floor is subjected to such loading conditions as would require deep wooden binders making the floor deep excessively, the depth of the floor can be appreciably reduced by providing R.C.C., steel or flitched binders.

The alternative methods of floor fixture using different types of binders are shown in the figures 14·10—14·13.

(3) **Framed floors.** When the shortest span of the room or hall exceeds 7·6 m., framed floors are provided. In this system of wooden flooring, boarding is supported by bridging joists laid parallel to the short span. Bridging joists are fixed to the binder laid parallel to the long span or at right angles to the bridging joists. The binders are further supported or fixed into large and heavy

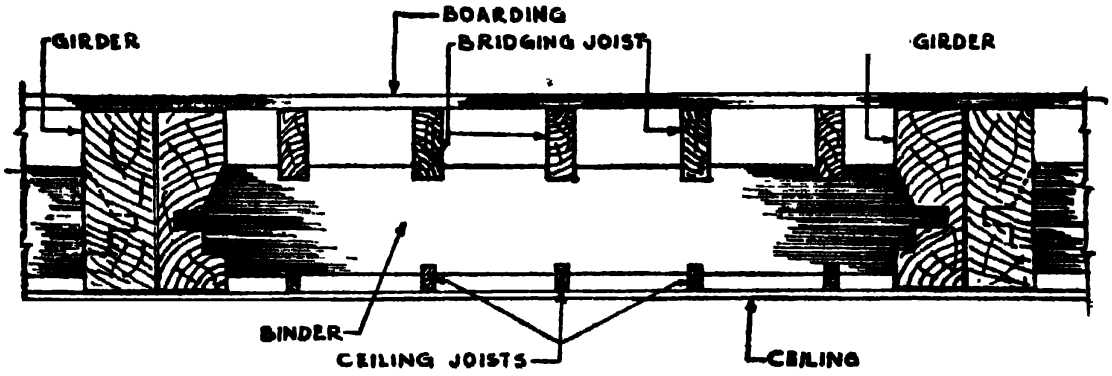


Fig. 14·14

Section through a framed floor

beams called girders and are placed parallel to the short span. The centre to centre spacing of the girders depend upon the loading conditions and the size of the binders. At their ends, the girders are supported on stone or concrete templates embedded in walls. To avoid the loss of headway or to reduce the thickness of floor, the binders are framed into the girders by means of tusk and tenon joint. A gap is left between the walls and end of girder so as to ensure a free circulation of air at the ends, and avoid the defect of

rot or decay. It is important to note that the ends of two binders from opposite sides should never be framed into the girder at one place, as it would weaken the girder considerably. The binders should be framed in a staggered fashion.

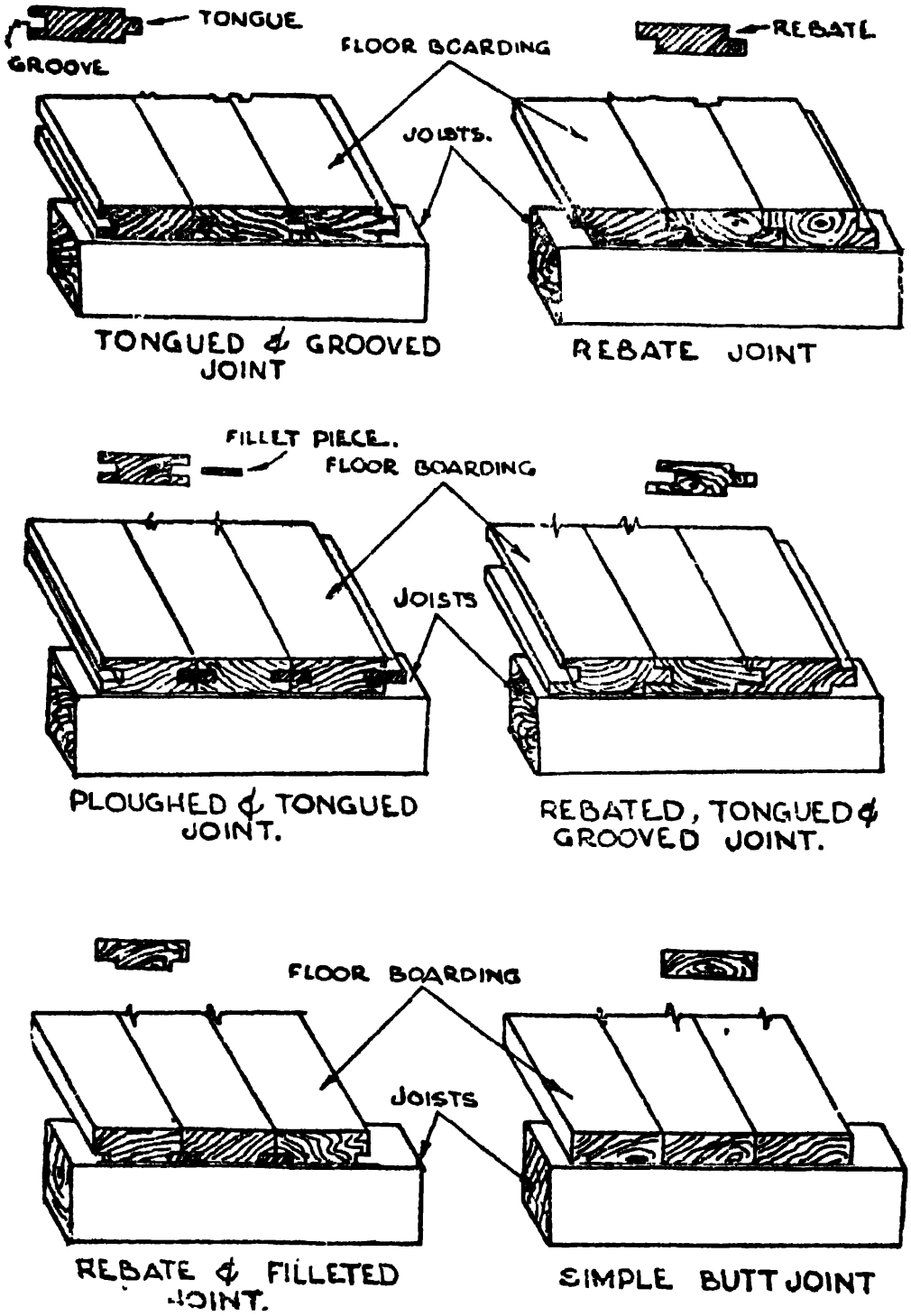


Fig. 14·15

Views shcwing different types of joists used in floor boarding

14·3 Timber Floors Supported on Rolled Steel Joists. This system of flooring is similar to ordinary timber floor except that wooden joists are replaced by rolled steel sections which are available in longer lengths. This enables the use of lighter sections of wooden members which ultimately make the floor economical. In order to reduce the depth of floor, the joists supporting the flooring are notched over the top flanges of the girder and are made to rest upon angle iron cleats bolted on either side of each rolled steel joist.

14·4. Flagstone Floors Resting on Steel Joists. It is a cheap and easy form of floor construction. If the width of the room is not more than 3·66 m., rolled steel joists of smaller sections are spaced at 30 to 45 cm. centre to centre along the width of the room.

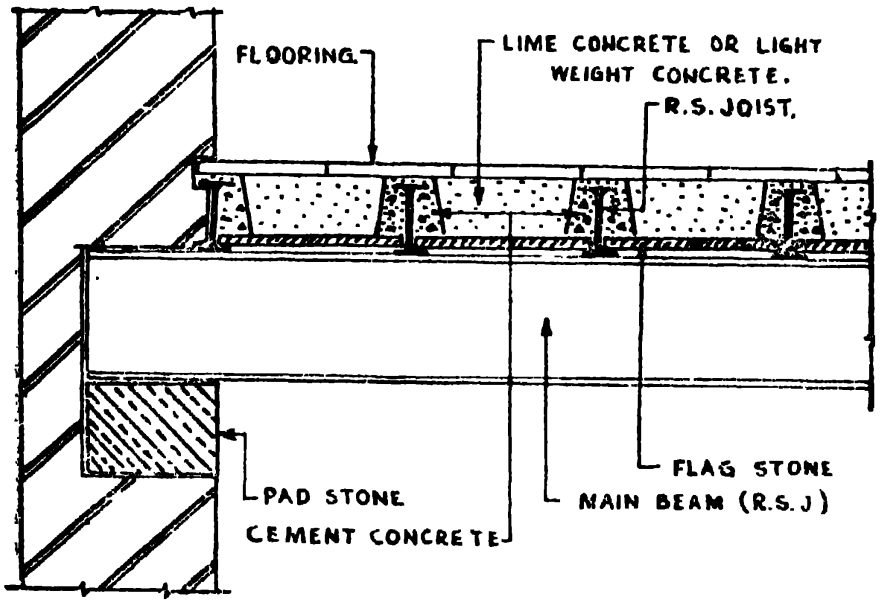


Fig. 14·16

Flagstone floor resting on steel joists

38 mm. thick flagstones of width equal to the centre to centre spacing of the joists are placed on the lower flanges of the R.S.J's. Portion above the flagstone is then filled with light weight concrete, lime concrete, moorum or mud so that the consolidated thickness of filling lies about 13 mm. above the flanges of joists. Finally tiles, cement concrete, flagstone or any other desired type of flooring can be laid upon the filled material. If lime concrete is used as filling material, the steel joists are protected from the rusting action of lime by providing a screen of cement concrete round them or by applying a coat of bitumen or paint on the surface of the joists.

If the shortest span of the room exceeds 3·66 m. in its dimensions, the smaller steel joists are supported by bigger rolled steel joists (or steel beams) of the designed sections. The steel beams

span the width of room and are spaced at 2·4 to 3 m. apart. The method of laying flagstones and filling above is the same as described above.

14·5. Jack Arch Flooring. This type of flooring may be constructed by using brick or concrete. The arches span between the lower flanges of rolled steel joists, spaced at centre to centre distance not exceeding 1·2 to 1·5 m. The arch is given a rise of $\frac{1}{12}$th of the span. As the arch action of floor develops tension in the supporting walls, mild steel ties (not less than three in a bay), are provided in end span at suitable distances apart. The diameter of the tie rods varies from 18 to 25 mm. and they are usually spaced at 1·8 to 2·4 m. apart. The tie rods are anchored into each wall with a stout washer. The floor may be finished with tiles, cement concrete, mosaic or any other desired finishing after filling the space above the arch with lime-concrete or other filling material. The ceiling in this type of construction is not plain and this is considered a defect of this flooring.

Method of construction of brick Jack arch flooring : The centring of the arch consists of a 38 mm. thick segmental piece of timber with a chord length equal to the span of the arch and the curved portion of the arc forming the soffit of the arch curve. The centring board is cut slightly at its ends and is laid on edge with the curved portion upwards, on the lower flanges of the rolled steel joists at a distance of 7·6 cm. from the wall. The selected bricks are then laid on edge on the centering board from both the ends of the arch. The end bricks are cut suitably to the required shape to enable them to fit in the joists properly. In order to prevent to joists from the rusting action of lime, the joint next to the joist is filled with cement mortar. In the first arch ring, the bricks are arranged in length of 20 and 10 cm. alternately. This is necessary to secure a bond between the first and the successive arch rings. The key brick is laid in stiff mortar and is filled in the arch as tight as practicable. The centring board is then advanced further by light hammer blows in a new position which is 20 cm. ahead of the previous one and the second arch ring is constructed.

Similarly, the successive rings are constructed. The entire work is kept wet for 10 days. After this. the space is filled with lime concrete, moorum or light weight concrete or any other desired fill. Finally, the required type of flooring is laid above the consolidated filling. The following precautions are necessary to be observed in the brick arch construction.

(1) Only first-class bricks, which are well wetted before, should be used in arch construction.

(2) It should be ensured that the steel joists are well secured to the supporting wall before starting the arch construction.

(3) If lime concrete is used for filling the haunches of the arches, the R.S.J's are protected from the rusting action of lime concrete by providing a screen of cement mortar round them.

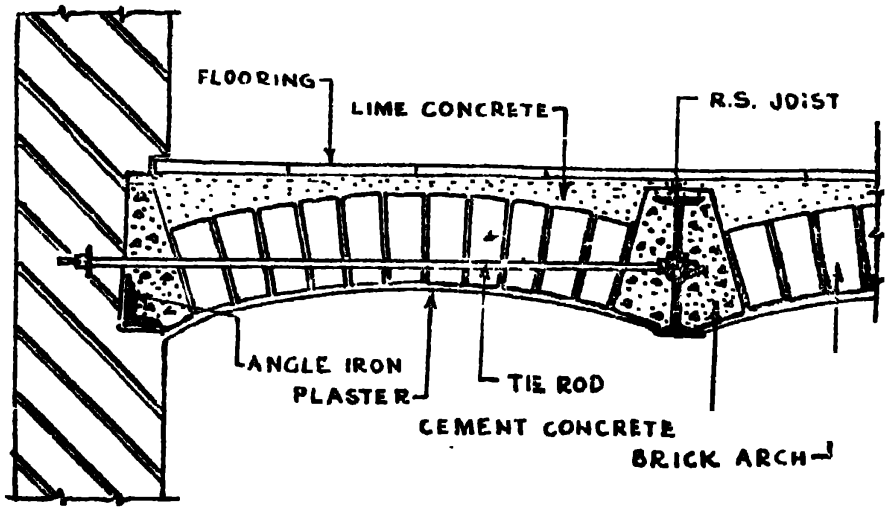


Fig. 14·17

Brick Jack arch flooring

(4) The work should be property cured for at least 10 days.

(5) Filling above the arch and construction of floor should start only after curing has been complete.

Construction of concrete Jack arch flooring : The centring for concrete arch construction consists of 3 mm. thick mild steel plate bent to the shape of the arch soffit. The steel plate has holes at 75 cm. centre to centre all along the length of the plate at each end. In order to support the mild steel centring two 12 mm. diameter iron rods of suitable length are employed. Each rod is hooked at one end so as to form eyes large enough to allow a 12 mm. diameter rod to pass through them. Each rod is passed through the eye of the other and the straight ends of the bars are then passed through the holes in the mild steel plate and are supported on the two flanges of the rolled steel joist. Thus the centring plate gets supported on the lower flanges of the joist through the iron bars at every 75 cm. along the length of joists. A wooden paking piece is tightly driven between the rods and the mild steel plate in order to make the centring more rigid.

Concrete of the specified mix is then laid on the top of the centring plate to the required depth and consolidated properly. Desired type of flooring is then laid over the concrete base and

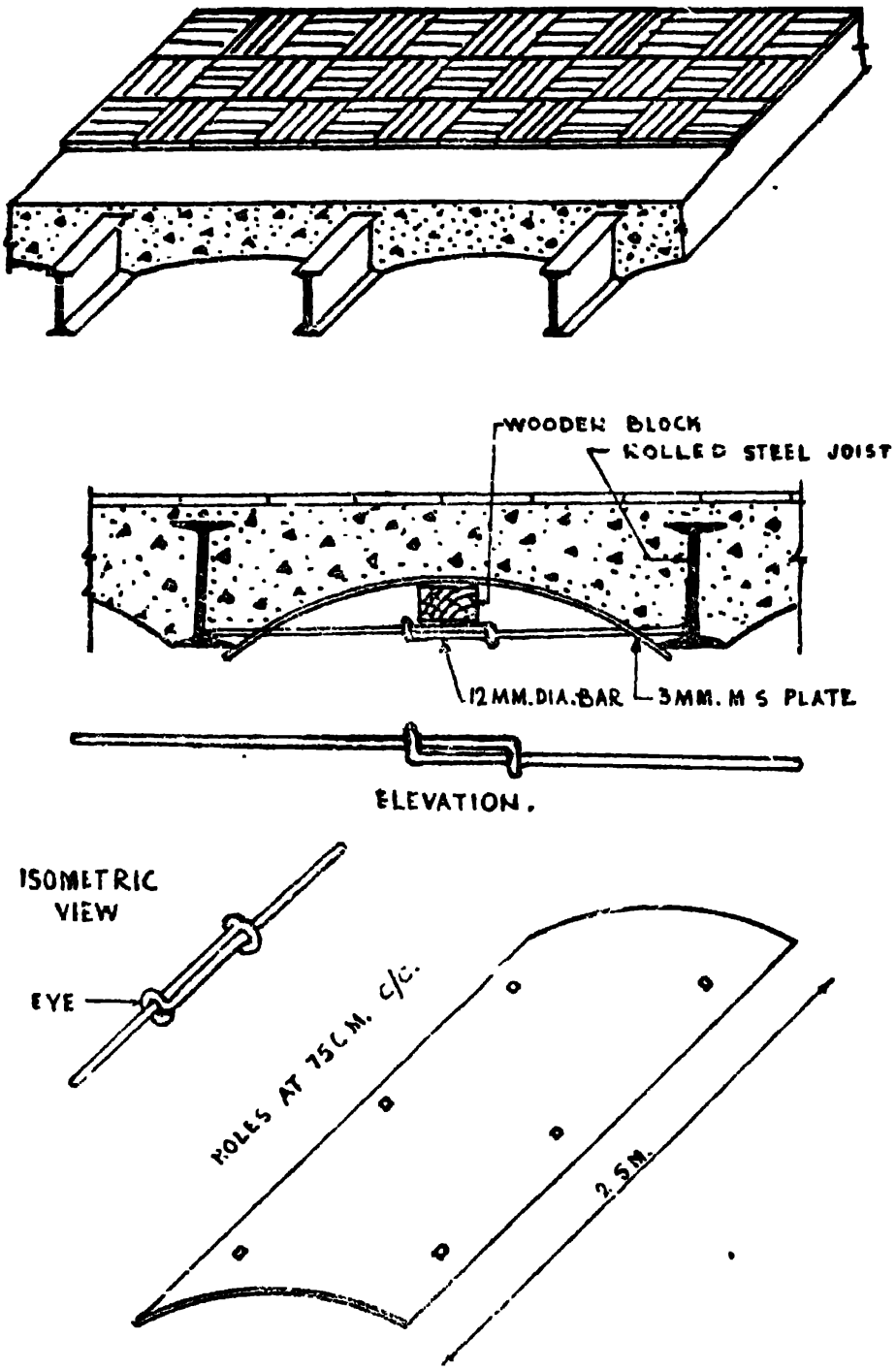


Fig. 14·18

Concete Jack arch flooring

finished. The whole flooring is kept wet for least 10 days. After the curing is complete, the centring is removed by removing the wooden packing piece and then hammering the eyes in the rods towards each other. The under-side of the arch is then plastered to improve the

appearance of the surface. The precautions for brick arch construction hold good for concrete Jack arch also.

14·6 Reinforced Cement Concrete Flooring. On account of a number of advantages of the material, R.C.C. flooring has become very popular these days. Though strong in compression, concrete is extremely weak in tension. Its resistance to tension is so low that plain concrete can be only used where the member is in pure compression. Steel is equally strong in compression. Thus the combination of concrete and steel has proved to be ideal for floor construction. R.C.C. floors can be classified in the following main types :

(*i*) R.C.C. slab flooring.

(*ii*) R.C.C. beam and slab flooring.

(*iii*) Flat slab flooring.

(*iv*) R.C.C. ribbed flooring (Hollow tiled flooring).

(*i*) *R.C.C. slab flooring* : For small spans say 3·66 m. which are not subjected to heavy loadings, a simple slab may suffice. When the ratio of length of the room to its breadth is greater than 2, the floor slab is designed to span a long the width of the room as a one-

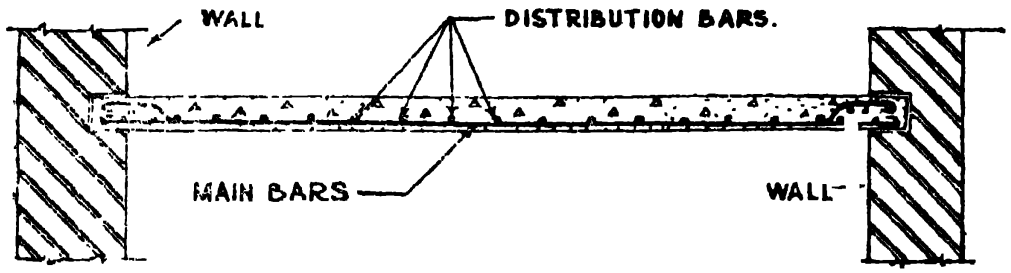
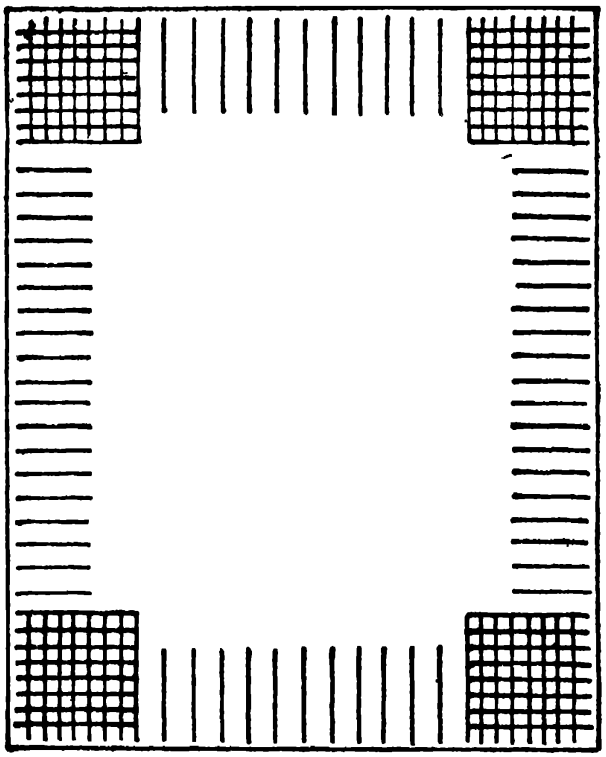


Fig. 14·19
Section through a one-way R.C. floor slab

way slab. In this case, the main reinforcement of the slab span along the width, while distribution bars are laid parallel to the length of room. Depending upon the building plan, the slab may be simply supported on the wall, or it may be continuous over intermediate walls. The design of a continuous floor slab is different from that of a simply supported one. If the length to breadth ratio of the room is less than 2, the floor slab is designed as a two way reinforced slab. In this case, main reinforcements are provided both along the length as well as along the breadth of the room. The details of reinforcements in such types of slabs are shown in the Fig. 14·20.

The maximum bending moment for which the slab should be designed varies with the nature of the slab (whether one way reinforced or two-way reinforced) loading conditions, the number of spans and the end conditions of the slab. The bending moment

which causes tension at the bottom of the slab, usually near the centre of the span, is called positive or sagging bending moment and the bending moment which causes tension at the top of the



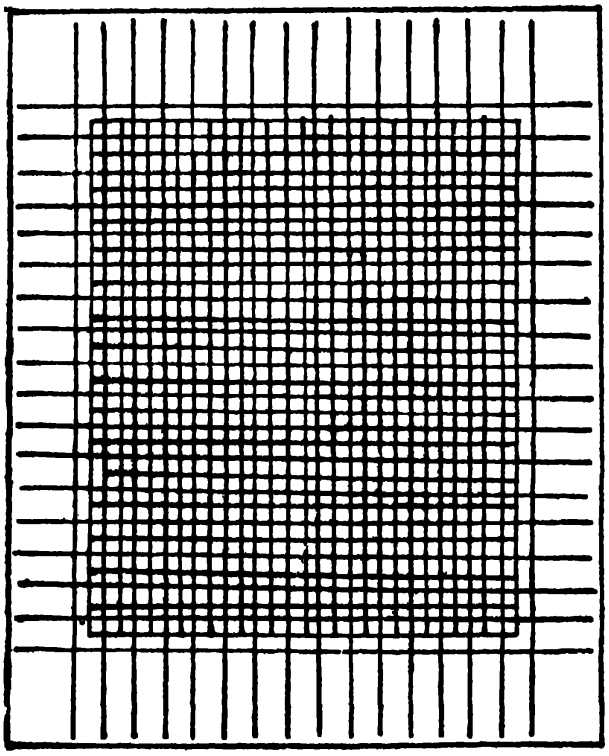


Fig. 14·20
Two-way reinforced slab

slab, usually over the supports, is called negative or hogging bending moment. Thus for positive bending moment, the main reinforcements are placed near the bottom face of the slab while for negative bending moment, the main reinforcements are placed near the top face of the slab.

(*ii*) *R C C. beam and slab floor* : For bigger spans and heavy loading conditions or in situations where intermediate walls are not provided, to reduce the span of the floor slab, R.C.C. beam and slab construction is adopted. The beams act as intermediate walls and

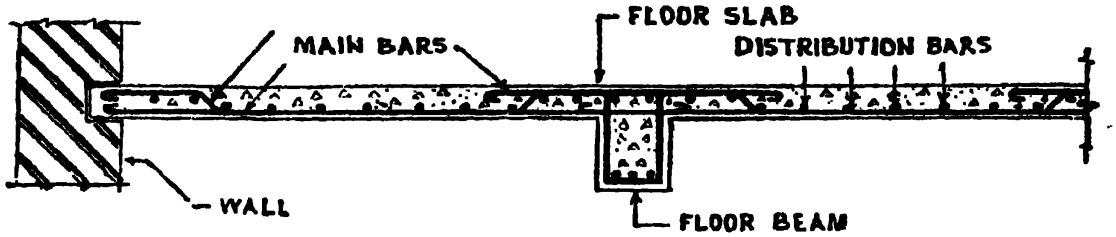


Fig. 14·21
R.C C. beam and slab floor

the floor slab is designed as a continuous slab monolithic with the beams. The beams thus used are known as T-beams because a part of the floor slab assists in resisting the compression developed in the beam. The projecting part of the beam below the slab is called the rib of the beam. In a framed structure the floor is usually supported on a system of main and secondary beams. The floor slab is laid continuous over secondary beams which are framed into and supported by main beams.

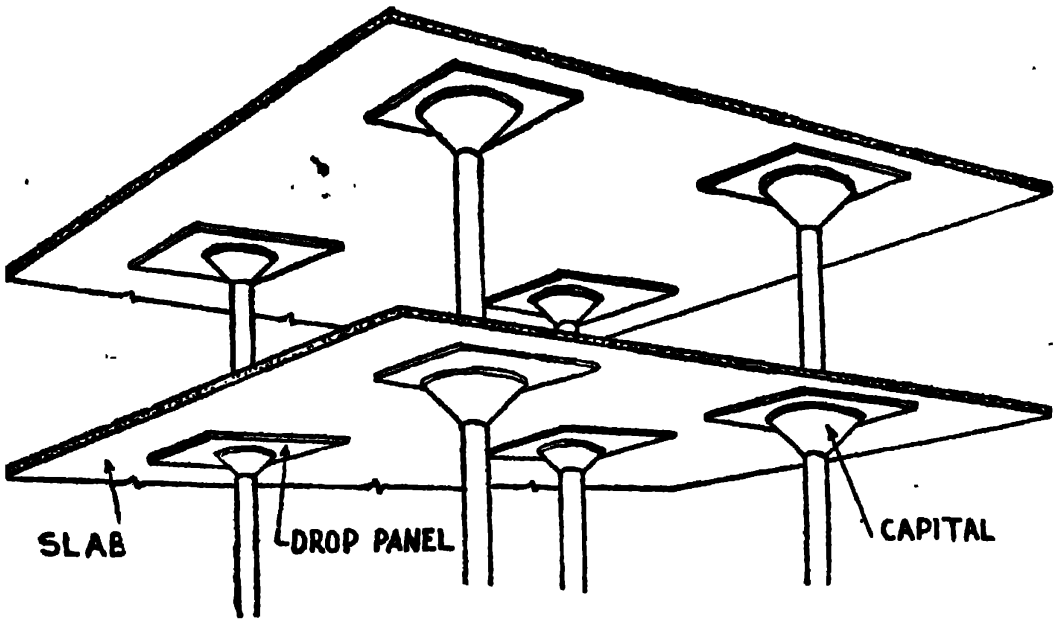


Fig. 14·22
View showing flat slab construction

(*iii*) ***Flat slab flooring*** : Flat slab, also known as beamless slab, is a type of construction in which the flooring slab is directly supported on columns without the agency of beams or girders. They are provided in theatres, factories, mills and other public buildings. The flooring consists of R.C.C. slab, 13 mm. or more in thickness and supported on R.C.C. column arranged in such a manner that they

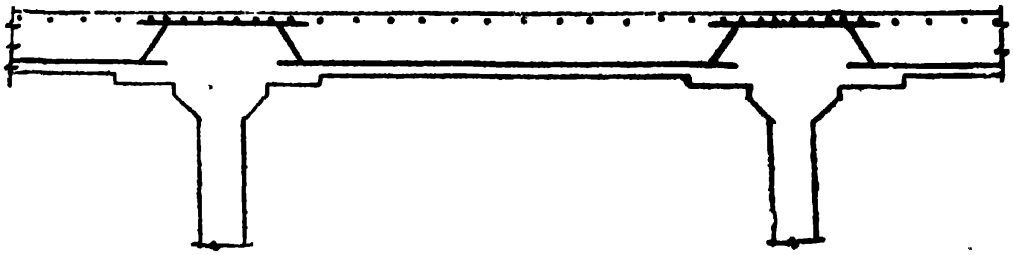


Fig. 14·23
Section through the column strip

form square of nearly square panels. The size of panel should not exceed 9 m. × 9 m. There must be at least three rows in two directions at right angles. The ratio of length to breadth of a panel should not be more than 4 : 3 and the length and breadth of any two adjacent panels should not differ by more than 10% of the greater length. Sometimes, instead of providing uniform thickness of slab, a portion of slab is thickened symmetrically round the column. The thickened portion is called drop. The flat slab may be designed either with or without drops. At their head, 4 cm below the drop, the columns are enlarged so as to form diameter equal to 0·21 to 0·25 of the span. This flared up portion of column head is called capital. There are two different systems of providing reinforcement in flat slabs, namely—

(*i*) Two-way system.

(*ii*) Four-way system.

In two-way system, reinforcements are carried from column to column parallel to the side of panels and a two-way system of reinforcement is placed in the central portion of the slab.

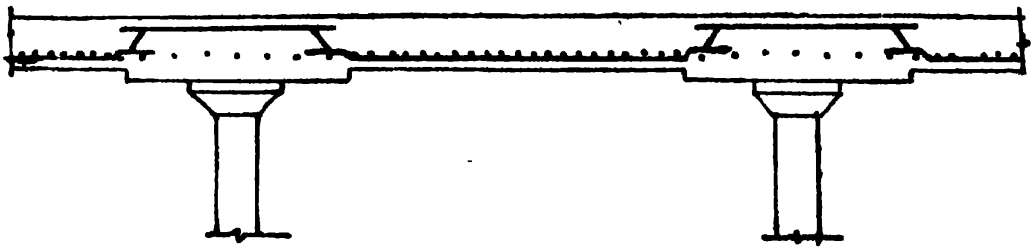


Fig. 14·24
Section through the midstrip

In four-way system, reinforcement is placed in four directions and it consists of two bands of main steel reinforcement carried directly from column to column, and two other bands placed diagonally across the panel from column to column.

Advantages : The advantages of flat slab flooring may be summarised as below :

(1) Since the slab is constructed without any beam or girder, the floor has a flat ceiling which gives a good appearance.

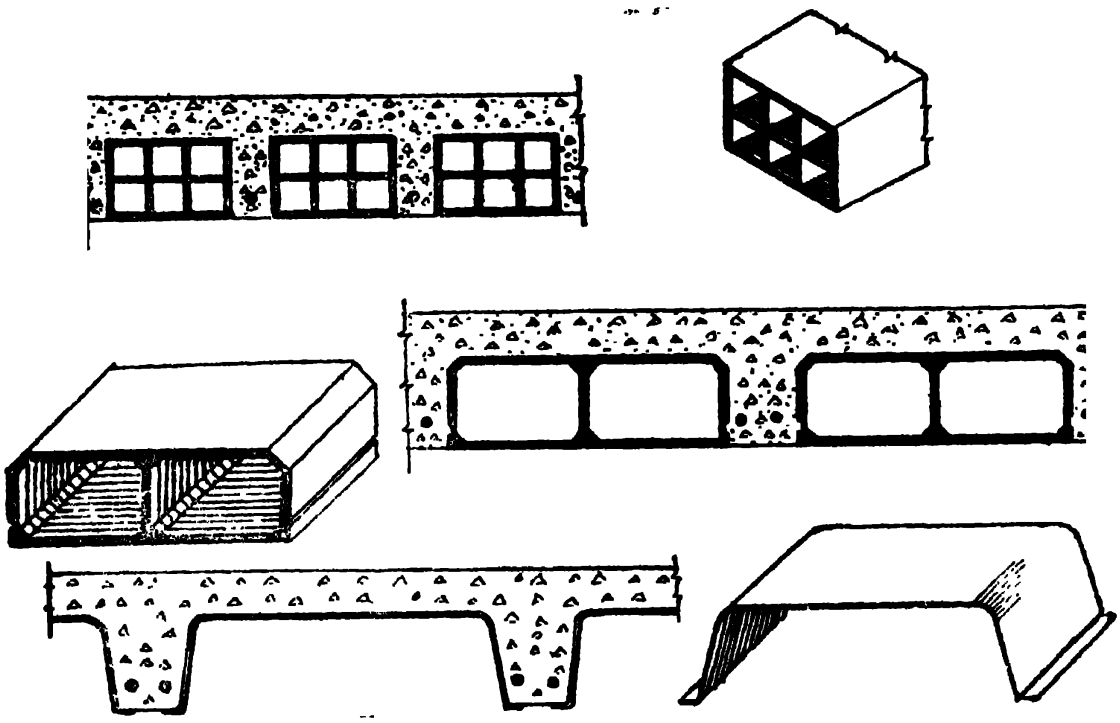
(2) Due to climination of beams and girders there is a saving in storey height.

(3) Due to flat ceiling, better lighting facilities are available.

(4) The formwork is simple and economical.

(5) It is structurally economical, especially when the live loads are more than 500 kg./m^2.

14·7 Ribbed floor. It is a form of reinforced concrete floor slab construction in which the portion of concrete below the neutral axis of slab is removed so as to form ribs at short distances apart. The ribs act monolithically with the concrete topping and behave



Figs. 14·25—14·30

Fig. 14·25 Section showing ribbed floor

Figs. 14·26—14·27 View of tiles used for filling the space between two rib

Figs. 14·28—14·29 Ribbed floor with steel forms

Fig. 14·30. View of a metal pan

like T-beams. The space between the ribs is filled with hollow tiles, which may be of clay, gypsum or concrete. For buildings supporting light weight and medium live load, this type of floor construction proves economical. The overall thickness of slab depends upon the loading conditions. When either metal pans or blocks are used, the only formwork necessary is the strip of wood work under each rib, thereby making an additional saving in the cost of the structure. Metal pans are made of light gauge metal, if they are to be left in place and are of a heavier gauge if they are to be removed and re-used in another place.

In case it is desired to have a smooth plastered flat ceiling, a continuous metal lath is fixed from the under-side of the rib and plastered.

In places where the loading conditions are such that the depth of R.C. ribs will work out to such a value that it cannot be adopted on account of certain practical considerations, the rolled steel joists are placed at suitable distances apart to support the floor (Refer to Figs. 14·33—14·34). The R.S J. may also be enclosed with concrete as shown in the sketch in (Figs. 14·32, 14·35 and 14 36)

14·8 Pre-cast Concrete Floor. With the development of reinforced concrete constructions, the pre-cast units like floor slabs, beams or girders, lintels etc. are being successfully manufactured by various factories. The pre-cast units of the designed depths are used in the floor construction. The members are made of such sizes as can conveniently be handled and transported. The advantages and disadvantages of this type of construction are given below :

Advantages

(1) The construction is quick.

(2) It is fire-proof.

(3) It is sound-proof.

(4) The members are light in weight which render the foundations economical.

(5) It does not require formwork in construction.

(6) No time is wasted for curing of the floor.

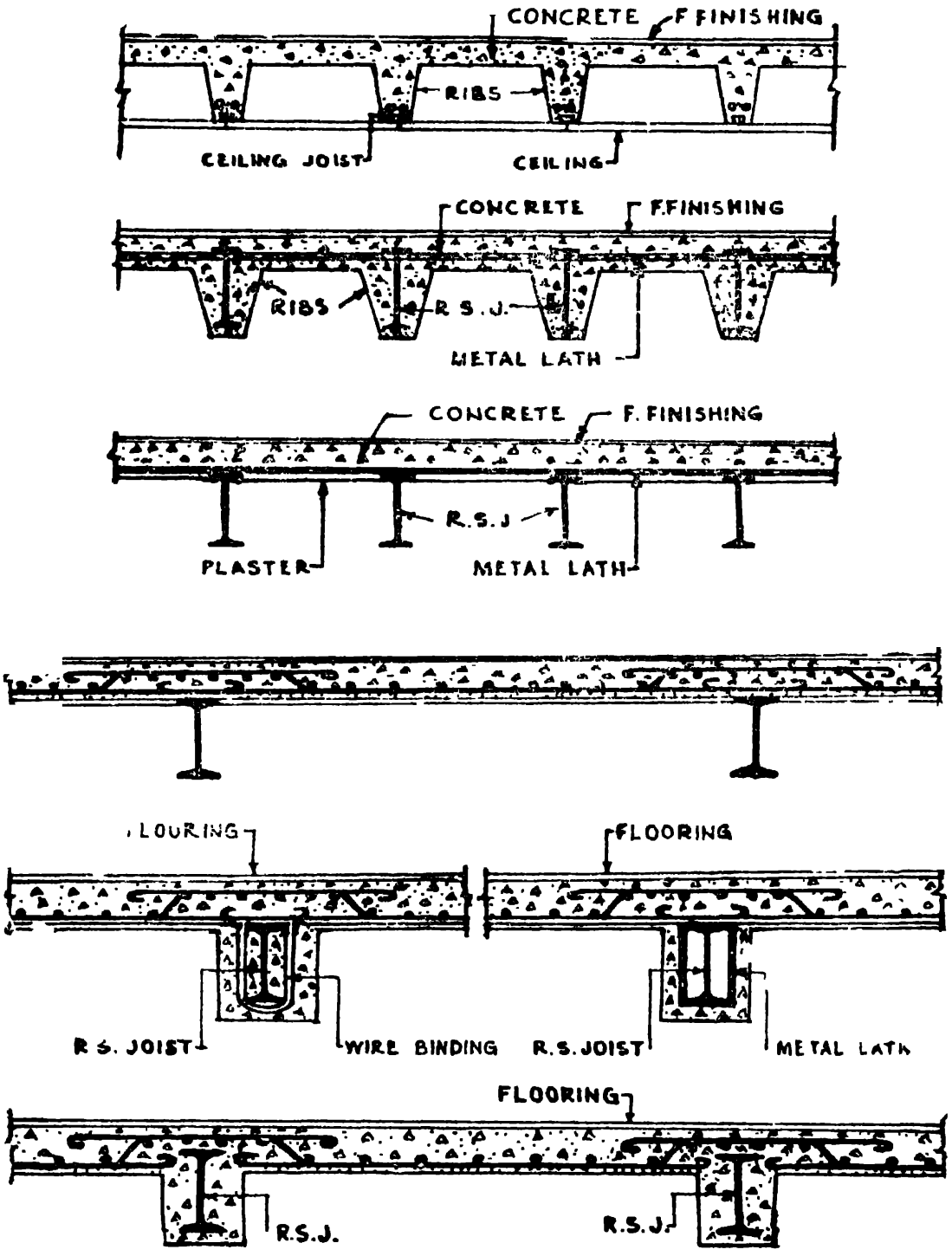
(7) It is economical.

(8) It has good thermal insulation effect.

Disadvantages

(1) It requires fairly uniform spacing of beams throughout the structure which becomes practically difficult.

(2) In order that the pre-cast members may be able to resist handling stresses, great care is taken in their construction and design.



Figs. 14·31—14·36

Alternative methods of supporting R.C.C. floor slab

(3) There is wastage due to breakages in transportation of the members from factory to the site of work.

(4) Careful supervision and skilled labour is required for manufacturing the units.

(5) The forms used for casting the units are very costly and as such the construcrion is economical only when the units are manufactured on a large scale.

Questions for Revision

1. Sketch and name different types of joints that are used in the construction of different types of wooden floors.

2. Draw with neat sketches the following types of floors:
   (*i*) Filled joist floor :
   (*ii*) Jack arched floor.
   (iii) Double framed timber floor.

3. Describe the disadvantages of a beamless floor. Draw a view to illustrate the following :
   (*i*) Capital.
   (*ii*) Drop-panel.
   (*iii*) Flat slab.

4, Draw to a suitable scale the plan and section of a teak wood flooring at first floor level, to be constructed over a 3·66×4·54 cm. room which has all four walls 1½ brick thick. Give sizes of teak wood supports and boarding.

5. Write short notes on :
   (*a*) Timber floors.
   (*b*) Jack arch floors.
   (*c*) Flag-stone floor supported on steel joists.
   (*d*) Ribbed floors.
   (*e*) Reinforced concrete floors.

6. A hall 10 m.×7·6 m. is to be roofed over with a R.C.C. floor slab. Propose the type of construction you would adopt. Explain fully the process of carrying out the whole work. Draw rough sketches wherever considered necessary.

15

Structural Design of Upper Floors

15·1 Design of Timber Floors. A timber beam which is strong enough to resist bending may not always be rigid to safe from consideration of deflection. Deep beams are more economical than the shallow ones, but in any case the depth of a beam should never exceed three times its breadth. For a well proportioned beam breadth should be 0 6 to 0 7 of its depth. The breadth of a timber beam should not be less than 5 cm. Timber beams seldom fail by shear, yet from consideration of safety, the designed section of beam should be checked for shear.

15.2 Deflection in Beam. As timber beam is liable to deflect under loads, the rules for deflection are more severe in timber beam than in steel beam. Normally the deflection allowed is $\frac{1}{360}$ of the span. In case of plastered ceilings, deflection should not exceed $\frac{1}{480}$ of the span and in case of beams supporting heavily plastered ceiling deflection should not exceed $\frac{1}{720}$ of the span.

The formula for finding deflection in beam under different conditions of supports or loadings is given below :

$$\delta = K \frac{Wl^3}{48EI}$$

δ = maximum allowable deflection in centimetre.

K = the coefficient, which varies with the condition of loading as well as condition of support. The value of K under different conditions of beam are given in table 15·1.

W = total load on beam including the weight of beam itself in kg.

l = effective span of beam in cm.

E = modulus of elasticity of the variety of timber used in kg./cm^2.

I = moment of inertia of the beam in cm^4.

TABLE 15·1

TABLE GIVING VALUES OF *K*, FOR DIFFERENT CONDITIONS OF BEAM

S. No.	*Condition of Beam*	*Value of K*
1.	Cantilever with a point load at free end.	16
2.	Cantilever with load uniformly distributed over its length.	6
3.	Simply supported and loaded with a point load at mid-span.	1
4.	Simply supported and loaded with uniformly distributed load throughout the span.	5/8

15·3 Wooden Floor Boarding. The boarding is generally not designed. Under normal circumstances 30 to 40 mm. boarding 10 to 15 cm. wide and 2·44 to 3·66 m. long supported on bridging joists spaced not further apart than 38 cm. will be found to be adequate for supporting ordinary floor loads. In case of good quality teak wood, the thickness of the boarding may be only 25 mm.

15.4 Step to be Followed in the Design of Timber Beam. The procedure to be adopted in the design of a timber beam can be broadly divided in to the following steps.

(*a*) Calculate the total load on the beam in kg.

(*b*) Find the effective span of the beam in metre.

(*c*) Assuming the beam to be simply supported, find the maximum bending moment by the formula.

$$\text{Bending moment} = \frac{Wl}{8} \text{ kg. m.}$$

or
$$M = \frac{Wl}{8} \times 100 \text{ kg. cm.}$$

(*d*) Equate the bending moment (M) as obtained from above to fZ.

or
$$M = fZ \qquad \ldots(i)$$

where f = safe working stress in the quality of timber used.

Z = section modulus of the section of beam

$= \frac{bd^2}{6}$ [where b is the breadth and d, the depth of the beam in cm.].

Substituting this value of Z in equation (i), we have

$$M = f \times \tfrac{1}{6} bd^2$$

$$bd^2 = \frac{6 \times}{f} \qquad \ldots(ii)$$

By adopting suitable value of b which may be ($b=2d$ or $b=3d$) value of d can be found out from equation (ii).

(c) Check the designed section for deflection by the formula

$$\delta = K \frac{Wl^3}{48EI}$$

(f) Check the designed section for shear by the formula

$$\text{Max. shear stress} = \frac{3}{2} \times \frac{W}{24}$$

The value of the result obtained from the above formula should not exceed the maximum allowable shear stress in the type of timber used.

Case 1 : Design of a single timber floor.

Example. *Design a timber floor for a class-room in a primary school building. The flooring should consist of 4 cm. thick deodar wood boarding supported on teak wood joists placed at 45 cm. centre to centre, the effective length of the joist being 3·5 m. The following data may be assumed in the design.*

$$f = 125 \text{ kg/cm}^2$$

$$E = 113000 \text{ kg/cm}^2$$

$$\delta = \frac{1}{360} \text{ of the span.}$$

Weight of deodar wood $= 520 \text{ kg/m}^3$

Weight of teak wood $= 660 \text{ kg/m}^3$

Safe allowable shear in timber joists

$= 8{\cdot}8 \text{ kg/cm}^2$.

Solution :

Load per sq. m. due to flooring :

(i) Due to 4 cm. thick deodar wood boarding

$= 0{\cdot}4 \times 520 = 20{\cdot}8$ kg.

(ii) Live load on flooring as per I.S. code $= 400$ kg.

(iii) Ceiling load (assumed) $= 20$ kg.

Total $= 440{\cdot}8$ kg.

$= 441$ kg. say

Area of flooring to be supported by one joist

$$= 0{\cdot}45 \times 3{\cdot}5$$

$$= 1{\cdot}575 \text{ sq. m.}$$

$\therefore$ Load due to flooring on one joist

$$= 1{\cdot}575 \times 441$$

$$= 695 \text{ kg.}$$

Self wt. of 7 cm. $\times$ 21 cm. (assumed) joist

$$= 0{\cdot}07 \times 0{\cdot}21 \times 3{\cdot}5 \times 660$$

$$= 34 \text{ kg.}$$

Total design load for one joist

$$= 695 + 34$$

$$= 729 \text{ kg.}$$

$$\text{Max. B.M.} = \frac{Wl}{8}$$

$$= \frac{729 \times 3{\cdot}5}{8}$$

$$= 319 \text{ kg. m.}$$

$$= 31900 \text{ kg. cm.}$$

Since $M = fZ$

$\therefore$ $125 \times \frac{1}{6} \times b.d^2 = 31900$

or $b\,d^2 = 31900 \times \frac{6}{125}$

$$= 1532$$

Taking $d = 2b$, we have

$$4b^3 = 1532$$

$\therefore$ $b = \sqrt[3]{\frac{1532}{4}}$

$$= 7{\cdot}25 \text{ cm.} = 8 \text{ cm. (say).}$$

Hence 8 cm. $\times$ 16 cm. joist will be sufficient to resist the bending moment.

Check for deflection :

$$\delta = \frac{5Wl^3}{384\,EI}$$

or $\frac{350}{360} = \frac{5 \times 720 \times 3{\cdot}5^3 \times 10^6 \times 12}{334 \times 113000 \times b.d^3}$

or $b.d^3 = \frac{5 \times 729 \times 3{\cdot}5^3 \times 10^6 \times 12 \times 360}{384 \times 113000 \times 350}$

$$= 44000 \text{ cm}^4$$

The value of $b.d^3$ taking

$$b = 8 \text{ cm. and } d = 16 \text{ cm.}$$

work out to $$b.d^3 = 8 \times 16^3$$
$$= 32768 \text{ cm}^4.$$

Which is less than 44000 cm^4, hence the section has to be modified to be safe from consideration of deflection.

If $b = 8$ cm. and $d = 17$ cm ; $b.d^3 = 39300$ cm.^{4}

If $b = 8$ cm. and $d = 18$ cm, ; $b.d^3 = 45600$ cm.^{4}

Which is more than 44000 cm.^{4}, hence a section of 8 cm. $\times$ 18 cm. will be safe both from bending moment and deflection considerations.

Check for Shear

$$\text{Maximum intensity of shear} = \frac{3}{2} \times \frac{W}{2A}$$
$$= \frac{3}{2} \times \frac{729}{2 \times 8 \times 18}$$
$$= 3{\cdot}8 \text{ kg./cm.}^2$$

which is less than 8·8 kg./cm.^{2}, hence safe

Result

Breadth of joist = 8 cm.

Depth of joist = 18 cm.

Case II : Design of a double floor.

Example. *A wooden floor is required to be constructed in an office building situated near a hill station. The room size is 6 metre $\times$ 7·5 metre. Teak wood available for the floor construction has the following properties.*

(*i*) $f = 125$ *kg./cm.*^{2}

(*ii*) $E = 113000$ *kg./cm.*^{2}

(*iii*) *Weight* $= 660$ *kg./m*^{3}

(*vi*) *Safe allowable shear stress* $= 8{\cdot}8$ *kg./cm.*^{2}

The weight of floor boarding and bridging joist may be assumed to be = 150 kg./m^2

Solution

Design of bridging joist : It is assumed that the bridging joists are spaced at 30 cm. c/c and the arrangement of binder is as shown in Fig. 15·1.

Loads per sq. metre on the joists.

(*i*) Due to flooring ... ... = 150 kg.

(*ii*) Live load ... ... = 400 kg.

Total = 550 kg.

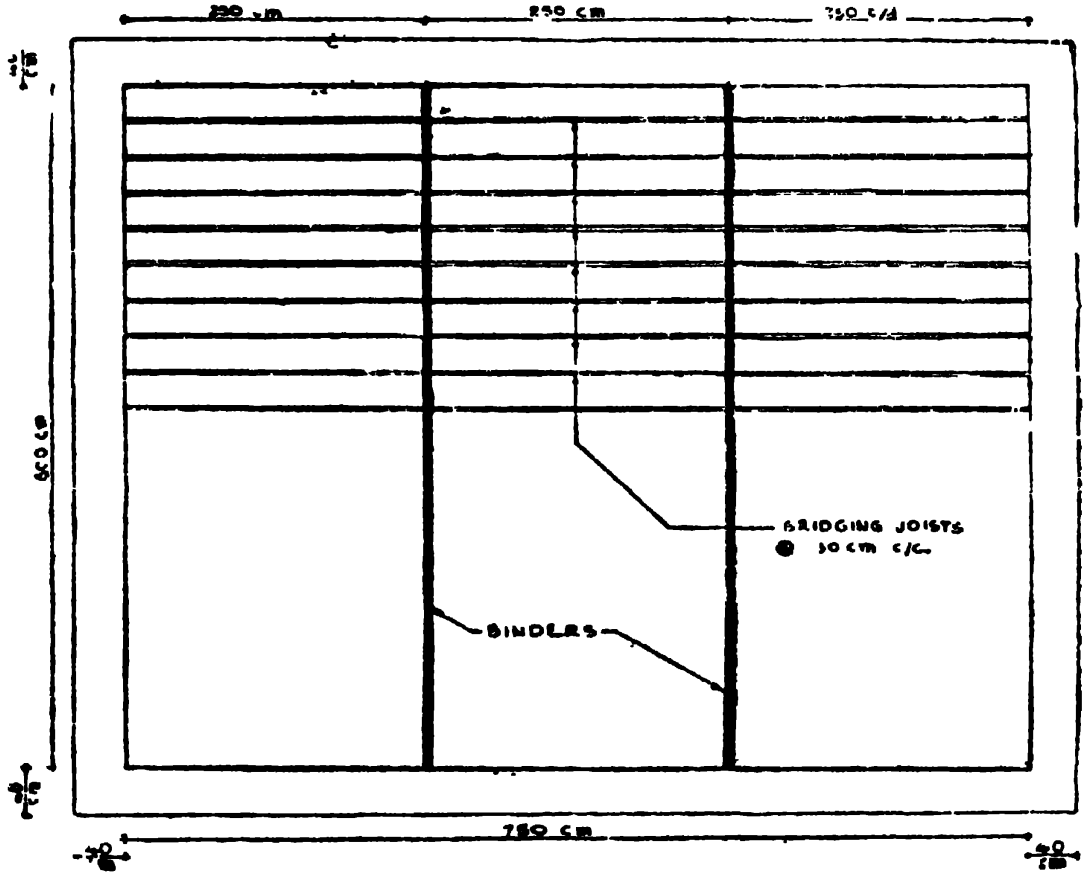


Fig. 15·1

Floor load on one bridging joists will be due to an area of

$$2{\cdot}5 \times 0{\cdot}3 = 0{\cdot}75 \text{ sq. m.}$$

$\therefore$ Total load on one bridging joist

$$= 0{\cdot}75 \times 550$$

$$= 413 \text{ kg.}$$

$$\text{B.M.} = \frac{Wl}{8}$$

$$= 413 \times \frac{2{\cdot}5}{8}$$

$$= 129 \text{ kg. m.}$$

$$= 12900 \text{ kg.-cm.}$$

Since $M = fZ$

or $\frac{1}{6}bd^2 \times 125 = 12900$

or $bd^2 = \frac{12900 \times 6}{125}$

$= 620$

If $b = 5$ cm.

$d^2 = \frac{620}{5}$

$= 124$

$\therefore \quad d = 11{\cdot}12$ cm.

Hence the size of bridging joist from consideration of bending moment may be taken as 5 cm. × 12 cm.

Check for deflection :

$$\delta = \frac{5Wl^3}{384\,EI}$$

or $\frac{250}{360} = \frac{5 \times 413 \times 2{\cdot}5^3 \times 10^6}{384 \times 113000 \times \frac{1}{12}bd^3}$

or $bd^2 = \frac{5 \times 413 \times 2{\cdot}5^3 \times 10^6 \times 12 \times 360}{384 \times 113000 \times 250} = 12830$

If b, is 5 cm., the value of d, in order that the joist may be safe from deflection consideration, will be :

$d^3 = \frac{12830}{5}$

$= 2566$ cm.^{3}

$\therefore \quad d = \sqrt[3]{2566}$

$= 13{\cdot}7$ cm. $= 14$ cm. (say)

Hence the size of joist should be

$= 5$ cm. × 14 cm.

Check for Shear :

Max. shear stress $= \frac{3W}{2 \times 2 \times A}$

$= \frac{3}{2} \times \frac{413}{2 \times 5 \times 14}$

$= 4{\cdot}42$ kg/cm^2

which is less than 8·8 kg/cm^2, hence safe.

Design of binders. It is assumed that the wall supporting the flooring is 40 cm. thick. In order to calculate the effective span for binders, it is safe to take the centre to centre distance between the supporting wall as the effective span.

$\therefore$ Effective span $= 6+0{\cdot}4$

$= 6{\cdot}4$ m.

Load on binder due to each bridging joist

$= 2{\cdot}5\times3\times550$

$= 413$ kg.

Since the bridging joists are spaced 30 cm. c/c, the load from them may be assumed to be equivalent to a uniformly distributed load.

$\therefore$ Equivalent uniformly distributed load per metre.

Length of binder $= \frac{413}{30}\times100$

$= 1377$ kg.

Total load on each joist

or $W = 1377\times6{\cdot}4 = 8810$ kg.

$$\text{B.M.} = \frac{8810\times6{\cdot}4}{8}$$

$= 7048$ kg.-m.

or $M = 704800$ kg.-cm.

Since $M = fZ$

or $\frac{1}{6}bd^2\times125 = 704800$

or $$bd^2 = \frac{704800\times6}{125}$$

$= 33850$

Assuming $d = 2b$

$\therefore$ $4b^3 = 33850$

or $$= \sqrt[3]{\frac{33850}{4}}$$

$= 20{\cdot}35$ cm.

$= 21$ cm. say

$\therefore$ $d = 2\times21 = 42$ cm.

Hence the section of the joist from bending moment consineration should be 21 cm. $\times$ 42 cm.

Check for deflection :

$$\frac{5Wl^3}{384\ EI}$$

or $$\frac{640}{360} \quad \frac{5\times 8110\times 6{\cdot}43\times 10^6}{384\times 11300\times \frac{\pi}{12}bd^3}$$

or $$bd^3 = \frac{5\times 8810\times 6{\cdot}4^3\times 10^6\times 360\times 12}{384\times 113000\times 640}$$

$$= 1797000 \text{ cm}^4.$$

If $b = 21$ cm.

$$d^2 = \frac{1797000}{21} = 85600 \text{ cm.}^3$$

$$\therefore \quad d = \sqrt[3]{85600} = 44{\cdot}1 \text{ cm.}$$

Hence adopt the size of binder to be 21 cm. × 45 cm.

Check for Shear :

Max. shear force at end

$$= \frac{W}{2}$$

$$= \frac{8810}{2}$$

$$= 4405 \text{ kg.}$$

Shear stress $$= \frac{3}{2}\times\frac{W}{A}$$

$$= \frac{3}{2}\times\frac{4405}{21\times 45}$$

$$= 7 \text{ kg/cm.}^2$$

which is less than 8·8 kg/cm², hence safe.

Result :

(*i*) *Size of bridging joist* = *5 cm.* × *14 cm.*

(*ii*) *Size of binder* = *21 cm.* × *45 cm.*

Common data for R.C.C.

The following data has been adopted in R.C.C. design problems in this book :

Concrete mix. : M150 (1 : 2 : 4)

$$m = 18$$

Description	*Metric system*	*Foot-lb system*
Stress in steel (t)	1400 kg./sq. cm.	18000 lb./sq. in.
Stress in concrete (c)	50 ,,	750 ,,
Average bond stress (S_b)	6 ,,	100 ,,
Local bond stress	10 ,,	175 ,,
Shear stress (s)	5 ,,	75 ,,
Neutural axis factor (n_1)	0·39	0 429
Lever arm factor (a_1)	0·87	0·857
Resisting moment co-efficient (Q)	8·48	137·5
Weight of R.C.C.	2400 kg./cu. m.	144 lb./cu. ft.

COMMON CONVERSION FACTORS

Multiply	*To convert*	*To*
2·54	Inches	Centimetres
0·3048	Feet	Metres
0·4536	Pounds	Kilograms
1·488	lb. per ft,	Kg./metre
0·07	lb. per sq. in.	Kg./sq. cm.
4·883	lb. per sq. ft.	Kg./sq. metre
16	lb. per cu. ft.	Kg./metre^3
1·016	Tons	Tonne
3·338	Ton per ft.	Tonn/metre
10 937	Ton per sq. ft.	Tonne/sq. metre
0·138	Ft. lb.	Kg. metre
1·15	In. lb.	Kg. cm.

15·5 BASIC RULES FOR THE DESIGN OF BEAMS AND SLABS

(1) Effective Span

(*a*) *For freely supported beam or s,ab.* The effective span of a freely supported beam or slab is taken as the "Distance between the centres of the supports or the clear distance between the supports plus the effective depth of the beam or slab, whichever is smaller.

(*b*) *For continuous beam or slab.* In case of a continuous beam or slab, where the width of the mid supports is greater than $\frac{1}{12}$ of the clear span, the following rule should be followed for finding out the effective span.

(*i*) In case of a continuous beam or slab fixed at ends, the effective span shall be the clear distance between the supports.

(*ii*) The effective span for the end span of a continuous beam or slab, with one end free and the other continuous, shall be equal to the clear span plus half the effective depth of the beam or slab.

(*iii* In case of a continuous beam or slab where the width of the mid supports is less than $\frac{1}{12}$ of the clear span, the rule mentioned in (*a*) above will be followed for finding out the effective span.

(2) **Slab Thickness.** For estimating the thickness of slab approximately allow 4 cm. for every metre of span for slabs carrying load more than 750 kg./sq. m.

From considerations of adequate stiffness of the slab it should be ensured that the designed depth of the slab should be such, that the ratio of the effective span to overall depth of the slab should in no case be less than the values given in the table 15·2 for various types of slabs. This is as per the reconmmendations of Indian Standard Code of Practice (Revised I.S. 456—1964).

Table 15·2

S. No.	*Type of slab*	*Maximum value of effective span of slab/over-all depth of slab*
1	Simply supported slab spanning in one direction.	30
2	Continuous slab spanning in one direction.	35
3	Simply supported slab spanning in two directions.	35
4	Continuous slab spanning in two directions.	40
5	Cantilever slabs.	12

However the thickness of floor or roof slab should not be less than 9 cm.

(3) **Beam Dimensions.** The depth of beam for normal loading conditions should be assumed to be $\frac{1}{10}$th of the clear span. In the interest of economy, the breadth of a beam should vary from $\frac{1}{2}$ to $\frac{3}{4}$th of its depth.

As per recommendation of Indian Standard Code of Practice (Revised I.S. 456—1964) the ratio of the effective span of the beam to its over all depth should not exceed the value given in the table 15·3. The limitation is essential from consideration of adequate stiffness of the beam.

Table 15·3

S. No.	*Type of beam*	*Maximum value of the effective span of the beam/over-all depth of beam*
1	Simply supported beams.	20
2	Continuous beams.	25
3	Cantilever beams.	10

(4) **Minimum Reinforcement in Slabs**. The minimum area of reinforcement (Shrinkage and temperature, or distribution or main reinforcement) to be provided in either direction in solid reinforced concrete slabs should not be less than :

(*i*) 0·15% of the gross cross-sectional area of concrete in slabs where plain m.s. bars are used as reinforcement.

(*ii*) 0·12% of the gross cross-sectional area of concrete in slabs where high-yield strength deformed bars or welded wire fabrics are used as reinforcement.

(5) **Minimum Reinforcement in Beams**. In reinforced concrete beams, the minimum area of tensile reinforcement should not be less than :

(*i*) 0·30% of the gross cross sectional area of the beams when plain m.s. bars are used as reinforcement.

(*ii*) 0·20% of the gross cross-sectional area of the beams where high yield strength deformed bars are used as reinforcement.

The gross cross-sectional area of the beam being obtained by multiplying the overall depth of the beam with the width of the beam (width of the rib is taken as the width of beam in case of T or L beams).

(6) **Minimum Compressive Reinforcement**. The amount of commpressive steel should not exceed 4% of the gross-sectional area of the beam. The gross-sectional area of the beam is obtained by multiplying the over-all depth of the beam with the width of the beam.

(7) **Bar Sizes**. The diameter of the main reinforcement must not be less than 6 mm. nor greater than 50 mm. The diameter of the stirrups or distribution, temperature or shrinkage bars must not be less than 5 mm., although bars less than 6 mm. diameter are seldom used.

(8) **Distance between Bars**

(*a*) The minimum distance between two parallel main reinforcing bars must not be less than the diameter of the bar (in case

of unequal diameter bar, the diameter of the large bar is considered) or 6 mm. greater than the maximum size of the coarse aggregate used in the concrete, whichever is greater.

(*b*) In case where it is desired to provide main bars in two or more layers one over the other, the minimum vertical clear distance between any two layers of the bars, shall normally be 15 mm. or the minimum size of the coarse aggregate or the maximum size of the bar whichever is the greatest.

(*c*) The pitch of the main tensile bars in R.C. slab should not exceed three times the effective depth of the slab or 90 cm. which ever is smaller.

(*d*) The pitch of the bars provided to act as distribution bars or bars provided to guard against temperature and shrinkage in an R.C. slab, shall not exceed five times the effective depth of the slab or 60 cm. whichever is smaller.

(9) **Clear Cover**

(*a*) The clear cover for reinforcement in slab, should not be less than 13 mm. or the diameter of the reinforcing bar whichever is greater.

(*b*) The clear cover for longitudinal reinforcing bars in beams should not be less than 25 mm. or the diameter of the reinforcing bar, whichever is greater.

(*c*) The clear cover at each end of reinforcing bar in beams or slabs should not be less than 25 mm. or twice the diameter of main bar whichever is greater.

(*d*) When the R.C.C. member (beam or slab) is in contact with earth faces or moisture or is subjected to corrosive condition, the cover should be increased between 15 mm. and 40 mm. over and above the value provided in (*a*), (*b*) and (*c*) above.

(*e*) For R C.C. members in contact with sea water, the cover of concrete shall be 50 mm. more than the value specified in (*a*), (*b*) and (*c*) above.

(10) **Shear in Beams :**

(*a*) The intensity of shear stress should not exceed 4 times the safe permissible shear stress for the grade of concrete used in the beam.

(*b*) The diameter of the stirrups used as shear reinforcement to resist shear in a beam, shall not be less than 5 mm. and their spacing should not exceed the lever arm of the beam.

(*c*) Even if, the beam is safe from consideration of shear, nominal shear reinforcen ent in the form of stirrups shall be provided

throughout the length of the beam, at a spacing not more than the lever arm of the beam.

(*d*). In beams with compression reinforcements, the spacing of the stirrups for the compression reinforcement should not exceed 16 times the diameter of the anchored bar or 48 times, the diameter of the anchoring bar (stirrup) whichever is less. The diameter of the stirrups is designed from considerations of shear ; however, it should not be less than $\frac{1}{4}$ times the diameter of the anchored bar.

(*e*) Where steel beam theory has been used for calculating the compressvie reinforcement, the spacing of the stirrups should not exceed 8 times the diameter of the compression bar.

(11) **Bond and Anchorage of Reinforcements**

(*a*) The local bond stress in an R.C. member (beam or slab), at any section, shall not exceed the safe permissible local bond stress as given in table included in the chapter on 'Plain Cement Concrete'.

(*b*) Every bar (either in compression or tension) should be extended by 12 times the diameter of the bar or 23 cm., whichever is more, beyond the point, where it is no longer required to resist bending. The extension of bar for anchorage may either be in the form of straight length or in the form of a standard hook.

(*c*) At the end of every bar, end anchorage should be provided which may be in the form of a semi-circular standard hook or by introducing a 90 degree bend (L-hook). The anchorage value of the standard semi-circular hook, 45° bend and standard L-hook is taken as 16 diameter, 12 diameter and 8 diameter respectively of the hooked bar.

(12) **Curtailment of Bars**. The main reinforcement in beams or slabs may be curtailed or bent up, where they are no longer needed for bending moment purposes. In a beam at least 25% of the main tensile bars must be extended beyond the support for a distanee equal to or greater than their minimum bond length.

(13) **Laps in Bars**. When it is essential to provide laps in reinforcing bars, the laps should be provided in a staggered manner. The lap length of the bars should not be less than the values given below.

(*i*) *For bars in tension.* The minimum lap length should be greater of the following two :

(*a*) $30 \times$ dia. of bar

(*b*) $$\frac{\text{Dia. of bar} \times \text{Actual tensile stress in bar}}{4 \times \text{Permissible average bond stress}}$$

If ϕ be the diameter of bar ; 1400 kg./cm.^{2} be the actual tensile stress in bar, M 150 be the grade of concrete giving the value of permissible average bond stress as 6 kg./cm.^{2} ; the lap length of bar from formula in (b) becomes

$$= \frac{\phi \times 1400}{4 \times 6} = 58{\cdot}33 \text{ say } 58\,\phi.$$

(*ii*) *For bars in compressions* : The minimum lap length should be greater of the following two :

(*a*) 24 × Dia. of bar

(*b*) $\dfrac{\text{Dia. of bar} \times \text{Actual compressive stress in bar}}{5 \times \text{Permissible average bond stress}}$

(14) **Weight of R.C.C.** As given by the revised Indian standard Code of Practice (I.S. : 456—1964) the weight of the reinforced concrete for the purposes of calculating load etc. will be taken as 2400 kg /m^3.

(15) **Modular Ratio.** The modular ratio, m for any desired grade of concrete can be obtained by the empirical formula :

$$m = \frac{2800}{3c}$$

where 2800 is a constant and c is the maximum permissible compressive stress due to bending in that grade of concrete in kg./cm^2.

The value of m for M 150 grade of concrete has been taken as 18 in this book.

15·6 Loading on Slabs, Loading on slabs may be in the form of uniformly distributed load or concentrated load. The slabs in residential or public buildings or other structures are mostly subjected to uniformly distributed loads only. Slab in bridges, culverts or in other similar situations are subjected to the concentrated load on account of vehicles or trains passing over the slab. Thus the loading on a slab consists of :

(*a*) Live loads.

(*b*) External dead loads.

(*c*) Dead load of the slab itself.

Live loads and external dead loads may be given or these may be calculated with the help of given data, while the dead load due to self-weight of slab has to be calculated after deciding the probable thickness of the slab *vide* Basic Rule (2).

15·7 Arrangement of Reinforcements in Slabs. A standard bar bending arrangement of the designed reinforcement for a continuous slab has been shown in (Fig. 15·2).

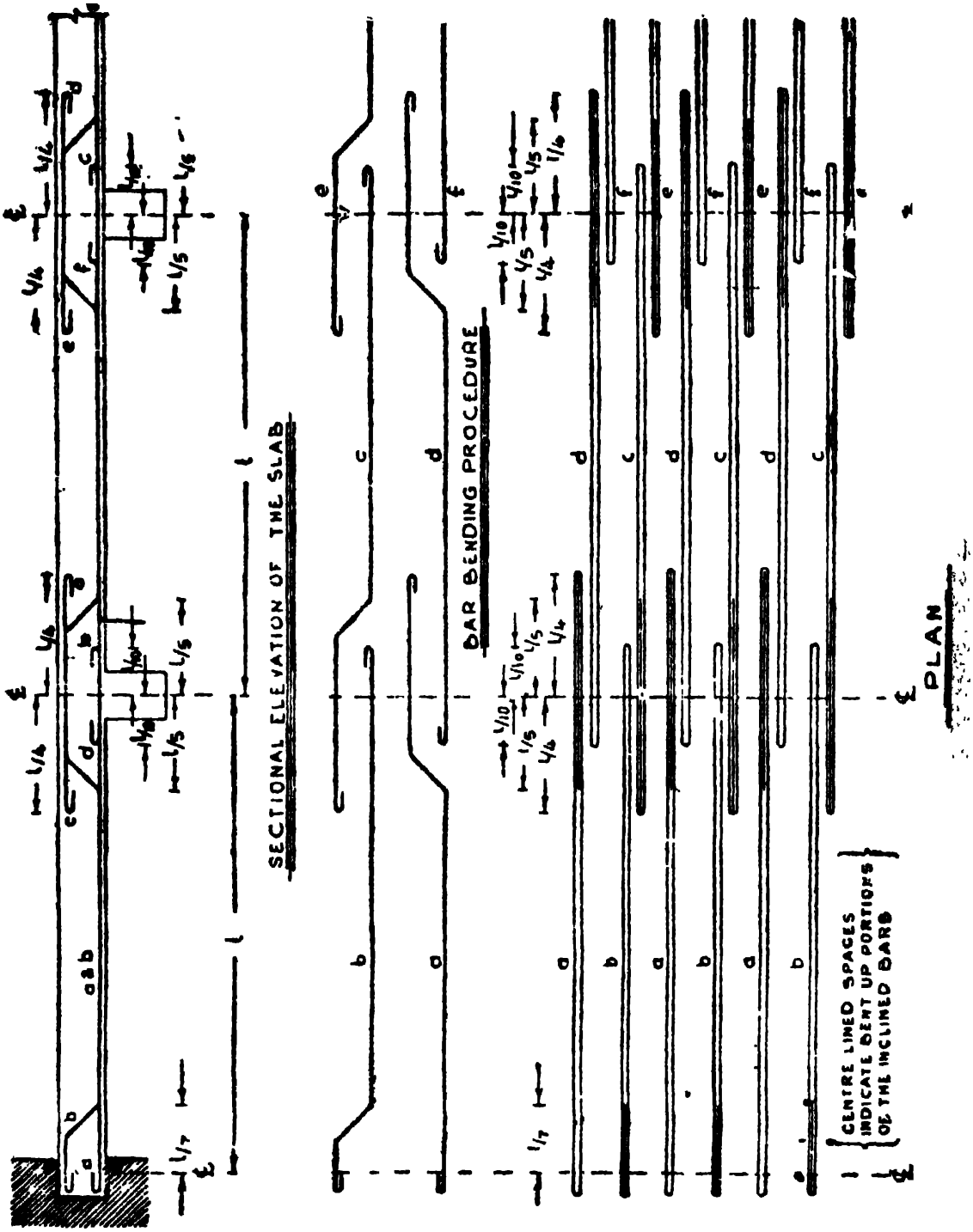


Fig. 15·2

15·8 Steps to be Followed in the Design of One-way Reinforced Slabs. Whatever may be the width of the slab it should always be designed for a width equal to one metre and the same design should be adopted for the rest of the slab. The design procedure of a uniformly loaded one-way reinforced slab, simply

supported or continuous over mid-supports has been divided in the following steps :

(*a*) Assume suitable thickness of the slab and calculate the effective span "*l*" of the slab in metre (vide Basic Rule 1).

(*b*) Calculate *w*, the total load in kg./m², *i.e.* = sum of the external loads in kg./m²+self-weight of the assumed thickness of slab in kg/m².

(*c*) Calculate the maximum bending moment (*M*) by the governing formula.

(*i*) For simply supported slab resting on two supports or slab having only one span.

Max. +ve B.M. near the centre of span.

$$M = +\frac{wl^2}{8} \text{ kg. m.}$$

(*ii*) For slabs continuous for two equal or approximately equal spans. (The spans are considered approximately equal when they do not differ in length by more than 15% of the longest span.)

Max. +ve B.M. near the centre

$$= +\frac{wl^2}{10} \text{ kg. m.}$$

Max. −ve B.M. over interior supbort

$$\frac{wl^2}{8} \text{ kg. m.}$$

(*ii*) For slabs continuous for more than two spans.

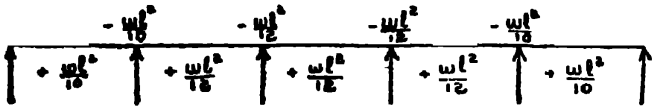


Fig. 15·3

Max. +ve bending moment near the centre of end span and max. −ve bending moment over the penultimate support.

$$= \pm\frac{wl^2}{10} \text{ kg. m.}$$

The max. +ve bending at the centre of all the intermediate spans and max. −ve bending moment over all the intermediate supports

$$= \pm\frac{wl^2}{12} \text{ kg. m.}$$

Multiply the bending moment thus obtained by 100 to convert it in kg. cm.

(*d*) Calculate the effective depth of the slab by the formula,

$$d = \sqrt{\frac{M}{Q \times b}}$$

where $b = 100$ cm.

and the value of Q for M 150 (1 : 2 : 4) concrete = 8·48

(*e*) Fix the over-all depth of the slab and obtain the final value of the effective depth.

(*f*) Calculate the required area of steel per metre width of slab by the formula,

$$A_t = \frac{M}{a_1.d.t} \text{ sq. cm.}$$

(*g*) Select suitable diameter of the bars and find their centre to centre spacing by the formula,

$$p = \frac{100 \times a_t}{A_t} \text{ cm.}$$

where a_t = area of one bar of the selected diameter.

(*h*) Calculate distribution steel at the rate of 0·15 per cent of the cross-sectional area of concrete.

Or area of distribution steel per metre

$$= 0{\cdot}15 \times D \times 100$$

where D is the overall depth of slab.

(*i*) Select suitable diameter of the distribution bars and find their centre to centre spacing as in step (*g*).

Example. *Find the thickness and reinforcement for an R.C. floor slab required to carry a superimposed load of 480 kg. per square metre, the span being 2·5 m. simply supported. The flooring is to be finished with 20 mm. thick terrazzo topping. Give dimensioned sketch of the slab.*

Assume $m = 18$

$c = 50$ *kg./sq. cm.*

$t = 1400$ *kg./sq. cm.*

Solution. Given $m = 18$

$c = 50$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

∴ The neutral axis factor :

$$n_1 = \frac{n}{d} = \frac{mc}{mc+t} = \frac{18\times 50}{18\times 50+1400} = 0.391$$

Lever arm factor

$$a_1 = 1-\frac{n_1}{3} = 1-\frac{0.391}{3} = 0.87$$

Coefficient of resisting moment

$$Q = \tfrac{1}{2}.c.n_1a_1$$
$$= \tfrac{1}{2}\times 50\times 0.391\times 0.87$$
$$= 8.48$$

Assume 12 cm. thick slab.

Effective depth of the assumed slab = 12—2 = 10 cm.

Effective span "l" = 2·5+0·1 = 2·6 m.

Loads per sq. metre :

(*i*) Self-weight of 12 cm. thick (assumed) slab
$= 0.12\times 2400 = 288$ kg.

(*ii*) Weight of 20 mm. thick terrazzo topping
$\frac{60}{25}\times 20 = 48$ kg.

(*iii*) Superimposed load = 480 kg.

Total 816 kg.

Consider a strip of slab 1 m. wide.

∴ Load per running metre = 816 kg.

Max. bending moment (M) $= \frac{wl^2}{8}$

$$= 816\times\frac{2.6^2}{8}$$
$$= 690 \text{ kg. m.}$$
$$= 69000 \text{ kg. cm.}$$

Req. effective depth of the slab.

$$d = \sqrt{\frac{M}{Q\,b}}$$
$$= \sqrt{\frac{69000}{8.48\times 100}}$$
$$= 9\,03 \text{ cm.}$$

Adopt over-all depth of the slab = 11 cm.

∴ Available effective depth = 11−2 = 9 cm.

Area of steel per metre width of slab

$$A_t = \frac{M}{a_1.d.t}$$

$$= \frac{69000}{0{\cdot}87 \times 9 \times 1400}$$

$$= 6\,29 \text{ sq. cm.}$$

c/c spacing of 12 mm. diameter bars ($a_t = 1{\cdot}13$)

$$p = \frac{100 \times a_t}{A_t}$$

$$= \frac{100 \times 1{\cdot}13}{6{\cdot}29}$$

$$= 17{\cdot}98 \text{ cm. say } 18 \text{ cm.}$$

Distribution steel @ 0·15 percent of the gross-sectional area of concrete

$$= \frac{0{\cdot}15 \times 11 \times 100}{100}$$

$$= 1{\cdot}65 \text{ sq. cm.}$$

c/c spacing of 6 mm. dia. bars ($a_t = 0{\cdot}28$)

$$= \frac{100 \times 0{\cdot}28}{1{\cdot}65}$$

and $$= 16{\cdot}98 \text{ cm.}$$

say 17 cm.

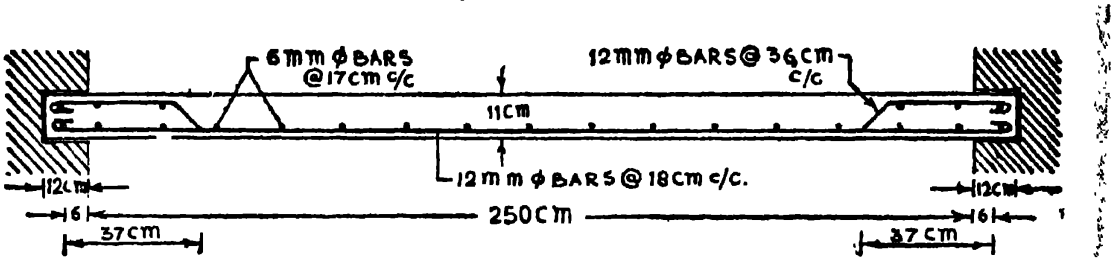


Fig. 15·4

Example 2. *Design the floor slab for a hall in a building 13·3 metre long and 6 metre wide. The slab is supported on R.C.C. beams suitably spaced as shown in Fig. 15·5. The floor is to be finished with 30 mm. thick granolithic flooring. The superimposed load on the floor may be assumed to be 300 kg. per square metre.*

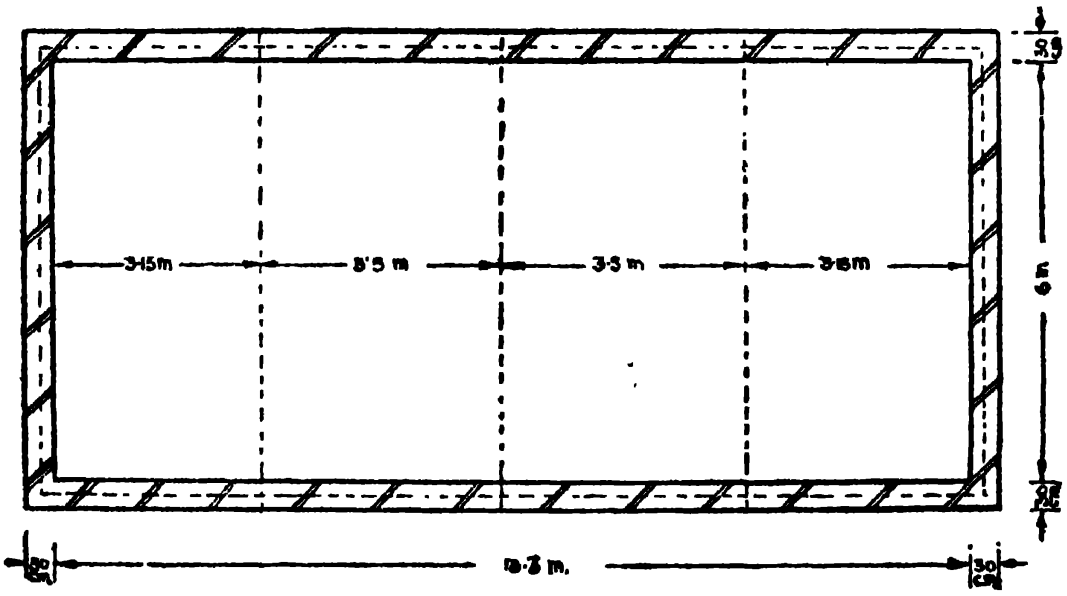


Fig. 15·5

Solution. The following assumptions have been made in the design :

(*i*) $c = 50$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

$m = 18$

$\therefore$ $n_1 = 0{\cdot}391$ and $a_1 = 0{\cdot}87$

(*ii*) The thickness of slab = 12 cm.

(*iii*) The bearing of the slab on the walls = 12 cm.

(*iv*) The width of the mid-supports or beams is less than $\frac{1}{12}$th the clear span.

$\therefore$ Effective span for end span $= 3{\cdot}15 + \frac{0{\cdot}12}{2}$

$= 3{\cdot}21$ m.

Effective span for mid-span = 3·5 m.

Load per sq. metre.

(*i*) Self-weight of 12 cm. thick (assumed) slab

$= 0{\cdot}12 \times 2400 = 288$ kg.

(*ii*) Weight of 30 mm. thick granolithic flooring

$= \frac{80}{100} \times 30 = 72$ kg.

(*iii*) Superimposed load 300 kg.

Total = 660 kg.

Consider a strip of slab one metre wide.

$\therefore$ Load per running metre = 660 kg.

Bending moment in the mid span of end span and penultimate support.

$$M = \pm\frac{wl^2}{10}$$

$$= \pm\frac{660\times 3{\cdot}21^2}{10}$$

$$= 680 \text{ kg. m.}$$

$$= 68000 \text{ kg. cm.}$$

Bending moment in the mid span of intermediate span and over intermediate support

$$M = \pm\frac{wl^2}{12}$$

$$= \frac{660\times 3{\cdot}5^2}{12}$$

$$= 674 \text{ kg. m.}$$

$$= 67400 \text{ kg. cm.}$$

The depth of the slab will be governed by the maximum bending moment out of the two

$\therefore$

$$d = \sqrt{\frac{68000}{8{\cdot}48\times 100}}$$

$$= 8{\cdot}96 \text{ cm.}$$

Provide over-all depth of the slab = 11 cm.

$\therefore$ The available effective depth = 11—2 = 9 cm.

Area of steel per metre width for the mid span of end span and penultimate support

$$= \frac{68000}{0{\cdot}87\times 9\times 1400}$$

$$= 6{\cdot}2 \text{ sq. cm.}$$

Area of steel per metre width for the mid-span of intermediate span and over intermediate support

$$= \frac{67400}{0{\cdot}87\times 9\times 1400}$$

$$= 6{\cdot}15 \text{ sq. cm.}$$

Since the area of steel in the end spans and in the intermediate span is nearly equal, the diameter of main bars and their centre to centre spacing will be kept same in the end spans as well as in the mid span.

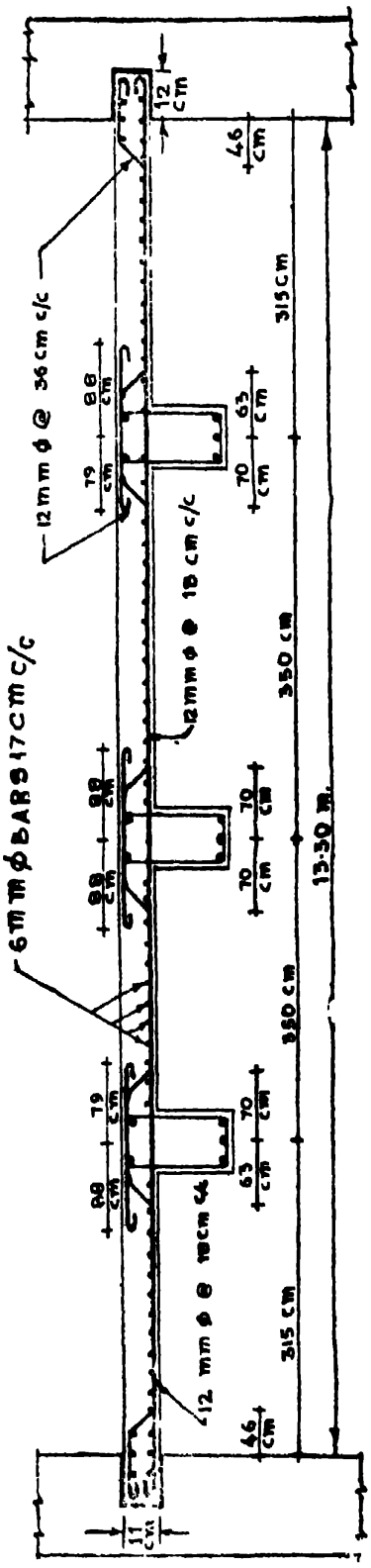


Fig. 15·6

c/c spacing of 12 mm. ϕ bars

($a_t = 1{\cdot}3$)

$$p = \frac{100 \times a_t}{A_t}$$

$$= \frac{100 \times 1{\cdot}13}{6{\cdot}2}$$

$$= 18{\cdot}22 \text{ cm.}$$

say 18 cm.

Distribution bars @ 0·15% of the gross sectional area of concrete

$$= \frac{0{\cdot}15 \times 11 \times 100}{100}$$

$$= 1{\cdot}65 \text{ sq. cm.}$$

c/c spacing of 6 mm. ϕ bars

($a_t = 0{\cdot}28$)

$$= \frac{100 \times 0{\cdot}28}{1{\cdot}65}$$

$$= 16{\cdot}98 \text{ cm. say 17 cm.}$$

15·9 Case of reinforced brick slabs. The main principles of reinforced brick design are the same as that of reinforced concrete design except that in the case of R.B. design the following additional specifications are observed.

(1) The depth of R.B. slab should be limited to 10 cm ; 15 cm ; 20 cm ; 25 cm. or 30 cm. A 15 cm. thick slab is obtained by 5 cm. thick titles on 10 cm. thick bricks.

(2) The supporting arrangement of the slab should be so planned that the depth of the slab does not exceed 20 cm. ; otherwise the slab becomes too heavy and expensive.

(3) The diameter of main reinforcement in slabs should be kept as small as possible and in any case it should not preferably exceed 12 mm. For reinforced brick beams the main bar may be upto 25 mm. in diameter.

(4) The width of the mortar joint should be such that the steel bars may not come into contact with the bricks. It is advisible to keep the thickness of joints in slabs as 20 mm.

(5) The clear cover for R.B. slab should be 13 mm. or the dia. of the main bar whichever is grater.

(6) The safe tensile stress in steel in R B. work is usually taken as 25 kg./sq. cm.

(7) The modular ratio is taken as 40.

(8) The safe shear stress in R.B. work may be taken as 1 kg. per sq. cm.

(9) The safe allowable local bound stress in R.B. work may be taken as 12 kg/sq. cm.

(10) Only first class bricks should be used in R.B. work and cement mortar 1 : 3 (one part of cement : three parts of coarse sand) should be used for joints. The joints may also be filled with cement concrete 1 : 2 : 4 but in that case the width of joints should be 4 cm. or more.

(11) The arrangement of the bricks should be so made, that the joints should preferably be broken and the bricks near the edges must rest half on the bearing wall thus avoiding vertical joints in the slab coming immediately above the edges of the bearing wall. This is essential to strengthen the slab against shear.

(12) The distribution, temperature or shrinkage reinforcement should be provided @ 20% of the area of main steel for +ve B.M.

Example. *Design a reinforced brick floor slab for a room 2·25 metre wide. The floor is to be paved with 20 mm. thick mosaic flooring. The superimposed load on the floor may be assumed to be 200 kg./sq. m.*

Solution : Clear span the slab = 2·25 m

Effective span of slab (assuming 10 cm. thick R.B. slab) = 2·25+0·8 = 2·33 m.

Load per square on the slab

(*i*) Self wt. of 10 mm. thick slab (assumed) = 0·10 × 1920 = 192 kg.

(*ii*) Wt. of 20 mm. thick mosaic flooring = 48 kg.

(*iii*) Super-imposed load = 200 kg.

Total 440 kg.

Consider a strip of slab one metre wide.

∴ Load per metre run = 440 kg.

$$\text{Max. B.M} = \frac{wl^2}{8}$$

$$\frac{440 \times 2{\cdot}33^2}{8}$$

$$= 298{\cdot}5 \text{ kg. m.}$$

$$= 29850 \text{ kg. cm.}$$

Since $c = 25$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

$m = 40$

$$n_1 = \frac{d}{} = \frac{mc}{mc+t}$$

$$= \frac{40 \times 25}{40 \times 25 + 1400} = 0{\cdot}417$$

$$a_1 = 1 - \frac{n_1}{3} = 1 - \frac{0{\cdot}417}{3} = 0{\cdot}861$$

∴ $Q = \frac{1}{2} c n_1 a_1$

$= \frac{1}{2} \times 25 \times 0{\cdot}417 \times 0\,861$

$= 4{\cdot}5$

∴ $d = \sqrt{\frac{M}{Q\,b}}$

$= \sqrt{\frac{29850}{4{\cdot}5 \times 100}}$

$= 8{\cdot}15$ cm.

Adopth over-all depth of slab = 10 cm.

and effective depth = 10−2 = 8 cm.

$$A_t = \frac{M}{a_1.d.t}$$

$$= \frac{29850}{0{\cdot}861 \times 8 \times 1400}$$

$$= 3{\cdot}1 \text{ sq. cm./m.}$$

c/c spacing of 10 mm. ϕ bars ($a_t = 0{\cdot}79$ cm^2.)

$$p = \frac{100 \times 0{\cdot}79}{3{\cdot}1}$$

$$= 25{\cdot}5 \text{ cm.}$$

The length of the standard brick is 20 cm. allowing 2 cm. wide mortar joint on either side of the brick, c/c spacing of the bars in the joint cannot exceed 22 cm.

Hence, provide 10 mm. ϕ bars @ 22 cm. c/c.

Check for shear :

Max. S.F. at the edges $= \frac{wL}{2}$

$$= 440 \times \frac{2{\cdot}25}{2}$$

$$= 495 \text{ kg.}$$

$$s = \frac{S}{a_1.d.b}$$

$$= \frac{495}{0{\cdot}861 \times 8 \times 100}$$

$$= 0{\cdot}781 \text{ kg./sq. cm. (safe).}$$

Check for bond :

$$S_b = \frac{S}{a_1 d.\Sigma_0}$$

$$= \frac{495}{0{\cdot}861 \times 8 \times \frac{2}{3}\pi \times 3{\cdot}14}$$

$$= 5{\cdot}02 \text{ kg/sq. cm. (safe).}$$

Although 50% of the main bars can be safely bent up near the support, without exceeding the permissible limit of bond stress, but by doing so, the spacing of the bent up bars will become too large, as such it is proposed to bend the bars through 180° after taking them straight at the bottom face of the slab, upto the edges. The bars thus available at top face of the slab will be extended upto $\frac{2}{7}\frac{3}{7}\frac{3}{1} = 33$ cm. (say) beyond the inner face of the supports.

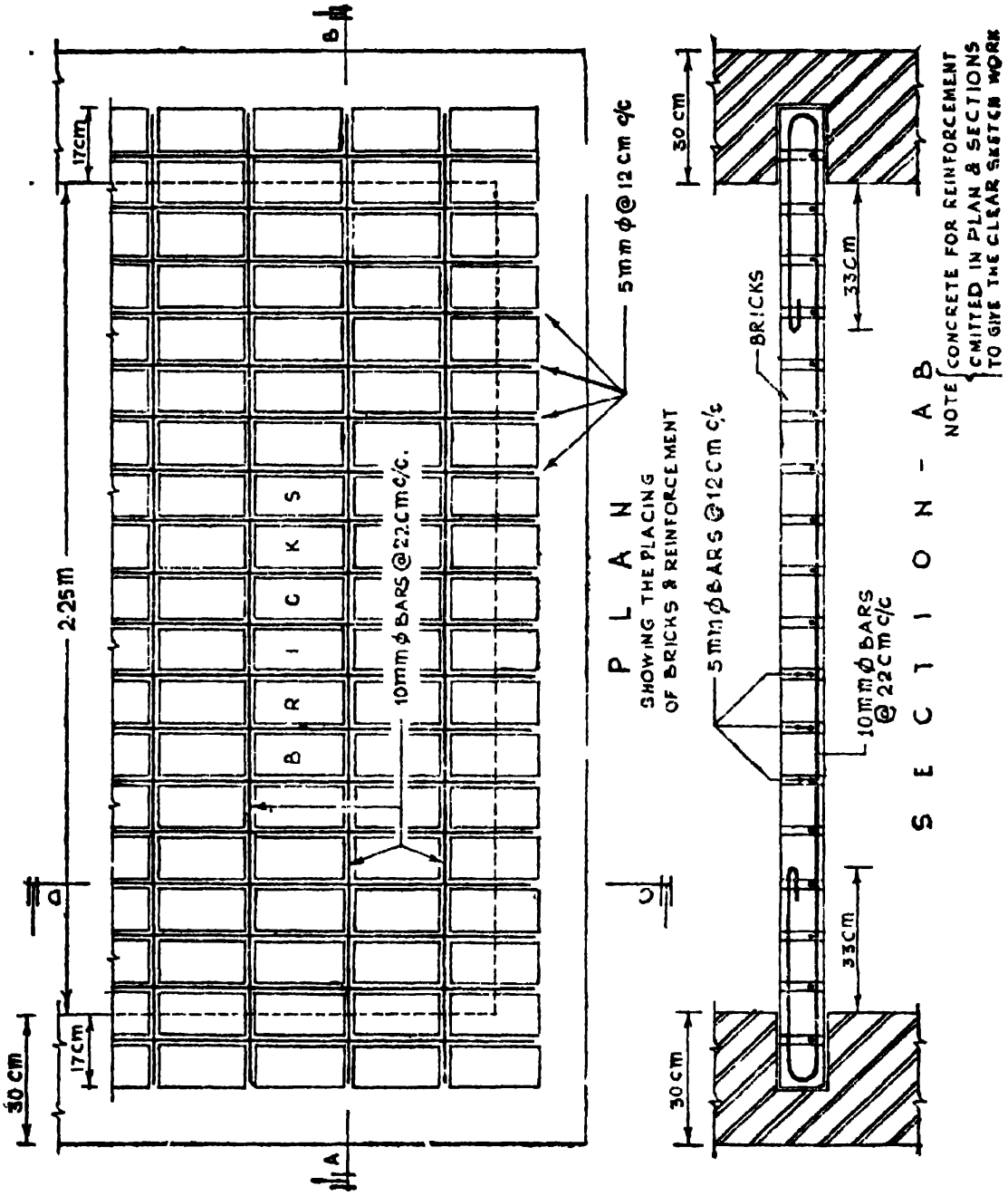


Fig. 15·7

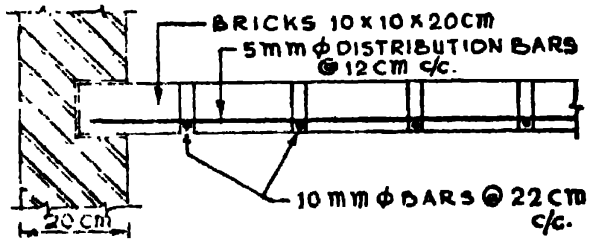


Fig. 15·8

Distribution bars @ 20% of the area of the main reinforcement for the B.M. at mid-span

$$= \frac{20 \times 3{\cdot}1}{100} = 0{\cdot}62 \text{ sq. cm.}$$

Provide 5 mm. ϕ bars @ 12 cm. c/c.

15·10 Simply Supported Two-way Slabs (corners free to lift). These slabs are commonly used as isolated roof slabs for individual rooms in single storeyed buildings. Thus the slabs are laid non-continuous on all the four edges and are not restrained by supporting walls or beams. Since the corners of the slab are not held down, no torsional reinforcements are provided in the slab. The design of such a slab is generally done by using Rankine-Grashoff Theory.

15·11 Steps to be Followed in the Design. The design procedure of simply supported two-way slabs with uniformly distributed loads, has been divided into the following steps :

(*a*) Calculate the effective span for short span (l_x) as well as long span (l_y) in metres.

(*b*) Calculate w, the total load in kg/m², *i.e.* w = sum of external load in kg./m²+self wt. of assumed thickness of slab in kg./m².

(*c*) Calculate the portion of the load w, carried by each span. Design load for short span is given by the formula

$$w_x = \frac{r^4}{1+r^4} \cdot w \text{ kg./m}^2.$$

Design load for long span

$$w_y = \frac{w}{1+r^4} \text{ or } w_y = w - w_x$$

(*d*) Calculate max. bending moment for each span by the following formulae :

(*i*) B.M. per metre width along short span (M_x)

$$= w_x \frac{l_x^2}{8} \text{ kg. m.}$$

(*ii*) B.M. per metre width along span (M_y)

$$= w_y \cdot \frac{l_y^2}{8} \text{ kg. m.}$$

(*e*) Calculate the effective depth of the slab by taking bigger of the two values of the bending moments, by the formula

$$\sqrt{\frac{M_x \times M_y}{Q.b}}$$

(*f*) Calculate the area of the steel per metre width required along each span by the formula.

(*i*) Area of steel per metre width along short span

$$= \frac{M_x}{a_1 \, d \, t} \text{ sq. cm.}$$

Select suitable diameter (ϕ_x) of the bars and find their centre to centre spacing.

(*ii*) Area of steel per metre width along span

$$= \frac{M_y}{a_1 \, (d - \phi_x).t} \text{ sq. cm.}$$

Select suitable diameter of the bars and find their centre to centre spacing.

(*g*) Calculate distribution steel at the rate of 0·15% of the gross-sectional area of the slab.

Example. *Design an R.C.C. floor slab for a residential building over a single room 4·5 m × 4·5 m. clear inside dimensions, with walls for support on all the sides. Make usual assumption as per Indian Standard Code of Practice.*

Solution : The following assumptions have been made in the design.

(*i*) $c = 50$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

$m = 18$.

$\therefore$ $a_1 = 0{\cdot}87$ and $Q = 8{\cdot}48$

(*ii*) The floor is finished with 20 mm. thick granolithic topping.

(*iii*) The live load on the floor is 200 kg./m.^{2}

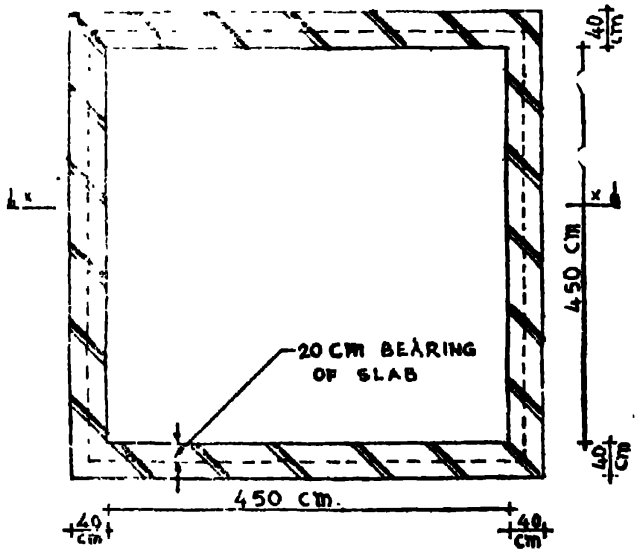


Fig. 15·9

(*iv*) The slab is simply supported on all the four sides with the corners not held down.

(*v*) The slab is 12 cm thick (assumption made for calculating the self wt. of the slab).

(*vi*) The bearing of the slab on supporting wall is 20 cm. while the thickness of the walls is 40 cm.

Since both the long as well as the short spans have the same dimension, the effective spans for both the directions will also be equal.

$$\therefore \quad l_x = l_y = 4{\cdot}5 + (0{\cdot}12 - 0{\cdot}02)$$
$$= 4{\cdot}6 \text{ m.}$$

or $$\frac{l_y}{l_x} = \frac{4{\cdot}6}{4{\cdot}6} = 1$$

Load per sq. metre on the slab :

(1) Due to self-weight of 12 cm. thick slab	= 288 kg.
(2) Due to floor finish 20 mm. thick	= 48 kg.
(3) Live load	= 200 kg.
Total	= 536 kg.

∴ Portion of the load carried by shorter span = Portion of the load carried by longer span

$$= \frac{536}{2} = 268 \text{ kg /sq. m.}$$

Consider a strip of the slab one metre wide.

∴ Load per metre run

$$= 268 \text{ kg.}$$

Max. B.M. along each span

$$= \frac{wl^2}{8}$$
$$= 268 \times \frac{4{\cdot}6^2}{8}$$
$$= 709 \text{ kg. m.}$$
$$= 70900 \text{ kg. cm.}$$

$$\therefore \quad d = \sqrt{\frac{70900}{8{\cdot}48 \times 100}}$$
$$= 9{\cdot}15 \text{ cm.}$$

Adopt overall depth of the slab = 11 cm.

Assuming 12 mm. ϕ main bars, available effective depth

$$= 11 - \left(1{\cdot}3 + \frac{1{\cdot}2}{2}\right)$$

$$= 9{\cdot}1 \text{ cm.}$$

Area of steel along one span (say, l_x)

$$A_t = \frac{70900}{0{\cdot}87 \times 9{\cdot}1 \times 1400}$$

$$= 6{\cdot}4 \text{ sq. cm./m.}$$

c/c spacing of 12 mm. ϕ bar ($a_t = 1{\cdot}13$ cm^2)

$$p = \frac{100 \times 1{\cdot}13}{6\,4}$$

$$= 17{\cdot}65 \text{ cm., say 17 cm. c/c.}$$

Area of steel along the span perpendicular to the above (say l_y).

Assuming 12 mm. ϕ main bars, available effective depth of slab $= 9{\cdot}1 - 1{\cdot}2$

$$= 7{\cdot}9 \text{ cm.}$$

$$A_t = \frac{70900}{0{\cdot}87 \times 7{\cdot}9 \times 1400}$$

$$= 7{\cdot}38 \text{ sq. cm./m.}$$

c/c spacing of 12 mm. ϕ bars,

$$d = \frac{100 \times 1{\cdot}13}{7{\cdot}38} = 15{\cdot}3 \text{ cm. say 15 cm. c/c.}$$

Distribution steel $= \frac{0{\cdot}15}{100} \times 11 \times 100$

$$= 1{\cdot}65 \text{ sq. cm.}$$

c/c spacing of 6 mm. ϕ bars ($a_t = 0{\cdot}28$ cm^2)

$$p = \frac{100 \times 0{\cdot}28}{1\,68}$$

$$= 16{\cdot}95 \text{ cm., say 17 cm. c/c.}$$

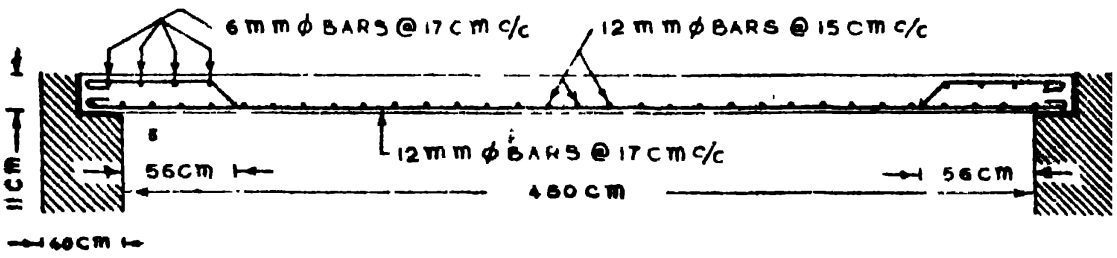


Fig. 15·10

Questions for Revision

1. Design a wooden floor for a recreation hall of a hotel measuring 8 m. × 8 m. The flooring is to consist of Deodar wood boarding supported on a system of bridging joists and binders. The following data may be assumed in the design :

$f = 125$ kg./cm^2

$E = 11300$ kg./cm.^{2}

$\delta = \frac{1}{360}$ of the span.

Weight of Deodar wood = 522 kg./m.^{2}

Weight of Teak wood = 660 kg./m.^{2}

Safe allowable stress in timber joists = 8·8 kg./cm.^{2}

2. (*a*) What are the guiding principles which should be kept in view, while designing timber floors? Describe them briefly, giving detailed information about deflection.

(*b*) Design a timber floor for a room in a residential building. The flooring should consist of an arrangement of boarding, supported on Teak wood joists spaced at 50 cm. apart. The maximum span for the joist is 4 m. Teak wood available for the floor construction has the following properties :

$f = 125$ kg./cm.^{2}

$E = 11300$ kg./cm.^{2}

Weight of Teak wood = 600 kg./m.^{3}

Safe allowable shear stress in Teak wood = 8·8 kg./cm.^{2}

3. (*a*) Describe briefly the important steps which are necessary to be followed in the design of a simply supported reinforced concrete floor slab.

(*b*) Design the floor slab for a room measuring 3 m. × 5·5 m. The slab is to be finished with 20 mm. thick terrazzo flooring. The walls supporting the slab are 30 cm. thick and the slab is to have a bearing of 15 cm. on the walls. The floor may be assumed to be used as a class-room in a primary school. The following data may be assumed in design :

$m = 18$

$c = 50$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

4. Design the floor slab for a hall 18 metre long and 6 metre wide. The slab is to be supported on R.C.C. beams spaced at 3 metre centre to centre. The floor is to be finished with polished stone slabs 3 cm thick. The hall may be a place of assembly and suitable live load should be taken in the design. Following assumptions may be made in the design :

$c = 50$ kg./sq. cm.

$t = 1400$ kg./sq. cm.

$m = 18$.

Draw a neat sketch of the designed slab.

5. (*a*) Distinguish between one way and two-way system of reinforcements in a reinforced concrete slab. Describe in brief the steps which should be adopted in the design of a two-way reinforced slab.

(*b*) Design a reinforced concrete slab for a room measuring 5 m.×5 m. The slab is to rest upon 35 cm. thick walls constructed all round. The flooring is to be finished with 25 mm. cement concrete layer. The floor may be assumed to be subjected to a uniformly distributed superimposed load of 440 kg./m.^{2} The following data may be assumed in the design :

c = 50 kg./sq. cm.

t = 1400 kg./sq. cm.

m = 18.

Draw a cross-section of the designed slab, showing clearly the bar bending schedule of the reinforcement.

6. The assembly hall floor in a club building at first floor is to be constructed in reinforced concrete. The size of the hall is 7 m.×6 m. In order to provide a plain ceiling effect in the ground floor, the slab is to be laid without the provision of beams. The flooring is to be finished with 25 mm. thick Mosaic finish. Design the slab making suitable assumption with regard to the superimposed loads, The following data may be adopted in the design :

m = 18

t = 1400 kg./sq. cm.

c = 50 kg./sq. cm.

Draw a dimensioned plan and section of the slab, showing the position of reinforcement. Also give a bar bending schedule of the slab.

7. (*a*) What special considerations should be kept in view while designing a reinforced brick slab ?

(*b*) A room 3 m.×7 m. is to be provided with a reinforced brick floor slab. The floor may be assumed to be subjected to a superimposed load of 250 kg./sq. m. Flooring is to be finished with 20 mm. Terrazzo finish. The following data may be assumed in the design.

(*i*) Safe tensile stress in steel = 1400 kg./sq. cm.

(*ii*) Safe compressive stress in brick = 25 kg./sq. cm.

(*iii*) m = 40.

Draw dimensioned sketch of the designed slab.

16

Lintels and Arches

16·1 Lintels. Openings for doors, windows or cupboards etc. must be bridged over by some means to support the superimposed masonry. The support to the load above the opening is usually given by providing an arch or a lintel. Lintel acts like a beam and transfers the load vertically to the supporting walls. The ends of lintels are built into the masonry so as to convey the weight carried by them to the masonry in jambs. The amount of bearing which the supports provide for the ends of lintel is an important factor. As a general rule the bearing of a lintel at its ends should be 10 cm. (depth of one brick) or 3·8 cm. for every 30 cm. of span, whichever is greater. Lintels are made of various materials such as wood, stone, brick, reinforced brick, steel and reinforced cement concrete.

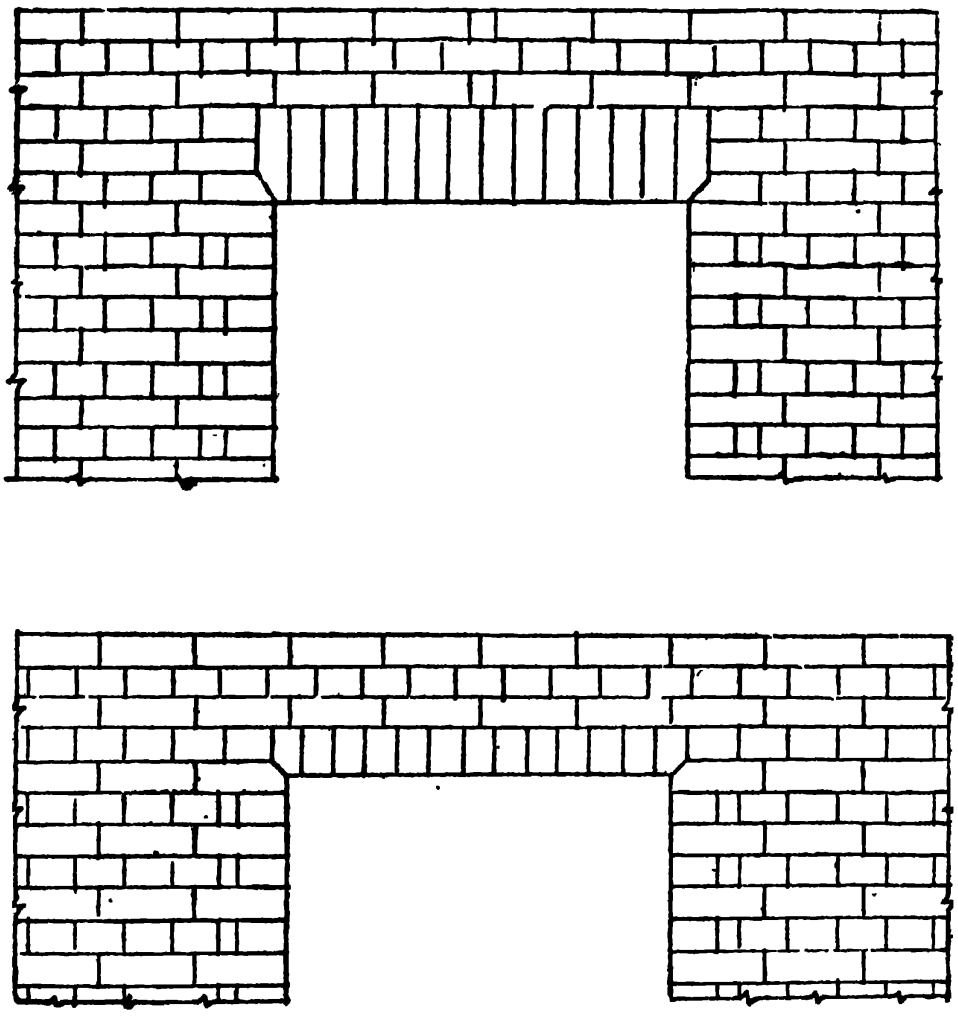
Classification of lintels by material

16·2 Wooden Lintels. In hilly areas, where timber suitable for the construction of lintel is easily available, wooden lintels are commonly used. In plains, the use of wooden lintel is very rare on account of high cost of the material. Timber, if not properly ventilated, is liable to decay. Wood being cumbustible, wooden lintels cannot be recommended for fire-proof construction. The minimum depth of the lintel should be 7 6 cm. Sometimes a rough arch is constructed above a lintel to relieve the latter of the weight above. When used for larger spans, the lintel should be properly designed as a timber beam simply supported at its ends.

16 3 Stone Lintels. The use of stone lintels is very common in stone districts. Its use is usually confined to stone masonry structures or buildings faced with stones. In general, stone lintel on account of the high cost of the material and its inability to withstand excessive transverse stresses, is rarely used. The minimum thickness of stone lintel in kept 7·6 cm. and as a thumb rule, the thickners is taken as 3·8 cm. per 30 cm. length of span.

16·4 Brick Lintels. They are constructed with hard well burnt, first class bricks laid on end or edge. Depending upon the span, their depth varies from 10 cm. (depth of one brick) to 20 cm. (length of one brick). They are suitable for small openings generally not more than 90 cm. in span. Bricks having frogs are more suitable for the construction of lintels. The frogs, when filled with mortar, form

joggles which increase the shear resistance of the end joints and ultimately result in increased strength of lintel.



Figs. 16·1—16·2

Different forms of brick lintels

16·5 Reinforced Brick Lintels. When brick lintels are required to be provided over large spans, they are reinforced with mild steel bars. The depth of the lintel is limited to 10 cm. (depth of a brick) or a multiple of one brick thickness. Bricks are so arranged that 1·9 cm. to 3·8 cm. wide space is left length-wise for the insertion of reinforcements. The gap is then filled with rich cement mortar or cement concrete.

16·6 Reinforced Concrete Lintels. On account of their durability, strength and fire resisting properties, reinforced concrete lintels are commonly used. The are economical and easy in construction. They can be used for bigger spans and heavy loading conditions.

R.C.C. lintels are constructed with 1 : 2 : 4 cement concrete reinforced with mild steel bars. They may be pre-cast or cast-in-situ. For smaller spans, say up to 1·2 m. pre-cast lintels are preferred.

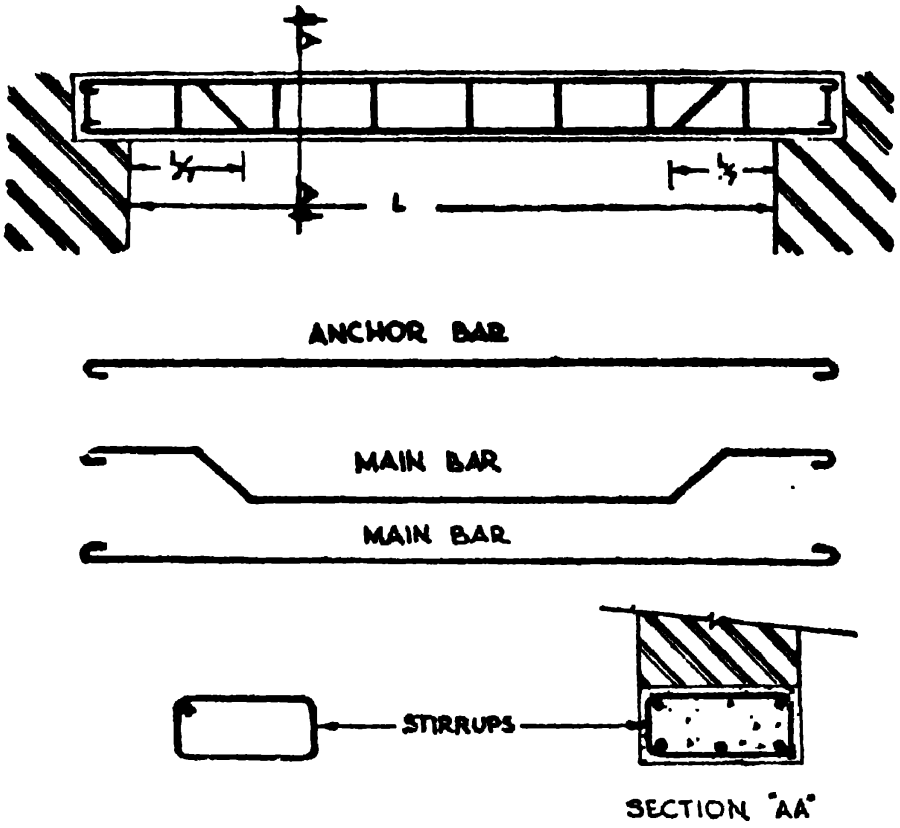


Fig. 16·3

Details of a reinforced concrete lintel

They are manufactured and cured well in advance and as such are economical as the same mould can be used a number of times. The use of pre-cast R C.C. lintels expedites the construction as no more time is needed for their curing. While laying a pre-cast lintel, special care should be taken to see that the marked face of the lintel (soon after pouring concrete in the mould, the top of the concrete surface is marked with some paint or tar so as to distinguish it from bottom face) is kept at top. If the lintel is placed in reverse position, *i e.* the marked face pointing downward, disasterous result may take place. For larger spans, lintels are cast-in-situ, as pre-cast lintels will have to be given additional bending treatment of reinforcements to guard against the lifting stresses. For lintels over large spans subjected to heavy loadings, the depth of the lintel and the area of the reinforcement should be accurately computed.

Depth of lintel for ordinary loading : Up to 1·2 m. length of span, a 15 cm. deep lintel is found to be safe. As a general rule add 25 mm. for every additional 30 cm. span.

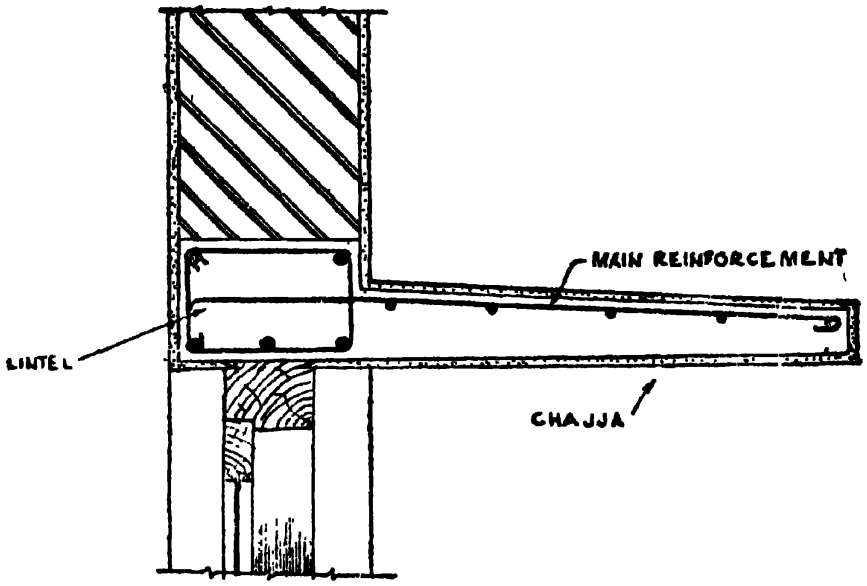


Fig. 16·4

Reinforced concrete lintel with a chajja projection

Reinforcement for lintels for ordinary loading : The number of main bars for a lintel depends upon the load from wall to be carried above and the span of the opening. As a general rule for each 10 cm. (half brick) thickness of wall, one main bar should be provided. The diameter of the bar varies with the span. Upto 1·2 m. span : 10 mm. ϕ bar ; from 1·2 m. to 2 m. span 12 mm. ϕ bar and from 2 to 3 m. span 16 mm. ϕ bar will be found adequate.

16·7 Steel Lintels. When a large opening carrying heavy wall load is to be spanned by a lintel, an R.C. lintel will work out to be very deep. If due to architectural reasons, the depth of the lintel

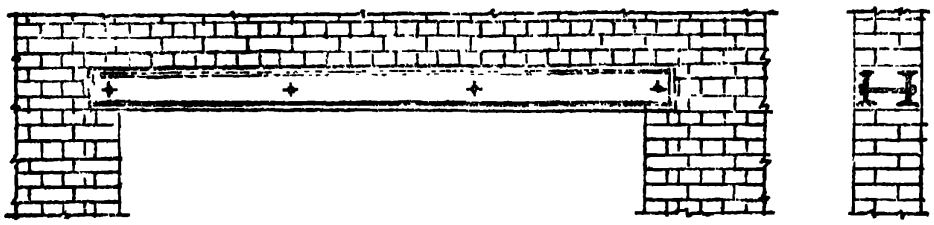


Fig. 16·5—16·6

Elevation and section of a steel lintel

is to be restricted, it is economical to use steel lintel. Steel lintel consists of section of rolled steel joists, used singly or in a combination of two or three. Built-up lintel consists of three R.S.Js. spaced together and connected to each other by bolts passing through them at intervals. This system is embedded in concrete and is cured like R C. lintel.

16·8 Arch. An arch may be defined as mechanical arrangement of wedge-shaped blocks of stones or bricks mutually supporting

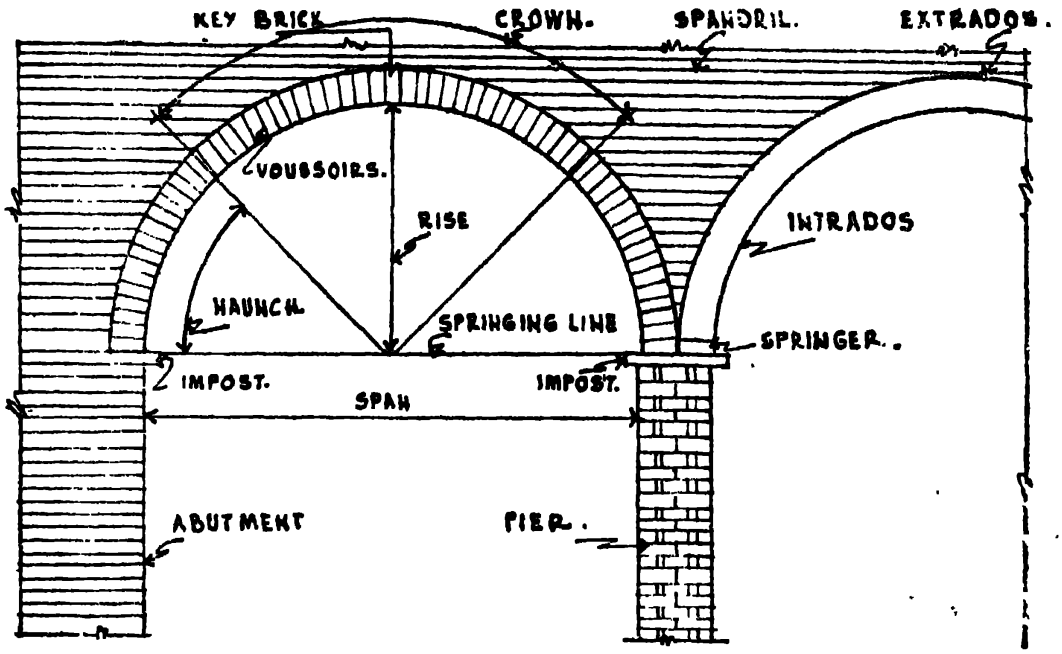


Fig. 16·7

each other and supported at the end by piers or abutments. In common with lintels, the object of an arch is to carry the weight of the structure above the opening. Because of their shape, the blocks support each other by the mutual pressure of their own weight and the structure remains in position by the resistance of the supports.

16·9 Technical Terms. The various technical terms used in arch work have described below :

(*i*) *Abutment or pier* is the part of the wall or pier on which the arch rests.

(*ii*) *Arch ring* is a course of stones or bricks having a curve similar to that of the arch.

(*iii*) *Intrados or soffit* is the under-surface of an arch.

(*iv*) *Extrados* is the outer surface of an arch or the outer curve of the arch ring.

(*v*) *Voussoirs or arch blocks or arch stones* are the wedge shaped units forming the arch.

(*vi*) *Springing stone or springer* is the first voussoir at springing level on either side of the arch.

(*vii*) *Springing line* is an imaginary line joining the two springing points.

(*viii*) *Crown* is the highest point of the extrados or it is the highest part of an arch.

(*ix*) *Key-stone* is the highest central wedge-shaped block of an arch.

(*x*) *Skew back* is the surface of the abutment on which the arch rests.

(*xi*) *Span* is the clear horizontal distance between the supports.

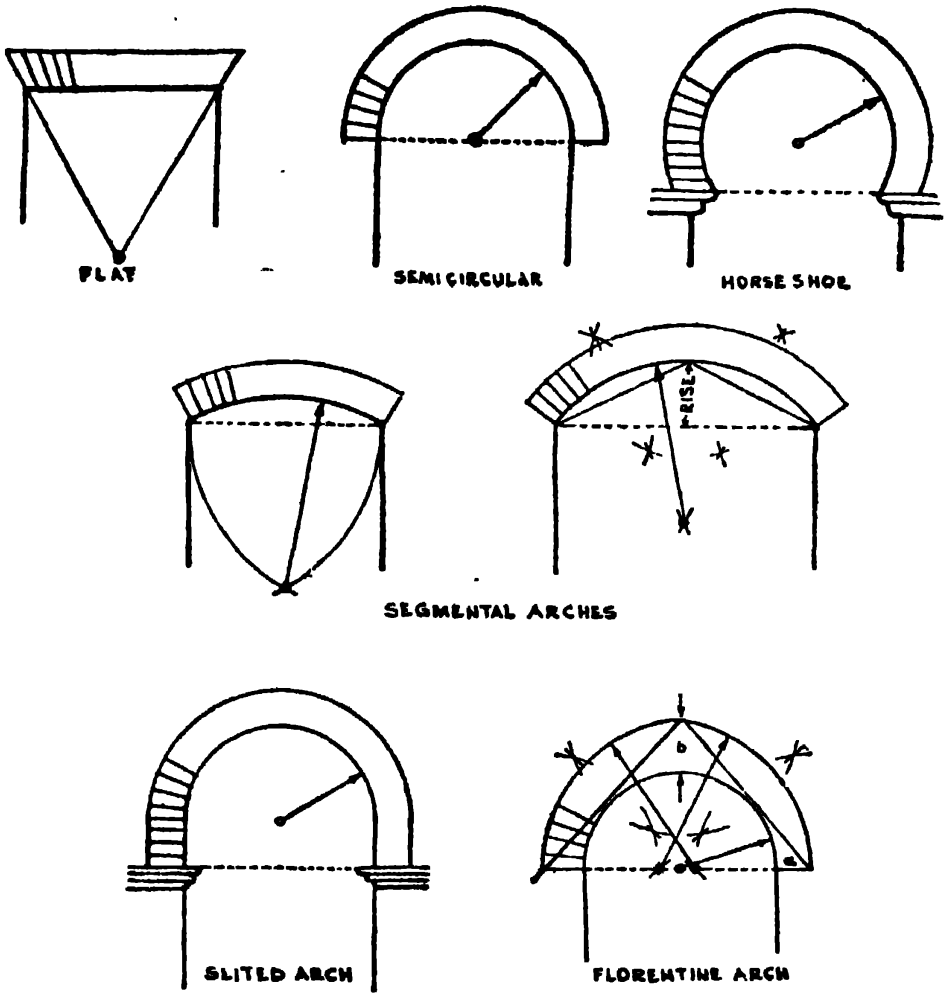


Fig. 16·8

Various types of arches

(*xii*) *Rise* is the vertical distance between the springing line and the highest point on the intrados.

(*xiii*) *Springing points* are the points at the extremities of the intrados.

(*xiv*) *Depth of the arch* is the perpendicular distance between the intrados and the extrados.

(*xv*) *Haunch of the arch* is the portion of the arch situated centrally between the key and skew backs.

(*xvi*) *Spandril* is the triangular walling enclosed by the extrados of the arch, a horizontal line from the crown of the arch and a perpendicular line from the springing of the outer curves.

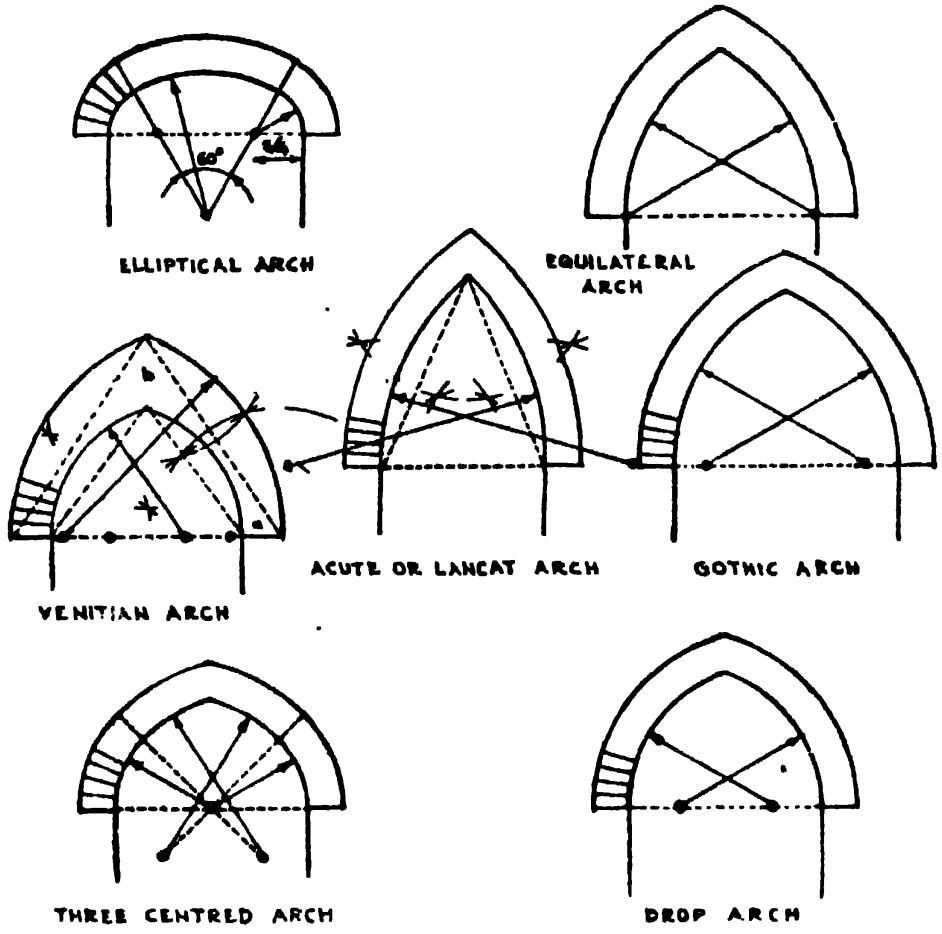


Fig. 16·9

Various types of arches

16·10 Type of Arches. Arches derive their names from the shape of curve formed by their soffit or intrados. The type of arches commonly adopted in construction work are :

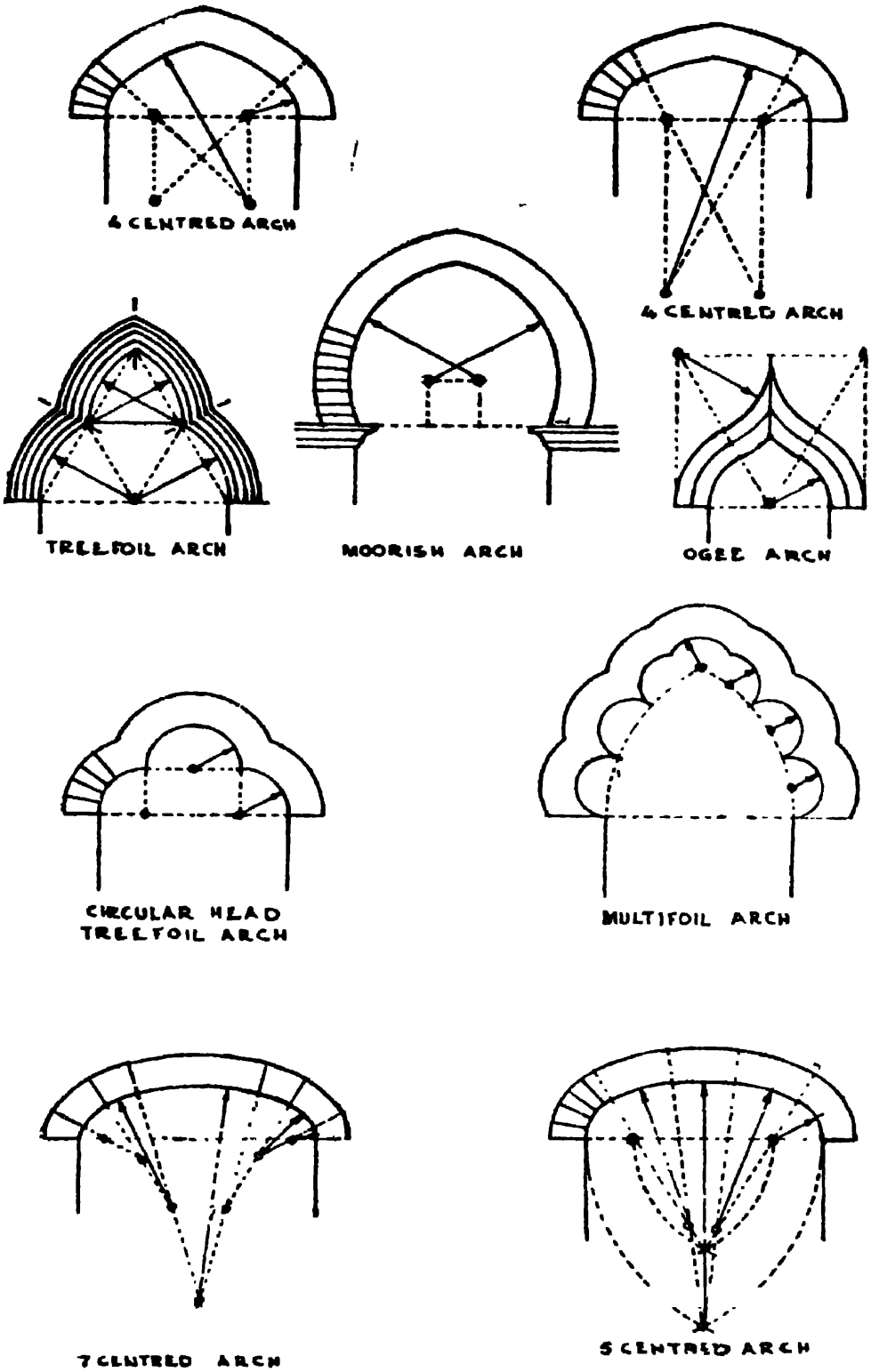


Fig. 16·10

Various types of arches

(1) Flat arch
(2) Semi-circular arch
(3) Segmental arch
(4) Relieving arch
(5) Dutch or French arch

In addition, there are various other types like elliptical arch, parabolic arch, four-centred arch or tudor arch, five-centred arch, points arch, etc. The various types of arches have been shown in Figs. 16·8—16·10.

16·11 Materials of Construction. Arches may be constructed with bricks, stones and concrete. Classification of arches by material is given below :

16·12 Brick Arches. Depending upon the nature of workmanship and the quality of brick used, brick arches may be classified as rough arches, axed brick arches, gauged brick arch and so on.

Rough arches : These arches are built with ordinary bricks which are not cut to wedge shape. In order that all the bed joints may be normal to the curve of arch, the joints are made wedge-shaped.

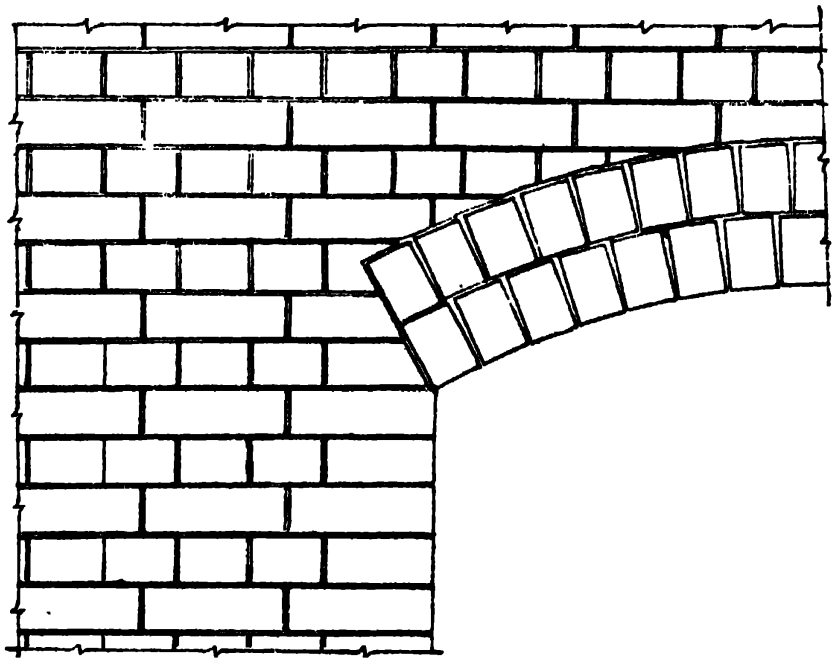


Fig. 16·11

Rough brick arch

Thus the joints at the extrados are wider than those at the intrados. The wedge-shaped joints spoil the appearance of the arch and as such rough arches are seldom used for facing brick-work.

These arches are generally used over wooden lintels in order to relieve the latter of the weight of the masonry above. Hence they are sometimes termed as 'relieving arches".

Axed brick arches : In this type of construction, the bricks are cut to wedge-shape. Thus the joints of the arch are of uniform thickness. Since the wedge-shaped units are not finely dressed, the appearance of the arch is not much attractive.

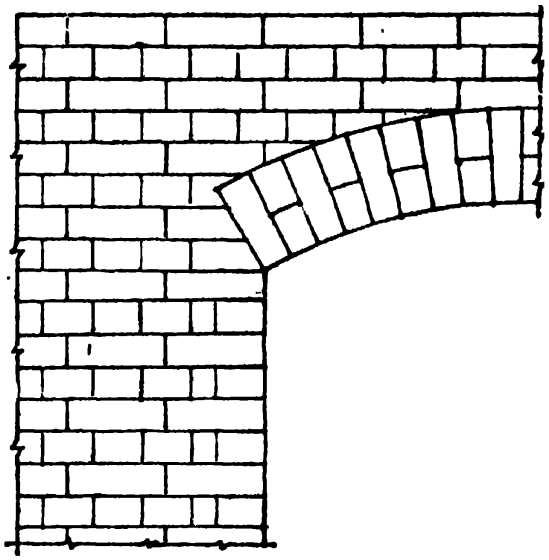


Fig. 16·12
Axed brick arch

Gauged brick arches: As the name suggests, gauge bricks are those which have been accurately prepared to a wedge shape for the arch construction. Hard bricks cannot be used in this type of construction as it is difficult to cut them to true wedge shape accurately. Hence specially made bricks known as "rubber bricks" are used in the arch construction. The bed joints are very thin usually 1·6 mm. thick. Cement mortar is considered too coarse for such joints, hence lime putty is used for binding the blocks. The thin white joints add to the appearance of the finished work.

Bonds in brick arches : For ordinary work, bricks in concentric rings of half bricks are laid with non-continuous radial joints. Each ring is fully completed before constructing the ring immediately above it. For spans above 7·6 m. the concentric rings of brick work have a tendency to separate and there is a continuous danger of the whole pressure being thrown to one ring, which might get crushed and thus collapse the entire arch structure. This danger is avoided either by laying bricks alternately as headers and stretchers in section with continuous radial joints or by providing key stones at intervals.

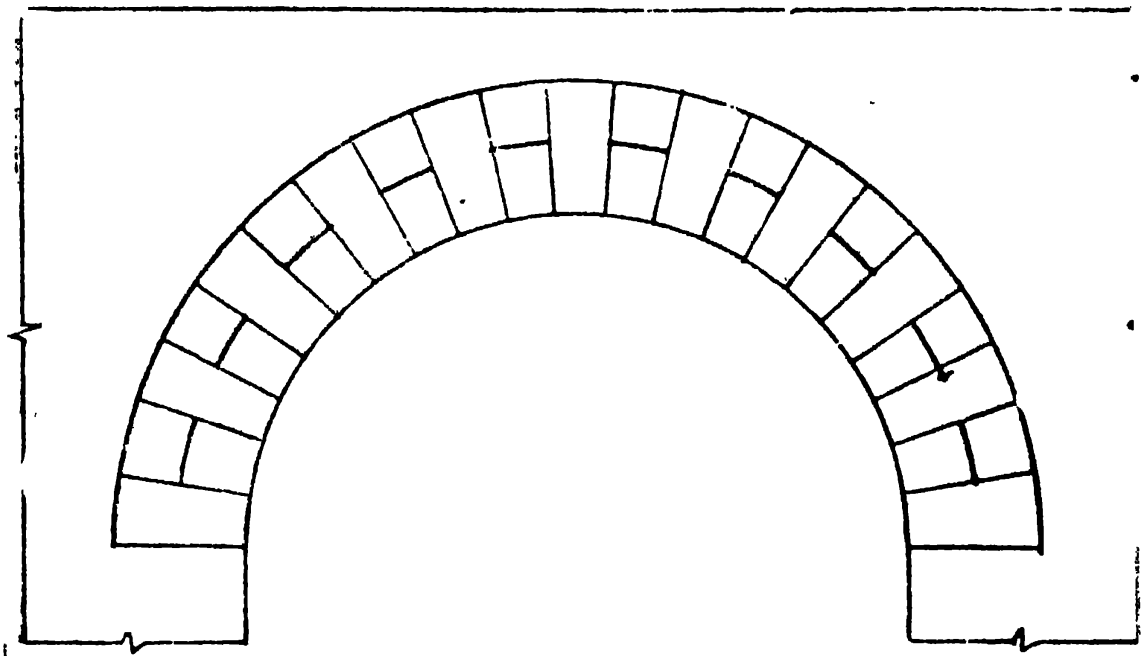


Fig. 16·13

Semi-circular brick arch showing bond in brick work

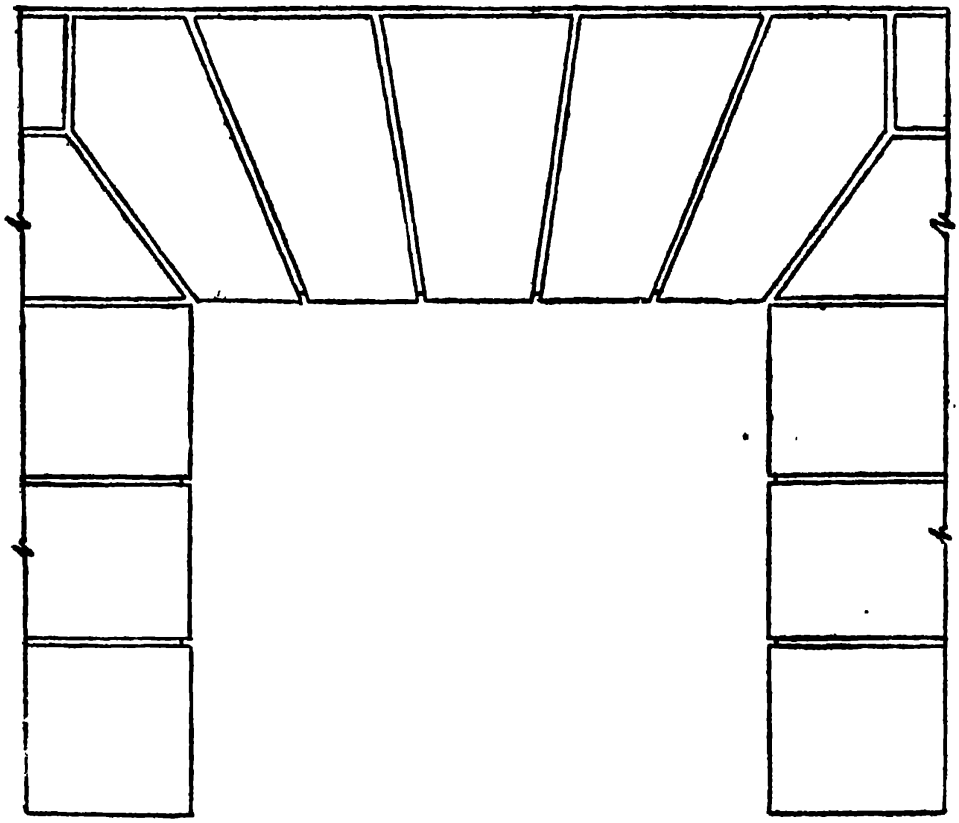


Fig. 16·14

Flat stone arch

16.13 Stone Arches. Considering the nature of workmanship and dressing of the material, stone arches may be divided in the following two categories :

1. Rubble arches
2. Ashlar arches.

Rubble arches : They are constructed with rubble stones which have been hammer-dressed, roughly to required shape and size of the voussoirs. In arch ring up to 38 cm. in thickness, all stones should be of the full depth of the arch. In arches above 38 cm. in thickness, the stones are laid in two rings in alternate course of headers and stretchers. This type of construction is weak in strength and is not attractive in appearance and is as such provided for small openings only.

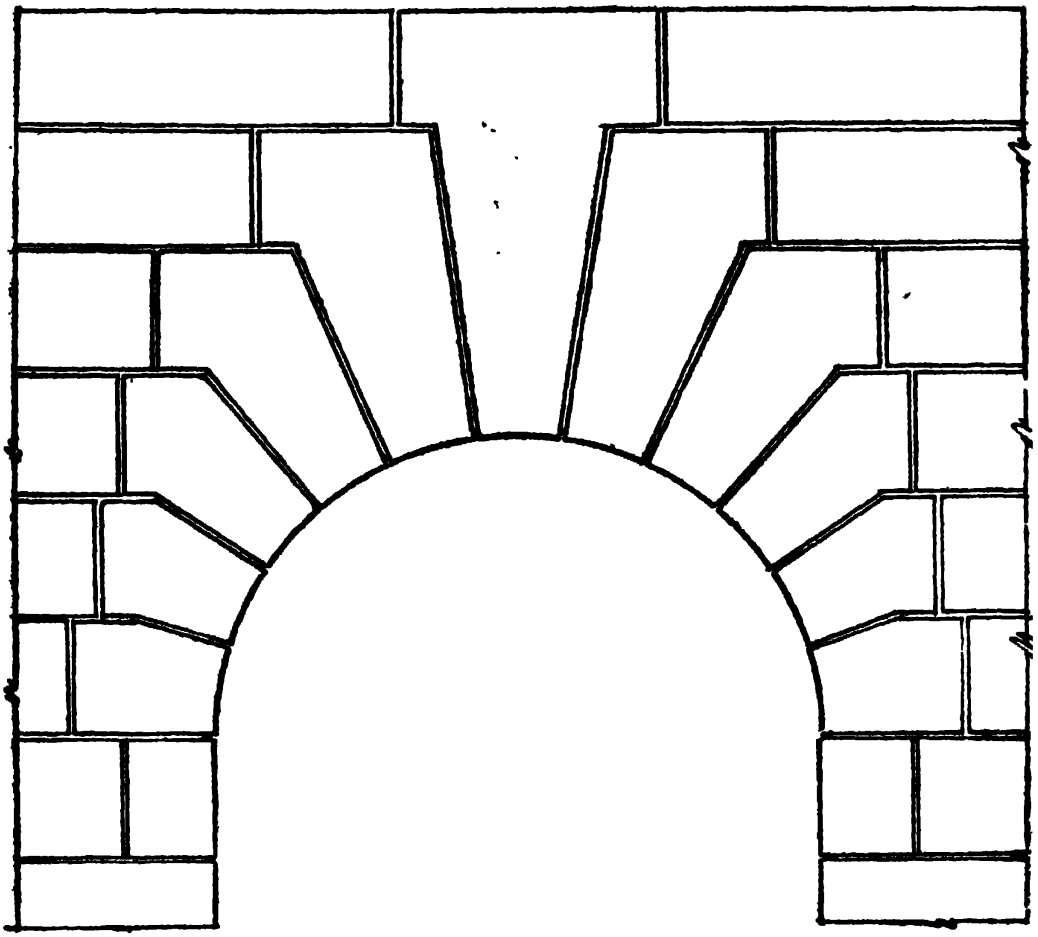


Fig. 16·15
Semi-circular stone arch

Ashlar arches : They consist of arch stones which have been dressed full and true to their proper shapes. In all the cases where the depth of the arch is 60 cm. the voussoirs are made of full thickness of the arch and are set in fine mortar with their radial joists.

The stones are laid as headers and stretchers alternately, all headers being of full depth of the ring and not more than two stretchers going to make the full depth of the arch ring. In case where the arch thickness has to be more than 90 cm. only the quoins and the key-stones are made of the full thickness of the arch ring. In order that the voussoirs may be dressed to wedge shape, a full size arch is first set out on a level platform. The sizes of voussoirs and that

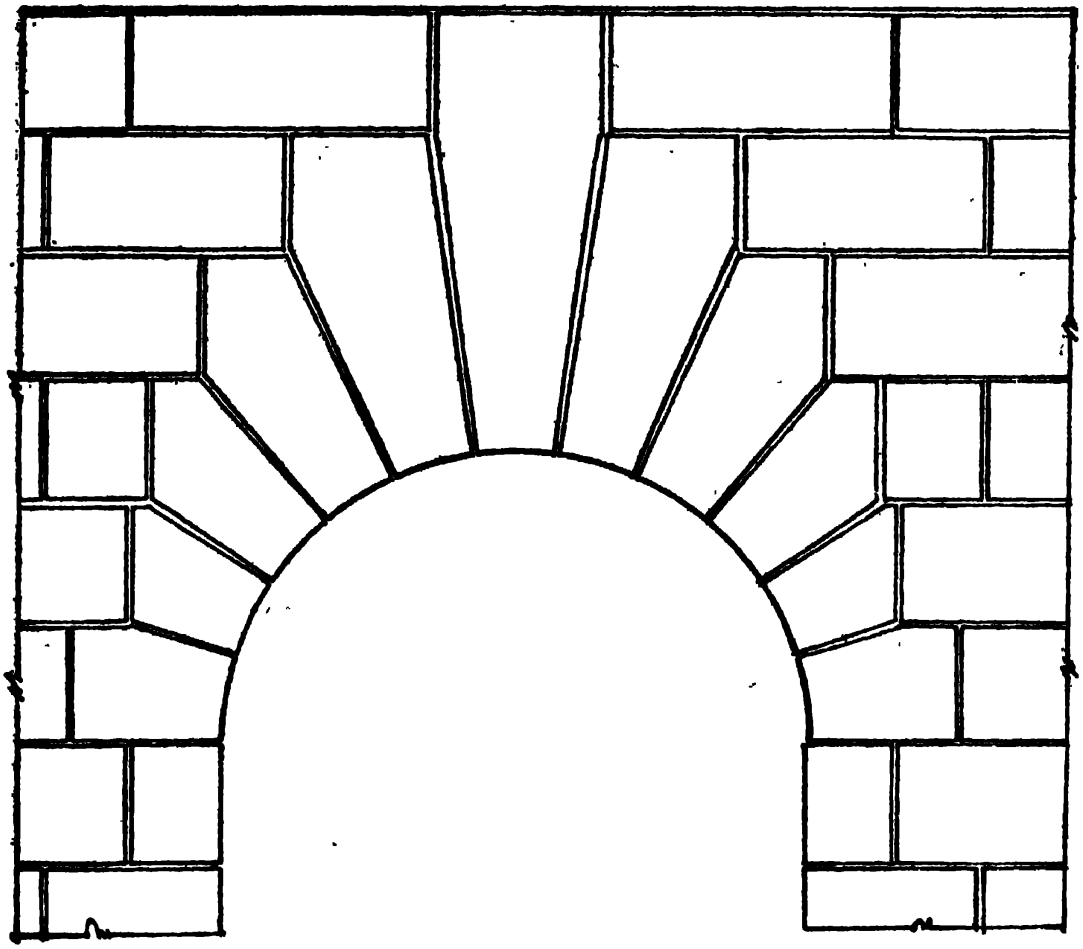


Fig. 16·16

Semi-circular stone arch

of the keystone are carefully marked on the platform after leaving gap for the mortar joints between them. This method of setting out requires slight adjustment and thereafter the required shape of the voussoirs and keystones is cut with the help of arch set out on the platform. Finally the stones are cut true to the shape of the template and the voussoirs thus formed satisfy specification of the ashlar arch construction.

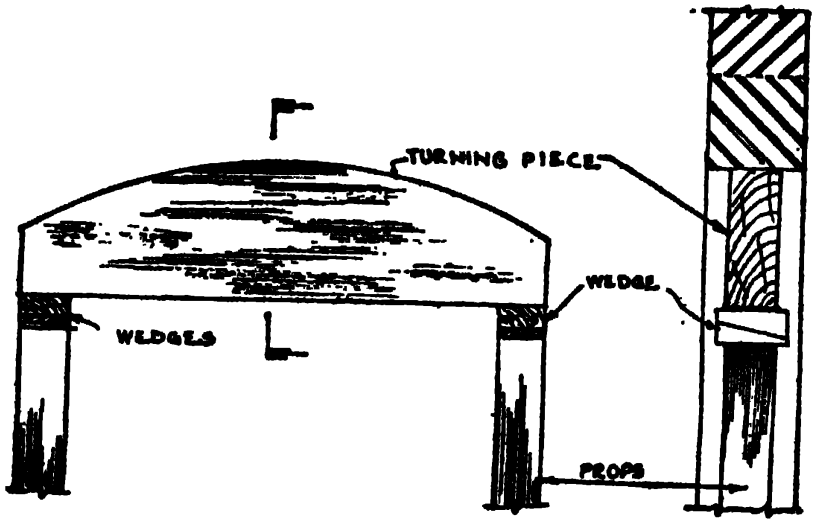
16.14 Concrete Arches. They are of two different types, namely, concrete block arches and monolithic concrete arches :

Concrete block arches : For small openings in a building, concrete block arches can be provided with advantage. The voustoirs, in the form of cement concrete blocks, are prepared in specially made moulds for the purpose. The moulds of concrete block for the 'key' or skew backs are of slightly different dimensions. The concrete mix usually adopted for block construction consists of one part of cement, two parts of sand and four parts of aggregate. After the concrete in the mould is fully set, the blocks of concrete are removed for curing in a water pond, constructed for the purpose. Generally, the concrete blocks are used without reinforcement. The arch construction with concrete blocks is similar to that for stone or brick arch construction.

Monolithic concrete arches : Monolithic concrete arching is frequently used for roofing of buildings, culverts and bridges. The construction for smaller span with ordinary loading conditions require no reinforcements. The arching can be done in lime concrete as well as in cement concrete. For roofing arches, a rise of 5 cm. for every 30 cm. of span is usually allowed when lime concrete is used. The minimum thickness of arch should not be less than 15 cm. for spans up to 3 m. As a general rule, add 38 mm. for each additional 30 cm. of span. For larger spans, arches have to be reinforced.

Method of Construction

Centering : The usual centering for arch construction consists of a horizontal frame of timber known as centre or turning piece. The centring differs according to the shape of arch curve, the material used in arch construction and the span of the opening.



Figs. 16·17—16·18

Centering for a segmental arch

The centring may be of timber or steel. Use of steel centring is very rare due to high cost of material and is usually preferred in huge construction works where the same centering is to be used a number of times. Wooden centering in its simplest form consists of a pair of solid ribs, cut from a plank of thickness required for centering. The upper surface of the ribs is given the shape of the soffit of the arch to be constructed. Lagging or cross battens are nailed across the ribs at close intervals for supporting the voussoirs at top. The spacing of laggings may be increased in case of stone

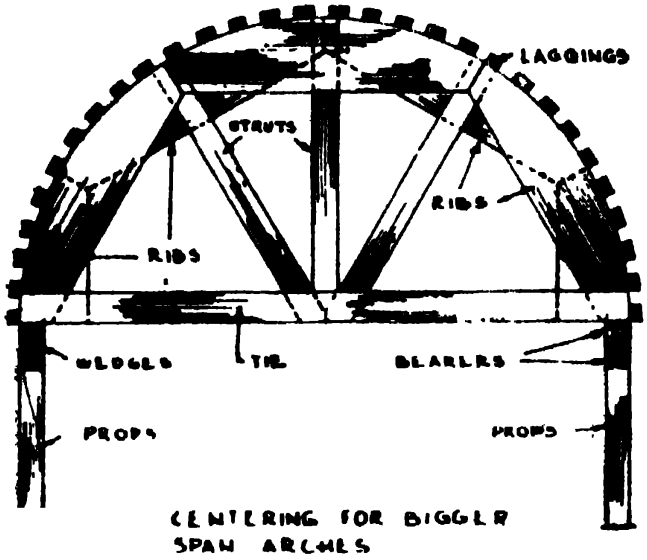


Fig. 16·19

Centering for a semi-circular arch

arch. The distance between the two ribs depends upon the thickness of wall to be carried by the arch. Bearing pieces are nailed at the bottom of the ribs so as to enable them to be supported on the the vertical props. For large spans, built up ribs are used instead of solid ribs. To facilitate easing or lowering of the centering, a pair of wedges is provided between the supports and the bearing pieces.

Procedure of construction : After the centering is properly erected in position, skewbacks are first prepared and voussoirs are arranged in the form of arch curves starting from the skewbacks and proceeding towards the crown. Keystone is finally inserted to lock all the voussoirs in position. The voussoirs must be properly bedded to ensure strength and stability of the arch. After the key has been placed in position, the centre should be eased by slackening the wedges. During the process of easing, great care should be taken to see that the centre is lowered only by a small height say 3 mm. The lowering of centre is necessary in stone arch construction so as it allows the voussoirs to settle upon their beds nicely. No load

should be super-imposed upon the arch work before it has fully set. The 'centre' is removed before the construction of masonry above the arch.

16·15 Flat Arch. When used over opening of door or window, the flat arch acts similar to a lintel. Flat arch also known as straight or camber arch is laid with its bed joints radiating to a centre. The

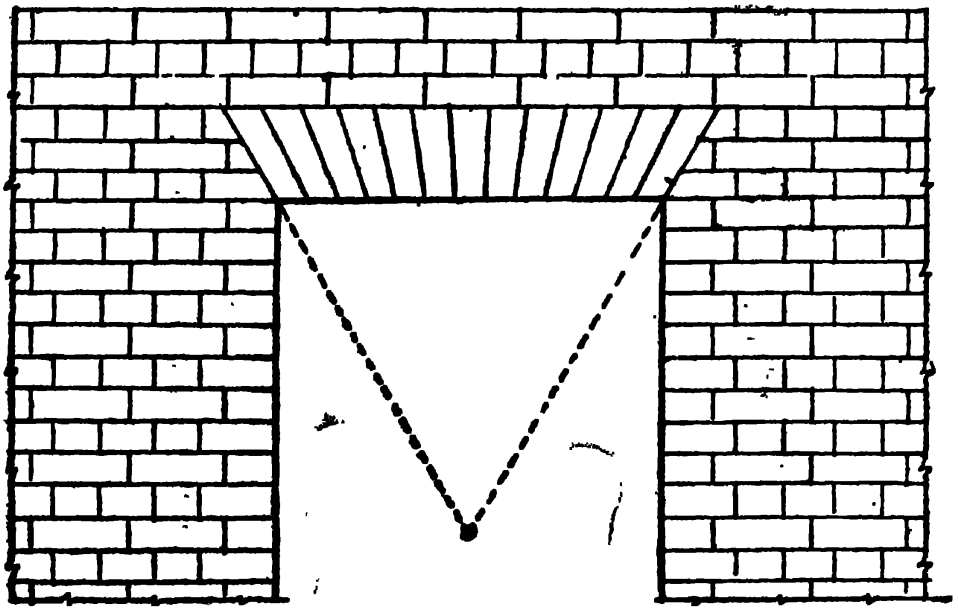


Fig. 16·20
Flat brick arch

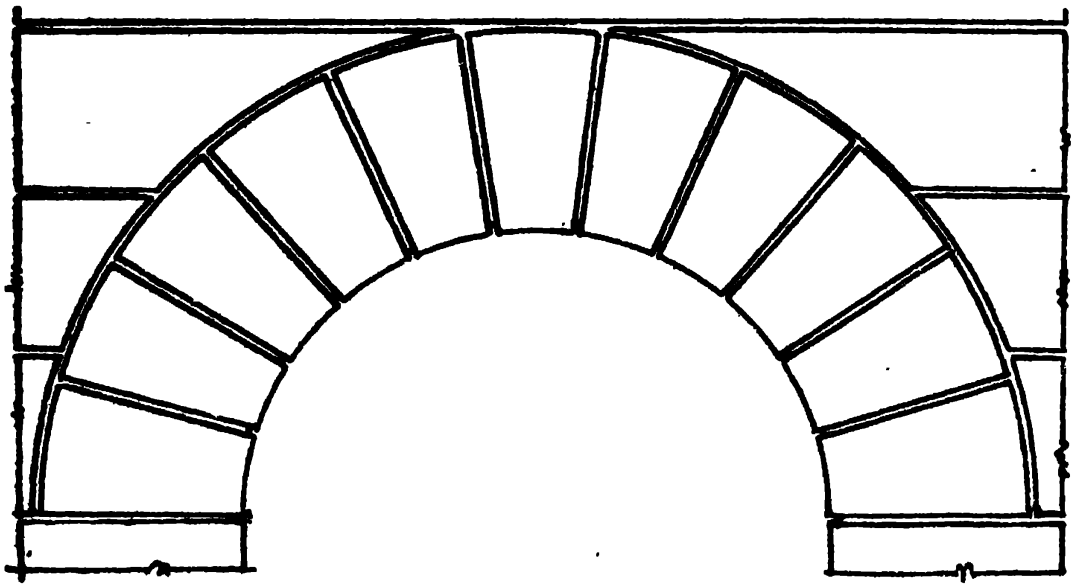


Fig. 16·21
Semi-circular arch

skewback is made to rest in an inclined position so as to make an angle of 60° with the springing line. The extrados of the arch is horizontal but the intrados has a straight camber or upward curvature. The camber is usually 3 mm. for every 30 cm. of span and is necessary to avoid optical illusion of sagging. Flat arches are not strong as compared with other forms.

16·16 Semi Circular Arch. The arch derives its name from the shape of the curve given to the arch soffit. The different types of semi-circular arches in stone and brick masonry are shown in Figs. 16·13, 16·15, 16·16 and 16·21.

16·17 Segmental Arch. This type of arch is segmental in shape and is commonly provided for openings of various sizes. The bed joints of segmental arch radiate from a common point, which lies below the springing line and is equidistant from all points on the arch curve. When used over a lintel, segmental arch is termed as "relieving arch".

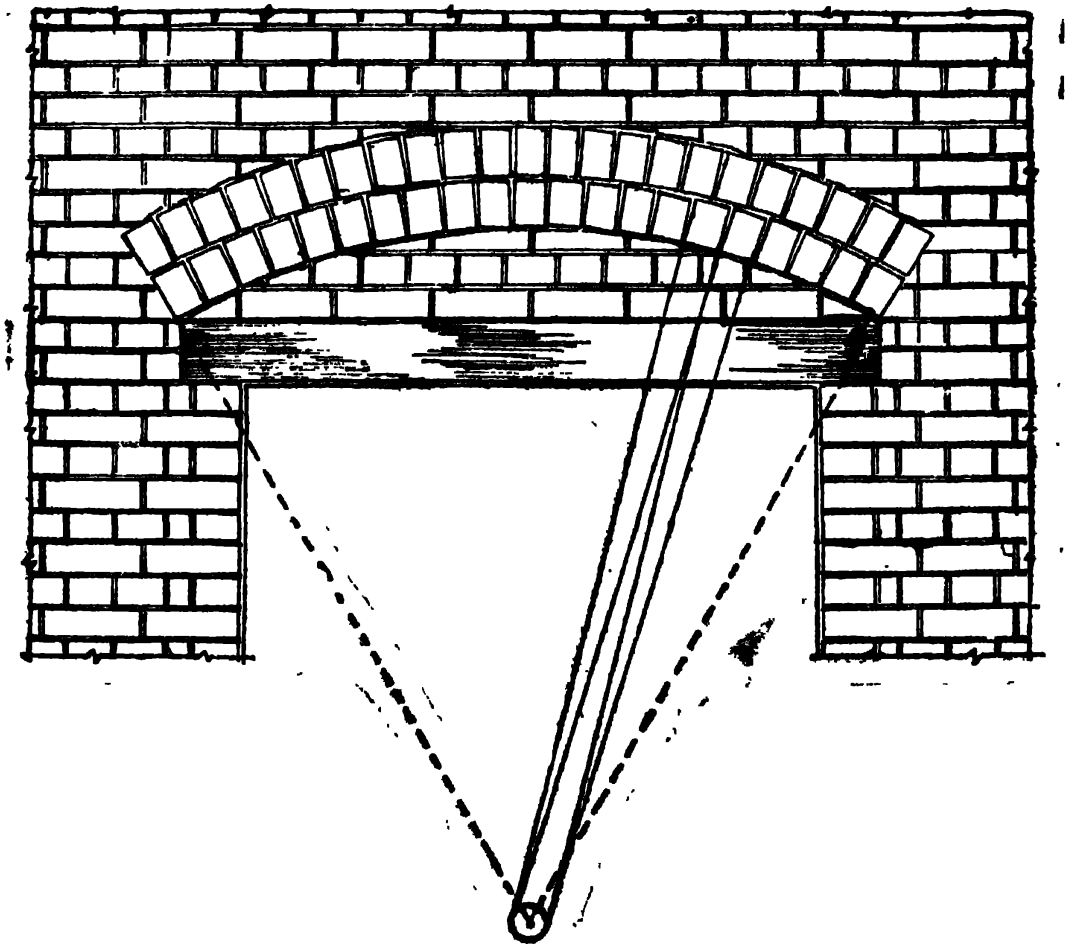


Fig. 16·22

Relieving arch

16·18 Relieving Arch. Where wooden lintel is required to span over wider opening, brick relieving arch is usually constructed above the lintel. The arch thus constructed relieves the lintel of the load from the masonry above and hence the size of the lintel can be appreciably reduced. The relieving arch should have its abutments clear of the ends of the lintel so that the skewback slopes outward and away from the top edges of lintel ends. Thus the span of a relieving arch will be equal to the clear span of the opening plus twice the bearing of the existing wooden lintel. The great advantage in this type of construction is that the wooden lintel when decayed can be replaced without affecting the stability of the structure.

16·19 Dutch or French Arch. This type of arch is similar to a flat arch in design but differs in shape and method of construction. This form of arch is not so sound and as such it is only suitable to be provided for small openings.

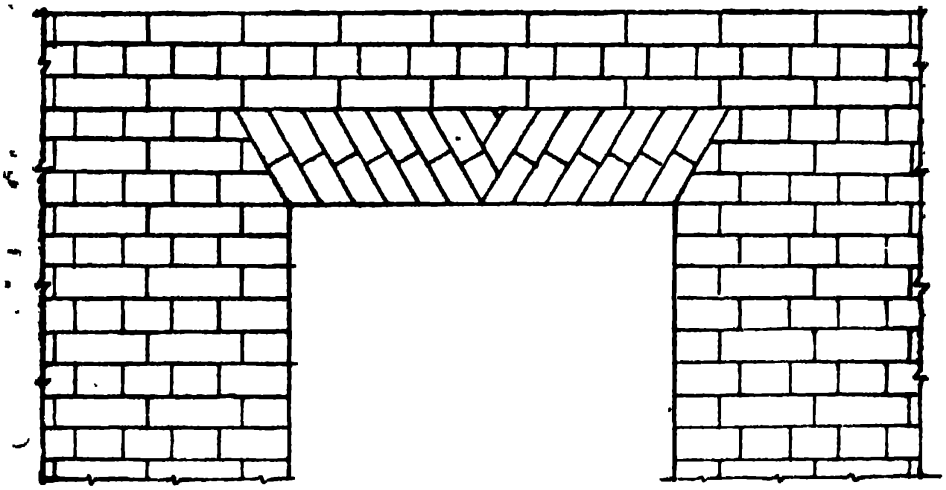


Fig. 16 23

Dutch or French arch

Questions for Revision

1. What are the functions of lintels and arches ? In a neat sketch show the component parts of the latter giving their technical terms.

2. A brick wall two-brick thick has an opening 2 m. in length. The height of the wall above the opening is 1·5 m. The roof supported on the wall consists of a 12 cm. thick R.C. slab finished with 10 cm. thick mud phuska terracing. The parapet wall above the wall is 90 cm. high and 10 cm. thick. Design a R.C. or R.B.C. lintel over the opening and draw a longitudinal section and a cross-section of the lintel showing clearly all the relevant details regarding the position of the lintel, arrangement of bars, etc.

3. How would you proceed to construct a big brick masonry arch ? What type of centering would you provide ? Sketch the entire arrangement showing the details of centering work.

4. An opening of size 1·83 m.×2·44 m. is to be provided in a solid wall above which there are two floors. What measures do you propose to go ahead with the work ? Recommend the type of lintel beam above the opening with a suitable dimenisoned sketch.

5. Write short notes on :

(*i*) Wooden lintels
(*ii*) Reinforced brick lintels
(*iii*) Flat arch
(*iv*) Segmental arch
(*v*) Relieving arch
(*vi*) Dutch or French arch.

6. What do you understand by the terms, arches and lintels ? Describe in brief the various types of arches used in modern constructions.

7. Define the following terms with regard to an arch :

(*i*) Abutment
(*ii*) Skew-back
(*iii*) Spandrel
(*iv*) Voussoir
(*v*) Key-stone
(*vi*) Crown.

8. Make a neat sketch of two adjacent segmental arches of brick-work consisting of three rings each in two-brick thick wall with a pier 75 cm. thick between. The span of each arch is 2 m. and the rise is $\frac{1}{8}$rd the span. On your sketch write down the following terms in their proper places :

(*i*) Springing
(*ii*) Haunch
(*iii*) Voussoir
(*iv*) Skewback
(*v*) Spandrel
(*vi*) Crown
(*vii*) Intrados
(*viii*) Key
(*xi*) Abutment
(*x*) Extrados.

9. Draw in plan, elevation and section a stone arch 3·66 m. centre to centre of supporting piers. The piers are 60 cm. square. Show clearly all stone jointing on the drawing and indicate by arrows the following terms :

(*a*) Extrados
(*b*) Radious
(*c*) Haunch
(*d*) Springing line
(*e*) Intrados
(*f*) Voussoier
(*g*) Key-stone.

10. Distinguish between a lintel and an arch. Make a neat sketch of a stone arch and name the various parts. What are the various materials used in the construction of lintels. Sketch a R.C.C. lintel.

11. What are the different types of arches that are used for engineering construction ? Describe any three types in detail with sketches.

(A.M.I.E. Nov. 1970)

17

Structural Design of Lintels

17·1 General. The load which a lintel carries when supporting a brick wall is usually considered as the weight of the wall

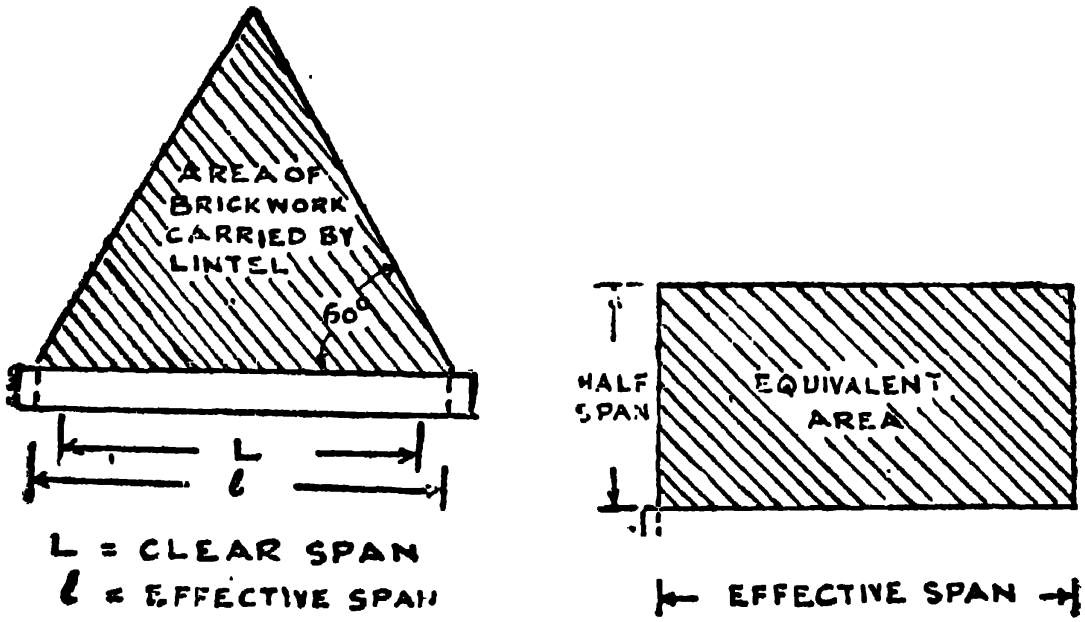


Fig. 17·1

enclosed in a triangle with a base equal to the effective span of the lintel and the side angles of 60°. This consideration is made on the assumption that if a lintel fails, the amount of brick-work which would collapse with it would probably be something between a semi-circular arch or an equilateral triangle. We can also assume that the same effect will be produced if the loading on the lintel is evenly distributed over a length equal to the effective span and for a height equal to half the effective span of the lintel (Fig. 17·1). The above assumptions hold good only when the lintel is situated in the middle of the wall.

For the other possible locations of the lintel the diagrams given in Figs. 17·2, 17·3 should be referred to. The hatched portion in the figures shows the load which should be considered for the design.

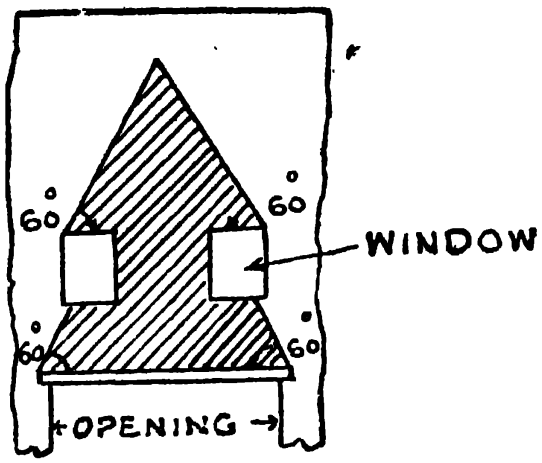


Fig. 17·2

17·2. Steps to be Followed in the Design of Lintels. The basic design steps described below are only applicable to the design of reinforced concrete or reinforced brick lintels.

(*a*) Assume suitable depth of the lintel with the help of thumb rule. The breadth of the lintel should, as far as possible, be equal to the thickness of the wall to be supported above the opening.

(*b*) Decide the bearing of the lintel on the end support and calculate the effective span of the lintel.

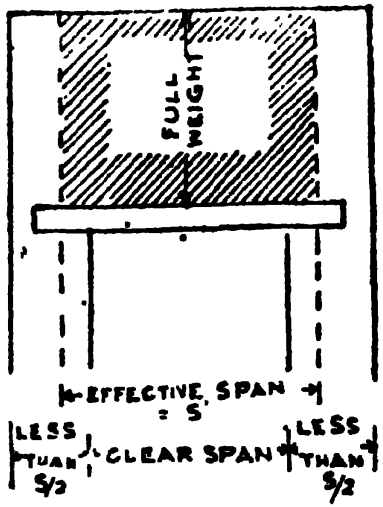
(*c*) (*i*) In case the lintel is so located that triangular loading is to be considered, calculate the total load (W) of the effective triangle of masonry. Also calculate the load per metre run due to self-weight of assumed section of lintel (w').

(*ii*) In case the loading on the lintel is to be considered in the form of uniformly distributed load calculate, total load (w) per metre run. Therefore, (w) will be equal to load due to masonry and self-weight of assumed section to lintel.

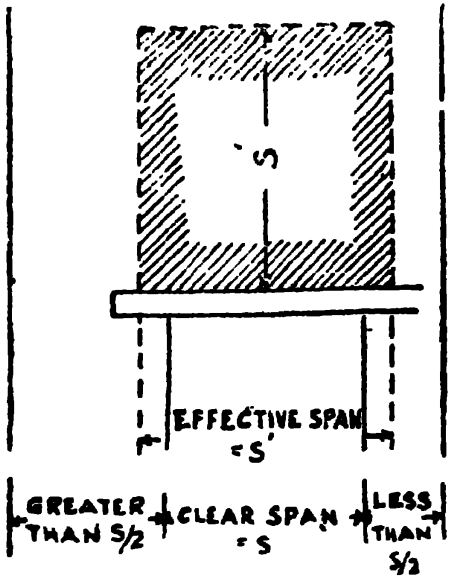
(*d*) Calculate the maximum bending moment by the governing formula.

(*i*) In case of simply supported lintel (resting on two supports) with triangular loading conditions, total bending moment will be obtained by calculating the maximum bending moment due to masonry above and due to uniformly distributed loading on account of self-weight of lintel separately and adding them.

Both ends of lintel close to ends of wall e.g., where a lintel spans an opening in a short wall.



One end of lintel close to end of wall



When there are window or ventilator openings in the wall carried by lintel

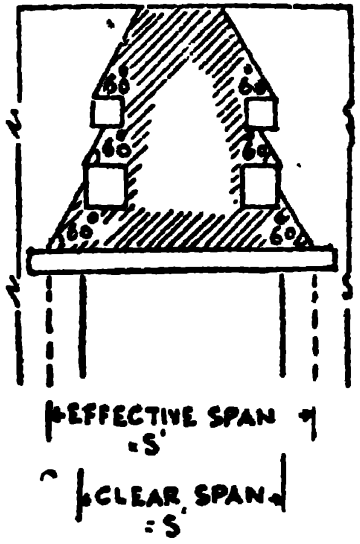


Fig. 17·3

Max. B.M. due to triangular loading $= \frac{Wl}{6}$ ...(i)

Max. B.M. due to uniform loading $= \frac{w'l^2}{8}$ ...(ii)

Therefore, Total max. B.M. $= \frac{Wl}{6} + \frac{w'l^2}{8}$

(i) In case of lintel constructed over several supports : If the location of the lintel is such that triangular loading is to be considered, convert the loading in the form of uniformly distributed load as decribed before and find the total uniformly distributed load including the self-weight of lintel.

Formula for B.M. for lintel continuous for two equal or approximately equal spans.
Max. +ve B.M. near the centre

$$= +\frac{wl^2}{10} \text{ kg. m.}$$

Max. −ve B.M. over interior support

$$= -\frac{wl^2}{10} \text{ kg. m.}$$

Formula for B.M. for lintels continuous for more than two spans.
Max. +ve B.M. near the centre of end spans and max. −ve B.M. over the penultimate support

$$= \pm\frac{wl^2}{10} \text{ kg. m.}$$

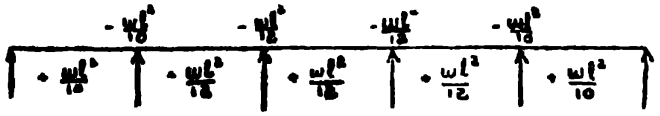


Fig. 17·4

The max. +ve B.M. at the centre of all the intermediate spans and max. −ve B.M. overall the intermediate support

$$= \pm\frac{wl^2}{12} \text{ kg. m.}$$

Multiply the B.M. thus obtained by 100 to convert it in kg. cm.

(c) Calculate the effective depth of the lintel by the formula

$$d = \sqrt{\frac{M}{Q.b}}$$

where b = assumed breadth of the lintel

and $Q = 8{\cdot}48$ (For M150 grade of concrete)

(*f*) Fix the over-all depth of the lintel and obtain the final value of the effective depth.

(*g*) Calculate the required area of steel by the formula,

$$A_t = \frac{M}{a_1.d.t} \text{ sq. cm.}$$

(*h*) Choose suitable diameter of the bars and find the number of bars required for A_t in step (*g*). Check that the bars should fit into the assumed breadth of the lintel.

(*i*) Calculate the maximum shear force in the lintel by the governing formula.

(*j*) In case of simply, supported lintel

$$\text{Max. S.F.} = \frac{w'L}{2} + \frac{W}{2}$$

where L = clear span of the lintel.

(*ii*) In case of continuous lintel. Shearing force at the outer edge of the first interior support = $0{\cdot}6\ wl$ kg. Shearing force at the interior support, other than the first support

$$= \frac{wl}{2} = 0{\cdot}5\ wl \text{ kg.}$$

(*i*) Find the shear stress by the formula

$$s = \frac{S}{a_1.d.b} \text{ kg./sq. cm.}$$

The value of safe shear stress (s) for M150 grade concrete is 5 kg./cm^2.

If the calculated value of shear stress works out to less than 5 kg./cm^2, no shear reinforcement is necessary and only nominal stirrups are provided at c/c distances not more than the lever arm ($a_1.d$) of the lintel. On the other hand, if the shear stress as calculated above exceeds $4 \times 5 = 20$ kg./cm^2, the lintel is considered to be unsafe and hence the assumed section of the lintel should be altered.

If the value of shear stress as calculated above is less than 20 kg/sq. cm. but greater than 5 kg/sq. cm., shear reinforcement should be provided.

The spacing of the stirrups to be provided as shear reinforcement is given by the formula

$$p = \frac{A_w.t\,a}{S} \text{ cm.}$$

where p = Pitch or c/c spacing of the stirrups.

A_w = Cross-sectional area of all the legs of the stirrup.

t = The permissible tensile stress in the shear reinforcement. (It is taken as 1400 kg./sq. cm.)

S = Shear force at the section.

a = Lever arm.

(*k*) Calculate bond stress by the formula

$$S_b = \frac{S}{a_1.d.\Sigma 0} \text{ kg/sq. cm.}$$

where S_b = Maximum value of bond stress developed

$\Sigma 0$ = The sum of the perimeters of the tensile bars available at that section.

The permissible value of local bond stress for M150 grade of concrete is 10 kg/sq. cm.

If the calculated value of bond stress exceeds the permissible limit, adopt the following alternatives to reduce the value to safe permissible limit.

(*i*) Use thinner diameter bars so that, for the same area of steel, larger perimeter is available for developing bond.

(*ii*) Increase the depth of the lintel.

Example 17·1 *Design a reinforced concrete lintel over a show case window opening two metre wide. The window is to be centrally located in the 20 cm. thick brick wall. The height of the brick work above the lintel may be taken as 3 metre.*

Solution. Assume the size of the lintel as 18 cm. deep and 20 cm. wide.

Let the bearing of the lintel on the end support be = 20 cm.

$\therefore$ effective span = $2+(0{\cdot}18-0{\cdot}03) = 2{\cdot}15$ m.

Loads

(*i*) To calculate the load due to triangular portion of the brick work.

Height of triangle having a base length of 2·15 m. and base angle as 60° each = $\sqrt{3} \times \frac{2{\cdot}15}{2} = 1{\cdot}863$ metre.

$$\therefore \quad W = \tfrac{1}{2} \times 2{\cdot}15 \times 1{\cdot}863 \times 0{\cdot}20 \times 1920$$
$$= 770 \text{ kg.}$$

(*ii*) Uniformly distributed load due to self-weight of the lintel

or $$w' = 0{\cdot}18 \times 0{\cdot}2 \times 2400$$
$$= 86{\cdot}4 \text{ kg./m.}$$

Total max. B.M.

$$= \frac{Wl}{6} + \frac{w'.l^2}{8}$$
$$= \frac{770 \times 2{\cdot}15}{6} + \frac{86{\cdot}4 \times 2{\cdot}15^2}{8}$$
$$= 276 + 50$$
$$= 326 \text{ kg. m.}$$
$$= 326000 \text{ kg. cm.}$$

Required effective depth :

$$d = \sqrt{\frac{32600}{8{\cdot}48 \times 20}}$$
$$= 13{\cdot}9 \text{ cm.}$$

Adopt an over-all depth of the lintel = 17 cm.

Available effective depth = 17 − 3 = 14 cm.

$$A_t = \frac{M}{a_1.d.t}$$
$$= \frac{32600}{0{\cdot}87 \times 14 \times 1400}$$
$$= 1{\cdot}911 \text{ sq. cm.}$$

No. of 8 mm. ϕ bars required

$$= \frac{1{\cdot}911}{0{\cdot}5} = 3{\cdot}83 \text{ say 4 No's}$$

$$\text{Max. S.F.} = \frac{W}{2} + \frac{w'L}{2}$$
$$= \frac{770}{2} + 86{\cdot}4 \times \tfrac{2}{3}$$
$$= 385 + 86{\cdot}4$$
$$= 471{\cdot}4 \text{ say } 472 \text{ kg.}$$

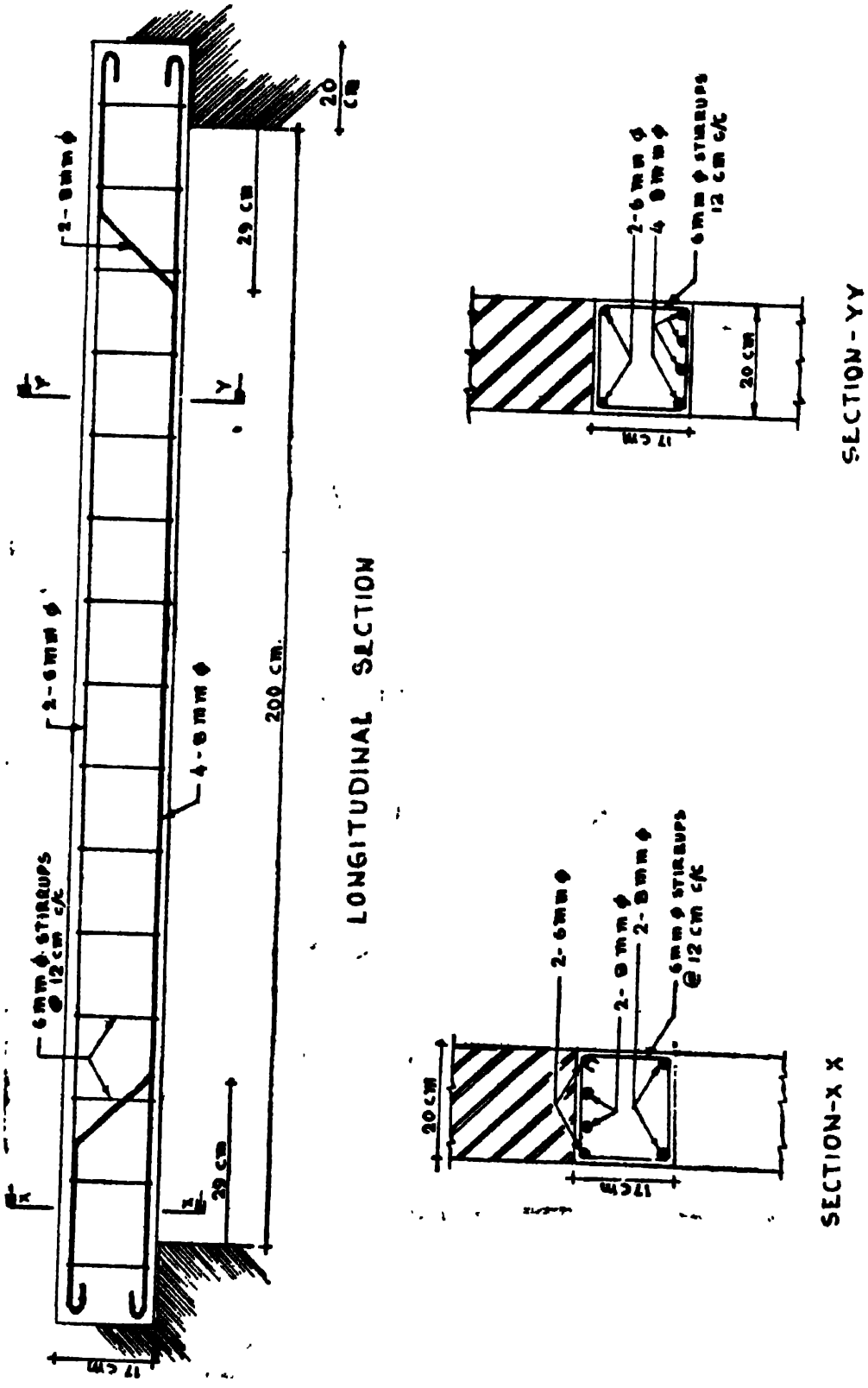

20 cm
2-8mm ϕ
29 cm
Y
Y
2-6mm ϕ
4-8mm ϕ
200 cm.
6mm ϕ STIRRUPS @ 12 cm c/c
29 cm
X
X
17 cm
LONGITUDINAL SECTION
2-6mm ϕ
4-8mm ϕ
6mm ϕ STIRRUPS 12 cm c/c
20 cm
17 cm
SECTION-YY
2-6mm ϕ
2-8mm ϕ
6mm ϕ STIRRUPS @ 12 cm c/c
20 cm
17 cm
SECTION-X X

Fig. 17·5

Check for shear :

$$s = \frac{S}{a_1 d.b}$$

$$= \frac{472}{0{\cdot}87 \times 14 \times 20}$$

$$= 1{\cdot}94 \text{ kg./sq. cm.} < 5 \text{ kg./sq. cm., hence safe.}$$

Check for bond:

Assuming 2 No's 8 mm. ϕ bars from mid-spans, bent up near supports

$$S_b = \frac{S}{a_1.d\Sigma 0}$$

$$= \frac{472}{0{\cdot}87 \times 14 \times 2 \times 2{\cdot}51}$$

$$= 7{\cdot}72 \text{ kg./sq. cm} < 10 \text{ kg/sq. cm., hence safe.}$$

Provide 6 mm. ϕ 2 legged stirrups at $0{\cdot}87 \times 14 = 12{\cdot}19$ say 12 cm. c/c.

Provide 2 No's 6 mm. ϕ anchor bars.

Example 17·2. *Fig. 17·6 shows plan and section of a room. Design a reinforced concrete lintel over the window opening. Following data may be assumed* :

(*i*) $c = 50$ *kg./sq. cm.*

$t = 1400$ *kg./sq. cm.*

$m = 18$.

(*ii*) *Weight of lime concrete terracing* = *1920 kg./cu. m.*

(*iii*) *Weight of brick masonry* = *1920 kg./cu. m.*

(*iv*) *Super-imposed load on the slab* = *200 kg/sq. m.*

Solution. Keeping in view the location of the lintel and the height of brick work above, it is very much apparent that the lintel will be subjected to uniformly distributed loads on account of roofing, brick-work above the lintel and self-wt. of the lintel itself. Assume the size of lintel as 45 cm. deep and 30 cm. wide.

Assume the bearing of lintel at each end = 30 cm.

$\therefore$ Effective span $= 2{\cdot}7 + 0{\cdot}3 = 3$ m.

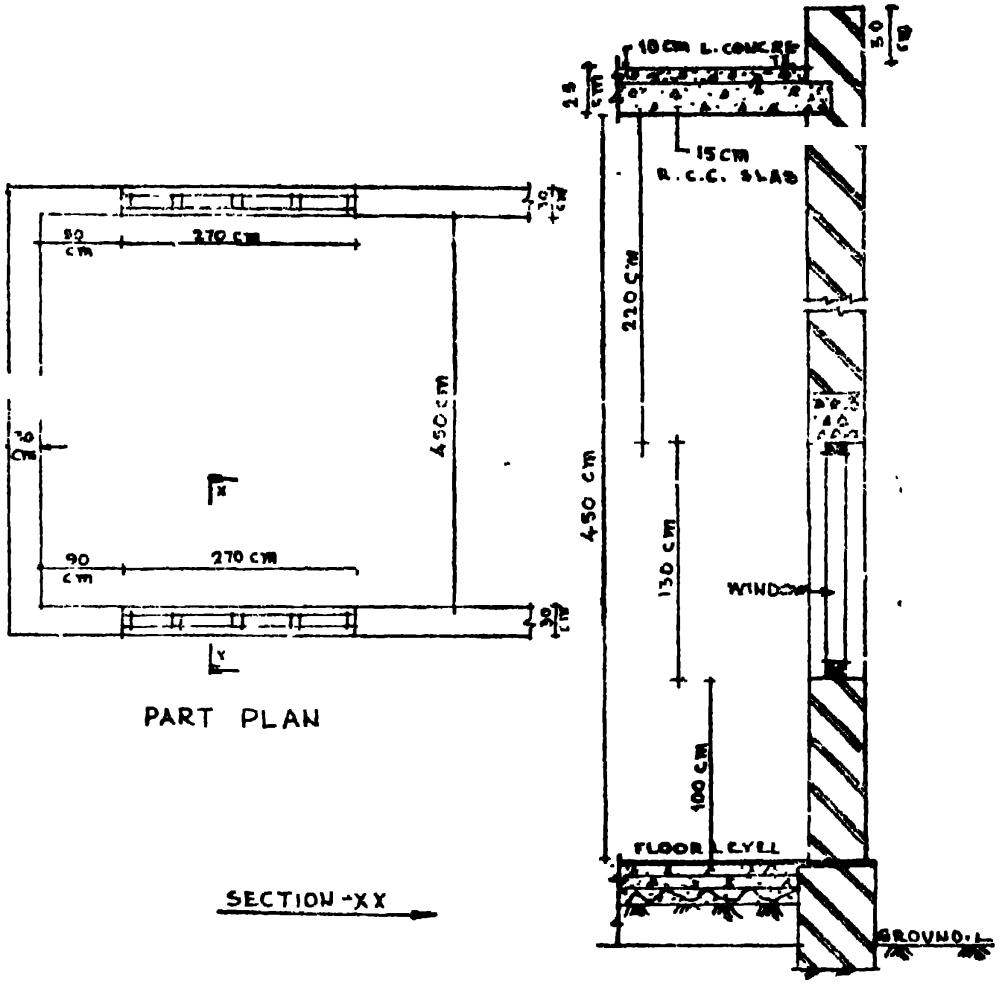


Fig. 17·6

Loads per metre run on the lintel consist of the following :

(1) Load due to self-weight of lintel

$$= 0{\cdot}45 \times 0{\cdot}3 \times 2400 = 324 \text{ kg.}$$

(2) Load due to brick masonry above the lintel. Since triangular loading is not possible in this case, the uniformly distributed load per metre run $= 0{\cdot}3\{(2{\cdot}2 - 0{\cdot}45) + 0{\cdot}15 + {\cdot}1 + 0{\cdot}3\}1920$

$$= 0{\cdot}3 \times 2{\cdot}3 \times 1920$$

$$= 1325 \text{ kg.}$$

(3) Load due to roofing :

Load per sq. m. due to roofing consists of the following:

(*i*) Wt. of 15 cm. thick R.C.C. roof slab (given)
$= 0{\cdot}15 \times 2400 = 360$ kg.

(*ii*) Wt. due to 10 cm. thick lime concrete terracing
$= 0{\cdot}1 \times 1920 = 192$ kg.

(*ii*) Super-imposed load on the slab $= 200$ kg.

Total 752 kg.

∴ Roof load per metre run on the lintel

$$= 752 \times \frac{4{\cdot}5}{2}$$

$$= 1693 \text{ kg.}$$

Total design load per metre for the lintel

$$= (1)+(2)+(3)$$
$$= 324+1325+1693$$
$$= 3342 \text{ kg.}$$

$$\text{Max. B.M.} = \frac{wl^2}{8}$$

$$= \frac{3342 \times 3^2}{8}$$

$$= 3760 \text{ kg. m.}$$
$$= 376000 \text{ kg. cm.}$$

Required effective depth of the lintel

$$d = \sqrt{\frac{376000}{8{\cdot}48 \times 30}}$$
$$= 38{\cdot}48 \text{ cm.}$$

Adopt over-all depth of the lintel = 42 cm.

Assuming 14 mm. ϕ main bars, available effective depth

$$= 49-(2{\cdot}5+0{\cdot}7)$$
$$= 38{\cdot}8 \text{ cm.}$$

$$A_t = \frac{M}{a_1 . d . t}$$

$$= \frac{376000}{0{\cdot}87 \times 38{\cdot}8 \times 1400}$$

$$= 7{\cdot}96 \text{ sq. cm.}$$

No. of 14 mm. ϕ bars required

$$= \frac{7{\cdot}96}{1{\cdot}54} = 5{\cdot}17 \text{ say } 5 \text{ No's}$$

Max. S.F. at ends of the lintel $= \frac{wL}{2}$

$$= \frac{3342 \times 2{\cdot}7}{2}$$

$$= 4510 \text{ kg.}$$

Check for shear :

$$s = \frac{S}{a_1.d.b}$$

$$= \frac{4510}{0{\cdot}87 \times 38{\cdot}8 \times 30}$$

$= 4{\cdot}46$ kg./sq. cm. < 5 kg./cm., hence safe.

Check for bond :

Assuming 2—14 mm. ϕ bars from mid-span bent up near support.

$$S_b = \frac{S}{a_1.d.\Sigma 0}$$

$$= \frac{4510}{0\ 87 \times 38{\cdot}8 \times 3 \times 4{\cdot}40}$$

$= 10{\cdot}12$ kg./sq. cm.

Since it is very slightly more than 10 kg./sq. cm., it may be allowed and no revision need be made.

Provide 6 mm. ϕ 2 legged nominal stirrups @ $0{\cdot}87 \times 38{\cdot}8 = 33{\cdot}8$ say 33 cm. c/c.

Provide 2 No's 12 mm. ϕ anchor bars.

Example 17·3. *Design a lintel continuous over four window openings each 2 metre wide and separated by 20 cm. × 20 cm. brick pillars. The height of brick work above the window openings is 1·5 metre. The windows are to be built along the width of a hall, and it may be assumed that no roof load is borne by the lintel. In addition a 60 cm. wide sun shade is required to be cast monolithic with the lintel. Design the sun shade also.*

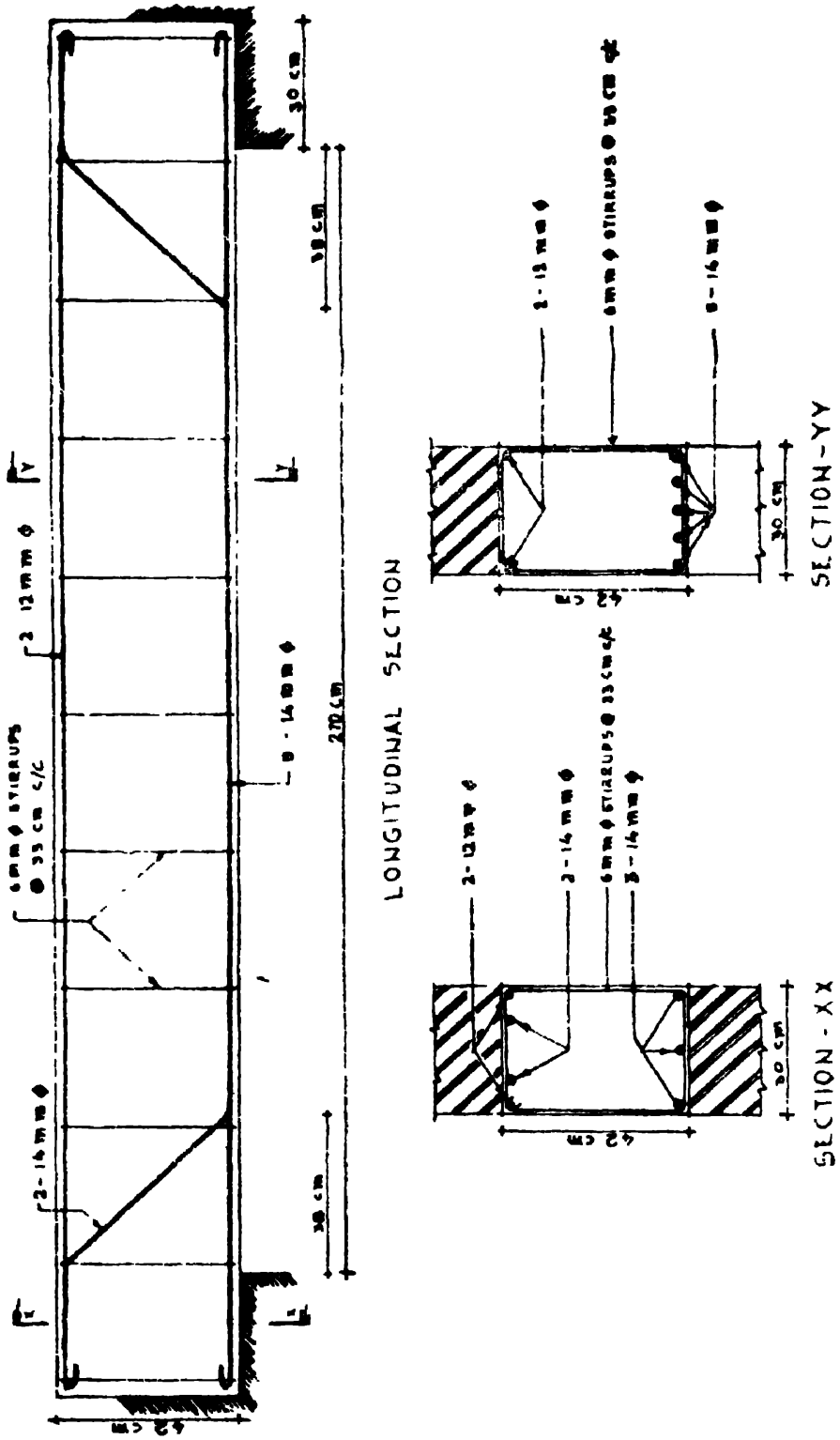


Fig. 17·7

Solution. In order to calculate the load transferred by the sun shade to the lintel, it is necessary to design the sun shade first.

Design of sun shade: Assume the thickness of the sun shade slab to be = 7 cm.

Span of sun shade = 60 cm.

Design loads for sun shade per metre run.

(*i*) Due to self-wt. of sun shade $= 0{\cdot}07 \times 2400$
$= 168$ kg.

(*ii*) Live loads etc. = 200 kg.

Total = 368 kg.

$$\text{Max. B.M.} = \frac{wl^2}{2}$$

$$= 368 \times 0{\cdot}6 \times \frac{0{\cdot}6}{2}$$

$$= 66{\cdot}2 \text{ kg. m.}$$

$$= 6620 \text{ kg. cm.}$$

$$d = \sqrt{\frac{6620}{8{\cdot}48 \times 100}}$$

$$= 2{\cdot}82 \text{ cm.}$$

However, from practical considerations, provide over-all depth of the lintel = 5 cm.

Assuming 6 mm. ϕ main bars effective depth

$$= 5 - \left(1{\cdot}3 + \frac{0{\cdot}6}{2}\right) = 3{\cdot}4 \text{ cm.}$$

$$A_t = \frac{6620}{0{\cdot}87 \times 3{\cdot}4 \times 1400}$$

$$= 1{\cdot}60 \text{ sq. cm.}$$

c/c spacing of 6 mm. ϕ bars ($a_t = 0{\cdot}28$ cm^2)

$$p = \frac{100 \times 0\,28}{1{\cdot}6} = 17{\cdot}5 \text{ cm.}$$

However, vide "Basic rule for design of Beam and Slabs," the maximum spacing of the main bars in a slab should not exceed three times the effective depth.

or $3 \times 3{\cdot}4 = 10{\cdot}2$ cm. say 10 cm. c/c.

Hence the spacing of 6 mm. ϕ main bars shall be kept as 10 cm. c/c.

c/c spacing of 5 mm. ϕ distributors $= 5 \times 3{\cdot}4 = 17$ cm. c/c.

In order to adjust the bars in equal spacing provide 5 mm. ϕ distributions @ 15 cm. c/c. Taper the slab to 4 cm. at the ends.

Design of continuous lintel : Assume the size of lintel
$= 20$ cm. $\times 20$ cm.

Clear span $= 2$ m.

Effective span $= 2{\cdot}2$ m.

Load per metre run :

(*i*) Due to self-wt. of the lintel $= 0{\cdot}2 \times 0{\cdot}2 \times 2400$
$= 96$ kg.

(*ii*) Due to brick work above the lintel $= 0{\cdot}2 \times 1920(1{\cdot}5 - 0{\cdot}2)$
$= 499$ kg.

(*iii*) Due to sun shade $= 0{\cdot}6(0{\cdot}05 \times 2400 + 200)$
$= 0{\cdot}6 \times 320$
$= 192$ kg.

Total $= 787$ kg.

Max. B.M. in the mid-span of end span and penultimate supports

$$= \frac{wl^2}{10}$$

$$= 787 \times \frac{2{\cdot}2^2}{10}$$

$= 381$ kg. m.

$= 38100$ kg. cm.

Max. B.M. in the mid-span of remaining spans and over intermediate supports

$$= \frac{wl^2}{12}$$

$$= 787 \times \frac{2{\cdot}2^2}{12}$$

$= 317$ kg. m.

$= 31700$ kg. cm.

Required effective depth from considerations of max. B.M.

$$d = \sqrt{\frac{38100}{8{\cdot}48 \times 20}}$$

$$= 14{\cdot}95 \text{ cm.}$$

Adopt over-all depth of the lintel = 18 cm.

Assuming 10 mm. ϕ main bars, available effective depth

$$= 18 - \left(2{\cdot}5 + \frac{1{\cdot}0}{2}\right)$$

$$= 15 \text{ cm.}$$

A_t for mid-span of end span and penultimate supports

$$= \frac{38100}{0{\cdot}87 \times 15 \times 1400}$$

$$= 2{\cdot}085 \text{ sq. cm./m.}$$

Provide 3 No's 10 mm. ϕ bars (A_t provided = 2·36 sq. m.)

A_t for mid-span of the remaining spans and intermediate supports

$$= \frac{31700}{0{\cdot}87 \times 15 \times 1400}$$

$$= 1{\cdot}735 \text{ sq. cm./m.}$$

Provide 2 No's 8 mm. ϕ bars and 1 No's 10 mm. ϕ bar (A_t provided = 1·79 sq. cm.)

In order to afford facility in the arrangement of bars, provide 2 No's 8 mm. ϕ anchor bars in the middle spans and 2 No's 10 mm. ϕ anchor bars in the end spans. These bars will serve both as anchor bars as well as main reinforcements for −ve B.M. over support as shown in the Fig. 17·9.

Max. S.F. in the lintel occurs at the outer edge of the first interior support.

$\therefore$ S.F. $= 0{\cdot}6\, wl$

$$= 0{\cdot}6 \times 787 \times 2{\cdot}2$$

$$= 1040 \text{ kg.}$$

Check for shear :

$$s = \frac{S}{a_1\, d.b}$$

$$= \frac{1040}{0{\cdot}87 \times 15 \times 20}$$

$= 3{\cdot}99$ kg./sq. cm. $<$ 5 kg./sq. cm., hence safe.

Check for bond :

At first interior support

$$S_b = \frac{S}{a_1.d.\Sigma 0}$$

$$= \frac{1040}{0{\cdot}87 \times 15 \times 3 \times 3{\cdot}14}$$

$= 8\,46$ kg./sq. cm. $<$ 10 kg./sq. cm., hence safe.

Check for bond :

At intermediate supports,

Max. S.F. at intermediate support

$= 0{\cdot}5\ wl$

$= 0{\cdot}5 \times 87 \times 2{\cdot}2$

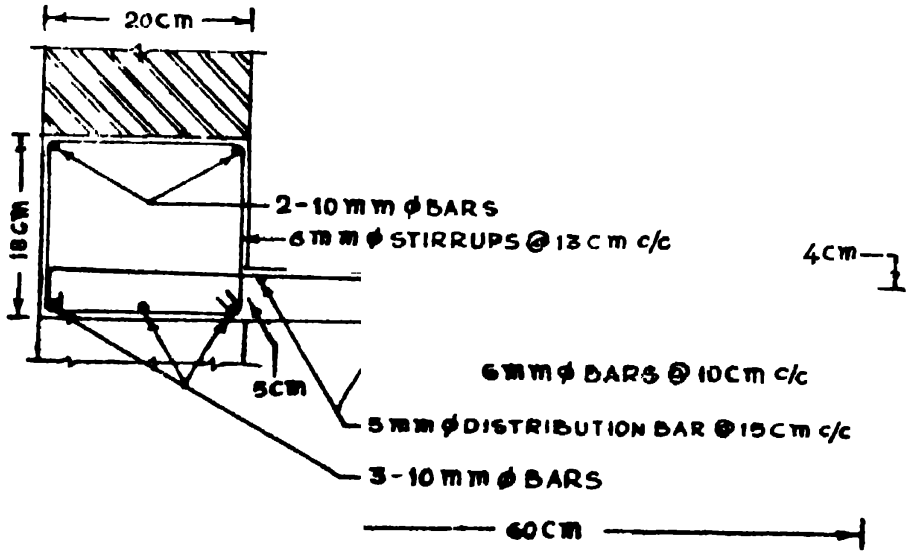
$= 865{\cdot}7$

$$S_b = \frac{865{\cdot}7}{0{\cdot}87 \times 15(2 \times 2{\cdot}51 + 3{\cdot}14)}$$

$= 8{\cdot}14$ kg./sq. cm. $<$ 10 kg./sq. cm., hence safe.

Provide 6 mm. ϕ 2 legged stirrup @ $0{\cdot}87 \times 15 = 13{\cdot}05$ cm.

Say 13 cm. c/c.



SECTION - YY'

Fig. 17·8

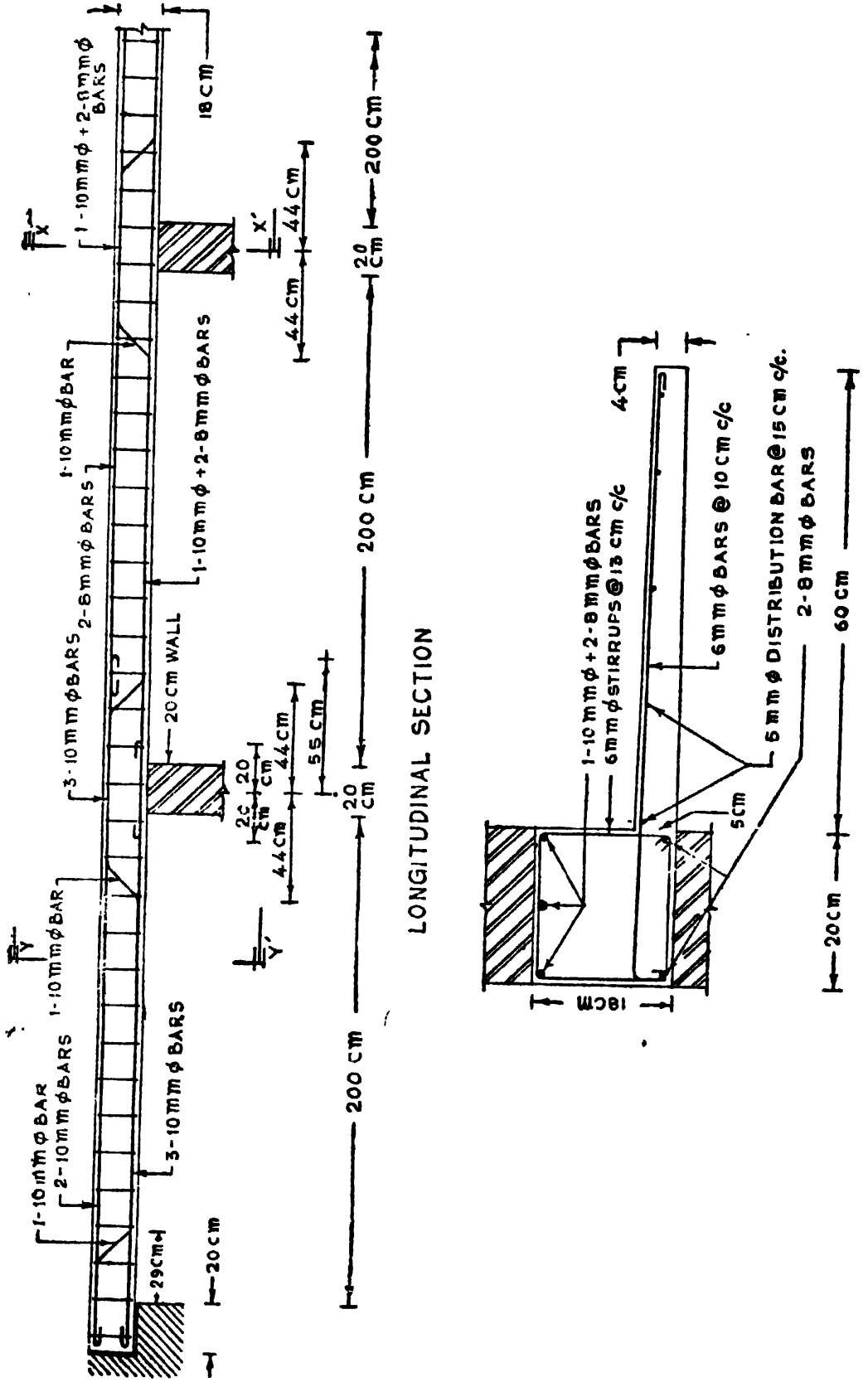

1-10 mm ϕ + 2-8 mm ϕ BARS
18 cm
X
X'
44 cm
44 cm
20 cm
200 cm
1-10 mm ϕ BAR
2-8 mm ϕ BARS
1-10 mm ϕ + 2-8 mm ϕ BARS
3-10 mm ϕ BARS
20 cm WALL
20 cm
44 cm
55 cm
20 cm
Y
Y'
1-10 mm ϕ BAR
2-10 mm ϕ BARS
3-10 mm ϕ BARS
29 cm
20 cm
200 cm
LONGITUDINAL SECTION
1-10 mm ϕ + 2-8 mm ϕ BARS
6 mm ϕ STIRRUPS @ 15 cm c/c
4 cm
6 mm ϕ BARS @ 10 cm c/c
6 mm ϕ DISTRIBUTION BAR @ 15 cm c/c.
2-8 mm ϕ BARS
5 cm
18 cm
20 cm
60 cm
SECTION - X X'

Fig. 17·9

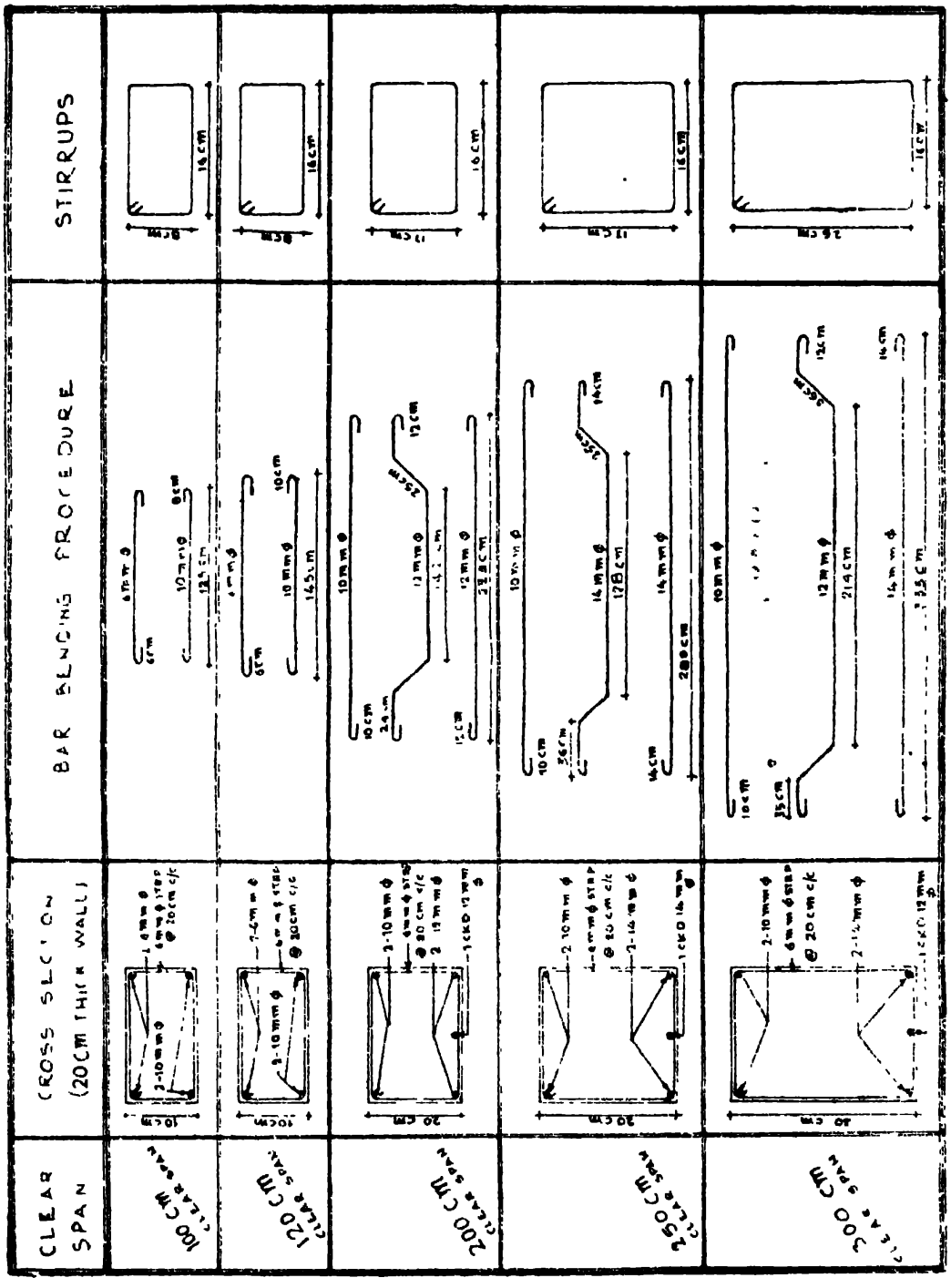


Fig. 17·10 Structural details of R.C.C. lintels for various spans for 20 cm. thick brick wall

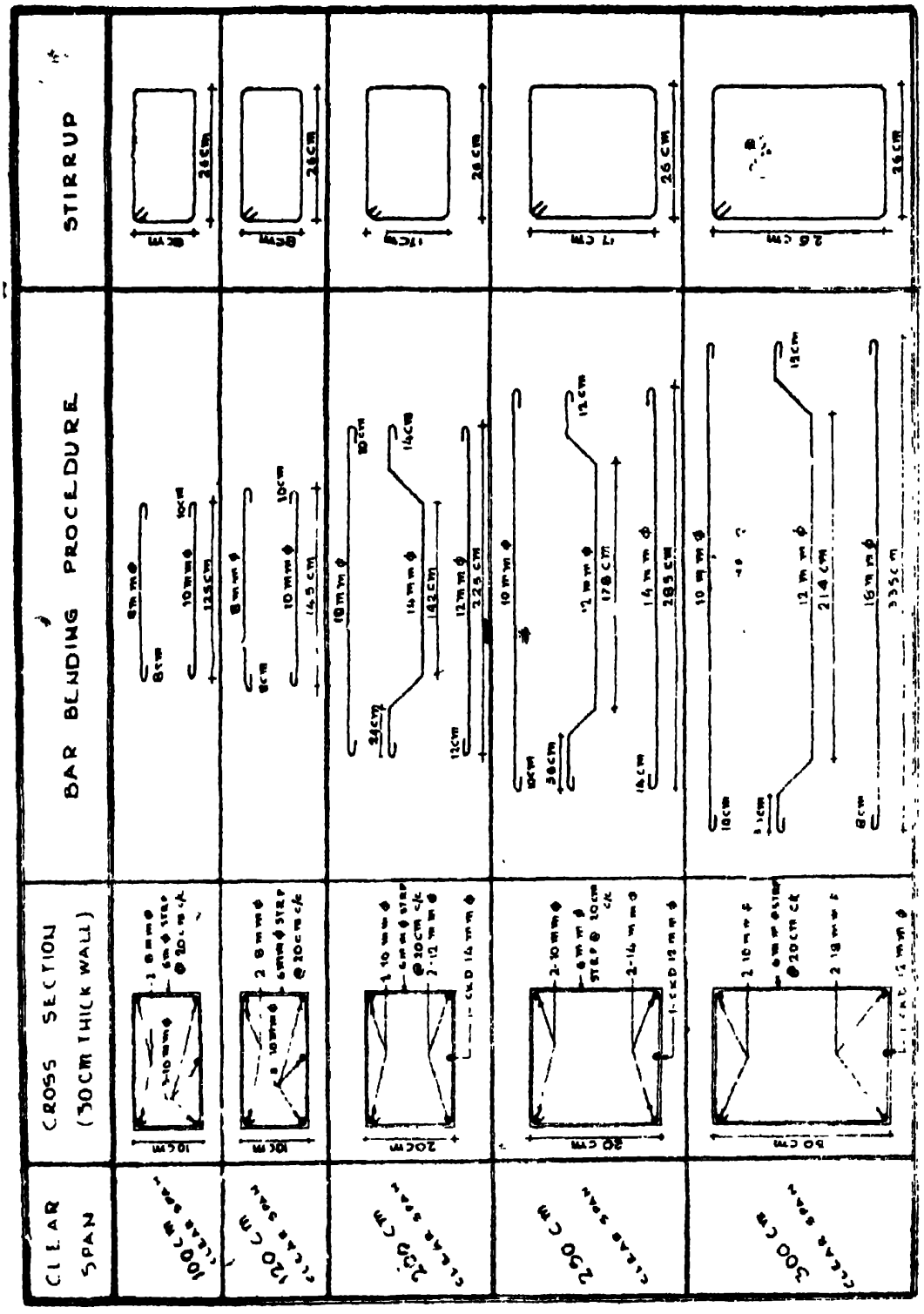


Fig. 17·11 Structural details of R.C.C. lintels for various spans for 30 cm. thick brick wall

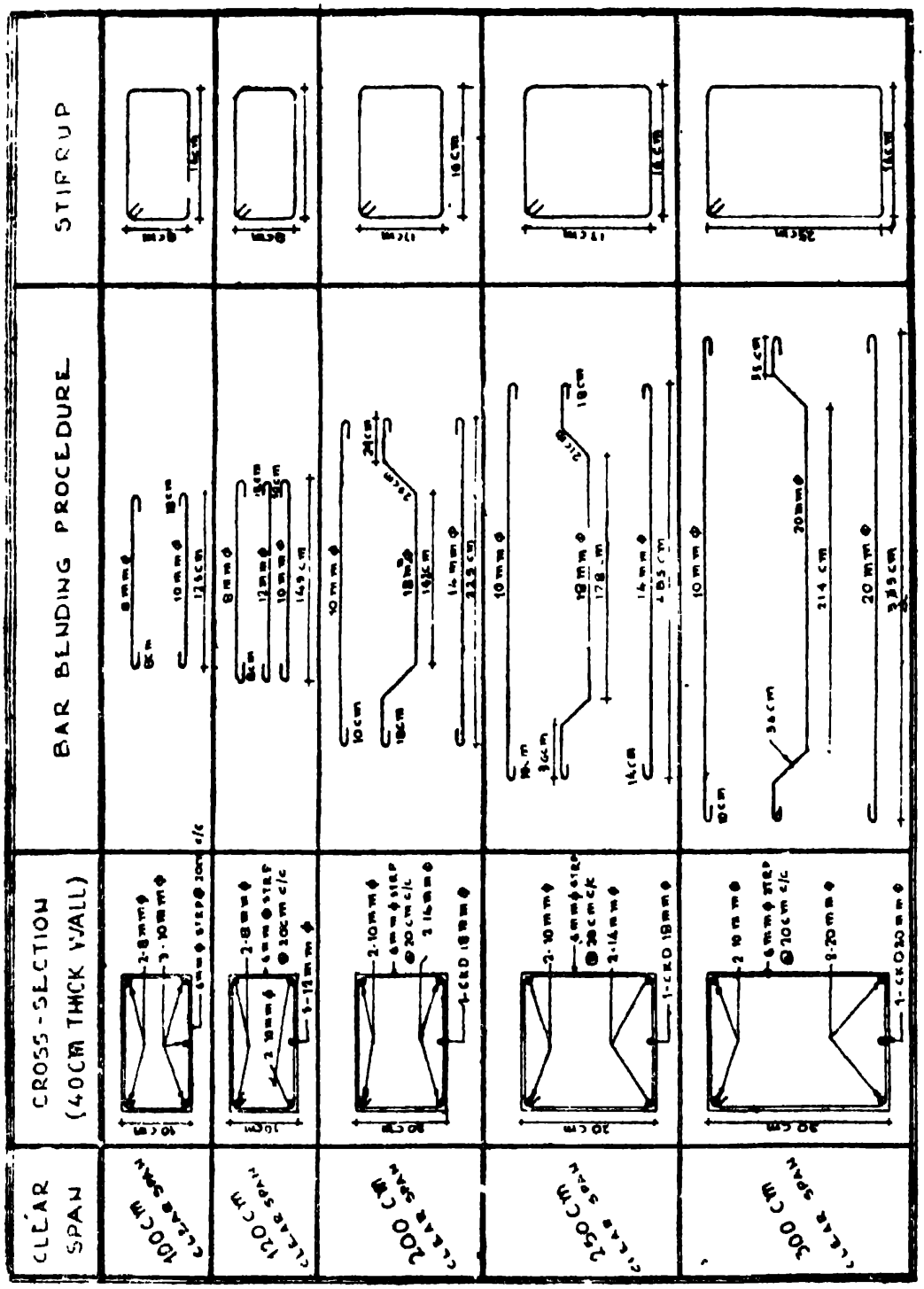


Fig. 17 12. Structural details of R.C.C. lintels for various spans for 40 cm. thick brick wall

Questions for Revision

1. Design a reinforced concrete lintel over a twin-window opening in a lecture hall. The total width of the opening is 3·5 m. The wall above the opening is constructed in stone masonry 45 cm. wide. The height of wall above lintel level is 4·2 m. The lintel is to be provided with a 90 cm. wide sun shade cast monolithically with it. Draw a dimensioned plan and section of the designed member.

2. Design a reinforced concrete continuous lintel over five windows separated by 30 cm. × 30 cm. brick pillars. The clear span for each window is 2·5 m. The wall containing the window is the load bearing wall of a hall measuring 5 m. × 15 m. The slab which lies 1·5 m. above the lintel consists of 15 cm. thick R.C. slab finished with 10 cm. thick lime concrete terracing. The super-imposed load on the roof may be taken as 200 kg./sq.m.

3. Design a lintel over door opening 130 cm. wide. The opening is left in the wall 45 cm. from one of its corners. The height of wall above the opening is 2 m. The thickness of wall may be assumed to be equal to 30 cm.

4. Design a reinforced concrete lintel over an opening 3 m. wide. The height of 30 cm. wide wall above the opening may be assumed to be 4 m. Draw a detailed longitudinal section and cross-section of the lintel.

5. State briefly the influence of reinforced concrete in the construction of a modern building.

The front portion of a memorial hall has to be provided with a R.C.C. cantilever projection. The site of the memorial hall is located near a highly fashionable shopping centre. The projection may be about 4·27 m. and the length about 7·62 m. Assuming that there is proper counter-weight, design the R.C.C. beam over the opening and the cantilever projection. Draw diamensioned sketches showing the details of the reinforcements.

18

Carpentry Joints

18·1. General. Carpentry is the term applied to that form of wood-work in which the wooden members are subjected to loads or thrusts. Depending upon the type of work, the members may be permanently subjected to bear loads as in case of wooden lintels, wooden floor joists or they may be provided to bear the load in a temporary capacity in a form of scaffolding, centering, shoring etc. Joinery may be defined as the trade in wood work in which skilled labour is required to render the wooden members capable of framing together. It is an art of cutting, preparing and joining the individual pieces of timber, so as to form the frame of the desired shape, size and finish. In this country, carpentry and joinery are treated as a single trade. The workman who handles the work of carpentry and joinery is called a carpenter. The wooden members may either be jointed by nails, screws, bolts, connections or by cutting the different members in different ways to form grooves or projections which when framed together serve the desired purpose. It is sometimes necessary to use iron castings in the form of straps, gibbs and cotters, to strengthen the joints in wood work.

18·2 Technical Terms. The various technical terms used in carpentry or joinery have been briefly described below :

1. *Chamfering* : It consists in taking off the edges of a wooden member. Thus a chamfered member has a sloping or bevelled edge. Chamfering is usually done by means of a plane. Chamfering is essentially done to prevent the exposed wood work to have sharp edges, and incidentally it imparts architectural beauty to the member.

2. *Planing* : The process of taking the shavings off a wooden member is called planing. The carpenter's tool used for the purpose is called a "Plane". The surface smoothened with a 'plane' is called dressed or wrought surface.

3. *Plank* : It is the name given to a heavy thick and wide wooden board.

4. *Rebating* : It is the process of cutting a rectangular groove along the edge of a member, so as to enable the edge or tongue of another member to fit in the former.

5. *Housing* : It is the process of cutting groove in a timber piece across its grain, so as to permit the insertion of another member in it. Housing may be plain, shouldered or dove-tailed.

6. *Scribing* : It is the process of framing one moulding to the face of another in an interior angle.

7. *Seasoning* : It is the process of rendering timber free of the sap either by natural or artificial means.

8. *Mitring* : It is the process of joining two wooden members, at an angle.

9. *Milled* : It is the term applied to a wooden member which has been run through a wood working mill.

10. *Bead* : It is a rounded or semi-circular moulding provided on the edges or surface of wood.

11. *Batten* : It is the name given to a narrow slip of wood nailed over joints of boards.

12, *Studding* : It is the term applied to the fixing of small timber battens, to timber walls, to which lathes and boards are to be nailed.

13. *Veneering* : It is the process of covering the exposed surface of a wooden member with a thin sheet of a costlier type of good-looking wood, to improve the appearance of the member. Veneering is done just for decorating the wood work and it does not contribute to the strength of the veneered member.

14. *Wain-scot* : It is the term applied to wooden panelling on the masonry walls for a height of 60 to 90 cm. from the floor level.

18·3. Classification of Joints. The various types of joints used in wood framing can be divided into the following categories :

1. *Lengthening, spliced or longitudinal joints*
2. *Bearing joints*
3. *Framing joints*
4. *Angle or corner joints*
5. *Oblique-shouldered joints*
6. *Widening or side joints*

18·4 Lengthening, Spliced or Longitudinal Joints. As the name suggests, these joints are used to lengthen a wooden member. The method of lengthening of the member varies with its situation

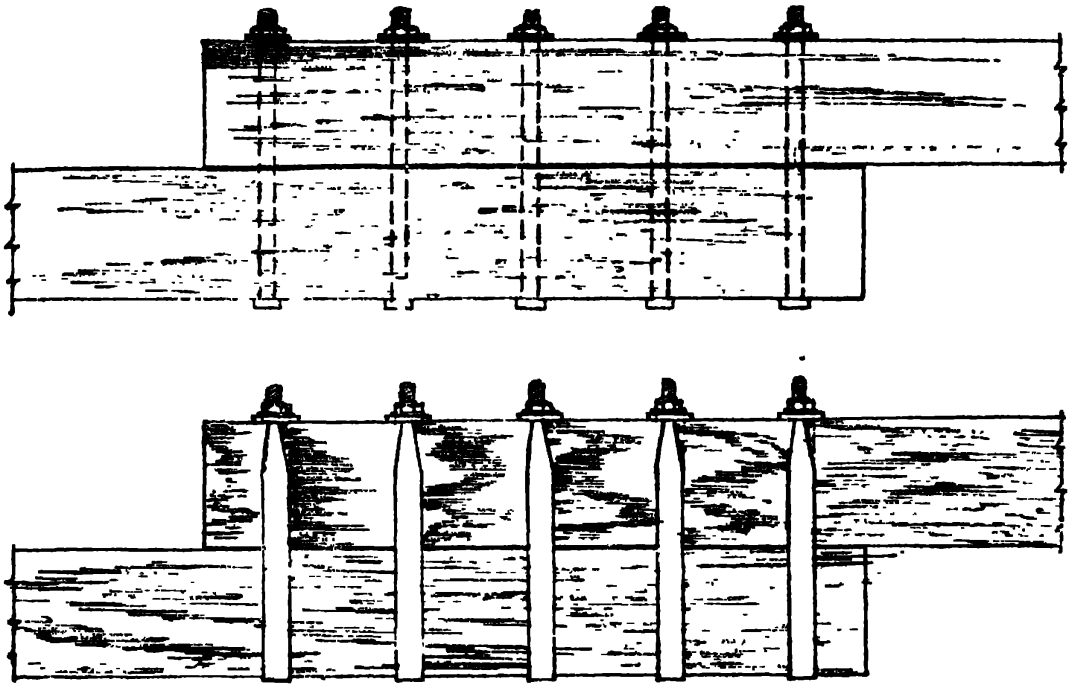


Fig. 18·1 Lapping joint with mild steel bolts
Fig. 18·2 Lapping joint with stirrup straps

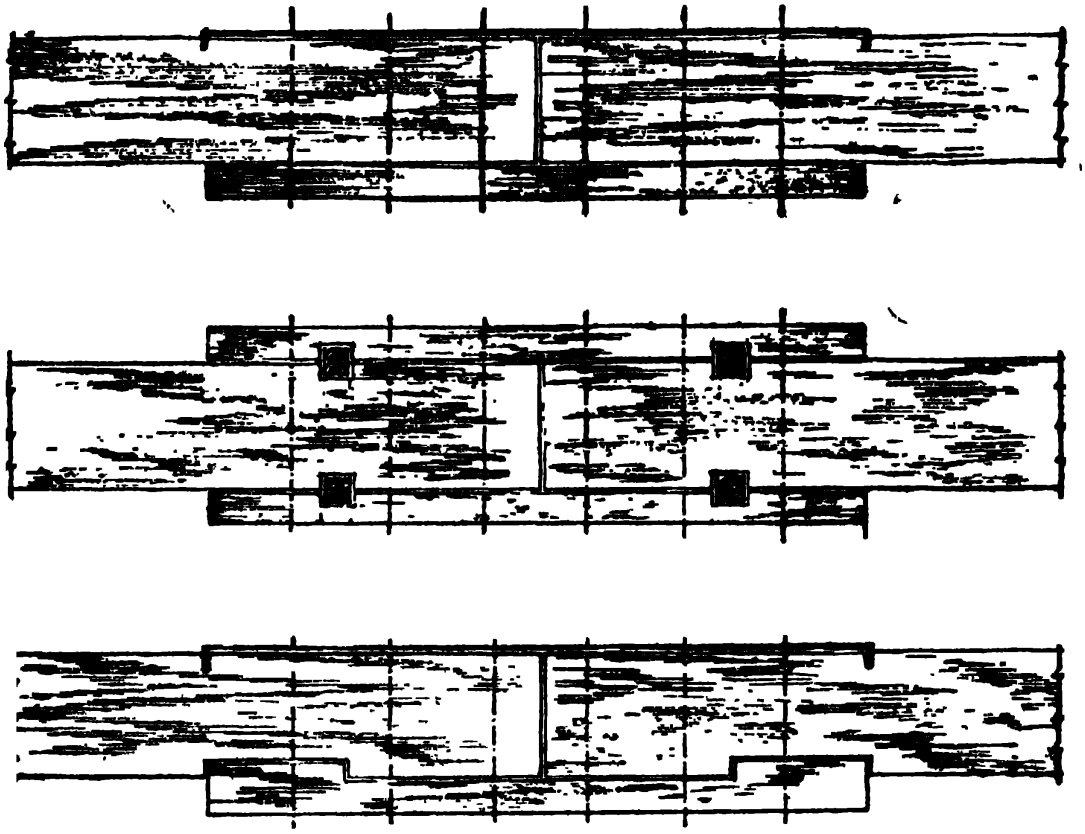


Fig. 18·3
Sectional elevations of various types of fishing joints

in a framed structure. Thus, lengthening joints are further sub-divided into the following types :

(*i*) Lapping joint.

(*ii*) Fishing joint.

(*iii*) Scarfing joint.

(*iv*) Tabling joint.

(*i*) *Lapping joint* : This is the simplest form of lengthening joint and is formed by lapping the end of one member over that of the other and fastening them together by bolting or by using connections. This type of joint should not be recommended for members subjected to large stresses because of the axis of the members at the joint not being in one line. The various types of lapping joints have been shown in Figs. 18·1—18·2.

(*ii*) *Fishing joints* : In this arrangement of jointing wood work, the ends of the two members butt together and the junction

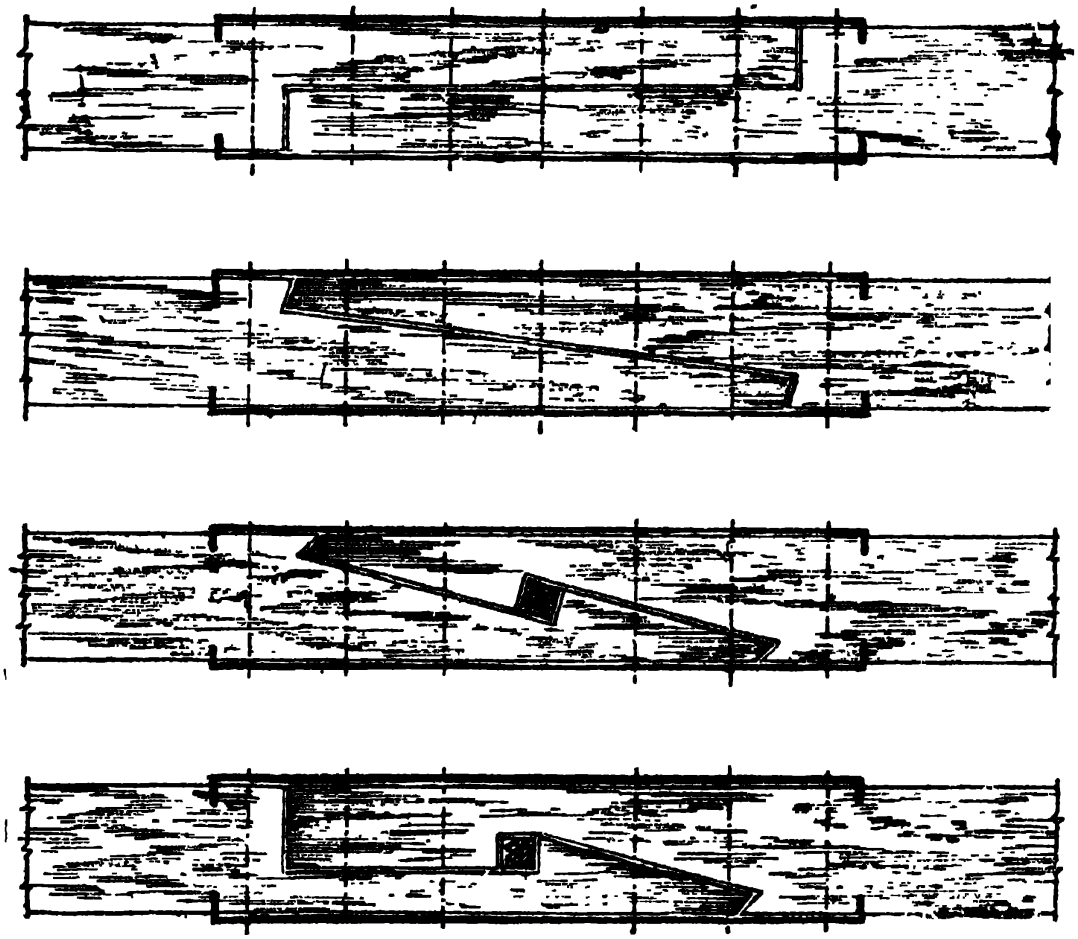


Fig. 18·4
Sectional elevations of various types of scarf joints

is bolted after providing wooden or steel pieces called "fish plates" on two opposite faces of the joint. The strength of the joint depends upon the fish plates and bolts used in the joint.

(*iii*) *Scarfing joint* : This system of lengthening wooden member, is especially suitable in places, where it is necessary to maintain the same depth and width of the member throughout its length. To achieve the said condition, a part of the thickness of the timber is cut from each member from opposite sides, so that they lap on each other when jointed. The strength of this joint depends upon the bolts used for jointing. The fish plates used in the joints are usually bent and let into the timber.

(*iv*) *Tabling joint*: This joint is very much similar to scarf joint in construction and is adopted where the member is subjected to both tension and compression.

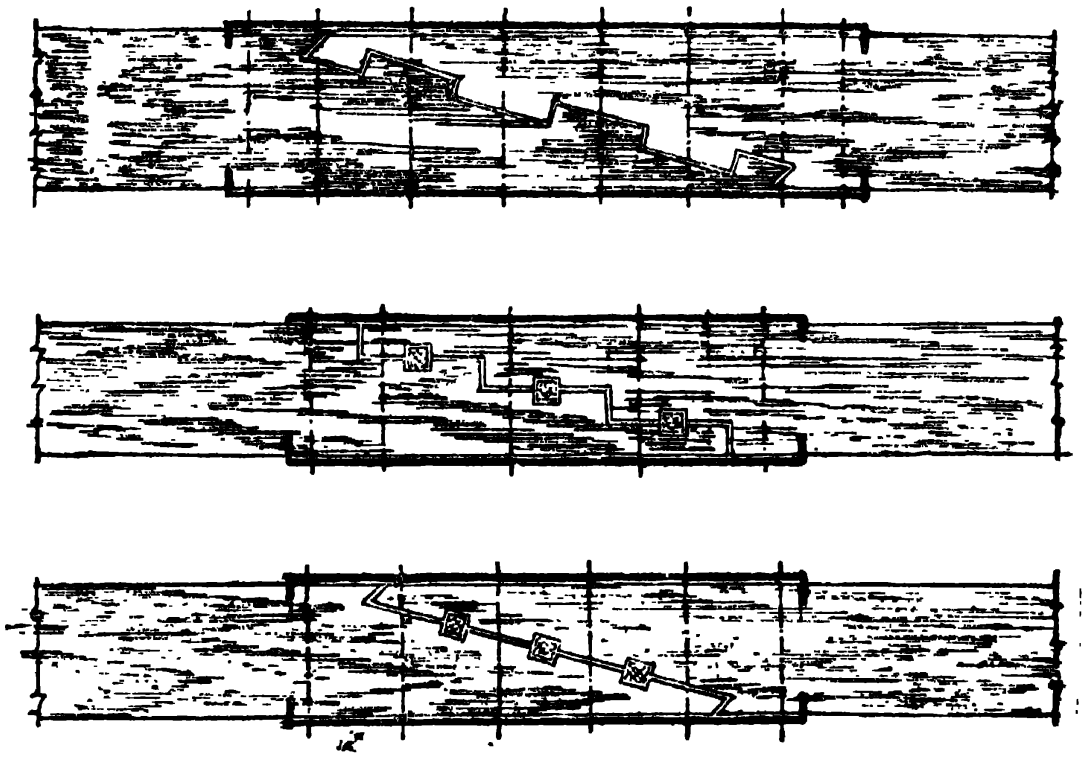


Fig. 18·5
Sectional elevations of various types of scarf joints

18·5 Bearing Joints. Broadly speaking, bearing joints may be divided into the following different types :

(*i*) Notching joint
(*ii*) Cogged joint
(*iii*) Halving joint
(*iv*) Housed joint

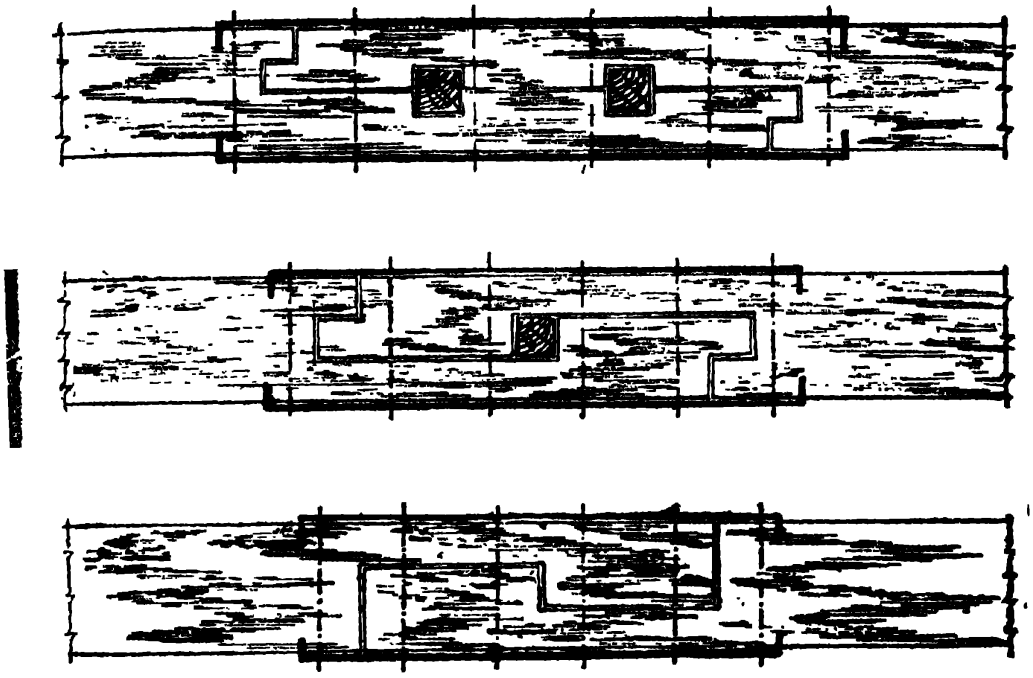


Fig. 18·6

Sectional elevations of various types of tabling joints

(*v*) Dovetailed joint.

(*vi*) Mortise and tenon joint.

(*vii*) Joggle or stump joint.

(*viii*) Dovetailed tenon joint.

(*ix*) Open mortice joint.

(*x*) Chase mortise joint.

(*xi*) Tusk tenon joint.

(*i*) *Notching joint*: This joint is commonly provided at the junction of two members meeting at right angles. Notching consists in cutting a depression to the full width of one member to enable it to be fixed to another member. In some cases both the members are cut to form the joint. In such cases the joint is called double notched joint. It is very much clear from the shape of the joint that the function of notching is to prevent the lateral movement of the two members.

(*ii*) *Cogged joint*: This joint is commonly provided between wall plate and the tie beam of wooden truss where it is essential to utilise the entire depth of the wall plate for bearing the tie-beam. The joint may be single or double cogged. In single-cogged joint, a small depression, equal in width to the width of the member to be placed over it, is cut in the lower member. In case of a double-cogged

joint, a projection is left in the lower member in middle of the recess formed for receiving the upper member.

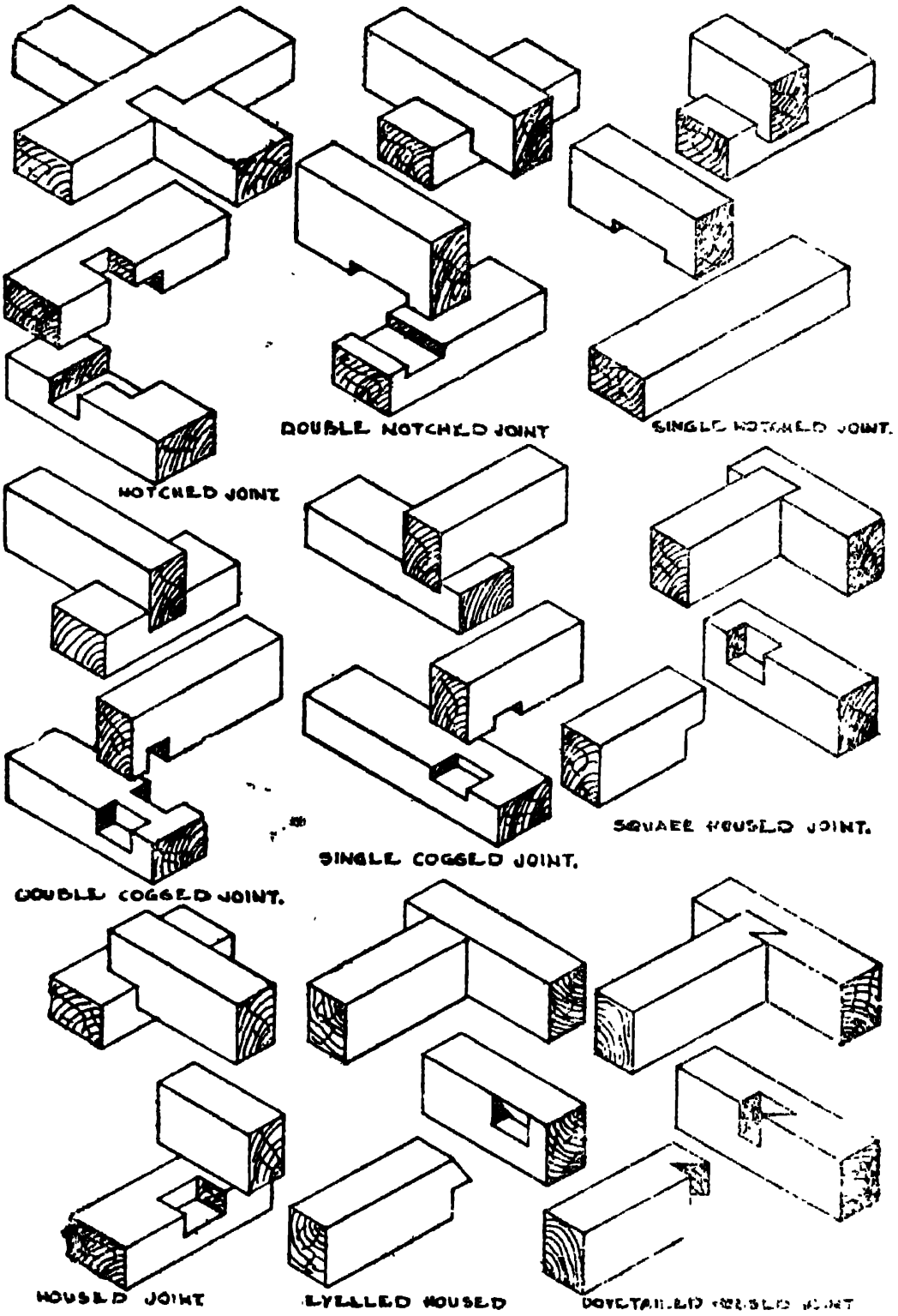


Fig. 18·7

Views showing various types of bearing joints

(*iii*) *Halving joint* : This joint is used in members crossing or meeting at an angle. In this method of jointing, each member on opposite sides is cut to half of its thickness, at the joint and lapped. Thus, if the two members are of different thicknesses, the top face of the member at the joint will be flushed. In case both are of the same thickness, both top and bottom face of members at the joint will be flushed. Sometimes the members are bevelled from consideration of strength ; in such cases, the halved joint is termed as bevelled halved joint.

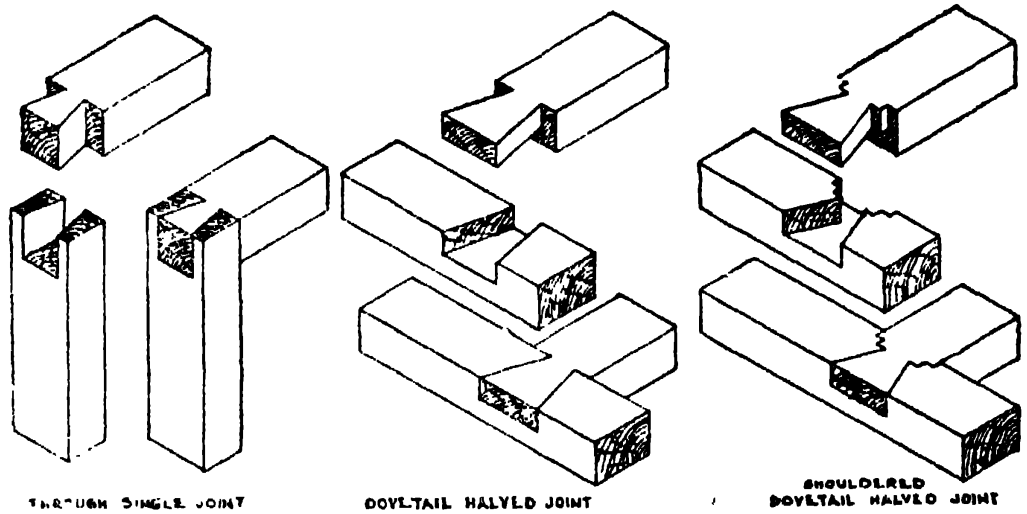


Fig. 18·8

Bearing joints

(*iv*) *Housed joint* : In the housed joint, the entire end or thickness of one member is let into the notch in another. This joint is commonly adopted in works of heavy nature, where other types of joints may not be practically suitable either from considerations of strength or expense.

(*v*) *Dovetailed joint* : In this method of fastening wood work, wedge-shaped or flaring shaped pieces are cut out of each member and the joint is formed by hooking the projection of one member into the other one. This joint is especially used in cabinet work. In such places, the interlocking tenons which are dovetailed are lapped and the junction is strengthened by means of pins which guard against the possibility of the members getting pulled apart.

(*vi*) *Mortise and tenon joint* : This type of joint is frequently adopted in framing wood work. It efficiently holds the pieces together and is simple in construction. This joint is formed by cutting one of the members, so as to form a projection termed as tongue or tenon and fitting it into a slot known as mortise cut into the other

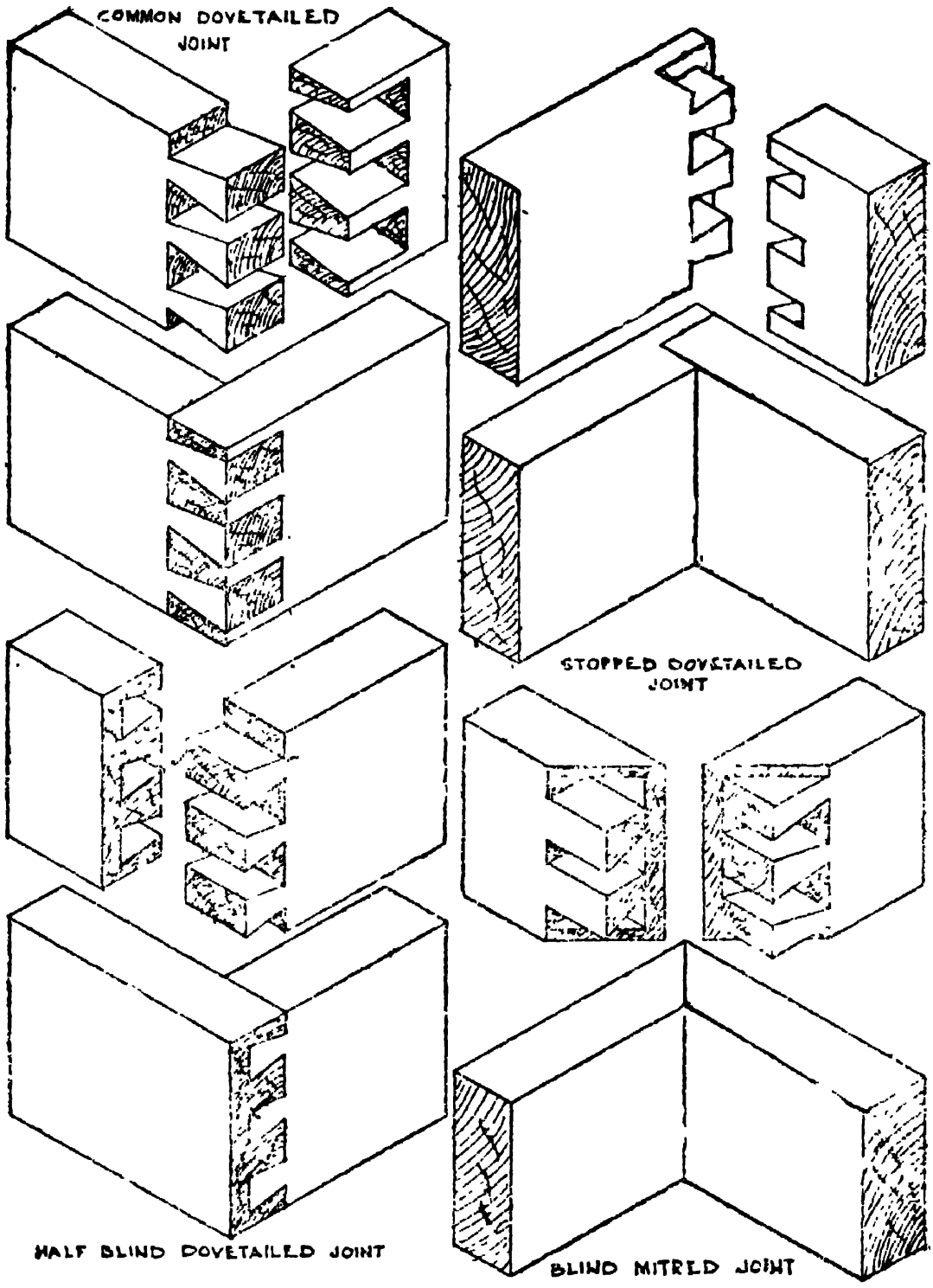


Fig. 18·9

Bearing joints

member. The mortise should be of sufficient length, breadth and depth. Generally the depth of mortise and tenon is one-third the thickness of the members. The joint is strengthened by inserting wooden wedges from back or by inserting dowel pins from the face.

(*vii*) *Joggle or stump joint* : This type of joint is commonly used for framing the studs into the sill of a wooden partition wall. Its

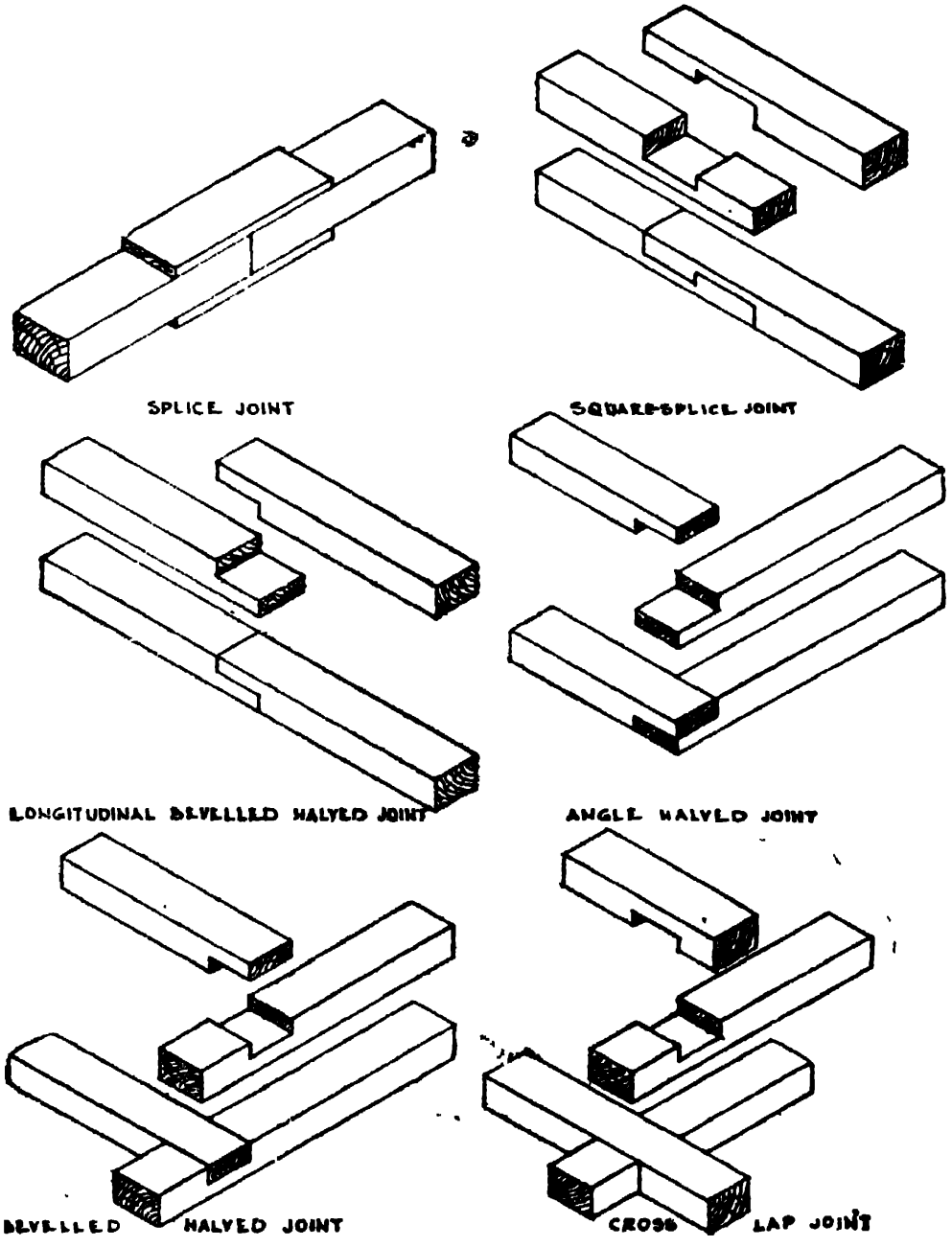


Fig. 18·10

Bearing joints

construction is essentially similar to that of mortise and tenon joint with the only difference that the tenon is cut shorter in length and does not extend to the full thickness of the mortise member.

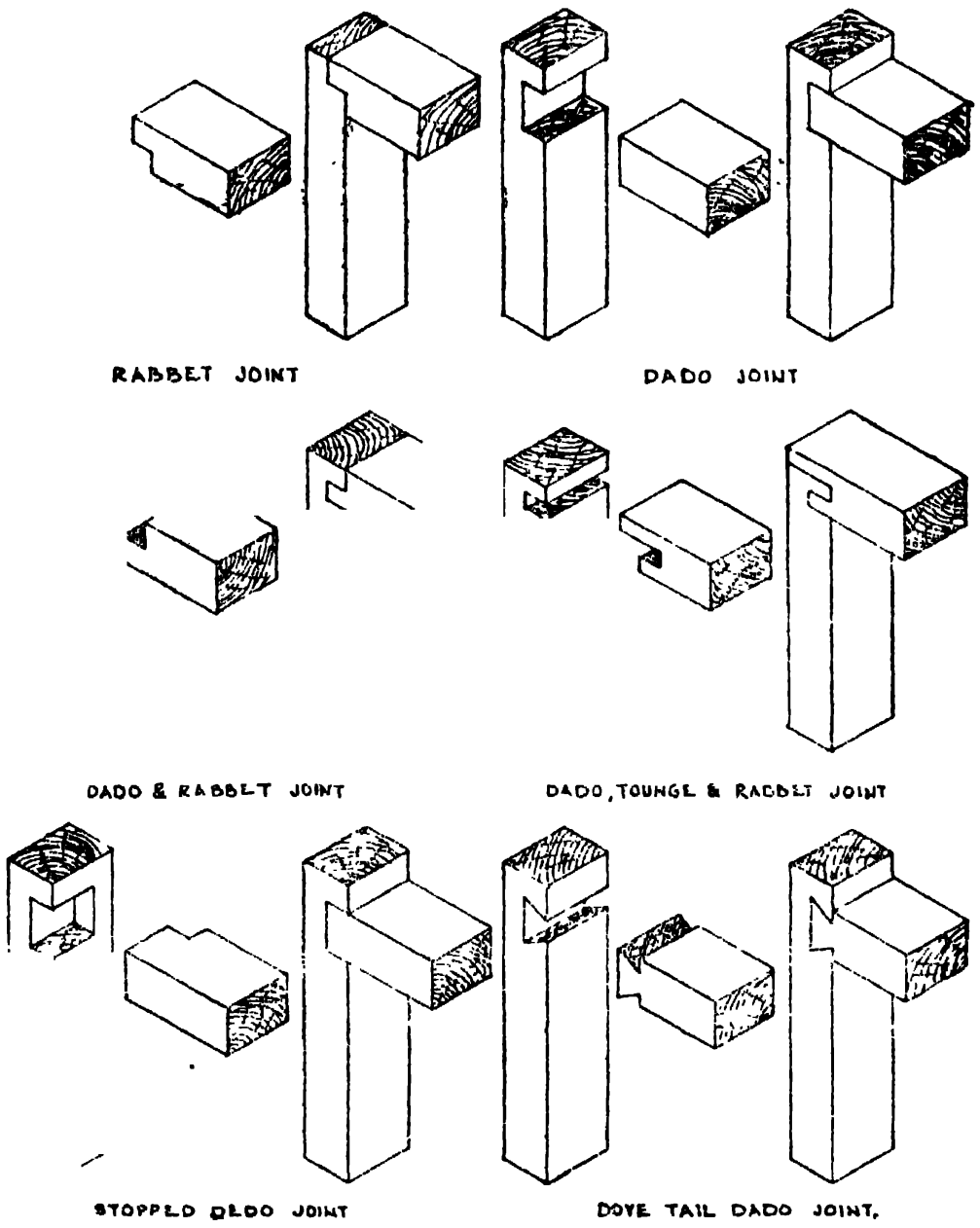


Fig. 18·11
Bearing joints

(*viii*) *Dove-tailed tenon joint* : This type of joint is not so common in use on account of its typical shape. Generally this joint is formed by cutting the tenon dove-tailed in shape and framing it into

the mortise of sufficient length, so as to permit the wide part of the member attached to the back of tenon to be fixed inside the mortise. The joint is further secured by a hard-wood wedge.

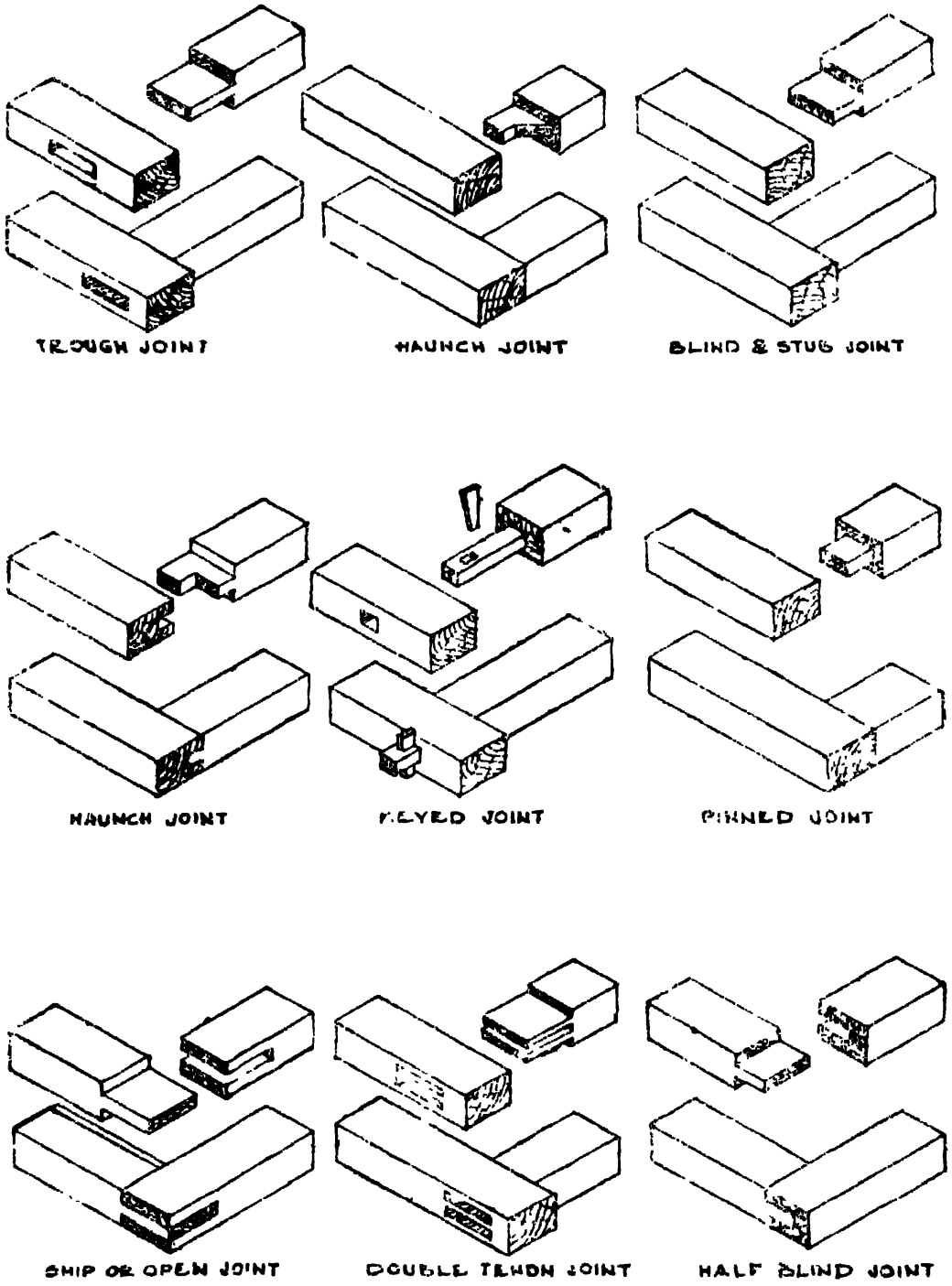
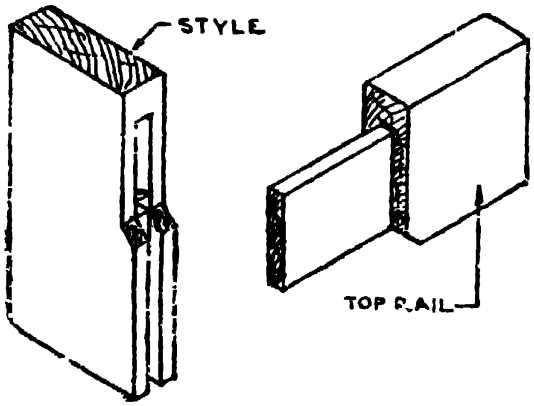


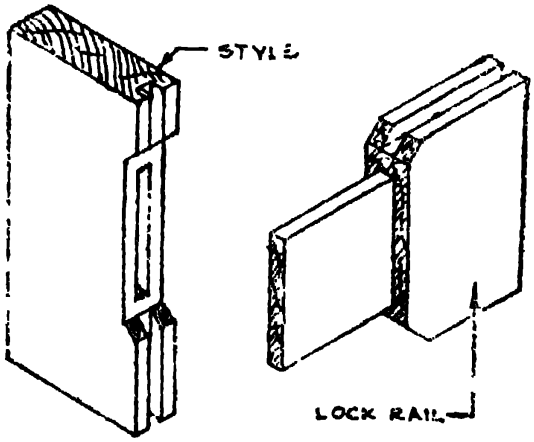
Fig. 18·12

Bearing joints

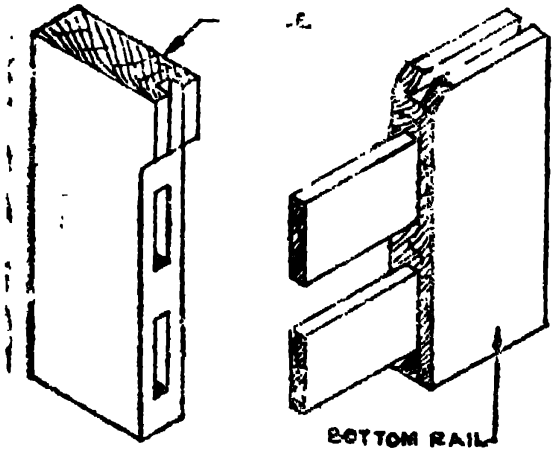
(*ix*) *Open mortise joint* : This is a form of mortise and tenon joint in which, a metal dowel bar has to be used to secure the mortise and tenon in their respective positions.



DETAIL FOR TOP RAIL



DETAIL FOR LOCK RAIL



DETAIL FOR BOTTOM RAIL

Fig. 18·13

Framing joints

(*x*) *Chase mortise joint* : This method of framing woodwork is adopted when it is required to fix wooden members between such timber members as are permanently fixed in position in a wooden structure long before.

(*xi*) *Tusk tenon joint* : This type of joint is commonly adopted in the construction of timber floors. In order to obtain maximum rigidity and strength, the tenon must be mortised in the centre of the members to be tenoned.

18·6. Framing joints. These joints are similar to the various forms of bearing joints described above with the only difference that the method of cutting the grooves and tongues in the members is suitably altered to obtain the desired form of joint. This type of joint is essentially employed in framing doors, windows, partition walls etc. This form of joint varies with the shape of door or window frame adopted and the architectural treatment desired In general, the type of joints used in such construction are just a modified form of mortise and tenon joints. For door frames over 11 cm. in width, double tenon joints are used.

18·7. Angle or Corner Joints. When two members are to be framed so as to form a corner or angular

edge, angle or corner joint is used. The joints commonly used are given below :

(*i*) Rebated butt and beaded joint.
(*ii*) Rebated butt and staff bead joint.
(*iii*) Mitre and feather joint.
(*iv*) Mitre and butt joint.
(*v*) Mitre rebate, butt and feature joint.
(*vi*) Mitre and rebate joint.
(*vii*) Grooved, tongued and mitred joint.
(*viii*) Housed joint.
(*ix*) Dovetailed housing joint.

The various forms of joints mentioned above have been thown in Fig. 18·14 below :

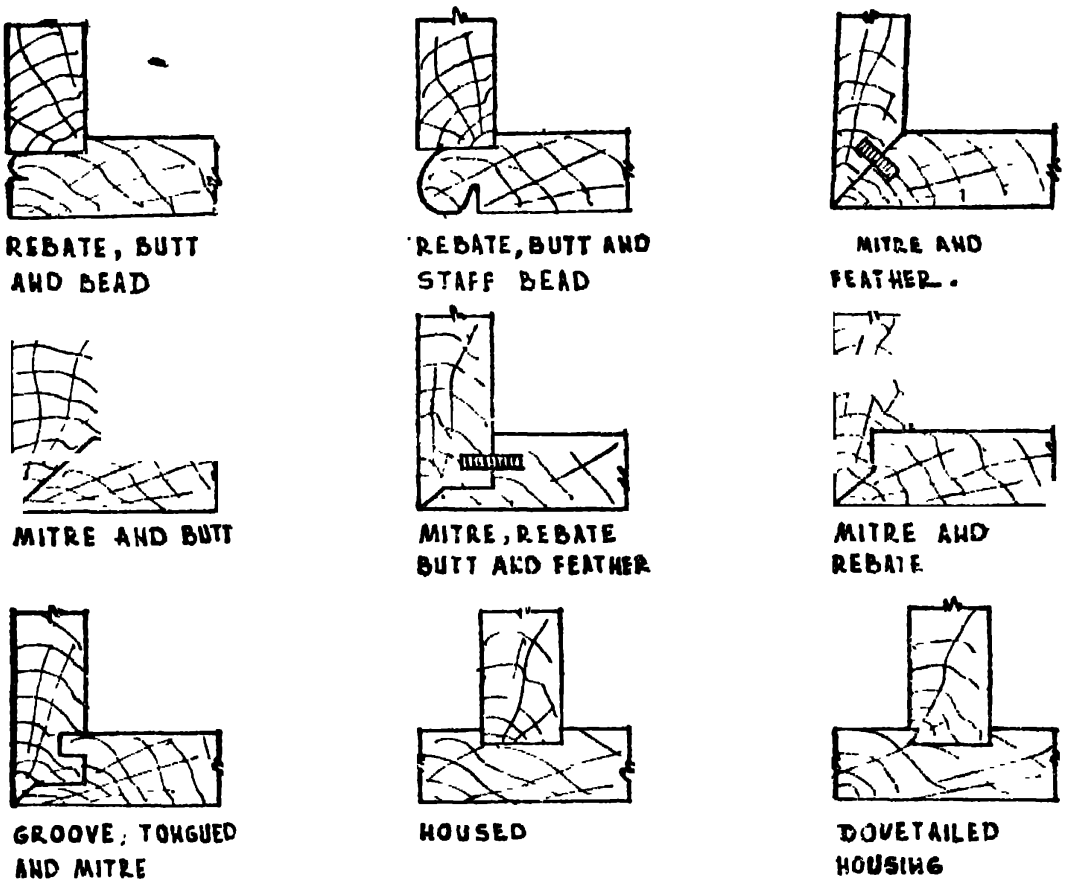


Fig. 18·14
Various types of angle or corner joints

18·8 Oblique-shouldered Joints. These joints are commonly adopted in timber truss construction where the members are jointed in acute or obtuse fashion. The various types of joints included in this category have been described in the chapter on *Roof and Roof Coverings.*

18·9 Widening or Side Joints. The joint between two wooden members placed side by side is termed as widening or side

joints. These joints are commonly used in flooring, siding, panelling etc. The various types of widening or side joints are given below :

(*i*) Butt or plain joint.

(*ii*) Tongued and grooved joint.

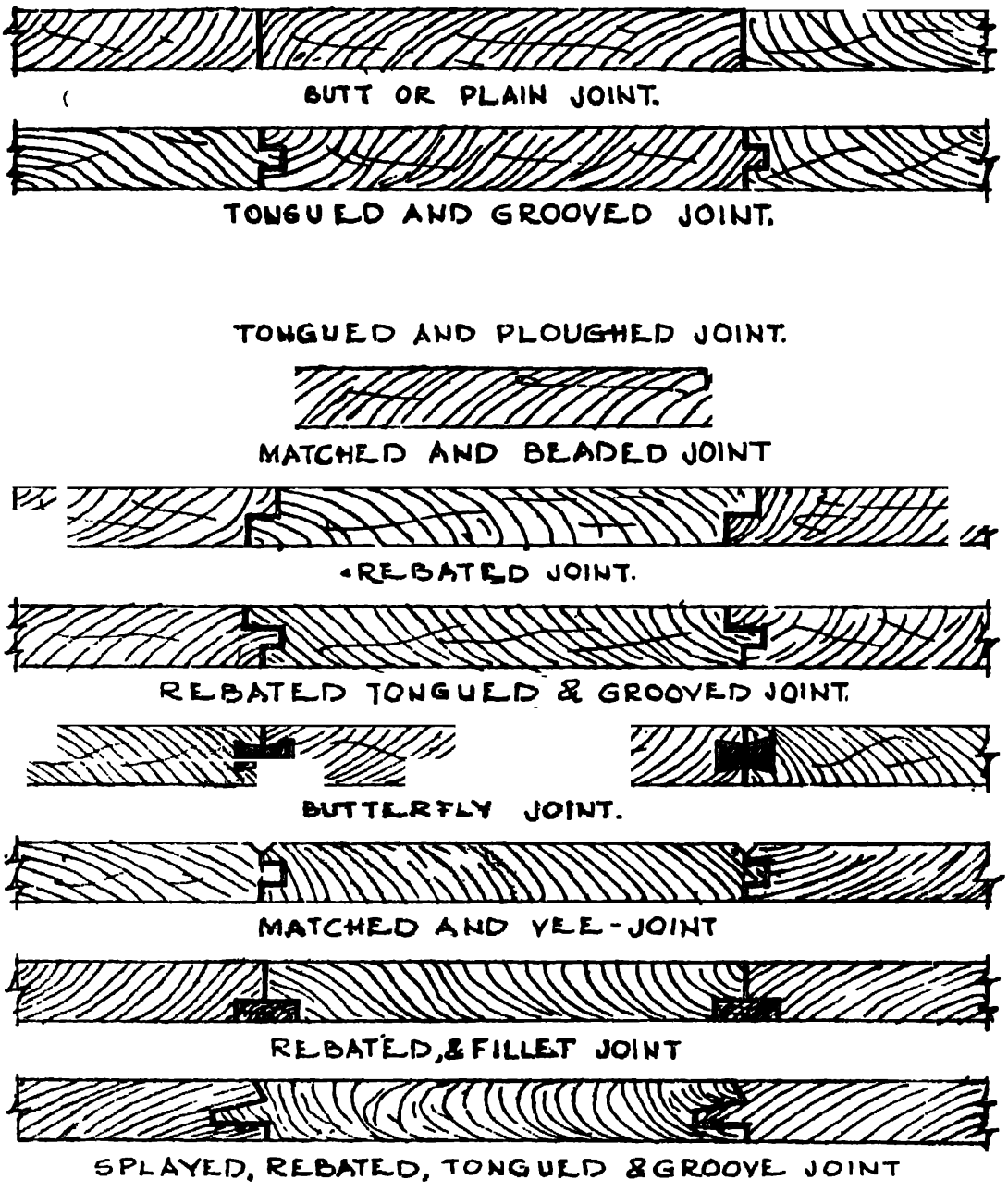


Fig. 18·15

Various types of widening or side joints

(*iii*) Tongued and ploughed joint.
(*iv*) Matched and beaded joint.
(*v*) Rebated joint.
(*vi*) Rebated, tongued and grooved joint.
(*vii*) Butterfly joint.
(*viii*) Matched and vee joint.
(*ix*) Rebated and filled joint.
(*x*) Splayed, rebated, tongued and grooved joint.
(*xi*) Dowelled joint.

Butt or plain joint is formed by laying the boarding side by side. The boards used in the work must be well-seasoned and sawn in such a manner that the annual rings remain perpendicular to the flooring joists.

In tongued and grooved joint each board is cut so as to have tongue on one edge and groove on the other.

In tongued and ploughed joint similar grooves are cut along the edge of the boards and hard wood piece called tongue is fitted tight between successive boards. Matched and beaded joint is a modified form of tongue and groove joint. In this type of joint the tongued edge of each board has special moulding. Rebated joint is formed by cutting rectangular depression in each board and the end, lapped over one another. Rebated, tongued and grooved joint is formed by so shaping the tongued and grooved end of the members that rebate is also formed by cutting an additional width on one side of the tongued member. Butterfly joint is similar to tongued and ploughed joint. Matched and vee-joint is similar to matched and beaded joint with the only difference that the moulded tongue of each board is given a vee-shaped moulding. Rebated and filled joint is similar to tongued and ploughed joint with the only difference that the hard wood piece is situated at the lower face of the boarding. Splayed, rebated, tongued and grooved joint is similar to rebated tongued and grooved joint except that the one side of the tongue is cut at an angle. Dowelled joint is similar to tongued and ploughed oint .

18 10 Fastenings. The fastenings which are commonly used in framing timber work, are briefly described below :

1. *Nails* : A nail may be defined as a slender piece of metal, circular or oval in section. The nails usually have a flat head at one end and a point on the other.

2. *Screws* : In places where it is not desirable to subject the joint to vibrations due nailing, screws are used. The screws thus

perform the same function as the nails do. The screws are manufactured in a variety of different shapes and are usually named after the shape of the head of the screw.

3. *Bolts* : Bolts are stronger than nails or screws and are used in places where the fastening is subjected to considerable tensile stresses. Bolts are commonly employed for rigidly holding the members (which may be of wood or steel) at the joint.

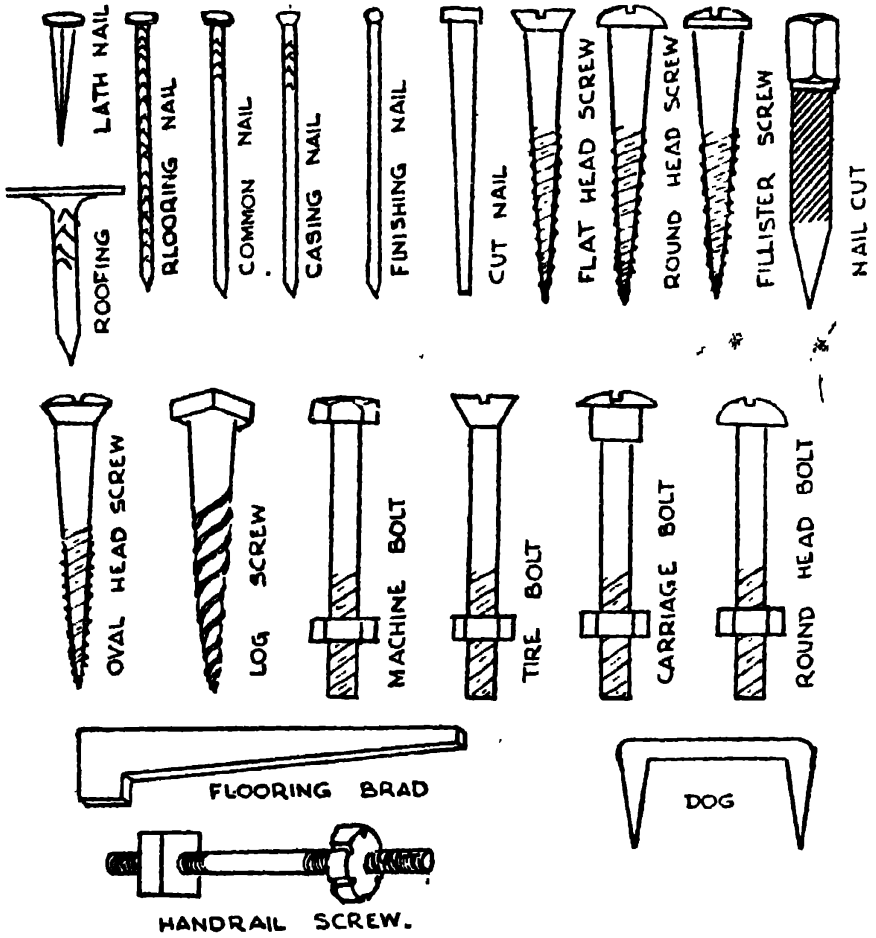


Fig. 18·16

Various types of nails, screws and bolts etc.

4. *Dogs* : These are metallic pieces of round or flat section bent at ends forming skipped hook.

18·11. Carpentry Tools. The tools commonly used in carpentry work have been shown in Fig. 18·17—18·18.

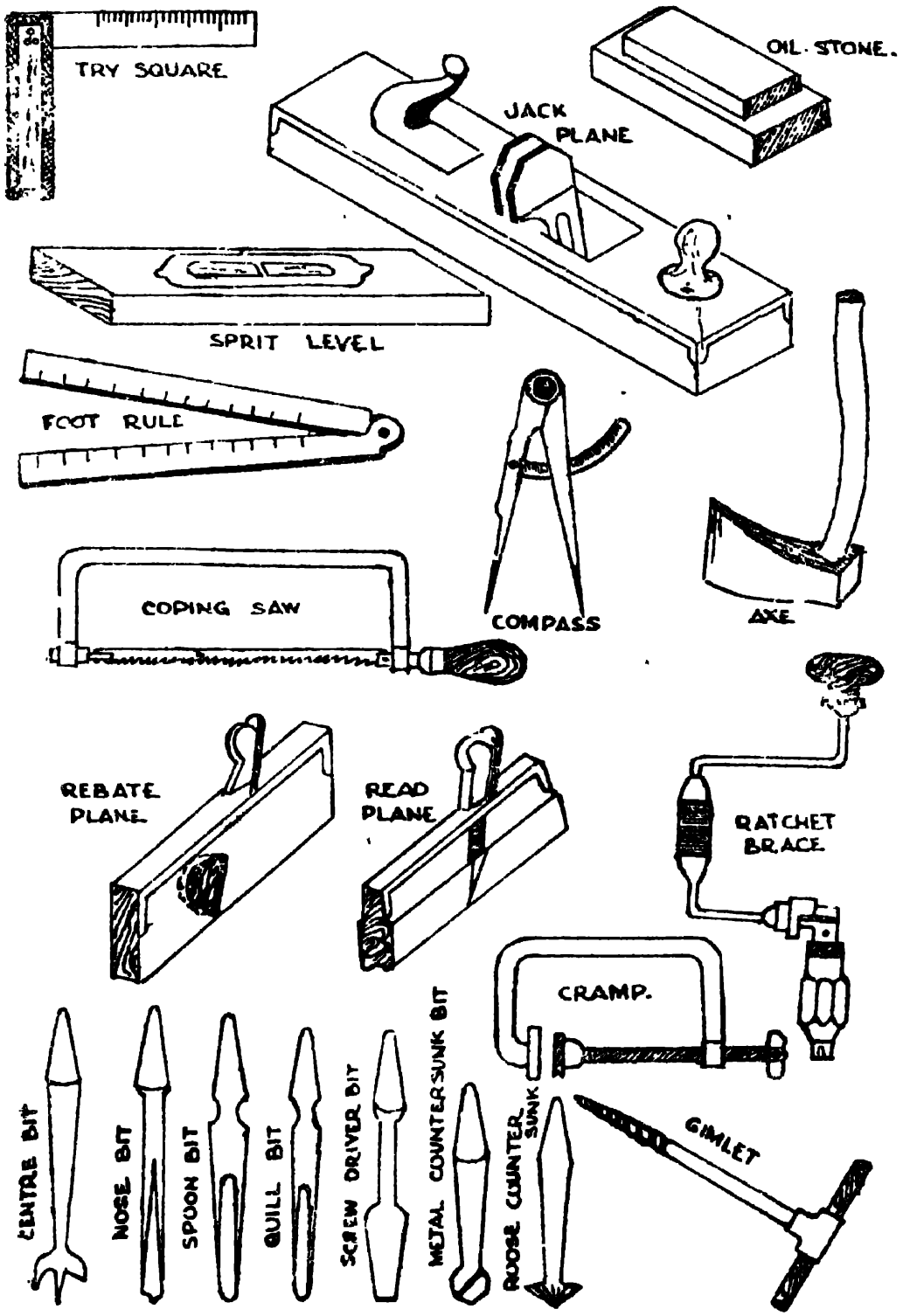


Fig. 18·17

Tools of a Carpenter

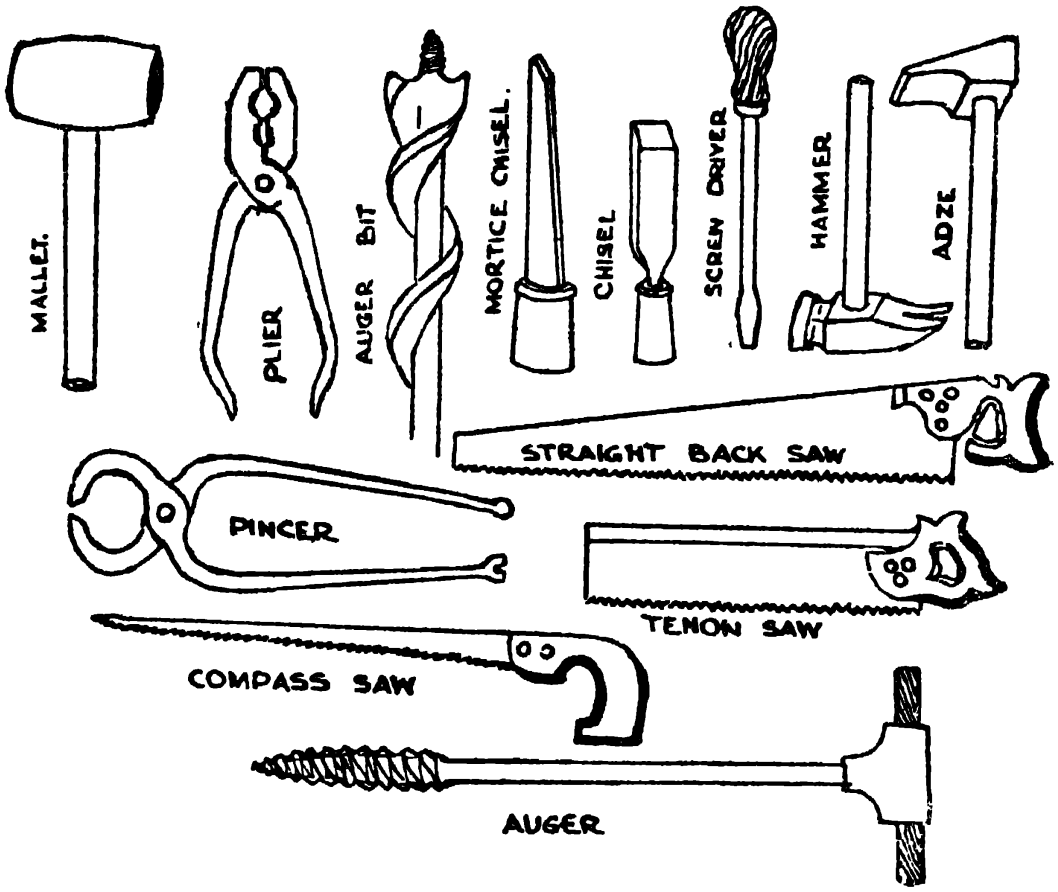


Fig. 18·18

Tools of a Carpenter

18·12. Connectors. With the advancement in timberconstruction, various types of metallic connectors are now commonly used for connecting timber pieces in such a way that transmission of stress from one member to another is perfectly ensured. Connectors are advantageously used in the construction of timber trusses, arches or other similar structures. They are usually embedded in the individual member in such a way that the danger of joint against sliding is completely guarded. Split ring connector and toothed-ring connector are the two varieties commonly used. In addition to the above mentioned types there are a large number of typical forms of connectors which are used only in special circumstances.

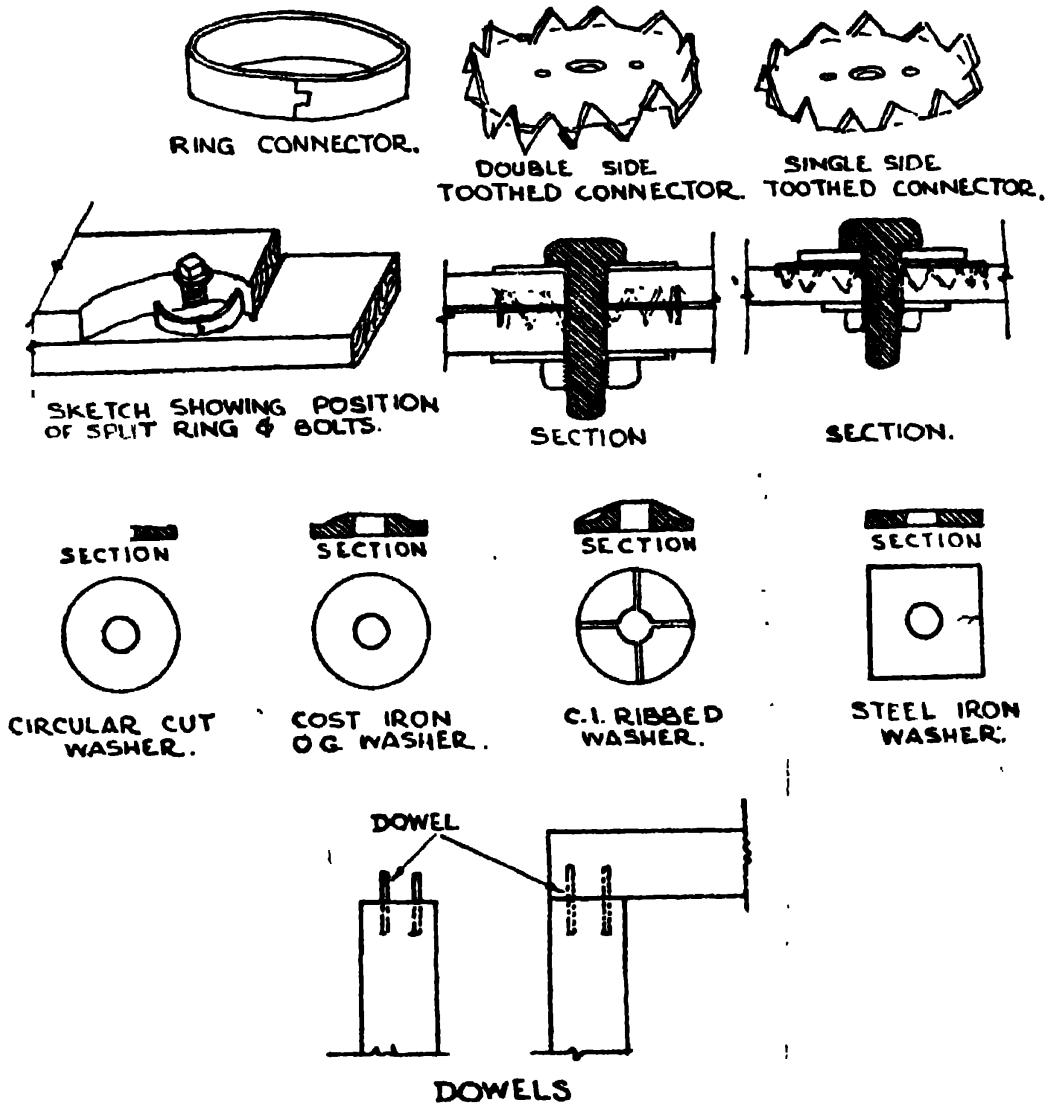


Fig. 18·19

Details of various connecting devices used in timber joinery

Questions for Revision

1. Describe briefiy. with the help of sketches, lengthening transverse and framing joints in wood work.

2. What is a bearing joint ? Show with sketches four different types of bearing joint.

3. Write short notes on :

(*i*) Notching
(*ii*) Cogging
(*iii*) Dove-tailing
(*iv*) Halving.

4. Illustrate any five types of carpentry joints used in buildings and state when they are used.

Name various types of fastenings used in wood work.

19

Doors and Windows

19·1 Doors. A door may be defined as a frame-work of wood, steel, glass or a combination of these materials, secured in an

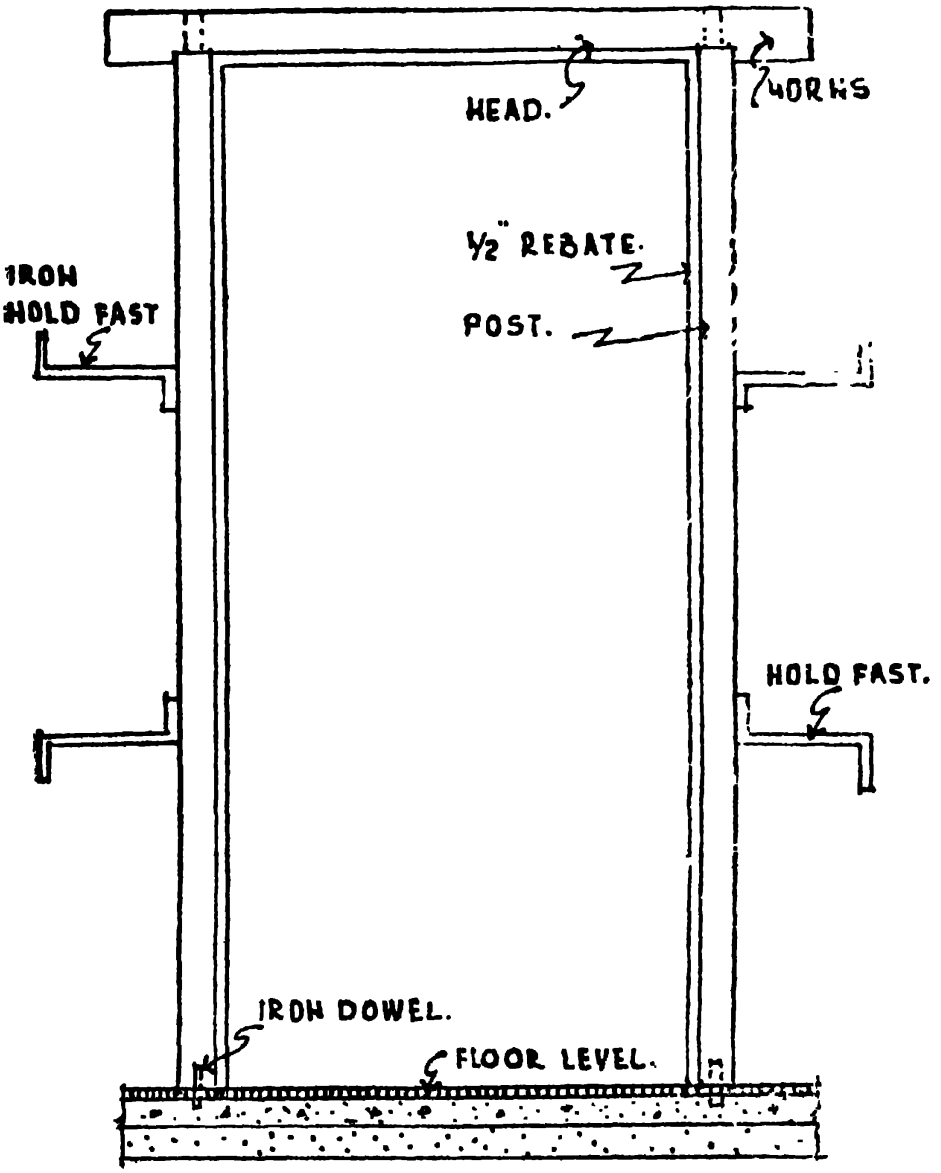


Fig. 19·1
Details of ᵐ door frame

opening left in a wall, for the purposes of providing access to the users of the structure.

19·2 Door Frame. Door frame is made up of two vertical members called jambs and a flat or arched member connecting the jambs at top. This top member is called head. The jambs are usually 7·6 cm. to 11·4 cm. wide and 5·7 to 7·6 cm. deep. The head is of the same size as the jambs. The jambs are tenoned into the head and wedged. The head generally projects out by 7·6 cm. from the jambs. These projections are known as horns which help in securing the head to the masonry. The frame is built in reveals formed in the masonry and is held in position by holdfasts. In some cases a horizontal member placed at the floor level binds the jambs at bottom. Very often the jambs are secured by dowels at their feet. The rear faces of the frame are often grooved for plastering or lining.

19·3 Types of Doors. Depending upon the material used, method of construction and the arrangement of several parts, doors may be classified as below :

1. *Battened and ledged door.*
2. *Battened, ledged and braced door.*
3. *Framed and braced door.*
4. *Framed and panelled door.*
5. *Glazed and sash door.*
6. *Sliding door.*
7. *Flush door.*
8. *Revolving door.*
9. *Collapsible steel door.*
10. *Rolling steel door.*
11. *Swing door.*

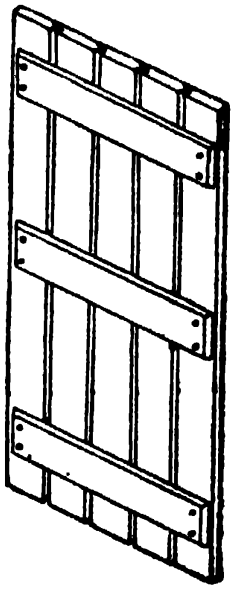


Fig. 19·2

View of a battened and ledged door

19·4 Battened and Ledged Door. This is the simplest form of door commonly used. The door consists of a series of battens or boards usually tongued and grooved and fixed together with ledges. The battens are 10 to 15 cm. wide and 16 to 32 mm. thick. There are three ledges, one each is fixed near the top and bottom of the battens and the third one is fixed in the middle. The middle ledge is also known as lock ledge. The thickness of ledges vary from 25 to 32 mm. and generally the middle and bottom ledges are wider than the top one. Usually the top ledge is 11 cm. wide while the middle and bottom ledges are each 18 cm. wide. The door is hung

by iron hinges called T-hinges or cross garnets fixed on the ledges. Battened and ledged doors are often used in cellars or small openings where appearance and strength is not of much importance and economy is to be achieved.

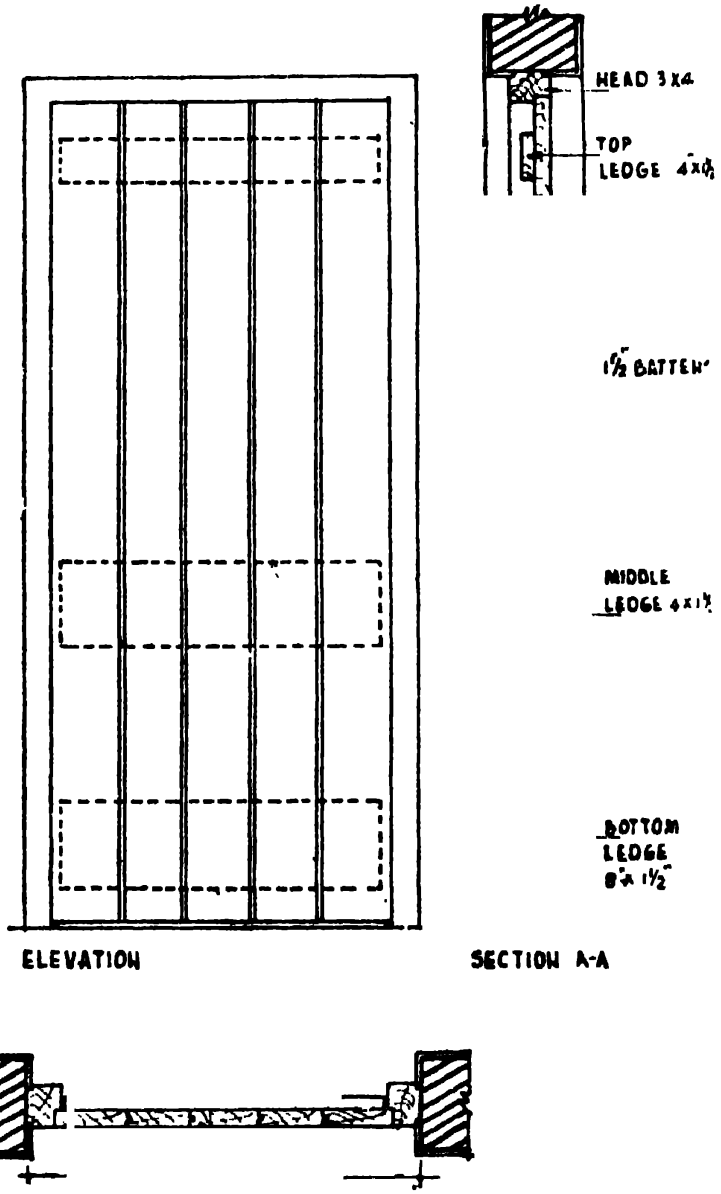
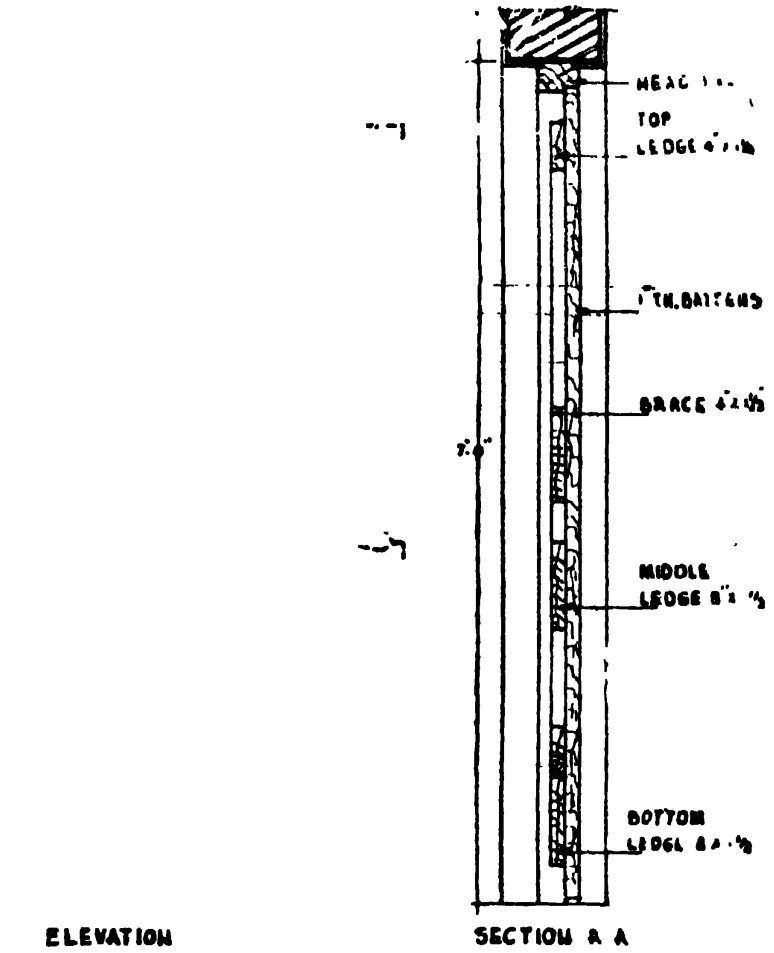


Fig. 19·3

Elevation, section and sectional plan of a battened and ledged door

19·5 Battened, Ledged and Braced Door. This is an improved form of battened and ledged door. In this type inclined braces are provided between the ledges as shown in Fig. 19·4. The braces are usually 25 to 32 mm. thick and 10 cm. wide. They act

like struts between the ledge and increase the strength and rigidity of the door. This door is commonly used for bathrooms and w.c's and in places where appearance is not so important as economy.





LEDGED AND BRACED

Fig. 19·4

Elevation, section and sectional plan of a battened, ledged and braced door

19·6 Framed and Braced Door. The frame-work of this door consists of two vertical members called styles ; three cross or horizontal pieces called rails ; battens and two inclined braces. The rails are tenoned and wedged into the styles, the battens are tongued

and grooved and V-jointed. At their upper end the battens are let into the top rail while at the mid height and lower ends, they go right over the middle and bottom rails. The styles and the top rails are generally 11 cm. wide while the lock rail and the bottom rail are 23 cm. wide each. Thus for a 5 cm. thick door with 25 mm. thick battens or boarders, the styles and the top rail are 11 cm. × 5 cm. but the braces, lock rail and the bottom rail are 23 cm. × 25 mm.

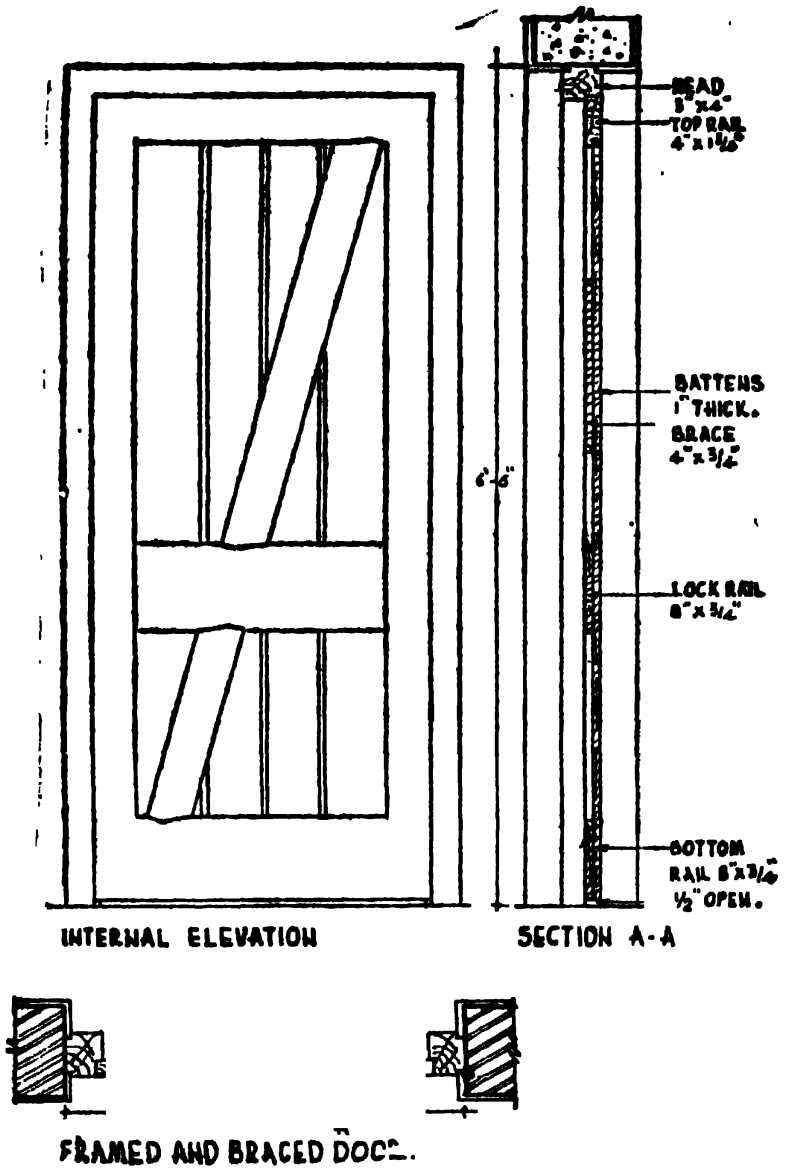


Fig. 19·5

Internal elevation, section and sectional plan of a framed and braced door

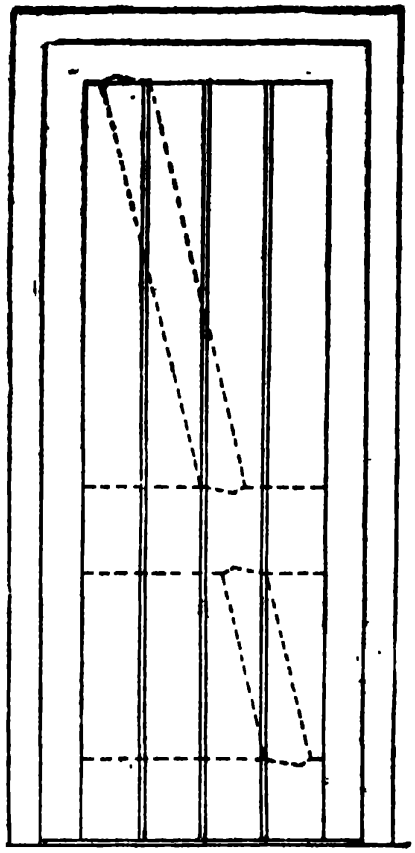


Fig. 19·6

External elevation of a framed and braced door

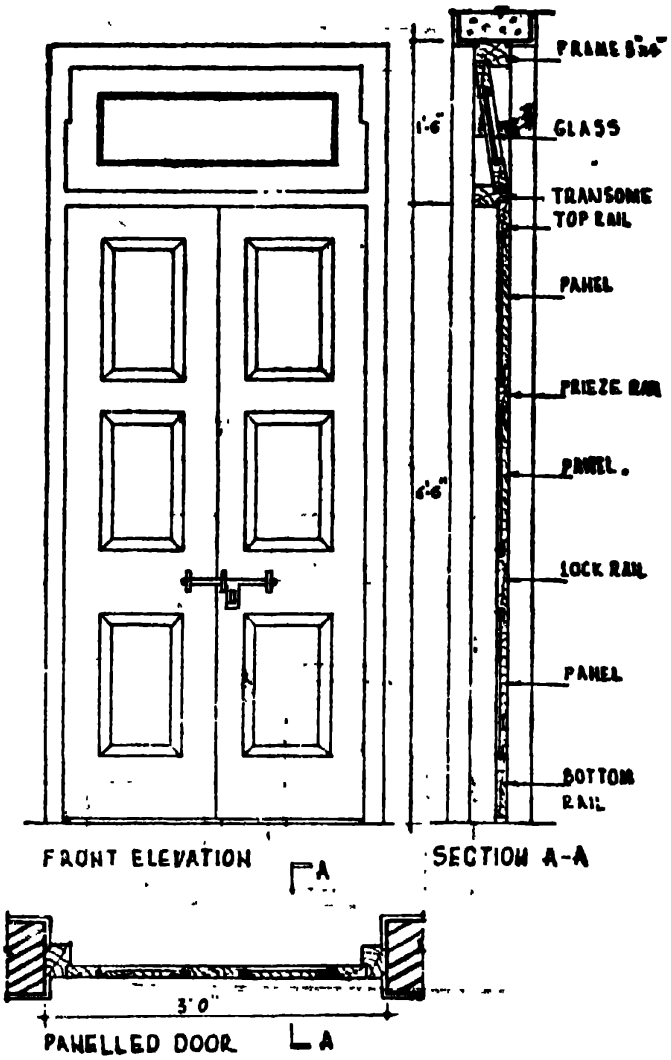


Fig. 19·7

Elevation, section and sectional plan of a framed and panelled door with a fan light

19·7 Framed and Panelled Door. This type of door is very common in use. They are constructed in various designs and elevations. The doors may be three panelled, four-panelled, and 6-panelled and so on. The framing consists of narrow pieces, mortice and tenoned to each other and grooved in the inside of panels which may be of wood or glass. The outside upright members called styles always run through the whole height of the door frame. They form the most important part of the structure as all the other members are directly or indirectly connected to them. The styles are tenoned to each, both at the top and the bottom by cross-pieces or horizontal members called rails. In a three or four panelled door, the central cross-piece is termed as lock rail and the upright member in the centre is called munting. The rails are tenoned into the styles and the mounting is tenoned into the rails.

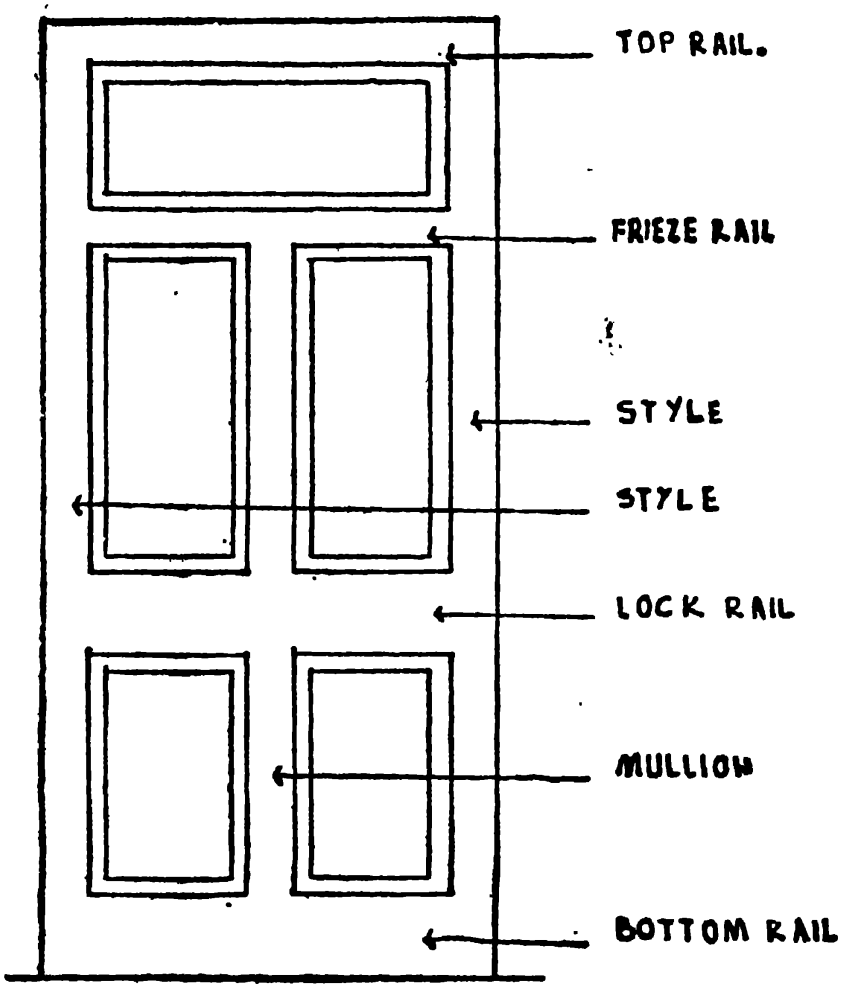


Fig. 19·8

Details of a panelled door

19·8 Glazed or Sash Door. This type of door is extensively used in residential as well as in public buildings. As a rule these doors consist of top and bottom rails and either one large panel of glass or two small wooden panels at bottom and the remaining area of glass consisting of one large panel or divided into a large number of panels by sash bars. In case of partly glazed doors, the styles are sometimes diminished at the lock rail to increase the elevational effect of the frame and incidentally to allow more area of glass in fixing. The diminished styles are called gun stock styles.

When the door is situated in external walls of the building, the glass panels are held in the rebates in sash bars by putty, but when they are provided in interior walls or in places where they may not be subjected to adverse weather effect, wooden beads or mouldings are used to secure the panels in the sash bars.

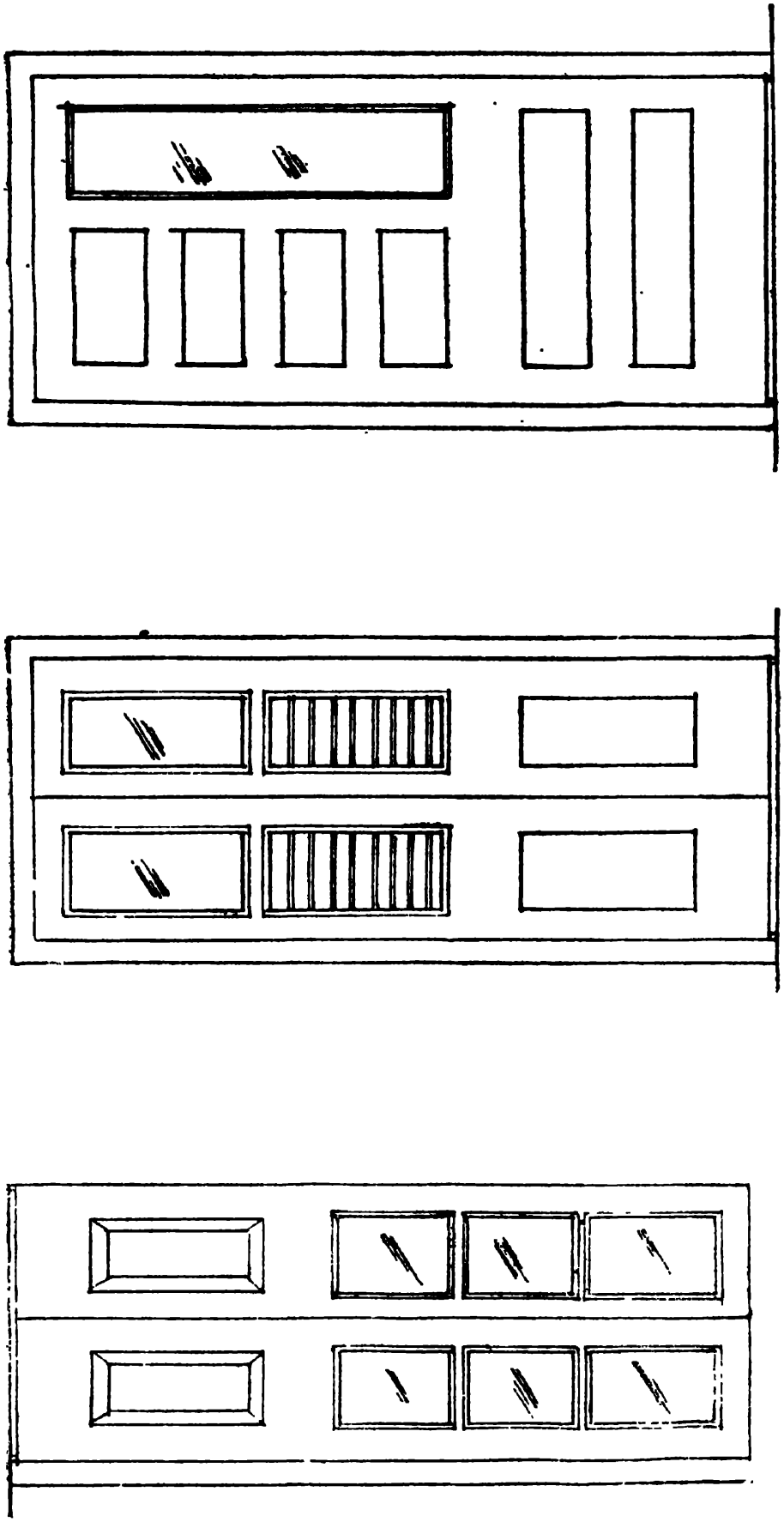


Fig. 19·9
Various forms of panelled and glazed doors

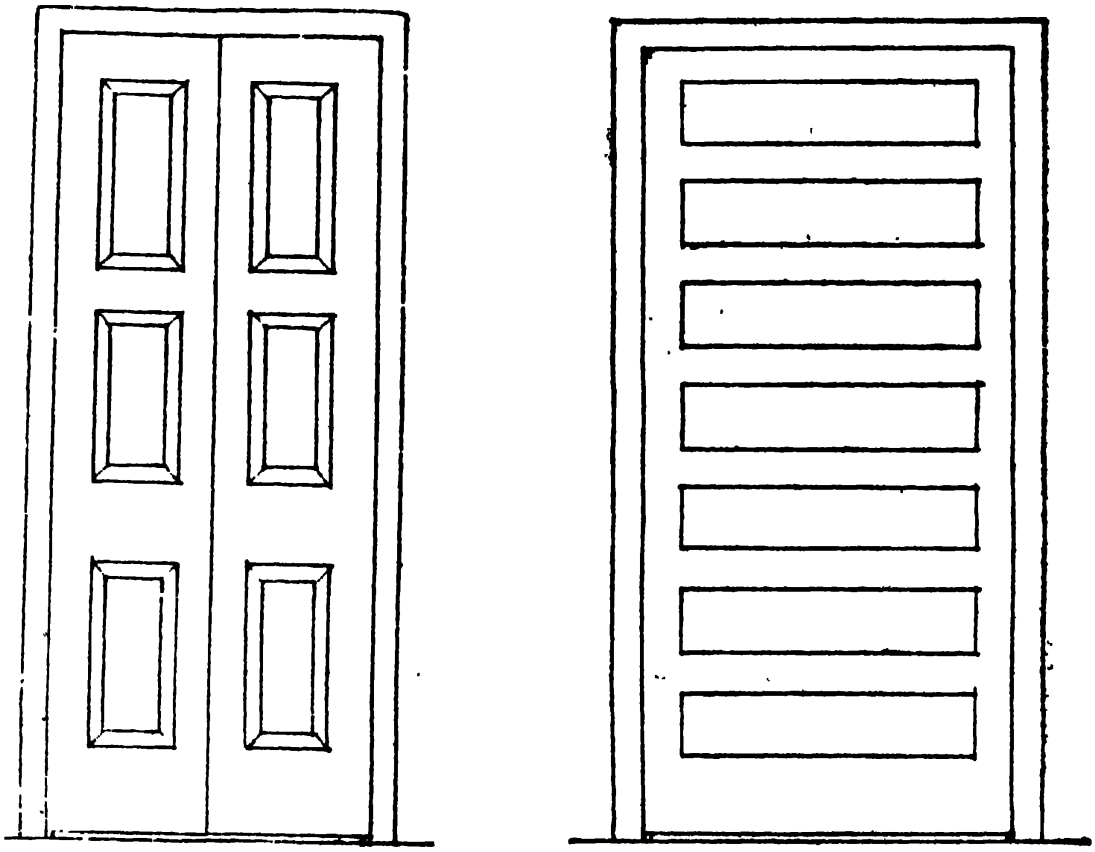


Fig. 19·10—19·11

Different types of panelled doors

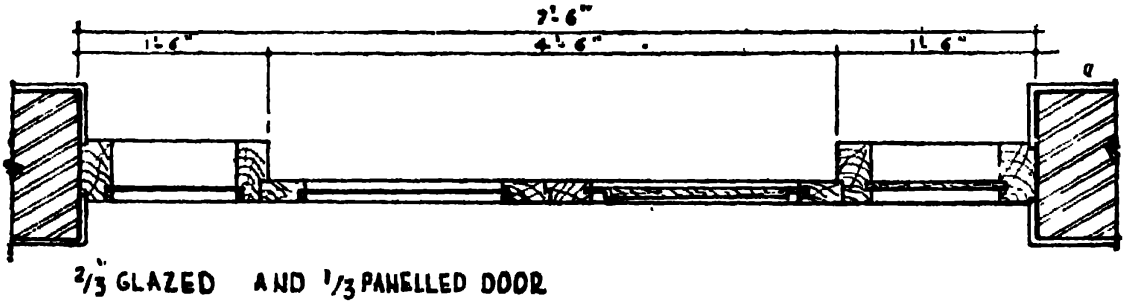


Fig. 19·12

Sectional plan of $\frac{2}{3}$rd glazed and $\frac{1}{3}$rd panelled door

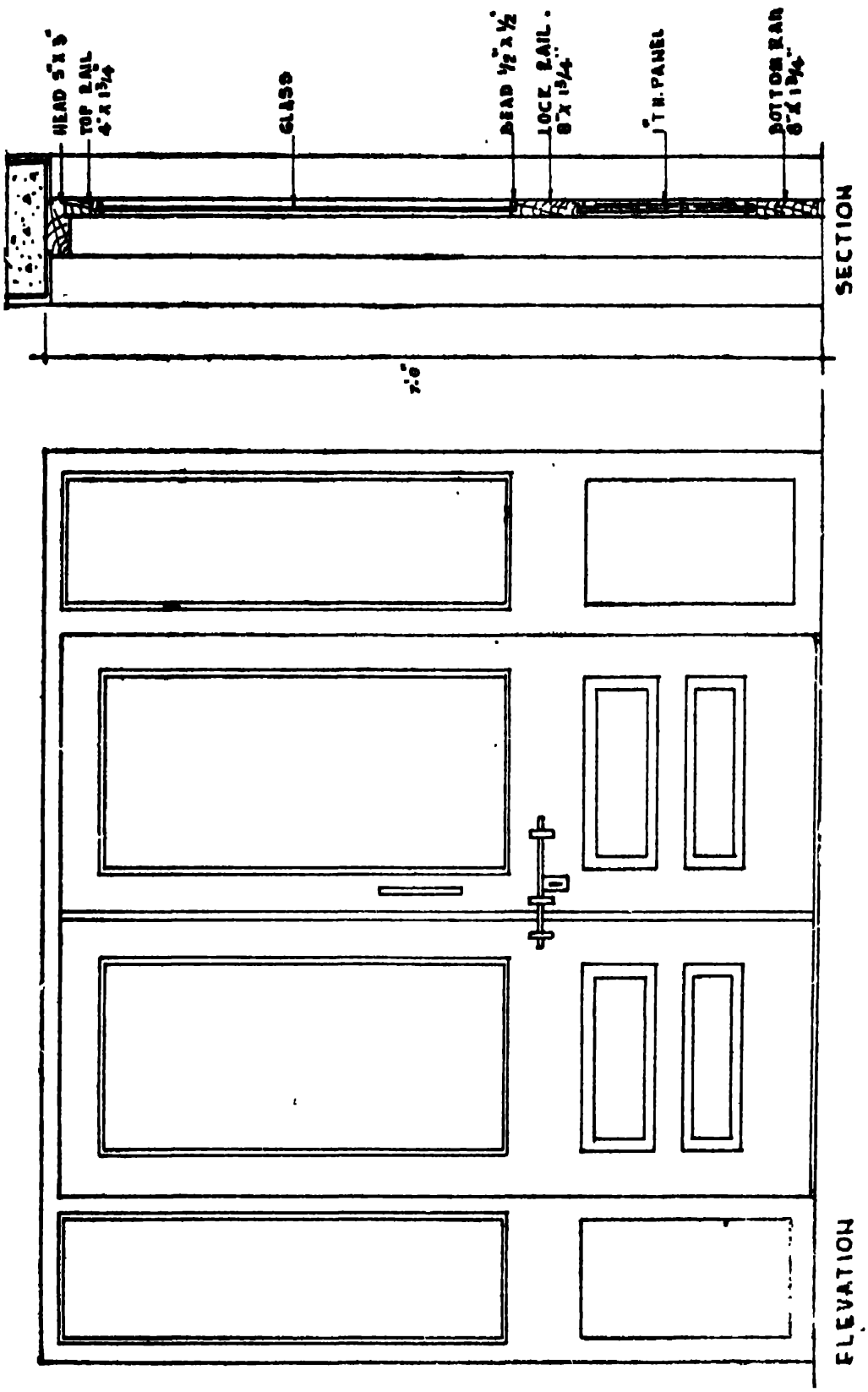


Fig.s 19·13—19·14
Elevation and section of a $\frac{3}{8}$rd glazed and $\frac{1}{8}$rd panelled door

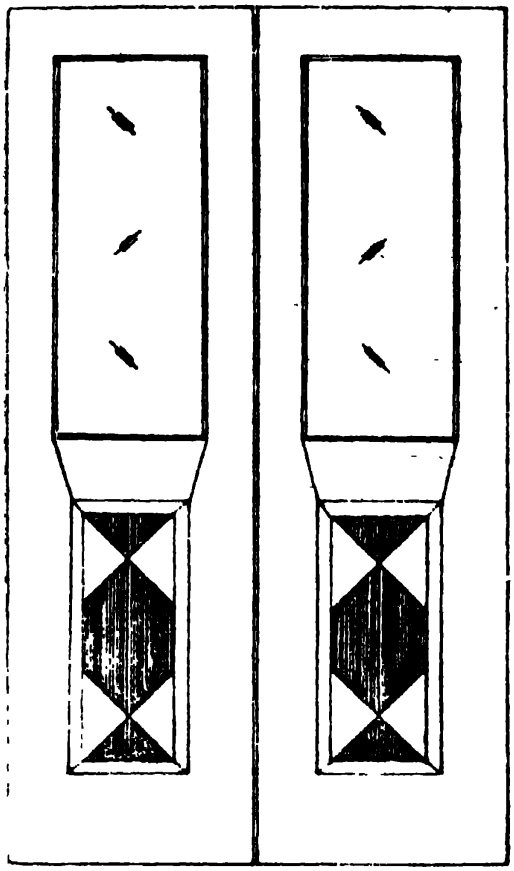


Fig. 19·15

Elevation of a panelled and glazed door with gun stock styles

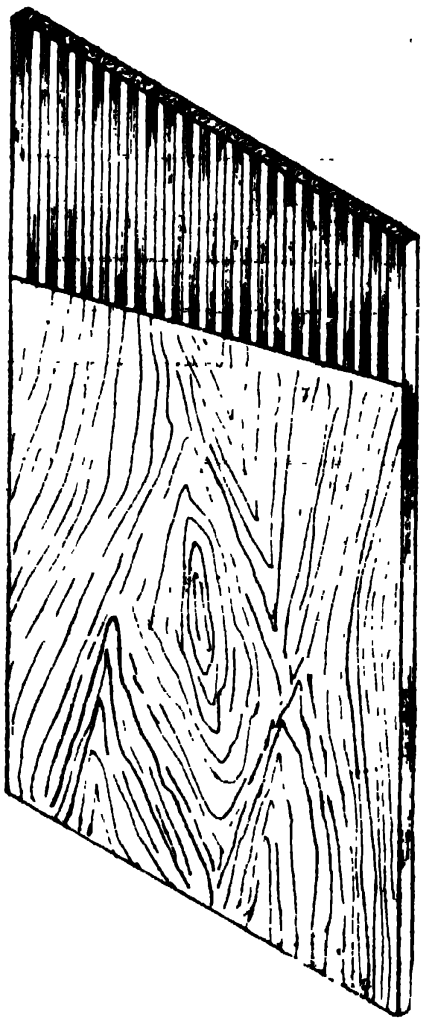


Fig. 19·16

Solid flush door

19·9 Sliding Door. This type of door consists of one or more panels fixed with wheels on their top or bottom. The wheels run over in iron or hard wood guides or runners and the door panel is opened by sliding action. The runners run past the opening for a distance equal to the width of the panel, so that when the door is required to be opened, the door shutter occupies a new position parallel to the wall face and clear off the opening. Depending upon the width of the opening and the space available on its either sides, the sliding door may either be double or single leafed. This type of door is suitable for goods sheds, shops, garages and in places where the use of hinges for fixing the shutters is to be avoided.

19·10 Flush Door. With the introduction of plywood and veneers, flush door has become very popular these days. This door has flat surface on both the sides. It consists of solid or semi-solid

framed skeleton covered on both the sides with laminated boards or plywood, giving a perfectly flush and jointless surface. The finished thickness of the door is usually 44 mm. The thickness of plywood used as facing varies from 3 to 6 mm. There are two types of flush doors :

1. *Solid flush door.*

2. *Hollow core flush door.*

1. *Solid flush door* : This type of door consists of a central core of narrow strips of soft wood (usually not less than 20 mm. in width) glued together under pressure. The grain of the soft wood strips which run vertically between the top and the bottom rails is arranged in such a manner that the annular rings are in alternate direction. Such an arrangement of the strips has the advantage that the warping of one strip is counteracted by the warping of strip next to it. The core is faced with sheets of plywood or laminated boards which are secured to core by being glued to it. under pressure. To prevent the core and the edges of the frame from damage, edge strips are fixed on all the edges. The edge strip consists of the same wood (usually harder variety) which has been used to face the two sides of the door. If only one layer of ply is used, it is 3 to 6 mm. thick. If two plies are used, the inner one is slightly thicker. The inner ply or cross-band is laid at right angles to the core while the outer ply is laid at right angles to the inner ply. The thickness of the door is usually 25 mm. to 45 mm.

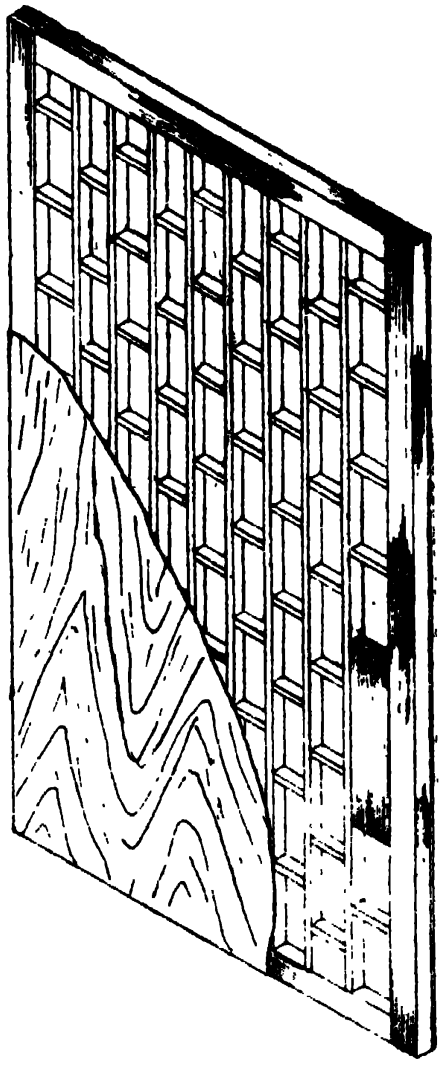


Fig. 10·17

Hollow core flush door

2. *Hollow core flush door* : Unlike solid door, the core of this type of door mainly consists of crossed wooden strips or some other form of grid construction. The width of the strips is generally not less than 25 mm. The edges of the door consist of solid wood and provision is made for the

insertion of mortice lock and fixing of hinge by strengthening the framework at these places. The core is finished by facing i t with plywood, which is glued to the grids under pressure. The hollow space between the grids is sometimes filled with cork, slagwool or other similar material for insulation purposes. These doors are light and economical as great saving is made in the timber used for forming core.

19·11 Revolving Door. Revolving door provides entrance on one side and exit on the other simultaneously, keeping the opening automatically closed when not in use. The door is so assembled as to exclude the draught. Thus these doors are advantageously provided in places where there is a regular foot traffic of people entering in and going out of the building, especially when it is air-

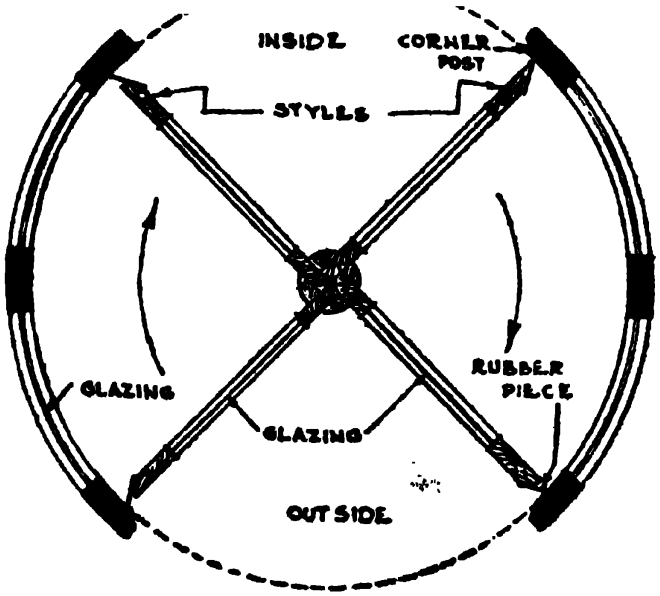


Fig. 19·18

Revolving door

conditioned or situated in a place where strong winds blow for most part of the year. The door essentially consists of four leaves, radially attach to a centrally placed mullion in a circular opening. The mullion or the central member is provided with ball-bearing at the bottom and bush-bearing at the top, so as to enable the door to revolve smoothly without producing jerks. The leaves and the mullion are enclosed in a vestibule. At their edges, the leaves are provided with rubber pieces which fit flexibly against the inside face of the vestibule. The attached leaves may be glazed panelled or partly glazed and partly panelled. Such doors are commonly provided in hotels, banks, offices and other important public buildings.

19·12 Collapsible Steel Doors. Depending upon the size of the opening, these doors consists of single or double shutters. The doors are fabricated from mild steel sections. This door essentially consists of vertical double channels each 16 to 20 mm. in width and spaced at 10 to 12 cm apart, The channels are braced with 16 to 20 mm. wide flat iron diagonals which allow the door open or fold. Two rails in the form of T-sections are fixed to the floor and lintel

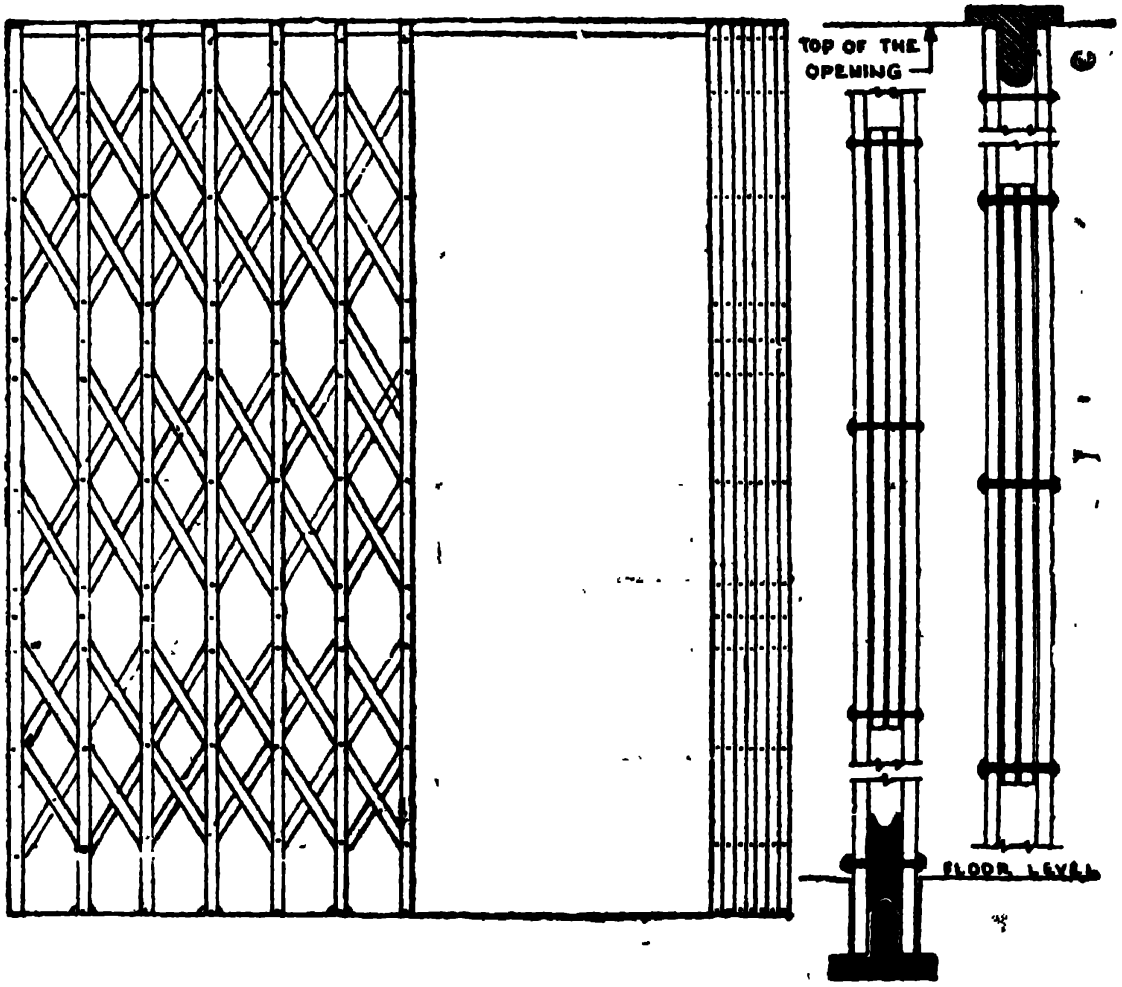


Fig. 19·19
Elevation and details at bottom and top of an opening provided with a collapsible steel door

respectively by means of anchor bolts. The door shutter slides over rollers mounted at its bottom and is held in position by the T-sections.

19·13 Rolling Steel Doors. They are commonly used for show windows, stores, shop fronts and godowns etc. The door consists of interlocked steel slabs coiled upon a drum at the top of the opening. The door shutter travels in steel guides mounted at the sides. The door is counterbalanced by means of helical spring

enclosed in the drum and a hood of steel protects the drum from the weather. When the openings do not exceed 9·3 sq. m. in area, the door can be pushed up and down in the same manner as a window shade. For heavier doors a reduction gear and endless chain or a shafting gear and crank are used to operate the door.

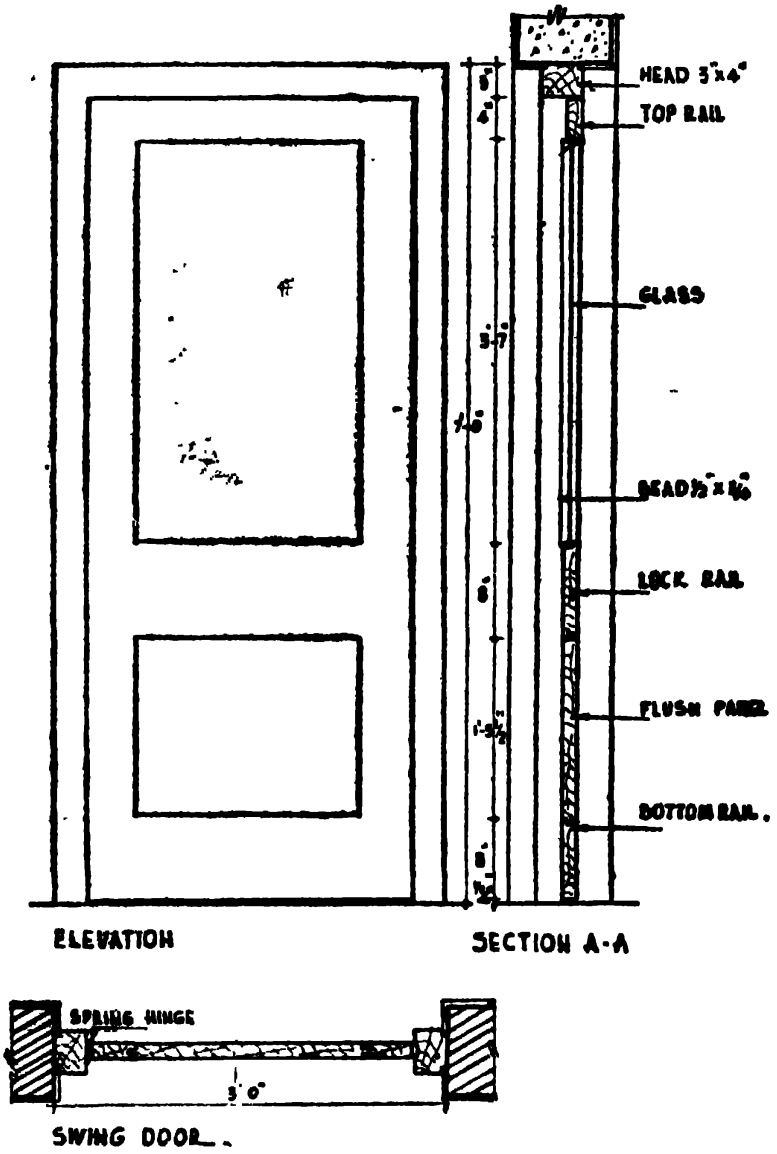


Fig. 19·20

Elevation, section and sectional plan of a swing door

19·14 Swing Door. This type of door is generally provided in passages of public buildings, like offices, banks, etc. The door may have a single shutter or two shutters. The shutters are fixed with special hinge known as double action spring hinges which hold the shutter in closed position when not in use. Since these doors are pushed open, they should have a panel of glass, so as to enable the

users to see the objects on other side of the door to avoid accidents. As the springs return the door with force, it is advisible that the glazing should be carried out with wired plate or protected by other suitable means. Such doors should not be rebated at the meeting styles. The closing edges of the meeting styles should preferably be segmental.

19·15 Windows. Windows are constructed for the purpose of providing light and ventilation in the structure. The transmission of light is effected by the glass panes while the ventilation takes place only when the window is open. Their size and shape is governed by the situation in which they are to be built. Window essentially consists of two parts *viz.* the frame and the sash. The frame is fitted into the opening while the sash, which consists of smaller frames (for glasses), is attached to the frame proper.

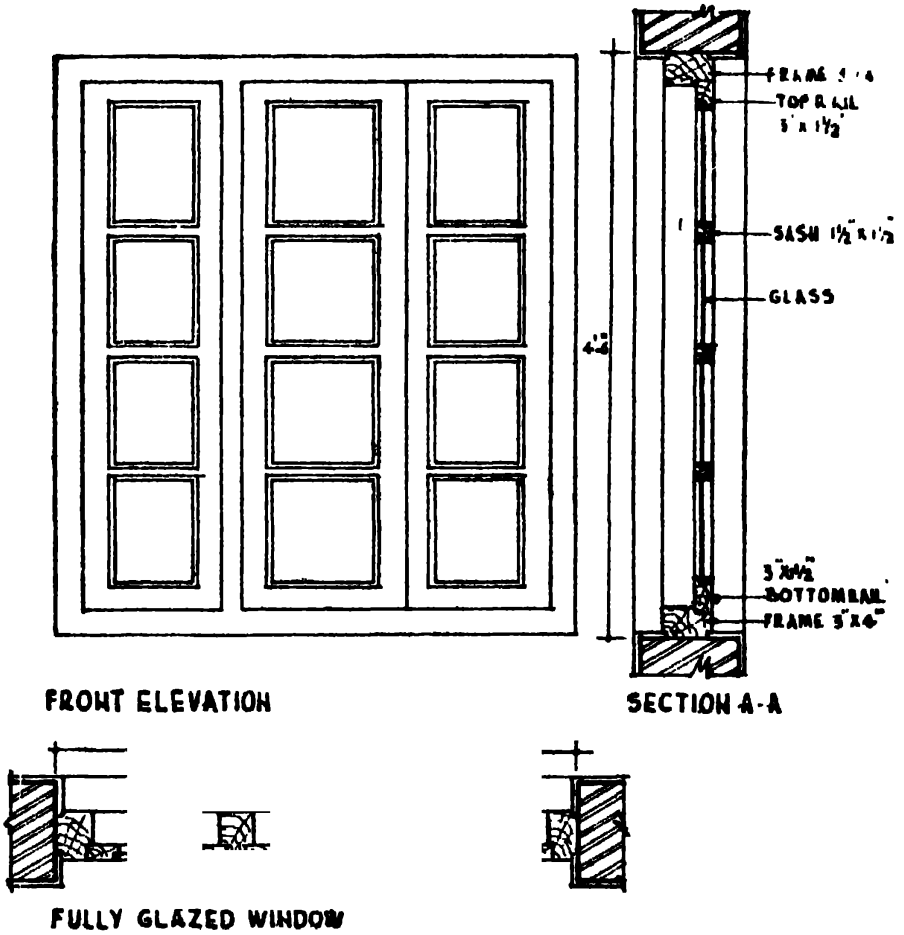


Fig. 19·21

Elevation, section and sectional plan of a glazed window

19·16 Sash. A sash consists of vertical members called styles; horizontal members called rails and some smaller members, which divide the area enclosed by the styles and rails into smaller units.

These dividing smaller members are termed as bars or sash bars. The panes are cut 1·6 mm. to 3 mm. smaller in size than the size of panel into which they are to be fitted. This is necessary to permit slight movement of the sash due to temperature variation. Sash may be

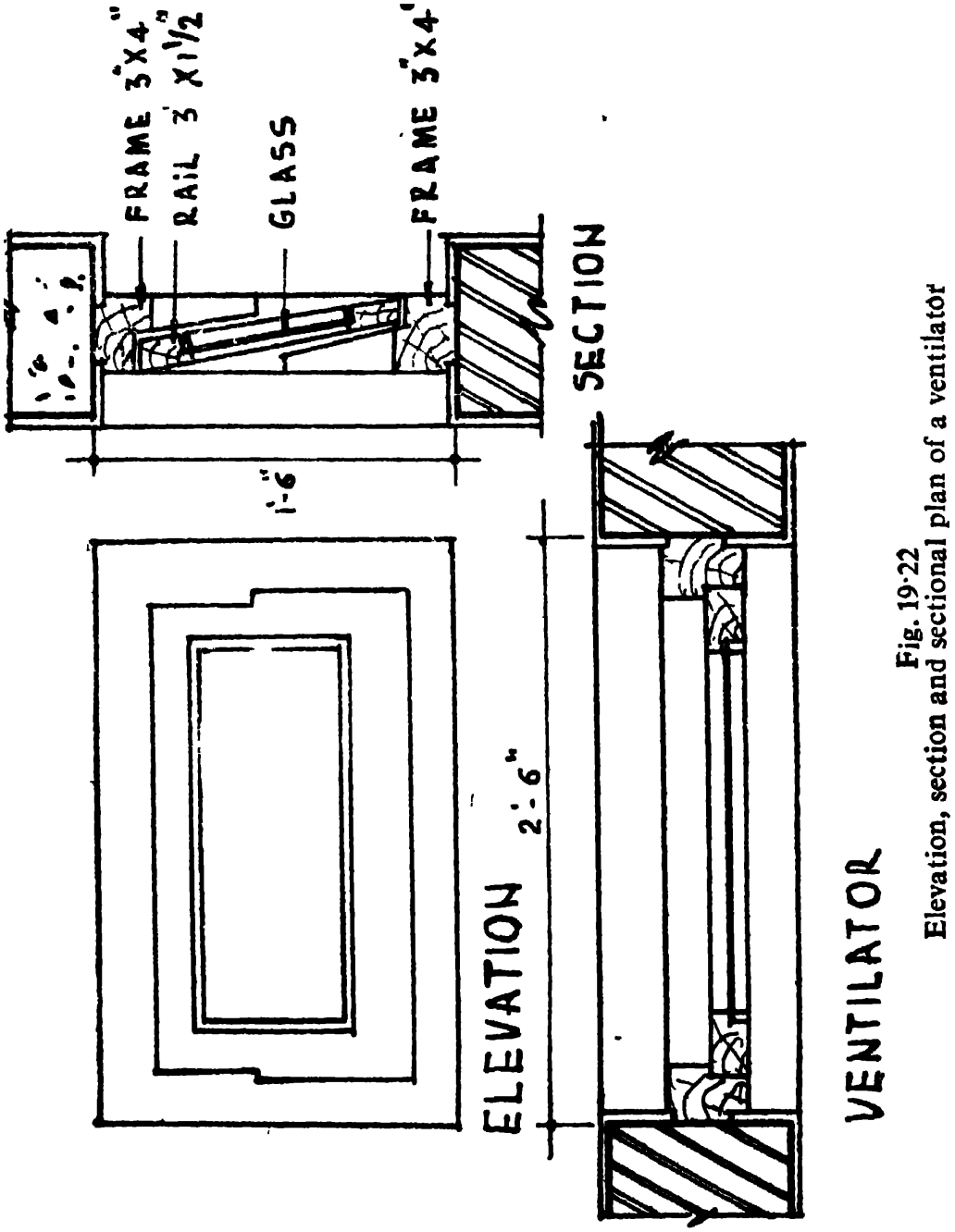


Fig. 19·22
Elevation, section and sectional plan of a ventilator

rigidly fixed to the frame, hinged at the styles or it may be capable of sliding horizontally or may be pivoted to rotate about a vertical or horizontal axis. In common practice, sashes are hinged to one style and invariably open out so that they will be water-tight. When double sashes without a mullion are to be used, the meeting styles of the sashes should be rebated.

19·17 Fanlight. The function of fanlight is to ensure cross-ventilation even when the door is closed. It also assists in lighting corridors or passages. Fanlight is fitted between the head of the door frame and the transome. The construction of fanlight is similar to that of a window sash. It may be pivoted at the centre or hung at top or bottom of its frame.

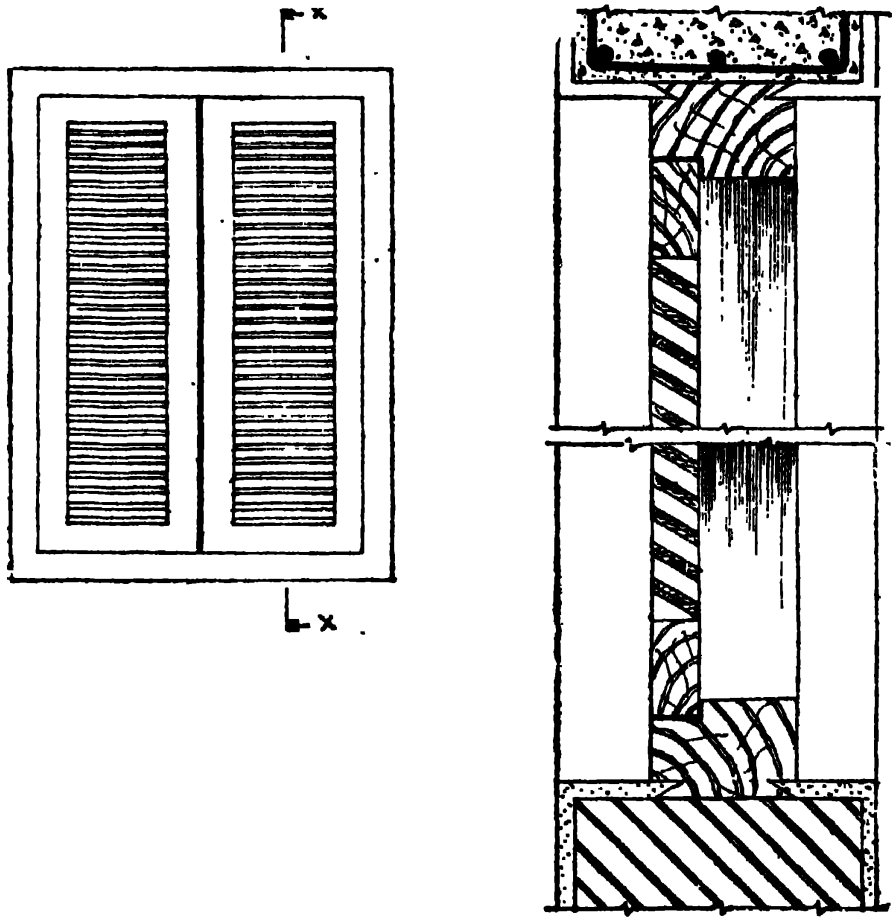


Fig. 19·23

Elevation and enlarged section of venetian shutter

19·18 Venetian Shutter. It consists of a wooden frame in which the styles are grooved to receive a series of louvers which may be of glass or wood or any other material. The louvers are set in the grooves in inclined position so that they slope downward to the outside in order to run off the rain water and obstruct the horizontal vision at the same time. For economical construction the angle of inclination of the louvers or blades to the vertical style is usually 45°. This type of shutter provides ventilation and light even when the opening is closed. They are largely used in bathrooms and w.c.s. workshops. railway compartments and other public places. However, it is difficult to maintain them clean as the dust gets easily deposited on the blades. Sometimes the louvers are pivoted to the

frame and in addition they are connected to a vertical timber piece to enable them to be lifted up or pulled down in series.

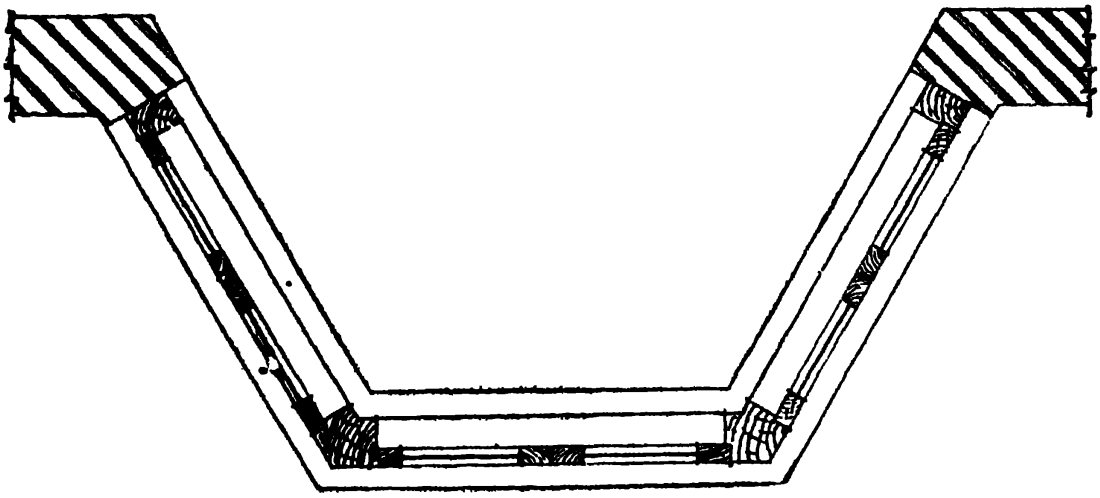


Fig. 19·24
Sectional plan of a bay window

19·19 Special Types of Windows. Some of the typical forms of windows have been described here. It will be evident from the sketches and the explanations, that the windows have mostly been named after their situation in a structure.

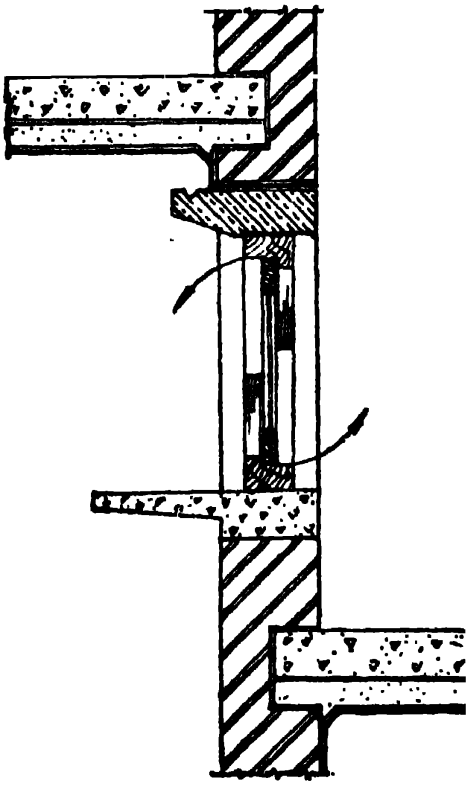


Fig. 19·25
Sectional elevation of a clerestorey window

19·20 Bay Window. Any window projecting outward from the walls of a room is termed as a bay window. Bay windows may be square or polygonal on plan and are employed to secure an increasd area of opening for admittance of light and ventilation.

19·21 Clerestorey Window. This type of window is provided from consideration of beauty as well as utility The window is usually provided near the main roof of a room and opens above the adjoining verandah. The shutter of the window is horizontally pivoted and can be operated by a chord passing over a pulley.

19·22 Dormer Window. It is a vertical window built on the sloping side of a pitched roof. It is used with the object of providing light and air to the enclosed space below the roof.

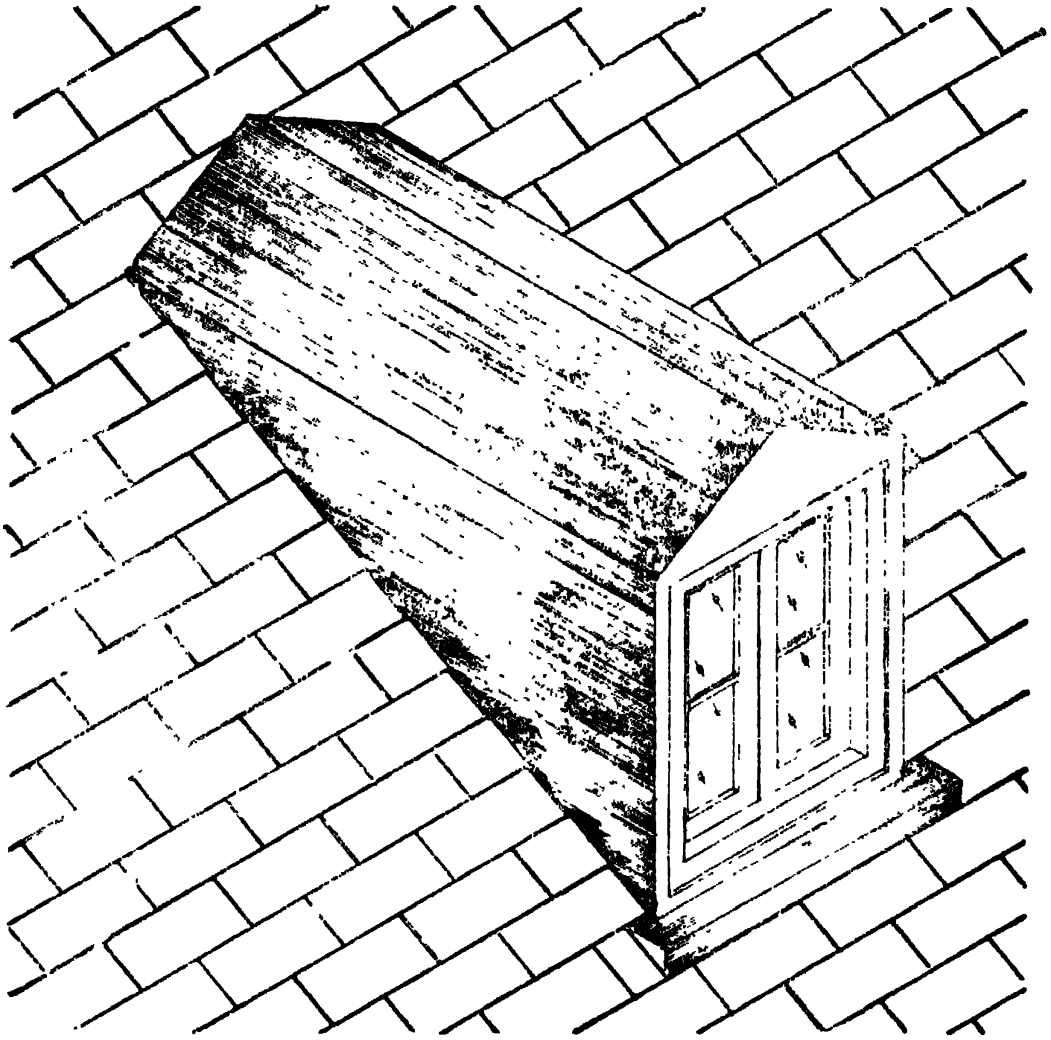


Fig. 19·26

View of a dormer window

19·23 Skylight. This is similar to a Dormer window and is providing in a sloping roof by cutting the principal rafters. The function of this type of window is to permit the room below to be fully lighted with natural light. The framework supporting the glass consists of an arrangement of trimming piece, curb, bottom rail and top rail. The opening made for accommodating the skylight is fully treated by lead flashing, so as to ensure complete water proofing of the roof surrounding the opening. The sketch of the skylight is shown in Fig. 19·27.

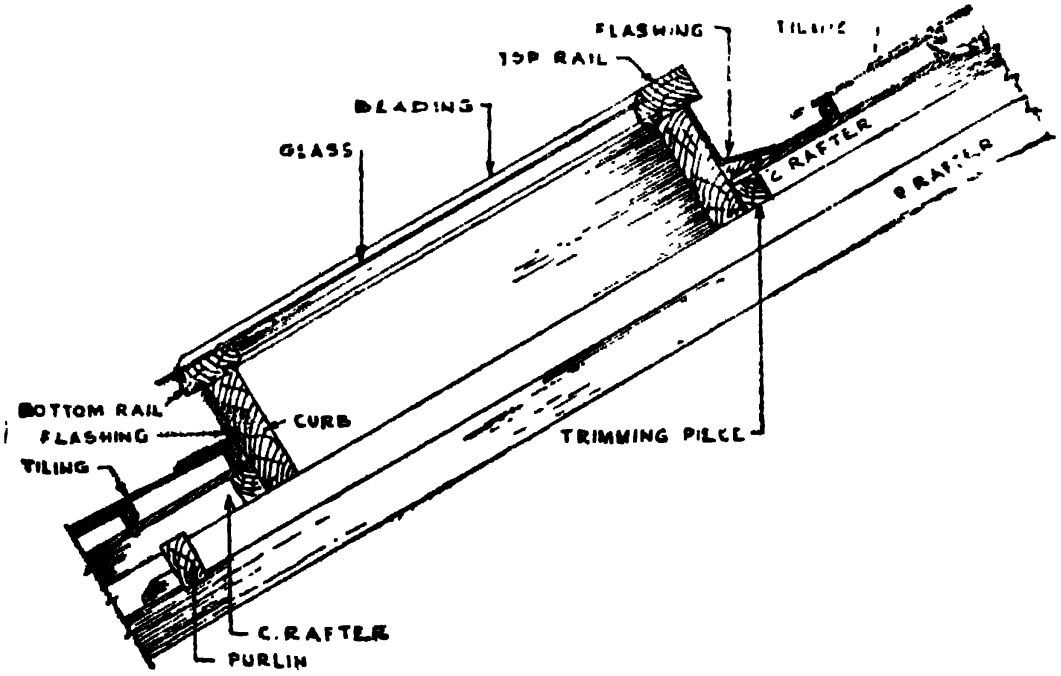
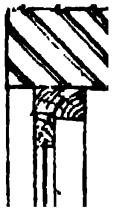


Fig. 19·27
Sectional elevation of a skylight

19·24 Corner Window. As the name suggests, this type of window is essentially provided in the corner of a room. The sectional plan of a corner window is shown in Fig. 19·28.



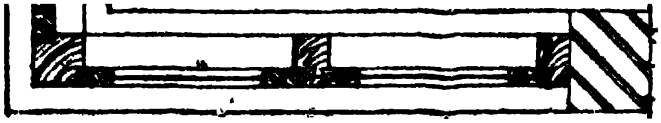


Fig. 19·28
Sectional plan of a corner window

19·25. Metal Windows. Metals like steel, bronze and aluminium are now-a-days generally used for the construction of metal windows. Bronze or aluminium windows can be made in any desired shape to suit the choice of the architect. On account of the

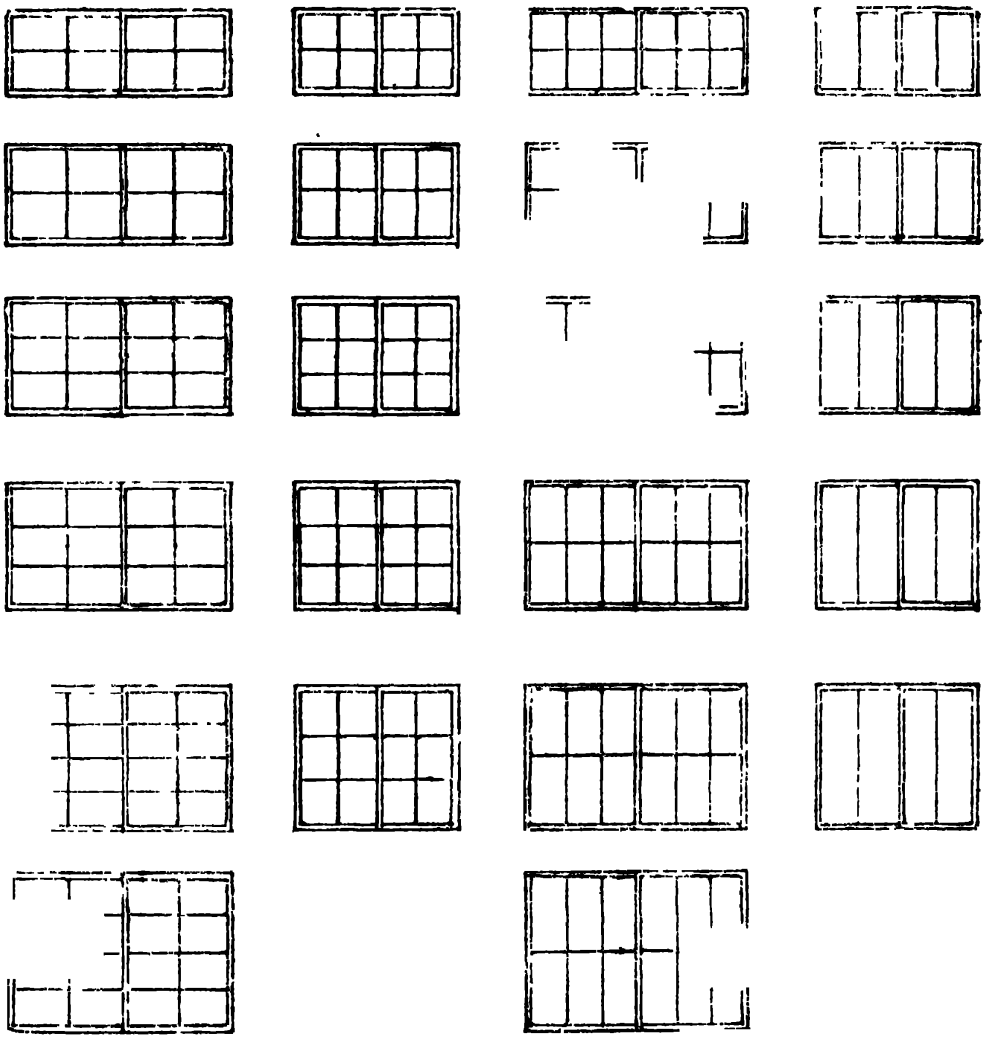


Fig. 19·29

Elevations of various types of steel windows

high cost of material, the usage of bronze and aluminium windows is restricted to important works only. Mild steel windows on the other hand are much less costlier and are extremely used. As a measure of economy, the manufacturers fabricate steel windows in a wide range of standard sections from which the windows of the required design can be made. These windows can be directly fixed in the reveals of the opening or they may be housed in the wooden frame.

In order that the windows may not be subjected to any structural loads, they are only fitted when the masonry work has been completed and the lintel above the opening provided. To accommo-

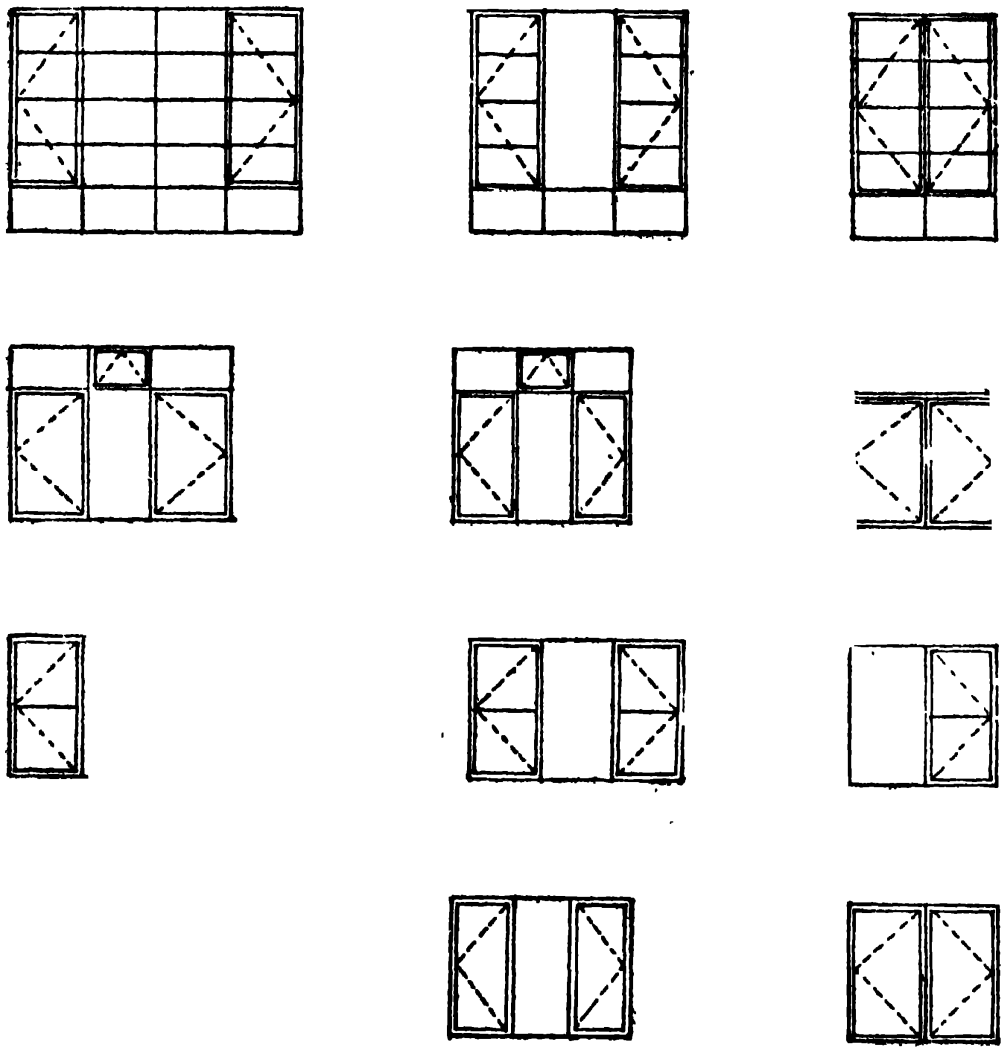


Fig. 19·30
Elevations of various types of steel windows

date slight settlement of the masonry above, which may be due to weather changes, ample clearance is maintained in the joint in the height of jambs.

19 26 Types of Steel Windows. Steel windows may be divided into various types mentioned below. The windows differ in shape and form by virtue of the method by which they are operated. Steel windows may be broadly divided in the following different types :

(*i*) *Pivoted windows.*
(*ii*) *Projected windows.*
(*iii*) *Horizontal rolling windows.*

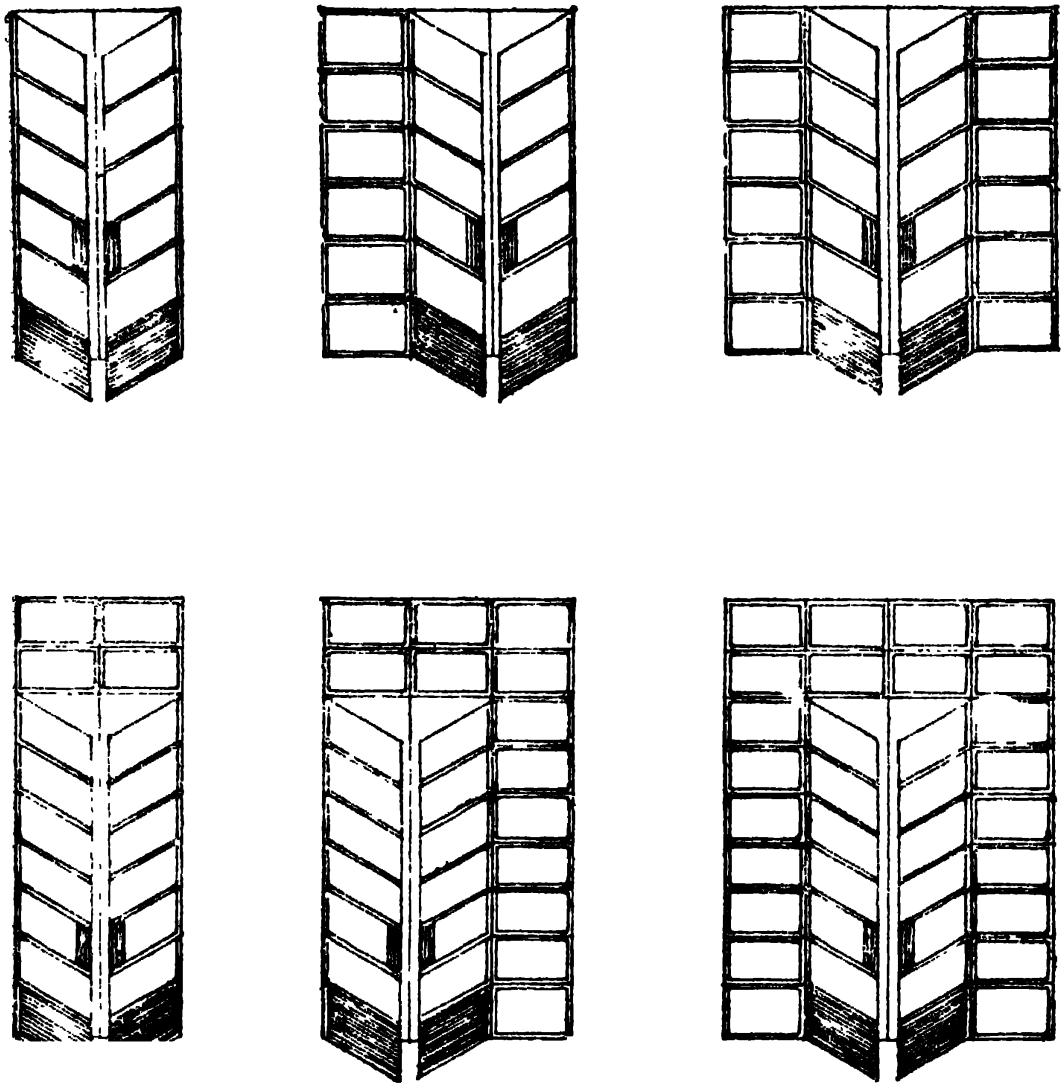


Fig. 19·31

Elevation of various types of steel windows

(*i*) *Pivoted Window* : In this form of window, smaller units are assembled to form one unit to act as a ventilator. The window may be top pivoted, vertically pivoted or horizontally pivoted.

(*ii*) *Projected Window* : This window is formed by uniting smaller units in such a way that some area of the window may be operated as a ventilator. which may be able to project inside or outside the fixed units of window.

(*iii*) *Horizontal Rolling Window* : As the name suggests, in this type of window provision is made for the window to roll either to the left or to the right of the opening.

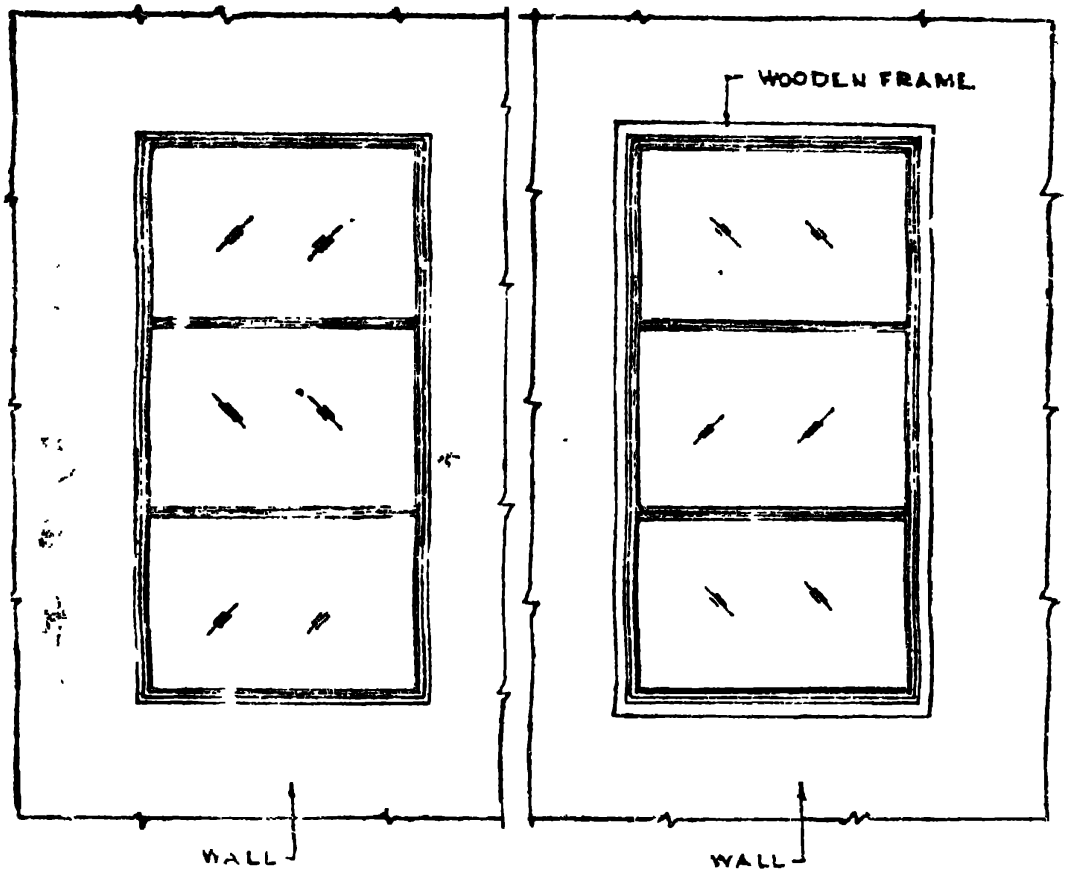


Fig. 19·32 Elevation showing metal window fixed direct to the wall of the opening

Fig. 19·33 Elevation showing metal window fixed in a wooden frame fixed in wall

19 27 Fixing of Steel Windows. Steel windows may be fixed in a wooden frame fitted in the opening or it may be directly fixed in the opening in brick or stone masonry, R.C.C. or steel work. The opening may be flushed or rebated. The window unit is never built as the work proceeds, but it is always fitted in a completed opening left in the wall. In case the window frame is to be fitted directly in brick or hollow concrete block masonry, the position of fixing holes is marked on the jambs and the masonry holes are cut and fixed with lugs. In case of reinforced concrete or structural steel work, the holes for fixing the window frame are already left in their correct position in the opening. When the window is to be fitted in a wooden frame, the wooden frame is rebated to receive the steel window. The steel frame is set in the opening using wooden wedges and fixed to the wooden frame with galvanized screws. In case where the window is to be fitted to the masonry opening without wooden frame, the steel window frame is fitted tight in the lugs fitted in the holes made in the opening.

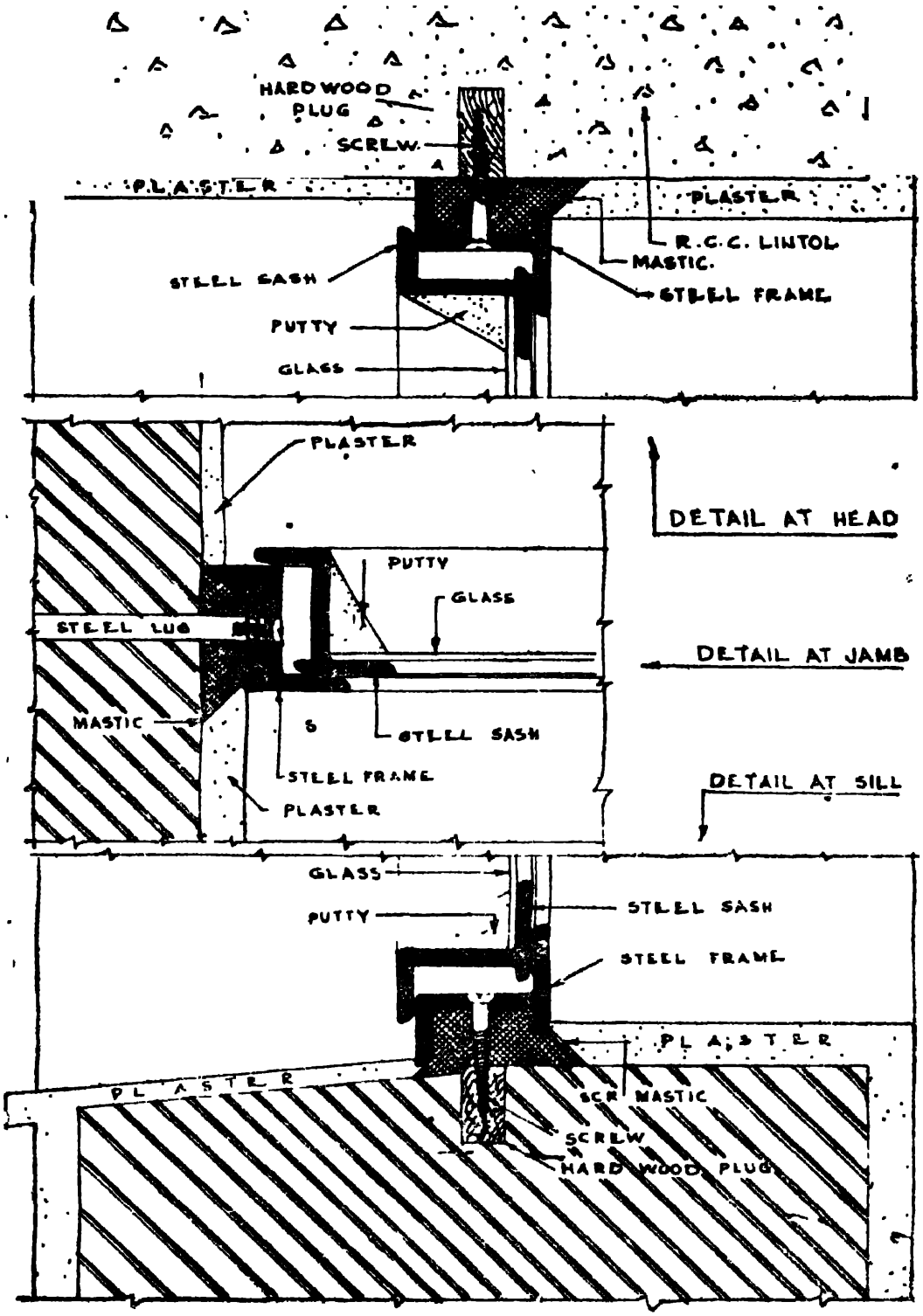


Fig. 19·34

Fixing details of window shown in Fig. 19·32

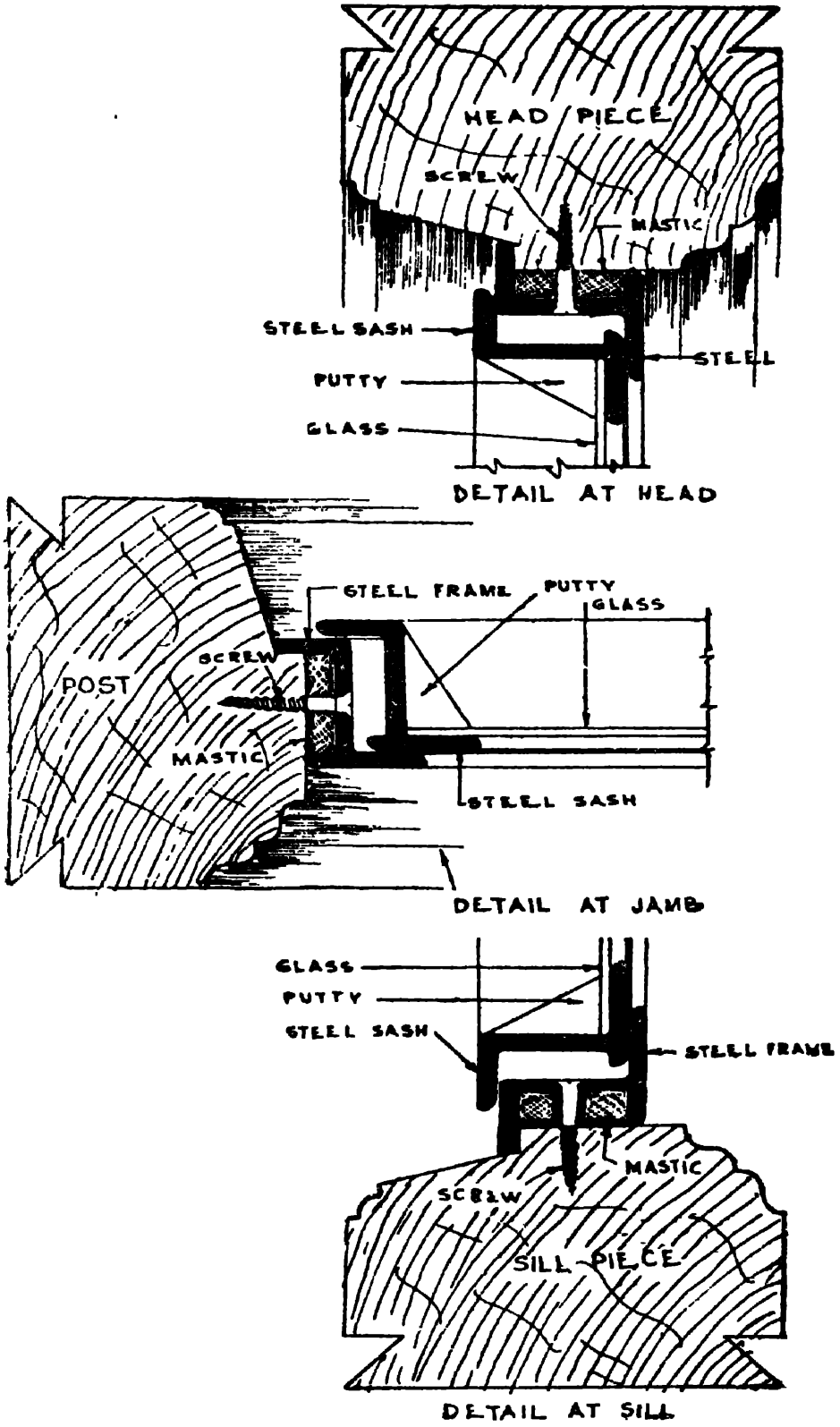


Fig. 19·35

Fixing details of window shown in Fig. 19·33

19·28. Advantagee of Steel Windows

1. The cost of maintenance is nil.
2. They are durable.
3. Their elegant show and streamlined finishing make them superior to wooden windows.

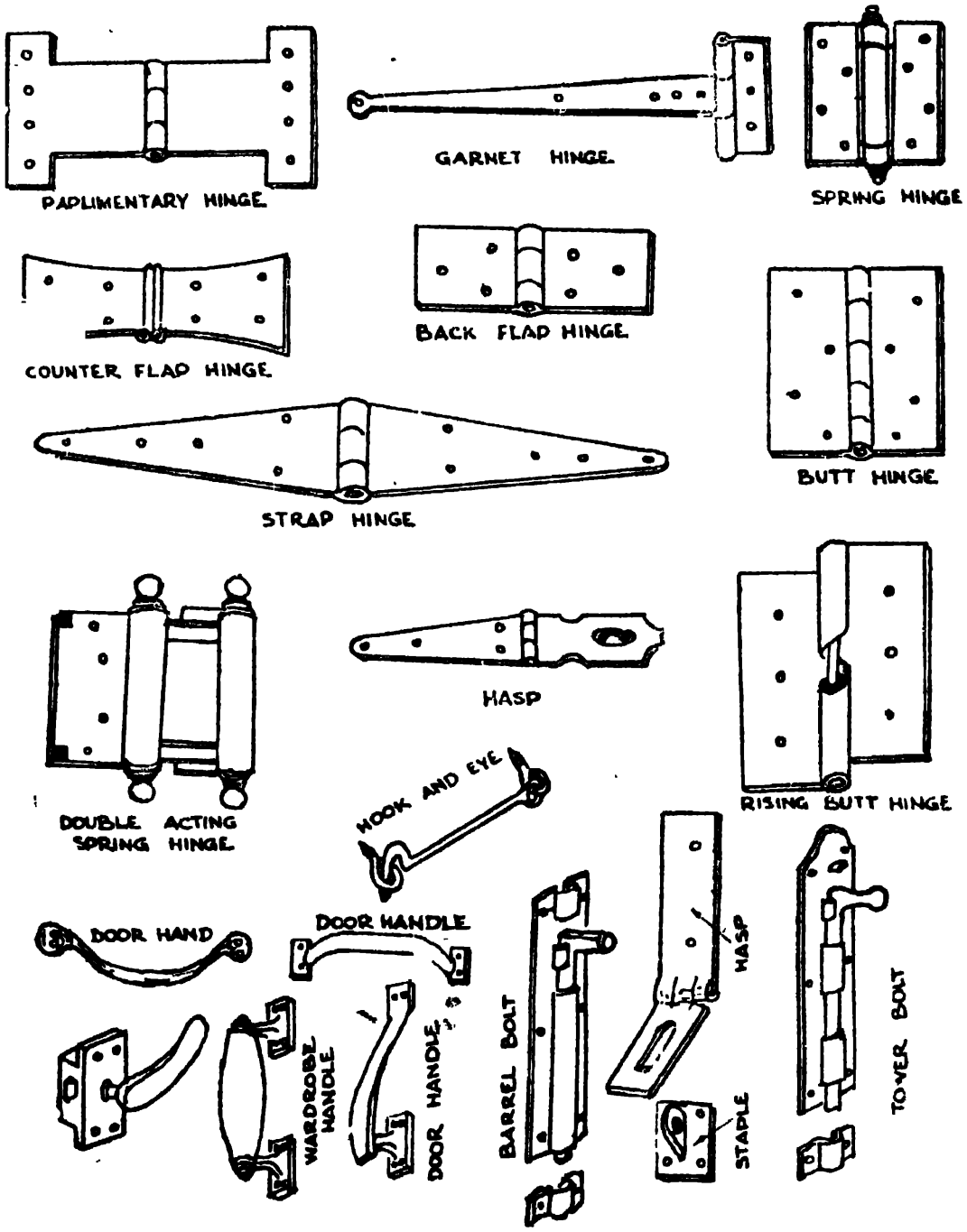


Fig. 19·36

Fixtures and fastening for doors and windows

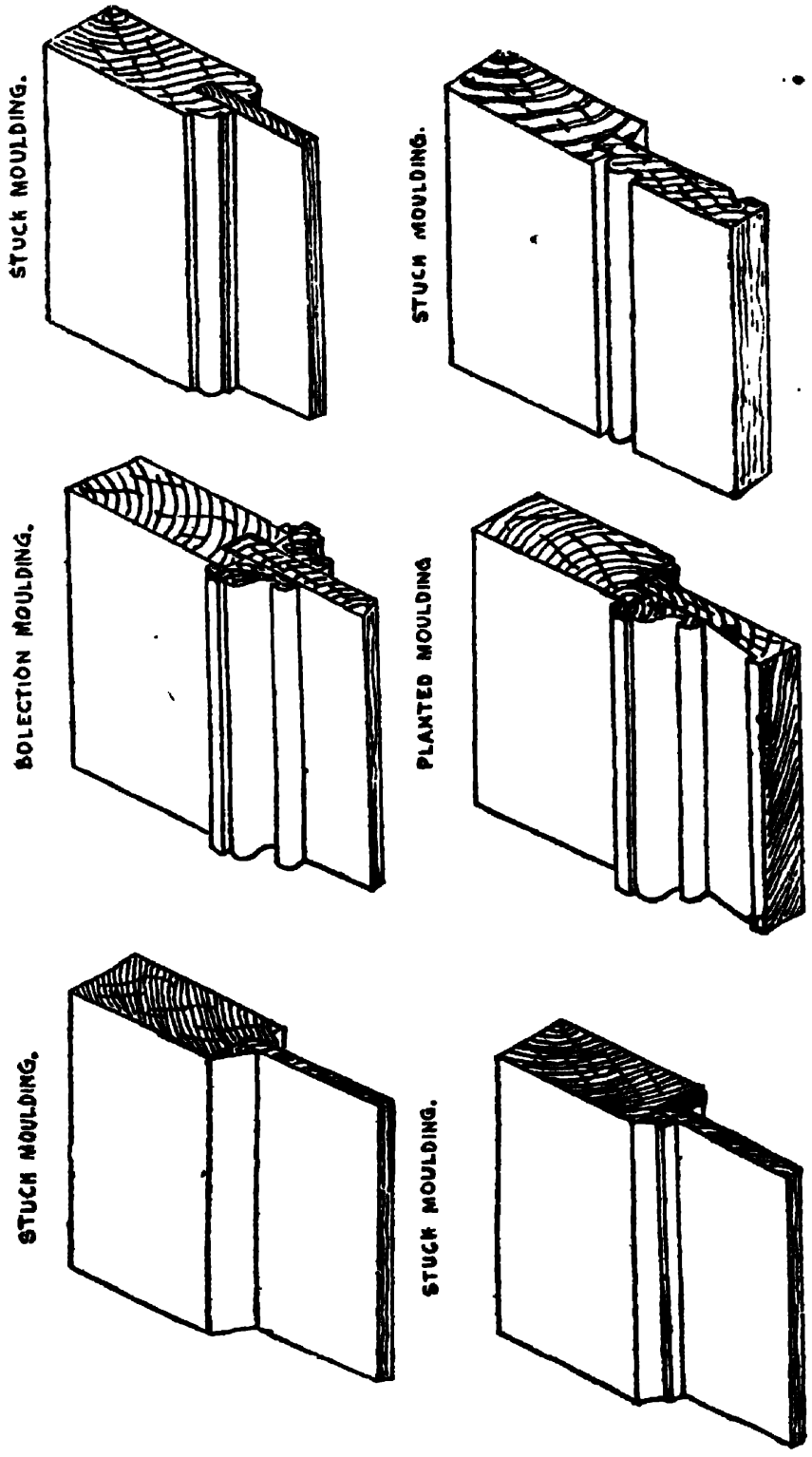


Fig. 19·37

Various forms of moulding

4. Weather does not have any adverse effect on steel windows and unlike wooden windows they are not subjected to expansion and contraction of joints.

5. When subjected to alternate dry and wet conditions, the steel windows do not decay and are proof against attacks by white ants.

6. They are free from hazard of fire.

7. For providing fixed glazed area in a room, size of the opening can be reduced by providing steel windows without reducing the area for light and ventilation.

Fixtures and fastenings for doors and windows. The various fixtures and fastenings used in the doors and windows are shown in Fig. 19·36. Some of the important fixtures are briefly described below.

Hinges. The various types of hinges used in the works are: butt hinge, T-hinge or cross-garnet, rising butt hinge, strap hinge etc. They are used for securing the door or window leaf to the frame.

Fastenings and locks. The various types of bolts used as fastenings are : tower bolt, barrel bolt, flush bolt, aldrop bolt etc.

Moulding. It consists in enhancing the appearance of a plane surface by forming various types of curves or patterns on the surface. The various forms of mouldings have been shown in the Fig. 19·37.

Questions for Revision

1. Give full details of construction with neat sketches of a corner window of a bed room measuring 6·1 m.×4·9 m.×4·6 m. high with 38 m. thick wall on all sides. The window is to be glazed with venetian.

2. (*a*) Draw a neat dimensioned sketch showing plan, elevation and section of a door 2/3 glazed and 1/3 panelled to fit in an opening 2·29 m.×1·22 m in the wall. Assume all necessary and reasonable particulars.

(*b*) Draw the sketches of the following types of doors and windows and state where they are generally used :

(*i*) Ledged and braced doors
(*ii*) Louvered windows
(*iii*) Flush doors
(*iv*) Sky-lights.

3. Write short notes on the following with suitable sketches wherever necessary :

(*i*) Door frame
(*ii*) Dormer windows
(*iii*) Rolling shutters

(*iv*) Swing doors

(*v*) Clere-storey windows

(*vi*) Panelled doors.

4. What are ventilators and where are they placed ? Describe with sketches the different types of ventilators used in buildings.

5. Draw to full scale plan, elevation and section of a window with fanlight suitable for a bed room. The window is 1·83 m wide and 1·8 m high in a wall 30 cm. thick. Give three half full size details to explain the construction.

6. Describe with neat sketches any five of the following :

(*i*) Battened and ledged doors

(*ii*) Battened, ledged and braced doors

(*iii*) Framed and braced doors

(*iv*) Framed and panelled doors

(*v*) Glazed and sash doors

(*vi*) Rolling shutters

(*vii*) Revolving shutters

(*viii*) Collapsible steel doors.

7. Design a wooden window fully glazed for a hospital building, 3 m. wide and 1·83 m. high with shutters side-hung 1·22 m. high and ventilators 60 cm. high centrally pivoted. Draw sketches of the cross-section showing dimensions of members and their names. Describe by sketches details of joinery.

8. Write short notes on the following with suitable sketches wherever necessary :

(*i*) Windows

(*ii*) Sashes

(*iii*) Fanlights

(*iv*) Venetian shutters

(*v*) Bay windows

(*vi*) Clere-storey windows.

9. Draw to 1 m. scale, plan, elevation and section of a French window opening out of a bed room on to an open terrace. The size of the opening is 2·4 m. × 1·52 m. and the wall thickness is 30 cm. The bedroom floor is 3 cm higher than the terrace to prevent water getting in. Give full size detail through head, jambs and bottom rails of French window.

10. Draw sketches to show the fixing arrangement of metal windows to wooden frames or metallic sub-frame. Sketch the various standard shapes of the windows manufactured in India these days.

11. Draw to 1 : 100 scale, the plan, elevation and section of a door suitable for the front entrance of a cottage. The door is 1·22 m. × 2·13 m. Give three half full size details to explain the construction.

12. Write short notes and give suitable sketches for any four of the following and mention where they are used in the building :

(*a*) Barrel bolts

(*b*) Venetian shutters

(*c*) Glass bricks

(*d*) Collapsible steel gates

(*e*) Rolling shutter.

13. What are the special types of doors and windows used in modern public buildings ?

Neatly sketch a wooden door one-third panelled and two third glazed, the size of the door being 2·29 m. × 2·13 m.

14. What do you understand by seasoned timber ? Describe common defects in wood work in chowkhats and shutters and state what precautions you will take to avoid them.

Give a sketch showing fixing of a door 'chawkhat' in the wall.

15. Draw to a suitable scale an entrance teak wood door 1·22 m. wide and 2·44 m. high, in a 60 cm. thick wall with stone facing and brick backing and with yellow basalt cut-stone steps. The height of the first-floor is 3·35 m. Draw little more than half the plan, elevation and cross-section through the doorway.

16. Draw neat sketches to illustrate a 4 cm. thick fully penelled door to fit into an opening 210 cm. by 120 cm. and the method of fixing it in or 1½ brick wall. Name the different parts of the door. Show details of any one of the canpentry joints.

20

Roofs and Roof Coverings

20·1 Definition. Roof is a covering comprising of roofing material supported on structural member, which is provided over the top of a building or other similar structure. Its function is to protect the building from the effect of rain, sun and wind. In selecting a roof for a structure, in addition to the weather effects. due consideration is paid to the length of span, weight of the roof itself, heat insulation, lighting and ventilation, etc.

20·2 Types of Roof. There are two main types of roofs used in modern construction, namely, pitched or sloping roof and flat roofs. These types will be dealt with separately in this chapter.

20·3 Pitched Roof. It is the most common form of roof and is generally regarded as the cheapest alternative for covering a structure. Pitched roofs are almost always constructed in wood or steel. Steel pitched roofs have been described in the chapter "Structural Steel Works". Wooden pitched roof consists of a system of joists, rafters and purlins arranged in the form of a triangular-shaped support known as truss. The lower ends of the rafters rest upon the wall plates and at their upper end they are connected to a common ridge piece.

The slope of the roof varies according to the span, the climatic conditions of the site, the nature of the covering material and other similar factors.

20·4 Technical Terms. The various technical terms used in timber pitched roof construction are given below :

(1) *Span* : The clear distance between the supports of an arch, beam or roof truss.

(2) *Rise of Roof* : It is the vertical distance between the wall plate and the top of the ridge.

(3) *Pitch of Roof* : The inclination of the sides of a roof to the horizontal is termed as the "pitch of the roof".

(4) *Eaves* : The lower edge of the inclined roof surface of a pitched roof is termed as eaves.

(5) *Ridge* : It may be defined as the apex of the angle formed by the termination of the inclined surfaces at the top of a slope.

(6) *Ridge Piece, Ridge Beam or a Ridge Board* : It is a horizontal timber piece provided at the apex of a roof truss. The common rafters are fixed to this piece and are supported by it.

(7) *Valley* : It is the acute angle or a gutter formed by the intersection of two slopes in a pitched roof.

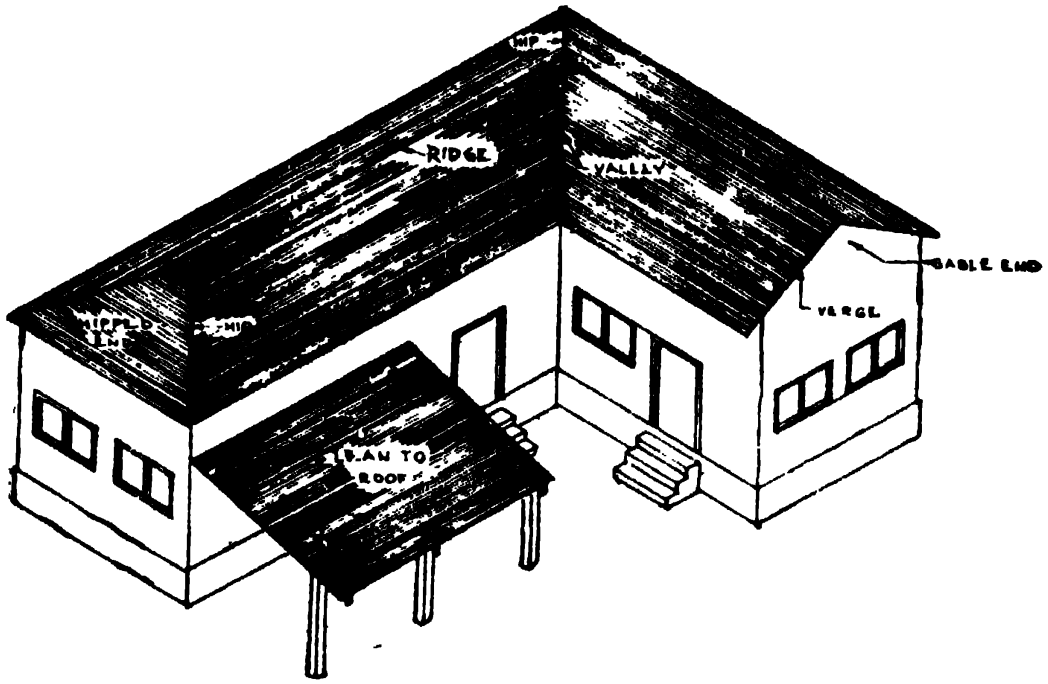


Fig. 20·1

(8) *Hip* : It is a ridge formed by the intersection of two sloped surfaces having an exterior angle greater than 180°.

(9) *Hipped end* : It is a sloped triangular surface formed at the end of a roof.

(10) *Gable* : It is the triangular portion of the end wall of a sloped roof, formed by continuing the end wall up within the roof. Thus the gable end has two slopes with ridge in between.

(11) *Verge* : The edge of sheets, slates or tiles, projecting beyond the gable end of the sloped roof.

(12) *Barge Board* : It is a timber board used to hold the common rafter forming verge.

(13) *Eaves Board or Facia Board* : It is a wooden plank usually 25 mm. thick and 15 cm. wide fixed along the eaves connecting the feet of the common rafters.

(14) *Common Rafters* : These are inclined wooden members laid from the ridge to the eaves. They are bevelled against the ridge piece at the head and are fixed to the purlins at intermediate points. They are usually spaced 30 to 45 cm. apart.

(15) *Purlins* : These are horizontal members of wood or steel, used to support common rafters.

(16) *Cleats* : These are short sections of wood or steel, nailed, screwed or bolted to the rafters of the truss for supporting purlins.

(17) *Wall Plates* : Timber pieces, which are provided over the top of a stone or brick wall for the purposes of fixing the feet of the common rafters.

(18) *Templat*e : This is a block of stone or masonry provided under the end of tie beam to spread the load from the roof over a larger area of bearing.

(19) *Hip Rafters* : These are the rafters which form the hip of a sloped roof. These rafters run from the ridge to the corners of the walls to support the covering over the hip. They also receive the end of purlins and jack rafters.

(20) *Jack Rafters* : These are rafters shorter in length which extend from hip or valley to the eaves.

(21) *Valley Rafters* : These are the rafters provided at slope to support the valley gutters.

(22) *Post Plate* : This is similar to a wall plate with the only difference that it is run continuous, parallel to the face of wall, over posts and supports the rafters at their feet.

(23) *Battens* : Small scantlings which are nailed to the rafters for laying tiles, over the sloped roof.

(24) *Boardings* : These act similar to battens and are nailed to the common rafters for laying roofing material above it.

The various types of pitched roofs are described below :

20·5 Lean to Roof. It is the simplest type of pitched roof consisting of rafters sloping on one side only. At their upper ends the rafters are nailed to the wooden wall plates, placed on corbel which may be of stone, brick or steel. The lower end of the rafters is notched and nailed to the wooden post plate. The post plate consists of a timber section running parallel to the wall and supported by posts which may be of wood, brick or stone at intermediate points. Battens spaced at 15 cm. centre to centre are nailed to the inclined rafter and upon this the covering material is laid. The

span for lean to roof is restricted to 2·44 m. and as such it is commonly used for covering verandahs, out-houses, sheds, etc.

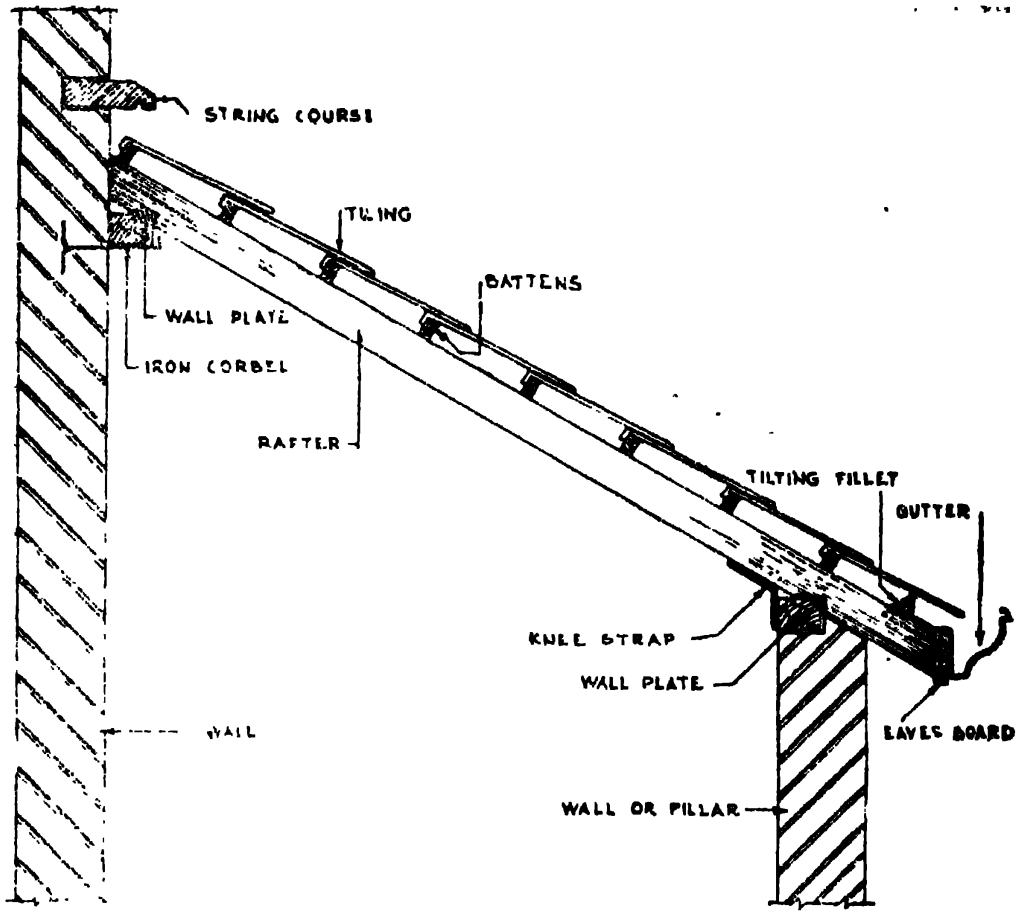


Fig 20·2

Lean to roof

20·6 Coupled Roof. Coupled roof is formed by a pair of inclined rafters with their upper ends nailed to a common ridge piece

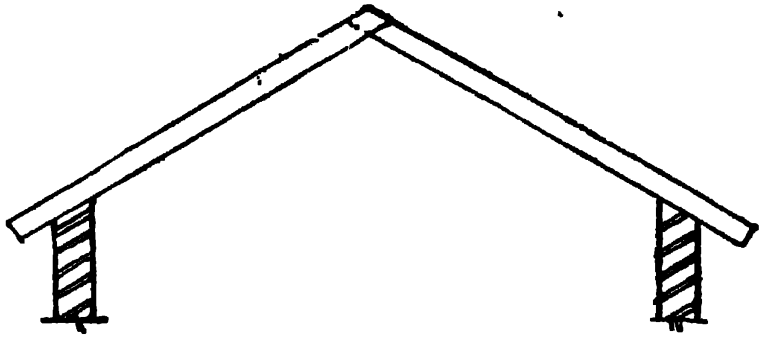
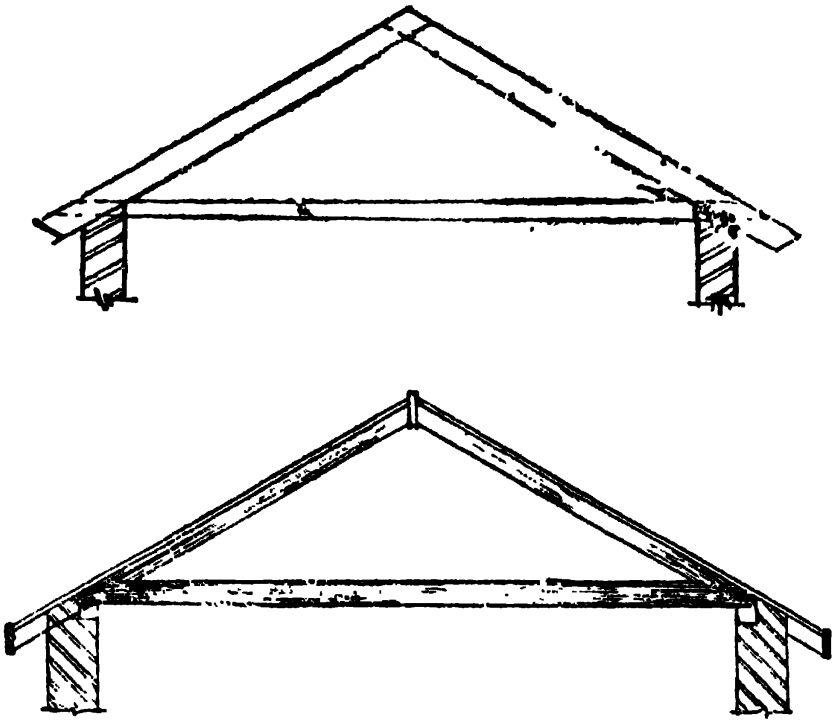


Fig. 20·3

Coupled roof

and their lower ends, notched and nailed to the wooden wall plates embedded in masonry on the top of the walls on either end. The rafters are spaced at suitable intervals and the battens are nailed on their top. Upon the frame work thus prepared roof covering is laid. This type of construction is suitable for spans upto 3·66 m. where the loading conditions are of ordinary nature.

20·7 Couple-close Roof. In a coupled roof the notch provided at the feet of the rafters prevent them from spreading. If the



Figs. 20·4—20·5
Different forms of couple-closed roof

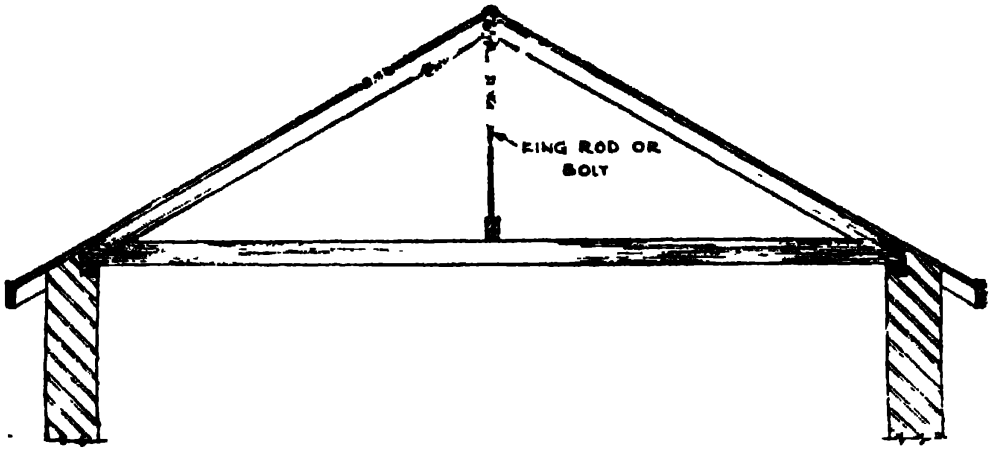
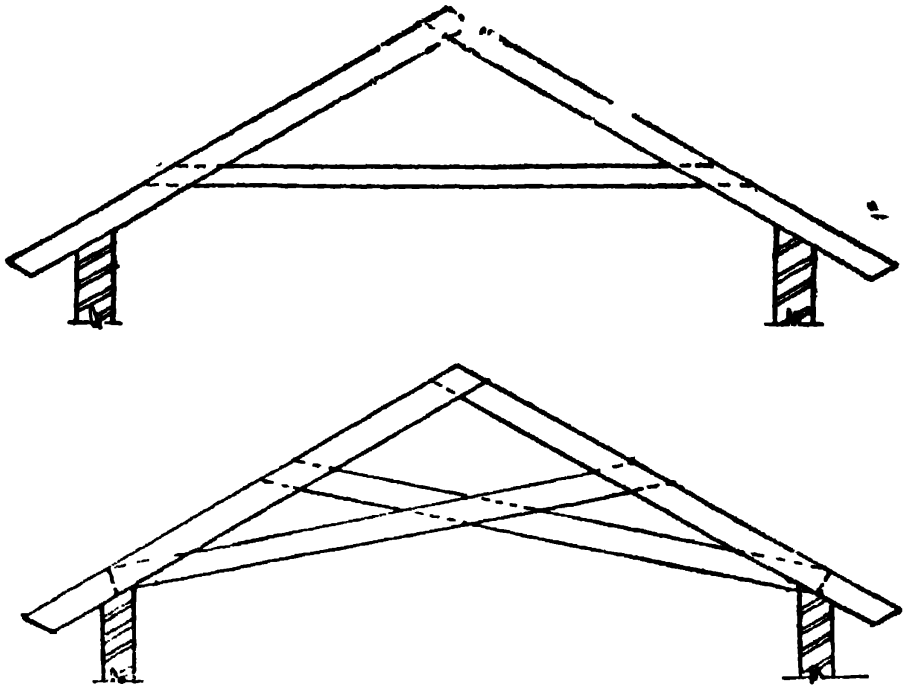


Fig. 20·6
Couple-closed roof with a king rod

span of the roof is increased or the loading on the truss is increased gradually, it will be found that at a certain stage the notch will be incapable of resisting the thrust at the end of the rafters and the roof will collapse. Thus, to prevent this, the feet of the rafters are jointed by a tie, which, by holding them in position, prevents them from spreading and thrusting out of the wall. This is called a couple closed roof. With ordinary loading conditions this type of roof can be used upto 5 m. span. For increased spans a vertical rod is introduced between the ridge piece and the centre of the tie. This rod is termed as king rod and its function is to prevent the tie from sagging.

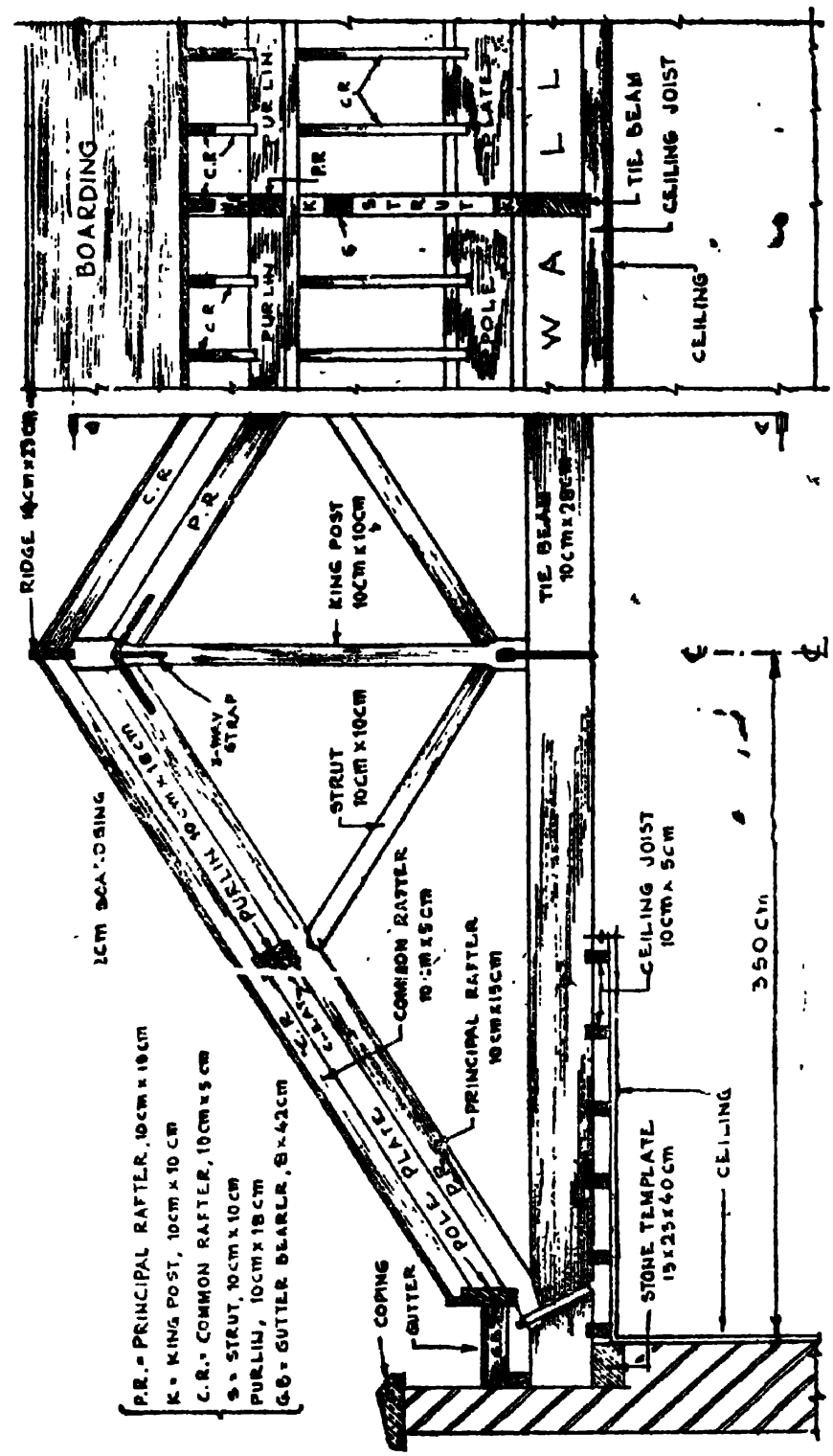


Figs. 20·7—20·8

Collar and scissors roof

20·8 Collar Roof. With excessive loading conditions or increased spans the rafter of the couple closed roof tends to bend in the middle. This defect is overcome by fixing the tie near the middle of the rafters. This is called collar roof. Thus collar roof is similar to couple-closed roof with the only difference that the tie instead of being placed at feet of the rafters is raised up. The tie in collar roof is termed as a collar beam. In this type of roof a part of the roof space can be utilised, as the ceiling can be attached to the collar beams and the exposed faces of the rafters.

20·9 Scissors Roof. As the name suggests the roof is shaped so as to have the appearance of a scissors. It is similar in function to collar roof. The truss has been shown in Fig. 20 8.



Figs. 20·9—20·10
King post roof truss

20·10 King Post Roof Truss. It is a form of roof truss which is commonly used for spans varying from 5 m. to 9 m. It consists of a frame work, comprising of two principle rafters, one tie-beam, two struts and a king post. The trusses are spaced not more than 3 m. centre to centre.

The trusses are connected to each other through purlins which are placed at right angles to the sloped rafters and are secured to them through cogged joints and cleats. The purlins also support the common rafters upon which roof covering is laid. In order to distribute the concentrated load due to the truss at its end, templates or bed blocks of stone or concrete provided under the end of the beam bearing on the wall.

20·11 Jointing of King Post Truss

(*i*) *Joint between the principal rafter and tie-beam* : At the feet, the principal rafter is jointed to the beam by a "Single abutment end

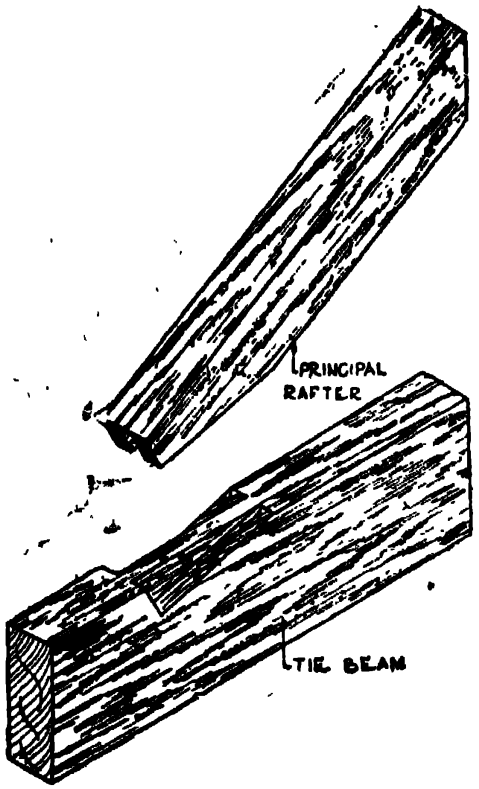


Fig. 20·11

Joint between the principal rafter and tie-beam

tenon joint" or by a "bridle joint". In the former, the abutting end is made at right angles to the length of the rafter to ensure direct thrust. In bridle joint, the principal rafter is bridled over a tenon

formed on the tie-beam. The joint may be further strengthened by a wrought iron heel strap, wound round the joint. If it is necessary to lengthen the tie-beam, a scarf joint is used.

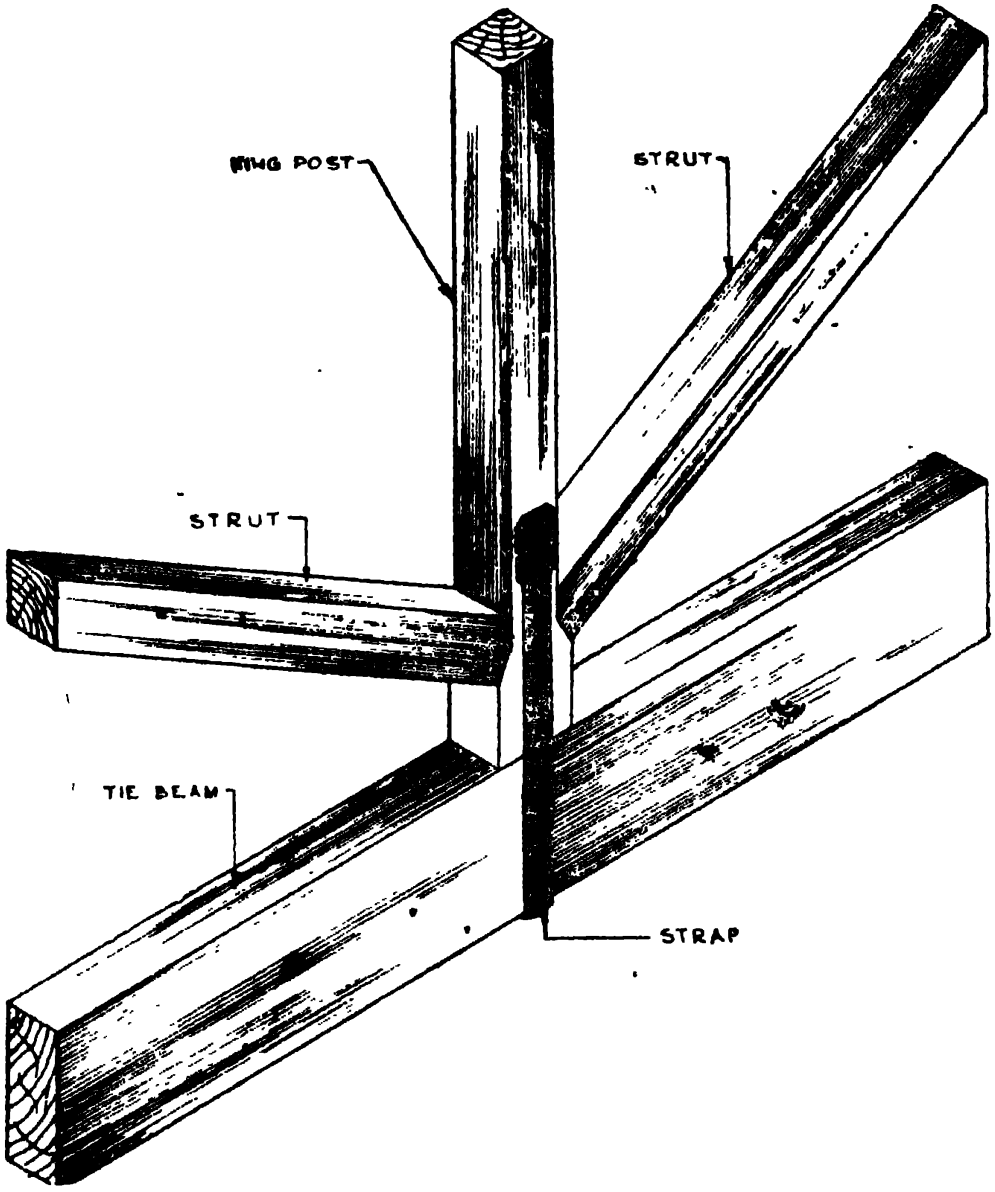


Fig. 20·12

View showing joint at the feet of king post

(*ii*) *Joint between the king post and tie-beam* : The king post is provided with splayed shoulders and feet and is tenoned into the tie-beam. The joint between the king post and the tie beam is further strengthened by wrought iron or mild steel strap. The stirrup strap is taken round the joint and is held up by metal pieces, clips and wedges termed as "gibs and cotters".

(*iii*) *Joint at the head and feet of rafter* : The foot of each strut is connected to the splayed foot of the king post, by an oblique mortise

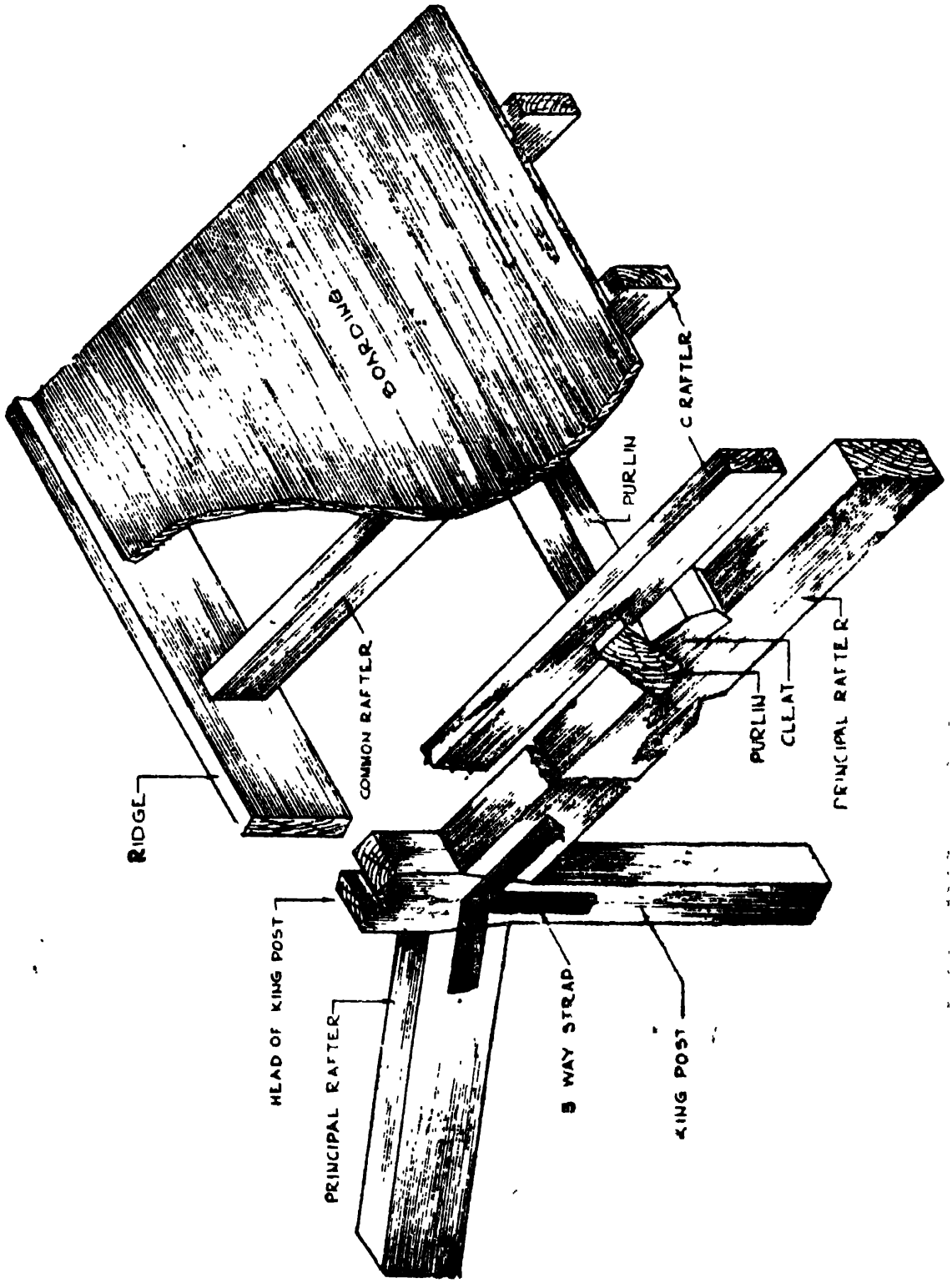


Fig. 20·13
Vicw showing joint at the head of the king point

and tenon joint. At their heads the struts are housed and tenoned (the shoulder abutment of the struts being cut to a vertical plane) in the principal rafters.

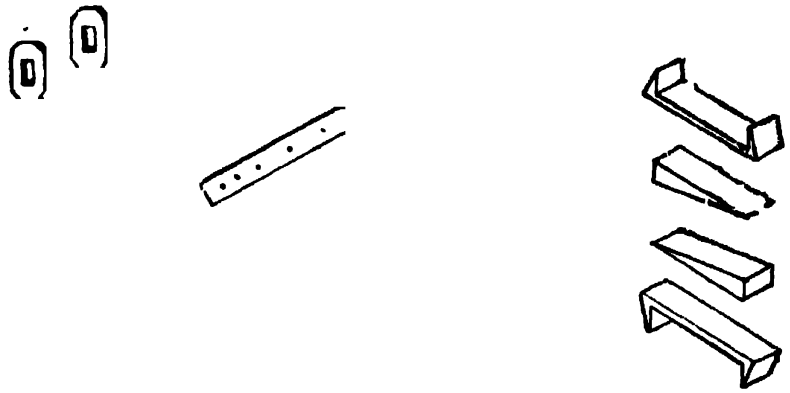


Fig. 20·14

Gibs Cotters and view of three-way strap

(*iv*) *Joint between the principal rafters and the king-post* : The principal rafters at their heads are housed in the splayed shoulders of

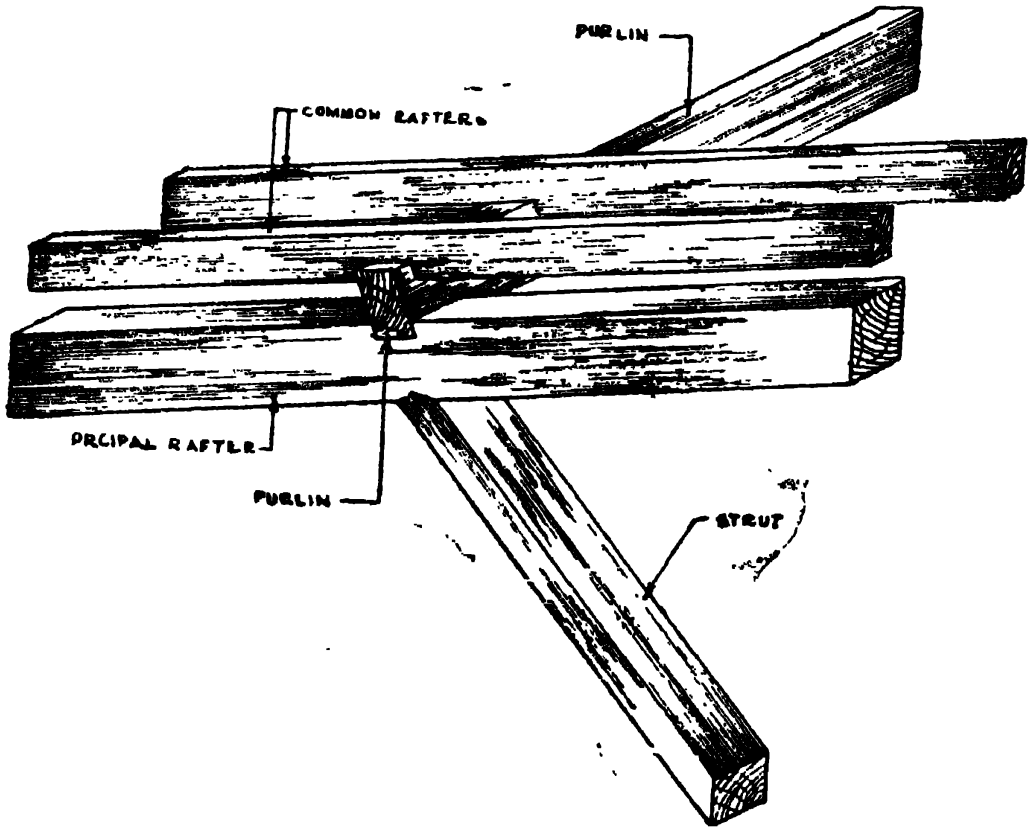


Fig. 20·15

Joint at purlin point (cleat is not shown in the sketch)

the king post. The joint is further strengthened by "three-way" straps bolted on each face of the frame.

20·12 Queen Post Truss. For spans greater than 9 m. and less than 14 m., queen post truss is commonly used in timber roof construction. It may be defined as frame-work consisting of two principal rafters, two queen posts, one straining beam, two inclined

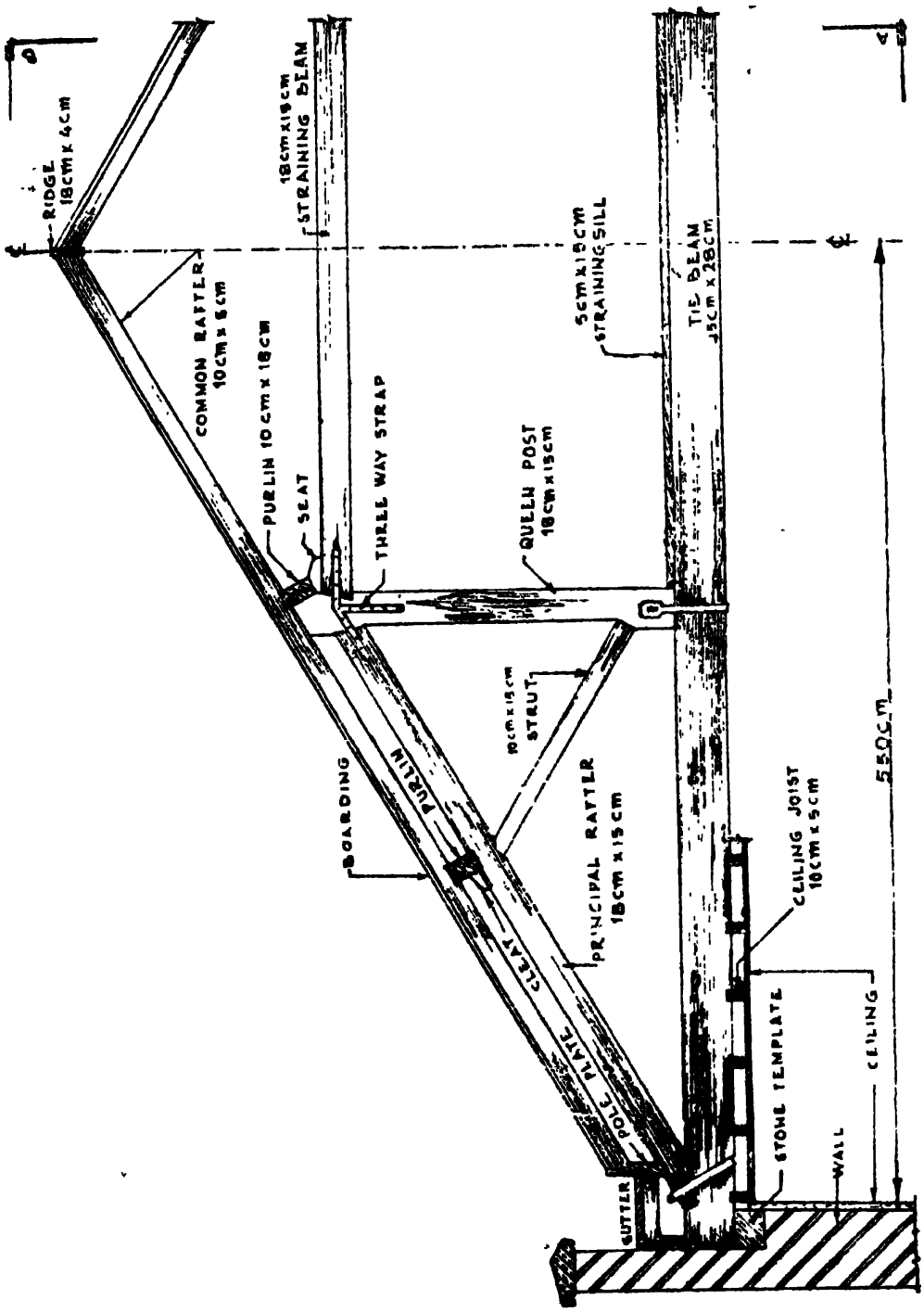


Fig. 20·16
Queen post truss

struts and a straining sill. It differs from the king-post truss in having two vertical tension members called queen posts. The heads of the queen posts are strutted apart by a horizonal member termed as straining beam. The straining beam receives the thrust from the head of the principal rafters and keeps the junction stable. The

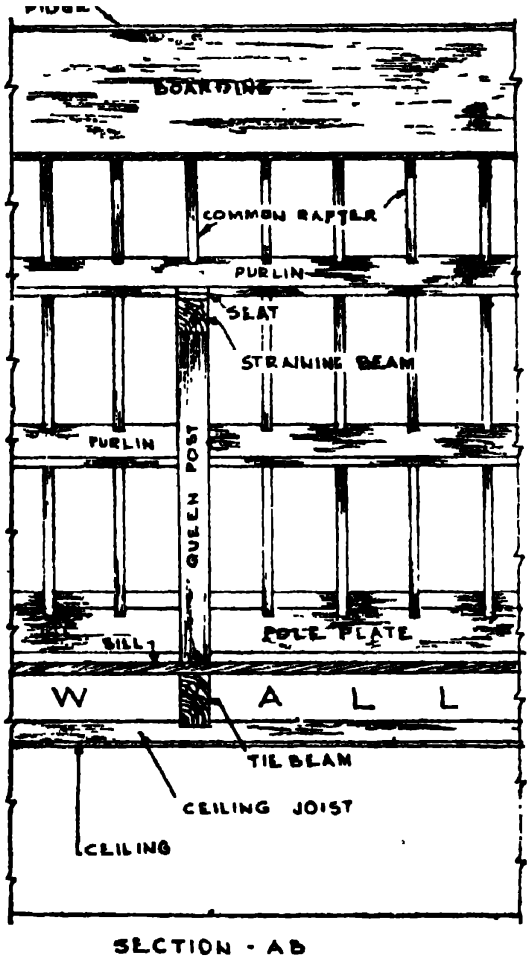


Fig. 20·17

queen posts have single splay shoulders at their feet to receive the struts. The thrusts from the two struts tend to force the feet of queen posts inwards which is combinedly resisted by the tension joint between the tie beam and the queen post feet and the straining sill fixed between feet of the queen posts.

The various joints in this truss are similar to that of a king post truss with the exception of joints at the head and feet of the queen post which have been described below.

(*i*) *Joint at the head of queen post* : This junction is formed by meeting of two compression members, *i.e.* principal rafter and the

straining beam and a tension member, *i.e.* the queen post. The head of the queen post is made wider to receive the two members. The head of the principal rafter and the end of the straining beam

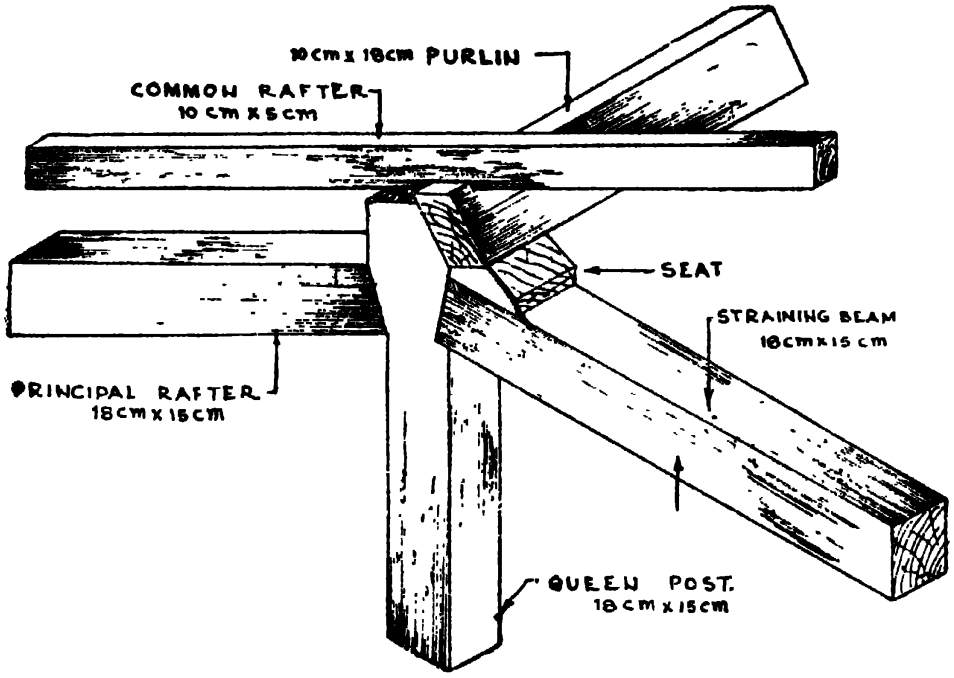


Fig. 20·18

View showing joint at the head of queen post

are tenoned into the widened head of the queen post. The joint is further strengthened by fixing a three-way, wrought iron or mild steel strap on each face of the joint.

(*ii*) *Joint at the feet of queen post* : The splayed shoulder of the queen post receives the tenon of the inclined strut forming a single abutment and tenon joint. The queen post itself tenons into the tie beam. This joint is further strengthened by wrought iron or mild steel stirrup strap held by gibs and cotters.

When it is desired to use wooden trusses beyond 14 m. span, the queen post truss is further modified by introducing one or more upright member called princesses. Diagonal bracing between the queen post and the ends of the tie beams is necessarily done as a rule. This type of frame-work is suitable for spans upto 18 m.

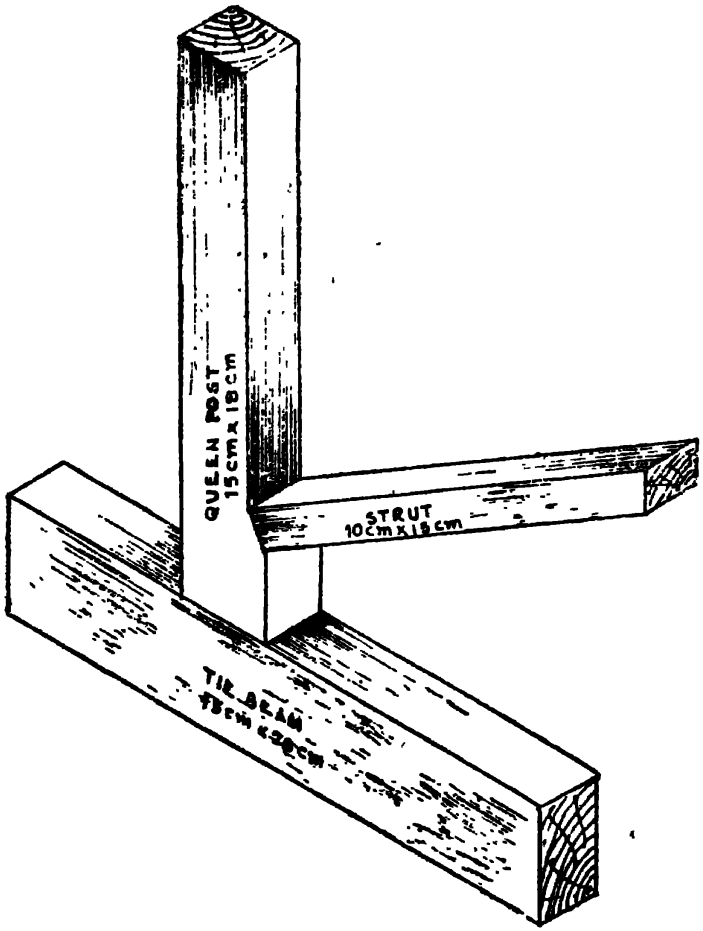


Fig. 20·19
View showing joint at the feet of queen post

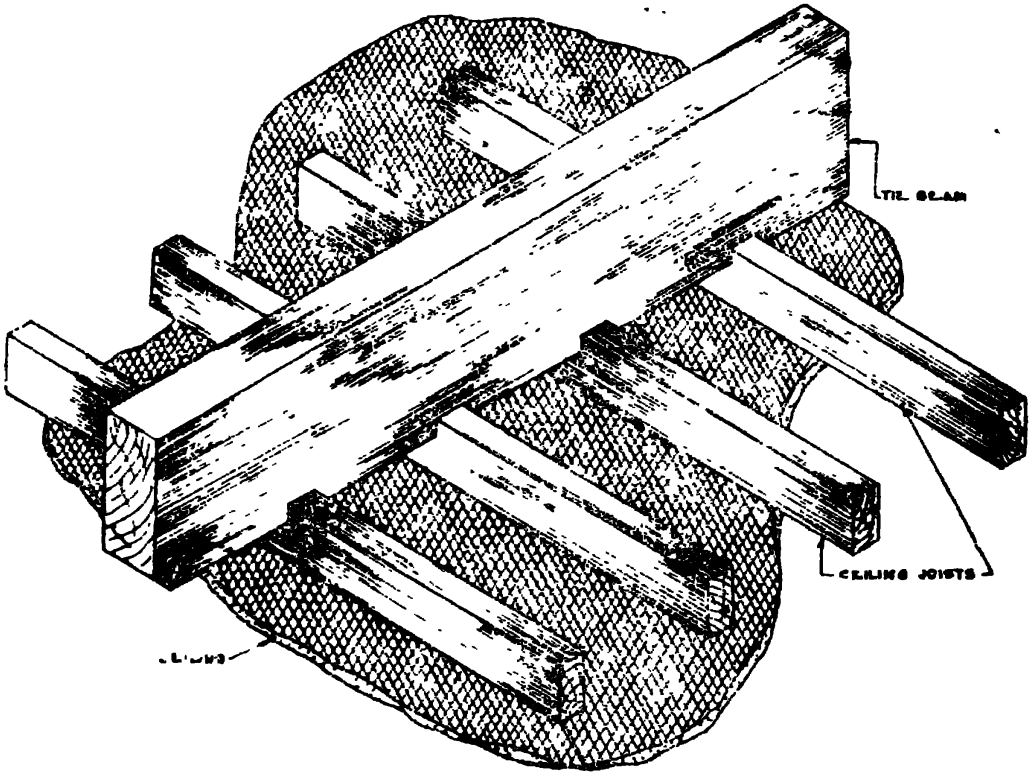
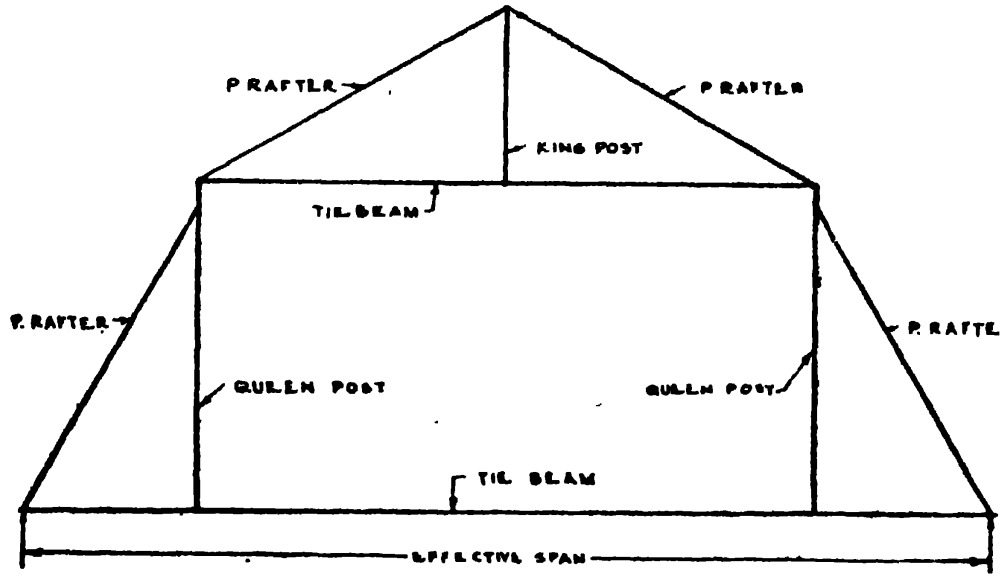


Fig. 20·20
View showing method of fixing ceiling to the tie beam of a truss

20·13 Mansard Truss. With the introduction of steel trusses, the Mansard roof truss is rarely constructed. The truss has two pitches, the lower varying from 60 to 70° and the upper from 30



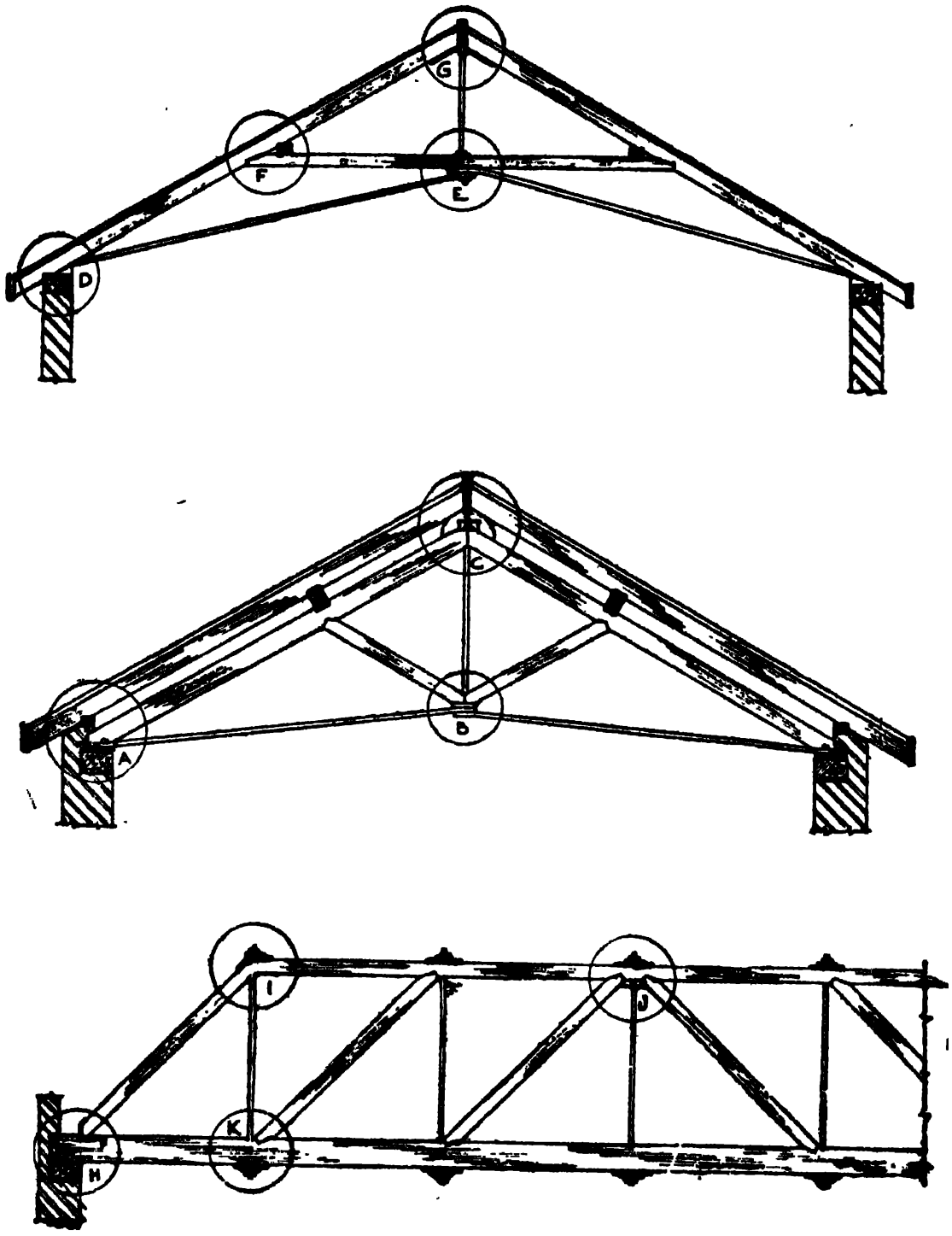
KEY ELEVATION OF
MANSARD ROOF TRUSS.

Fig. 20·21

to 40 °. This truss is more or less a combination of king post and queen post trusses. The upper truss is shaped exactly to a king post truss while the lower truss resembles queen post truss in all respects except that the vertical upright members which (may be called as queen posts) are placed almost near the end of the tie beam. This type of truss provides economy in space and cost, but beeause of its ungainly appearance, its use has become more or less obsolete these days.

20·14 Composite Roof Trusses. Trusses built with the combination of wood and steel are termed as composite trusses. In this combination, advantage is taken of the high tensile strength of steel. In the frame-work the tensional members are usually replaced by steel rods. The various types of composite trusses are shown in Figs. 20·22—20·24.

20·15 Flat Roofs. With the introduction of suitable building materials, flat roof construction has almost replaced the pitched roof type. Flat roofs may be constructed in reinforced concrete, flag stone supported on R.S.J., bricks, concrete or tiled arches etc. Although flat roofs are difficult to construct and expensive in cost,



Figs. 20·22—20·24

Different forms of composite roof trusses

yet keeping in view its various advantages flat roofs are commonly constructed these days.

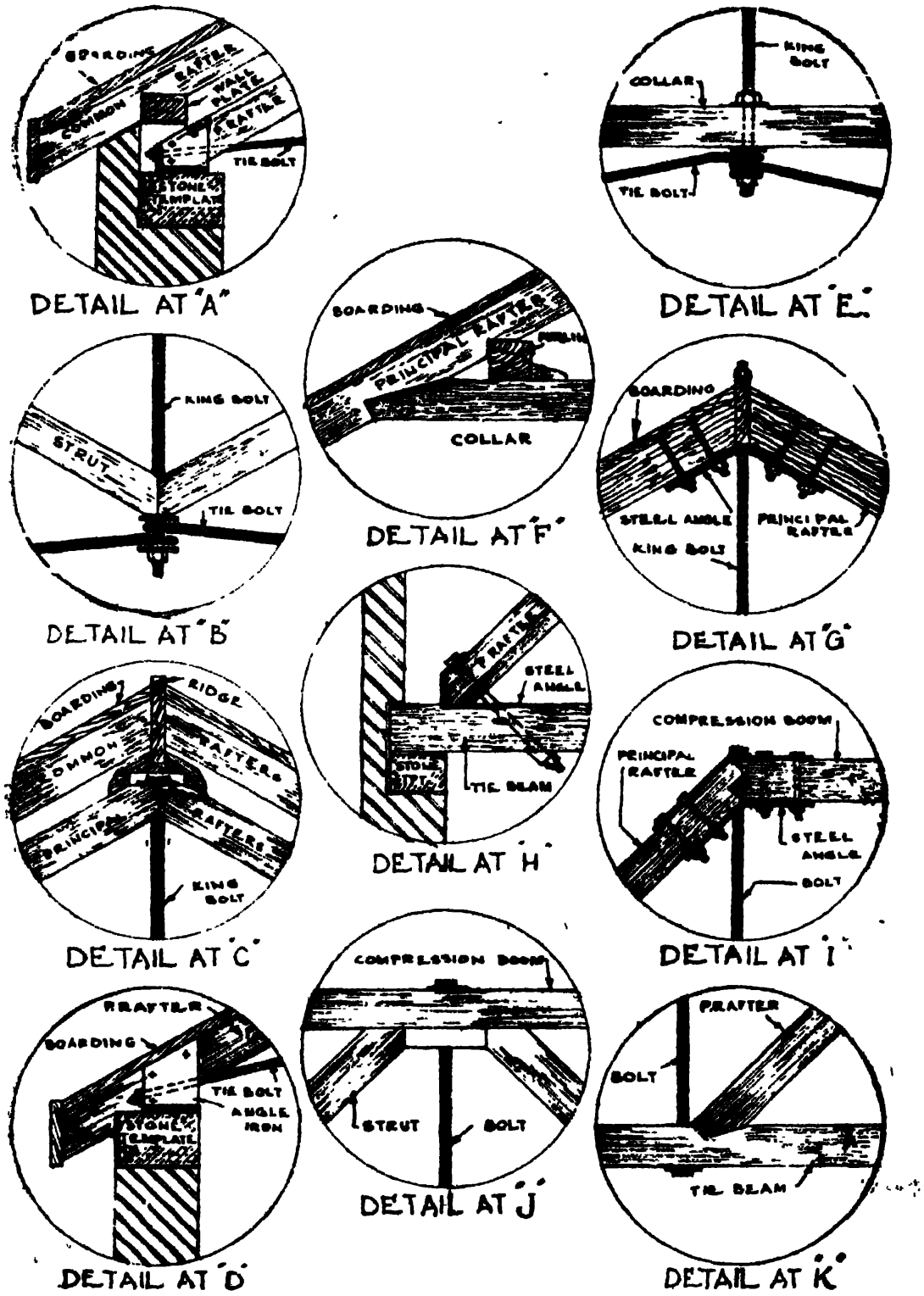


Fig. 20·25

Details of joints at various points of trusses shown in Figs. 20·22—20·24

Advantages of flat roof :

(1) The roof can be conveniently used as terrace for playing, gardening of sleeping purposes.

(2) It is easy to render flat roof fire resistant.

(3) It avoids the enclosure of the triangular space.

(4) It has good insulating properties.

(5) In this age of steel and reinforced concrete structures, the construction of flat roof is considered more simpler and architecturally suitable.

(6) In a multi-storeyed building, flat roof is considered to be the best choice.

(7) Pitched roofs require greater area of roofing material than flat roofs.

Disadvantages of flat roof ;

(1) Their span is restricted and as such they cannot be used for large spans without the introduction of intermediate columns and beams.

(2) Self-weight of the flat roof is considerable which makes the construction more expensive.

(3) Flat roofs are exposed to sun and are subjected to violent temperature changes, which may lead to cracks in the surface of the roof.

(4) The leak in a flat roof is difficult to trace and rectify.

(5) Its initial cost is much more than that of a pitched roof.

(6) Progress of construction of a flat roof is slow as compared with that of a pitched roof.

The different types of terrace roofing are described below :

20·16 Mud Terrace Roof. ·This type of roof is extensively used in places where rainfall is less. This is the cheapest form of roof terracing and is fairly water-tight. The terracing is made with white earth mud containing large percentage of sodium salts. The mud terrace roof commonly constructed in Punjab is described below.

The roof in this case consists of ⊥T-section 50 mm. × 50 mm. × 6 mm. spaced at 32 cm. centre to centre and supported on R.S.J. beam of the designed sections. The rolled steel joists, span along the width of the room and are spaced at suitable distance apart. Well burnt tiles measuring 30 cm. × 30 cm. × 5 cm. or 30 cm. × 15 cm. × 5 cm. are placed between the flanges of the T-sections.

and are set in lime mortar. A 15 cm. thick layer of stiff mud made from good white earth containing large percentage of sodium salt is then laid over the tiles. The layer is continuously beaten till the surface becomes hard and the beater rebounds when struck upon it. The surface is then plastered with mud cow-dung plaster and finally finished with cement cow-dung plaster 1 : 4 (1 cement : 4 cow-dung). To drain off rain water, the terracing is given a slope of 1 in 30.

In Maharashtra State and Madhya Pradesh, the mud terrace roofing is constructed as described below.

Teak wood boards 4 to 5 cm thick are nailed on the top of wooden joists of the designed section spanning along the width of the room. A 2·5 cm. layer of wood shaving is spread over the boards and covered with a layer of well-burnt bricks laid on edge and set in lime or mud mortar. This layer is further covered with a 8 to 10 cm. thick layer of mud which is beaten hard. The mud layer is finally covered with 2·5 cm. thick layer of white earth containing large percentage of sodium sats. This top layer has to be renewed once or twice a year.

20·17 Brick Jelly or Madras Terrace Roofing. It consists of a course of thoroughly burnt terrace bricks 15 cm. × 8 cm. × 2 cm. laid on edge in lime mortar 1 : 1½ (one lime : 1½ sand) diagonally across the joists of the timber roof. The bricks used are immersed in water 24 hours before use and the thickness of joint is kept 10 mm. After the bricks are completely set a 10 cm thick layer or brick concrete 2½ : 1 is laid over brick on edge course and beaten down to 7 6 cm. thickness by wooden hand beaters. The beating is continued till the beater makes no impression on the concrete and gets readily rebound by the surface when struck upon it. The whole surface is then cured for about a week by sprinkling lime water. After the concrete has set, three courses of Madras flat tiles, 15 cm. × 10 cm. × 12 mm are laid in lime mortar 1 : 1½. The thickness of the joints should not exceed 6 mm. and the vertical joints should be broken. The joints of the top layer are left open to afford a key for the plaster. This top surface is then plastered with three coats of lime mortar and finally rubbed to a polished surface. The roof is usually laid to a slope of 1 in 36. The slope of the roof is given to the joists themselves and not by increasing the thickness of terracing.

20·18 Mud Phuska Terracing with Tile Paving. This type of terracing is commonly adopted in Delhi over R.C.C. roof slab or jack arch roofing. It ensures thermal insulation and waterproofing of roof. The construction of terracing is described below :

Well selected earth, mixed with straw and water, is allowed to rot for 3 to 4 days. During this period, this mixture of earth is

worked with feet or phawras at intervals so that the mixture gets pugged into a homogeneous mass. The layer of mud thus formed is laid in thickness of 8 to 10 cm. over the roof slab and is well consolidated. The surface is given a slope of 1 in 30 to 1 in 48 to drain off rain water. When the surface gets somewhat dry it is plastered with a 13 mm. thick coat of cement cow-dung plaster mixed in proportion of 1 : 3 (one cement : 3 cow-dung). Tile bricks of the specified size are then laid flat on the green cement cow-dung plaster and ground with cement mortar 1 : 3. The terracing is cured for at least seven days.

20·19 Roof Covering. It is a material covering provided over the form-work of roof structure to act as a barrier for the rain, sun, wind or other such elements. The section of the covering material depends upon various factors such as availability of material, its initial cost and cost of maintenance, appearance and durability etc. There are various types of roof coverings and the ones which are commonly adopted in India are given below :

(1) *Thatch covering*

(2) *Shingles*

(3) *Tiles*

(4) *Asbestos-cement sheets*

(5) *Galvanised corrugated iron sheets*

(6) *Slates*

20·20 Thatch Covering. This form of roof covering is largely used in low cost houses and villages. It is suitable for rural areas mainly because it is the cheapest form of covering and is simple in construction. The frame-work for supporting the thatch consists of round bamboo rafters spaced at 30 cm. apart and tied with split bamboos laid at right angles to the rafters. The thatch is tightly secured to the frame-work with the help of ropes or twines dropped in tar. For adequate drainage of rain water, the thatch covering should be at least 15 cm. thick and laid with a minimum slope of 40°. Thatch is combustible, absorbs moisture and is liable to rot or decay. It harbours rats and the bad smell of rotting material makes it difficult to stay under the roof. On account of these defects, thatch covering is never allowed in good work.

20 21 Shingles. The use of shingles is generally restricted to hilly areas where wood is easily availabe at low cost. Wood shingle cut from well seasoned timber is laid in a similar manner as slates and tiles. Shingles are obtained in lengths varying from 30 cm. to 38 cm. and in widths varying from 6 cm. to 25 cm. Generally two courses of shingles are laid at the eaves.

20·22 Tiles. The tiles are named according to their shape and pattern and are manufactured in somewhat similar manner as bricks. The commonly used tiles are : Flat pan tiles ; Half round country tiles ; Mangalore tiles, Quilon and other similar tiles. Tiling is one of the oldest methods of roof covering but with the introduction of asbestos cement sheets, their use is gradually declining day by day. The method of laying of a few types of tiles is given below :

(*a*) *Flat or curved pan tiles and Half-round country tiles* : For laying the tiles the ground work consists of battens nailed to the common rafters of the pitched roof. The common rafters are usually spaced 22 to 30 cm. apart and battens are fixed to the rafters at 6 cm. centre to centre. The tiles are laid with sufficient overlap. Ridges, hips and valleys are formed with specially moulded tiles exclusively meant for the purpose. The last row of tiles laid near the eave, ridge, valley or hip is set in lime mortar. In order to avoid danger of water leaking through the valleys, lead flashing is sometimes done.

(*b*) *Mangalore or Corrugated Tiles* : In ordinary works, the tiles are laid on battens but for a sperior type of construction they are laid on boardings, covered with protective coat of tar or felt. Boarding is directly nailed to the purlin and tiles are laid on battens nailed on the boarding. In this case too, the ridge, valley and hip tiles are moulded into special shape. Ridge and hip tiles are laid dry and finally painted with cement mortar.

20·23 Asbestos-cement Sheets. Asbestos cement is a material obtained by the combination of cement with about 15 per cent of asbestos fibres. The sheets made out of this material are light, cheap, impervious, durable and fire resisting. It does not require any protective paint and cannot be eaten away by the vermin. On account of these properties, asbestos cement covering is commonly adopted as a roofing material for factories, workshops, offices, garages, generating stations and residental buildings. The two different types of sheets commonly used are "Big six" and "Trafford" sheets. These sheets are available in 2 to 3 m. length.

20·24 Fixing of A.C. Sheets. The following points should be carefully noted while fixing A.C. sheets.

(1) The sheets should be laid with smooth side upward and the end marked "Top" pointed towards the ridge.

(2) They are usually laid with an end lap of 15 cm, but this lap can be slightly varied to suit the purlin spacing.

(3) The side laps for 'Big six' and 'Trafford' sheets consist of half corrugation and one corrugation respectively.

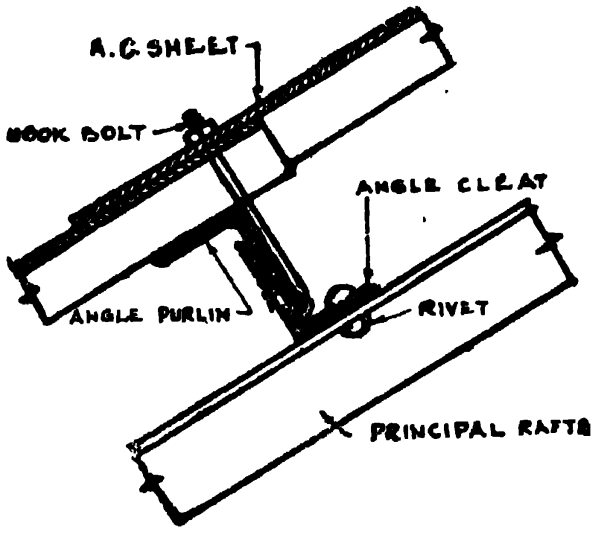


Fig. 20·26

Details of the end lap for A.C. sheets at purlin point

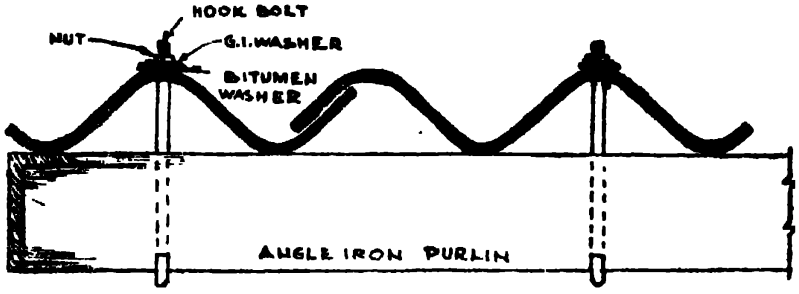


Fig. 20·27

Side lap for "Bix six" sheets

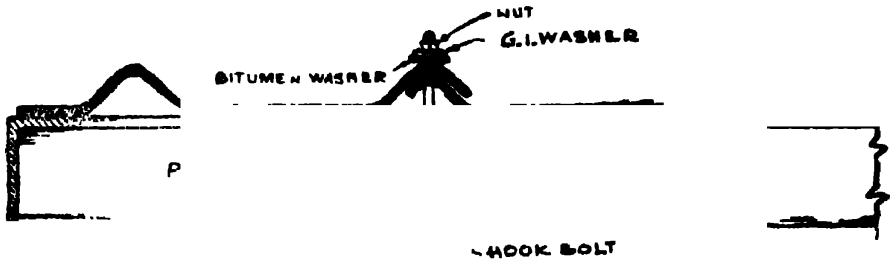


Fig. 20·28

Side lap for "Trafford" sheets

(4) The holes for fixing accessories must be drilled and not punched in the crown of the corrugations.

(5) The diameter of the hole should be 3 mm. greater than the diameter of the screw or bolt to be used.

(6) 8 mm. diameter hook bolts, crank bolts or coach screws are then inserted in the 11 mm. diameter drilled holes and screwed lightly. A bitumen washer must be provided under G.I. flat washer. When 10 or 12 sheets have been laid, the nuts of the screws or bolts are screwed tight. The screws or bolts on purlin are not screwed very tight.

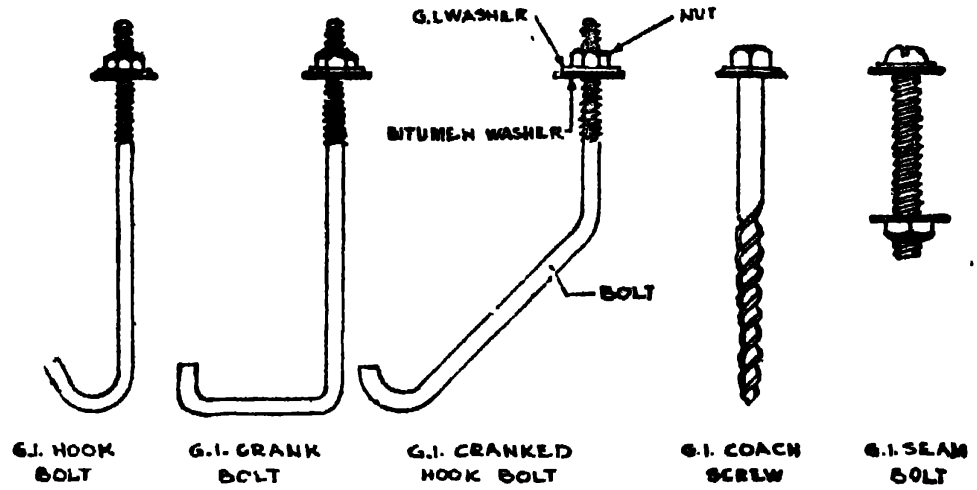


Fig. 20·29

Different forms of bolts and screws used for fixing A.C. sheets

(7) Ridge cappings should preferably be secured to the ridge purlin by the same kind of bolts which are used for fixing sheeting. "J" bolts should be used for angle purlins and crank bolts should be used for purlins made up of timber, rolled steel joist, channel etc. Coach screws may be used for timber purlins.

(8) Mitre (cut) is necessary to avoid gaps where four sheets meet at a lap.

(8) (*a*) In "Big six" sheets mitre may be defined as a cut formed at the required corner by cutting the corner of the sheet for a length of 15 cm. or the length of end lap whichever is more along the vertical edge and for a width equal to 5 cm. or length of the side lap whichever is more along the horizontal edge of the sheet.

(*b*) In Trafford sheets, mitre may be defined as a cut formed at the required corner by cutting the corner of the sheet for a length of 15 cm. or the length of the end lap whichever is more along the vertical edge and for a width equal to the width of one corrugation along the horizontal edge of the sheet.

(10) The unsupported overhang of the sheets at the eaves should not preferably be more than 30 cm.

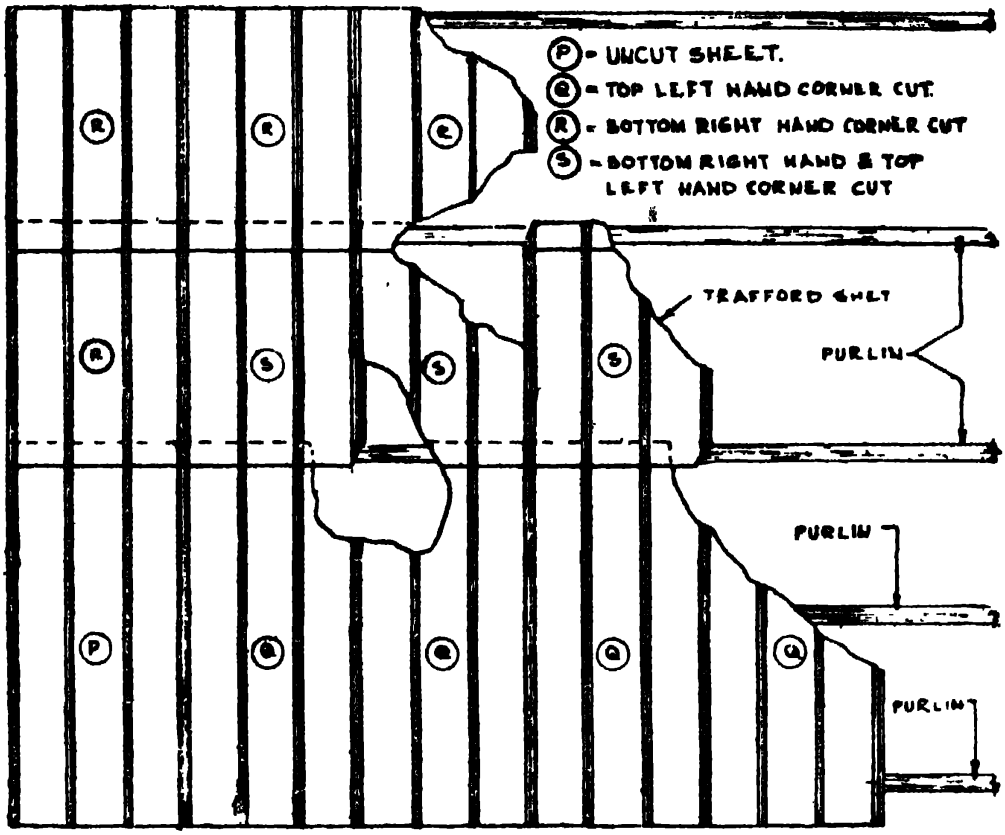


Fig. 20·30

Part-plan showing laying of A.C. sheets from left to right

20·25 Laying of Big Six Sheets. Sheets may be laid from left to right or *vice versa*, preferably laying should commence at the end opposite to the direction of the prevailing wind. The process of laying Big six sheets from left to right is described below :

The laying of sheets is started at the eaves. In the first row or in the eaves course, first sheet is laid uncut while the remaining sheets have top left-hand corners mitred. In the second or intermediate rows ; the first sheet in each row has bottom right-hand corner mitred while the other sheets have both top left-hand and bottom right-hand corners mitred. In the topmost row, all the sheets except the last one have bottom right-hand corners mitred. The last sheet is laid uncut.

If the sheets are laid from right to left, the whole procedure will be reversed.

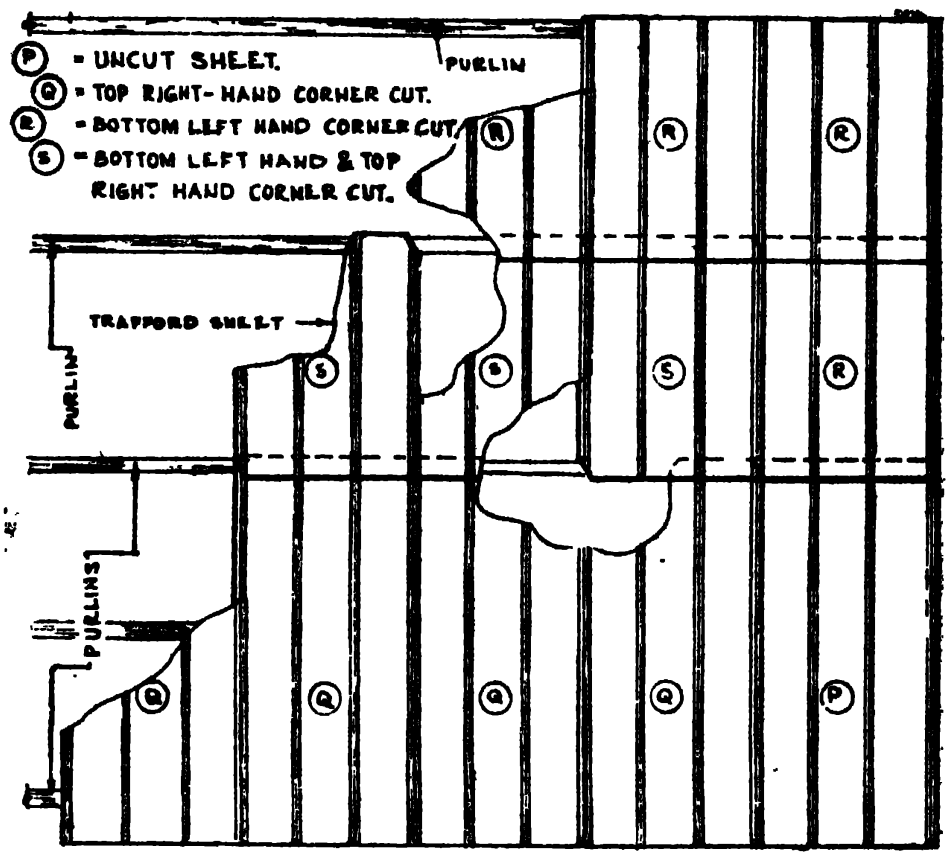


Fig. 20·31

Part plan showing laying of A.C. sheets from right to left

20·26 Galvanized Corrugated Iron Sheets. Ordinarily 22 gauge sheets are extensively used as roof covering material in factories, workshops, generator sheds etc. The sheets are generally not laid at a slope flatter than 1 in 4. These sheets are durable, fire-resistant, light in weight and require no maintenance. The purpose of corrugation is to give the thin sheet additional strength. Sheets are galvanised to protect them from rusting action of weather. The sheets are laid with end lap not less than 15 cm. and side lap varying from $1\frac{1}{2}$ to 2 corrugations. The sheets should be fastened above eaves by 25 mm. × 6 mm. flat iron wind ties. The holes in the sheet crowns may be drilled or punched. But when four sheets overlap at corners, the holes should be drilled and not punched. The sheets are secured to the purlins by means of galvanised iron hook bolts, screws and nails etc. with curved washers.

20·27 Slates. The stone used for slate roof covering is obtained from sedimentary rocks of limestone or sandstone. It is

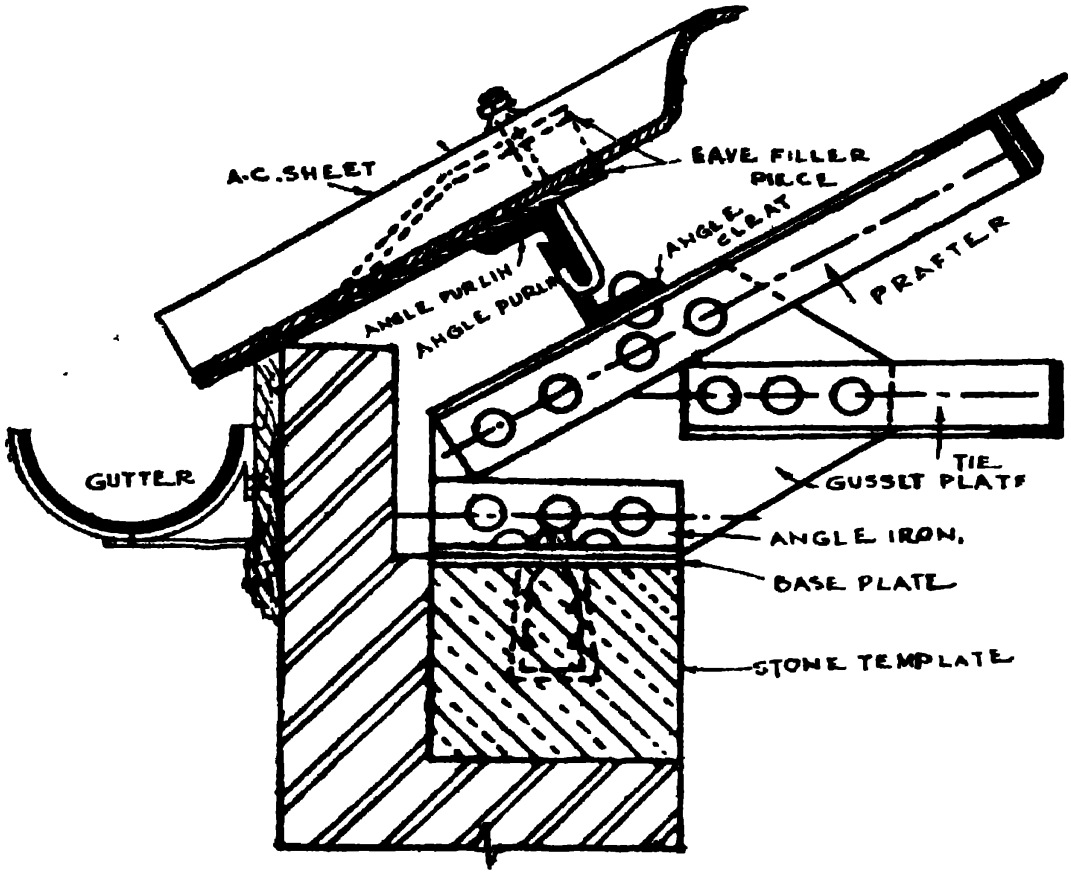


Fig. 20·32

Detail showing the arrangement of fixing A.C. sheets at the eaves level of a steel truss

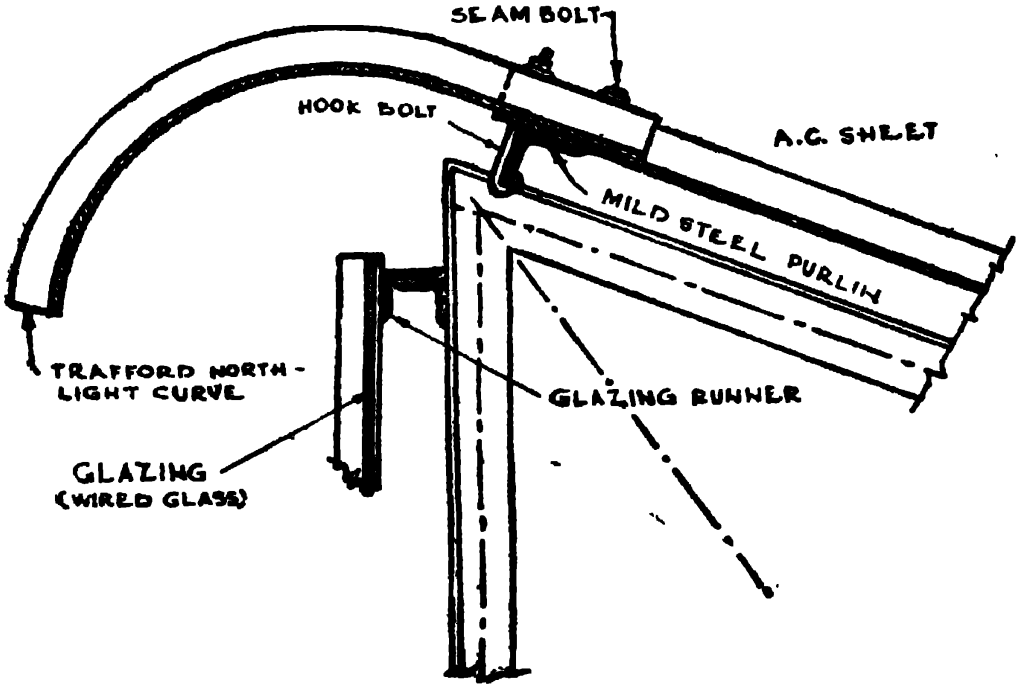


Fig. 20·33

Details showing A.C. sheet covering for a North light roof truss

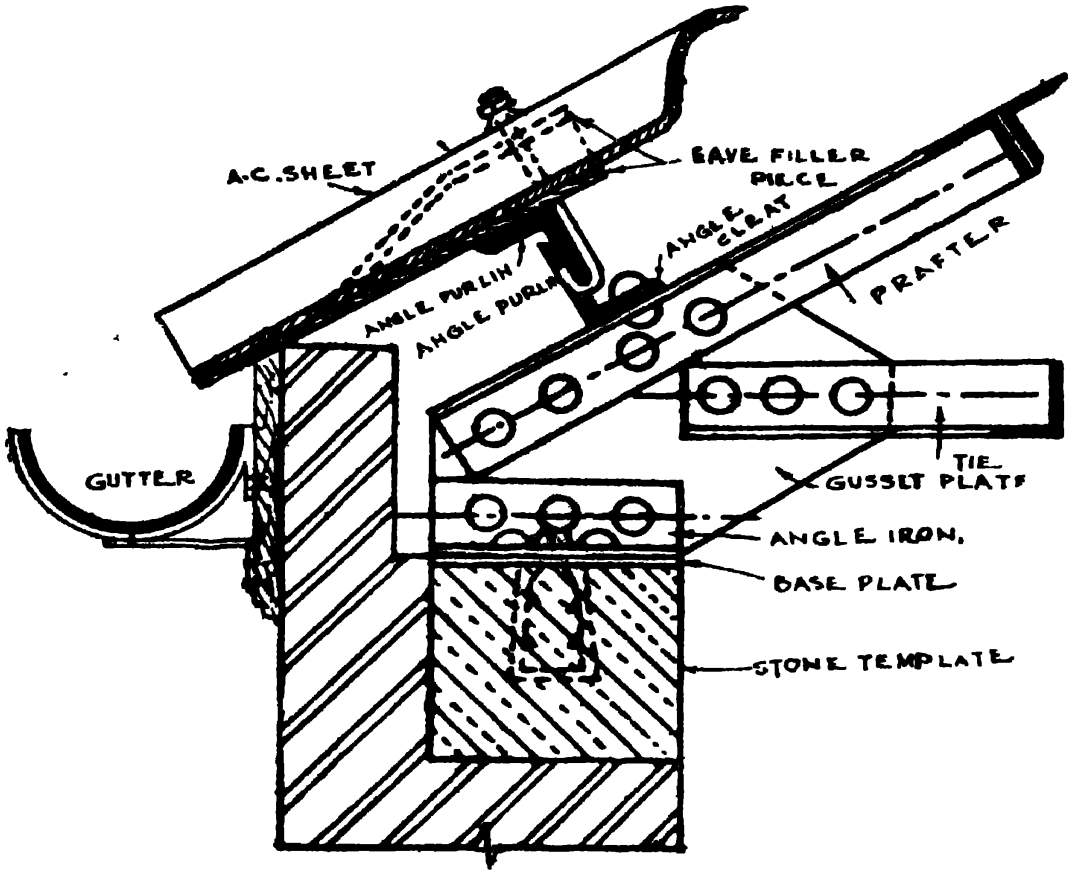


Fig. 20·32

Detail showing the arrangement of fixing A.C. sheets at the eaves level of a steel truss

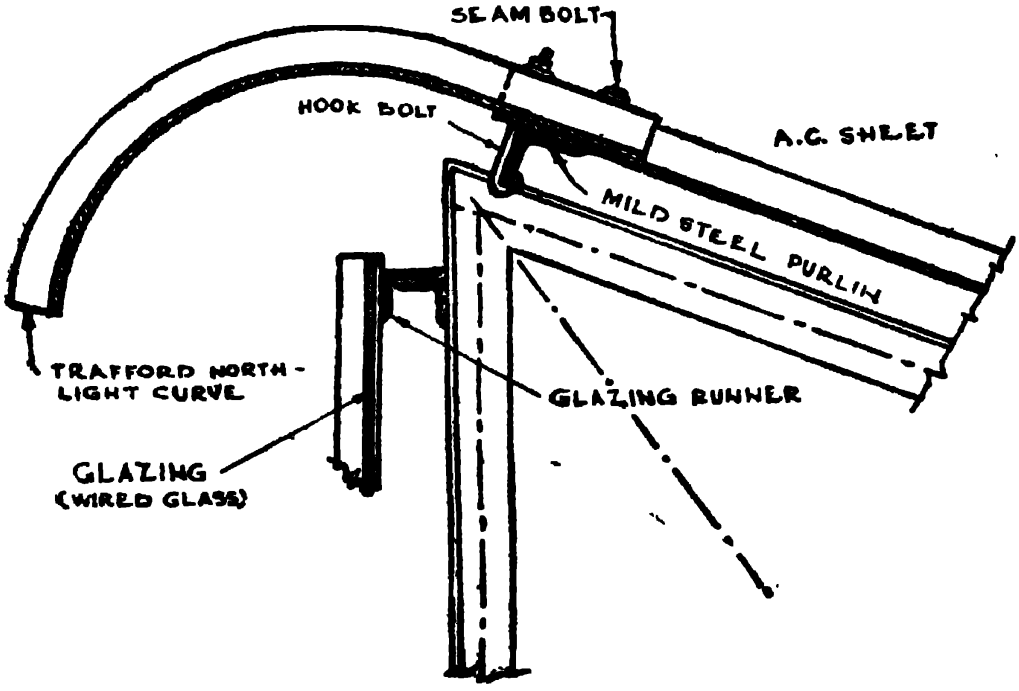


Fig. 20·33

Details showing A.C. sheet covering for a North light roof truss

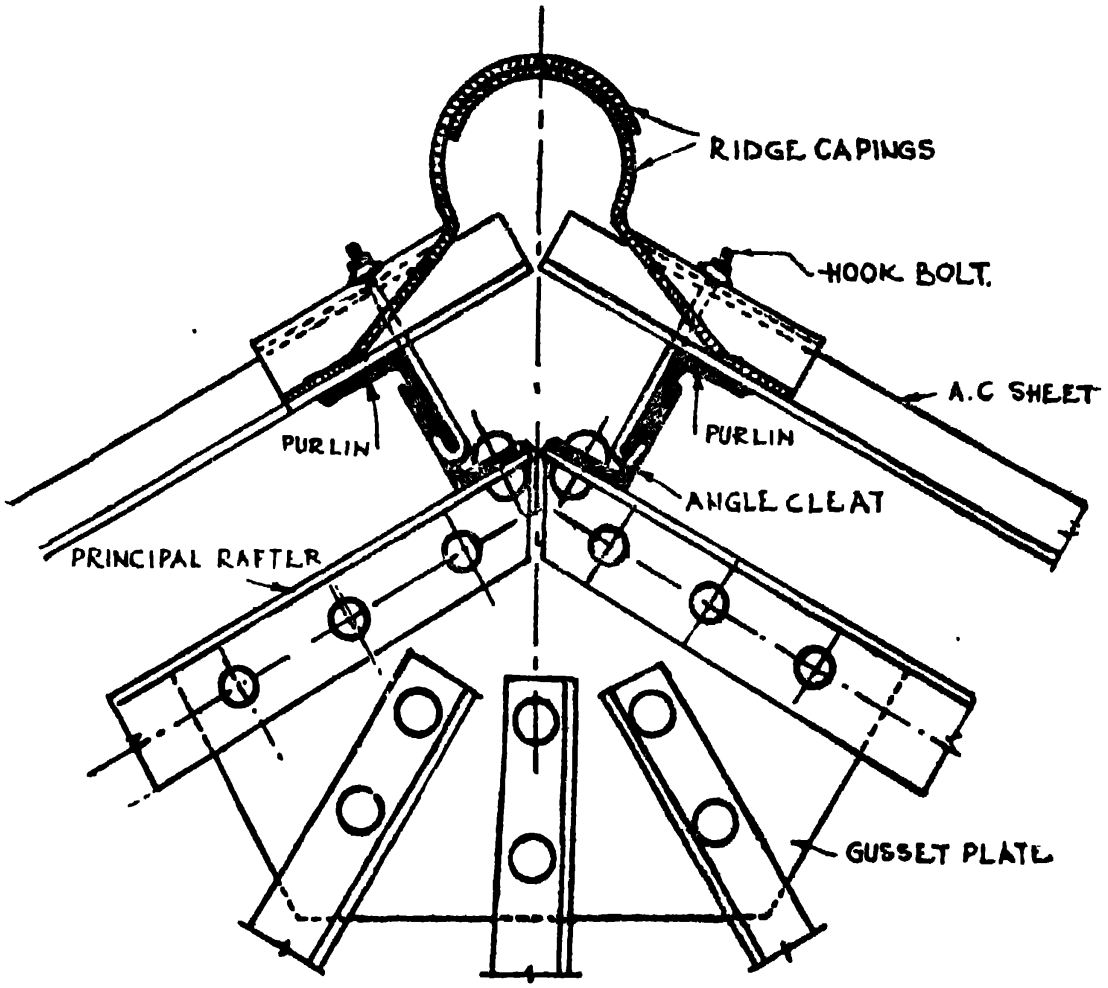


Fig. 20·34

Details showing the arrangement of fixing A.C. sheets at the crown of a steel truss

seldom confused with the slate obtained from metamorphic rock. Stone slates vary considerably in size, shape and weight. They form the most durable roof covering material, but in India it is rarely adopted. The common sizes of slates vary from 60 cm × 35 cm. to 25 cm × 12 cm. The thickness of the regular sizes stone slate varies from 1·6 mm. to 4·8 mm. for small size slates and 16 mm. to 13 mm. for bigger size slates. The slates may be fixed on the battens fixed on timber rafters, or they may be laid on wooden boarding fixed on the roof framework. The slates are secured to the base which may be of battens or boarding, through nails of zinc, copper or galvanised iron.

Questions for Revision

1. What are the various types of roofs commonly used in India ? Describe each stating clearly the distinction between the different types.

2. Draw to a scale of 1 : 25 a lean to roof over a verandah 3 m. wide and 7·32 m. long, with 60 cm. high plinth. The timber roof is to be supported by 35 cm. × 35 cm. piers and covered by Mangalore tiles. Draw half full size detail at the eaves and at its junction with the main wall, which is 35 cm. thick.

3. Write a detailed note on the different types of the roof covering for pitched roofs which are generally used in India. Describe the method of laying and fixing them with the aid of sketches.

4. Define the following terms as used in pitched roof construction :

(*i*) Pitch of roof.

(*ii*) Hipped end.

(*iii*) Ridge.

(*iv*) Gable.

(*v*) Eaves board.

(*vi*) Template.

(*vii*) Valley rafters.

(*viii*) Boardings.

5. Sketch neatly large views to show details of the following :

(*a*) The joint at the junction of the principle rafter with the tie-beam of a timber queen post roof truss.

(*b*) The joints at the junction of principal rafter, head of queen post and the straining beam.

6. A workshop building of floor area 46 m. × 12 m. has to be roofed over by asbestos cement sheet roofing. Show by free hand sketches the general arrangement of colums, trusses and roof coverings, wind ties and gutters for drainage assuming suitable dimensions. Height of columns is to be 6 m. above ground level.

7. Write short notes on :

(*i*) Lean-to-roofs.

(*ii*) Coupled roofs.

(*iii*) Coupled-close roof.

(*iv*) Collar roof.

(*v*) Mansard roof truss.

(*vi*) Composite roof trusses.

8. A 3 m. wide corridor, 9 m. long, connecting a school building with its physical training hall is to be covered with Mangalore tiled roof, The plinth is 30 cm, high and the roof is supported on brick piers. Draw the plan and cross-section of the corridor to a scale of 1 : 50 and give quarter full size details of the roof at its junction, with the pier, showing also the eaves.

9. (*a*) Write a short note on the several types of flat roofs and add sketches to illustrate their construction.

(*b*) It is proposed to provide Madras terrace over an apartment 12 m. × 6 m. as only teak wood is available for use as beams and joists in a certain locality.

Draw longitudinal section and cross-section of the apartment to illustrate your design for its construction.

10. A bungalow has a drawing room measuring 4·88 m. × 7·32 m. which is covered with a pitched roof. Draw the plan and cross-section of the roof to a scale of 1 : 25 and give sizes of the scantlings used.

11. Write short notes on any four of the following :

(*i*) Laying of asbestos-cement sheets.

(*ii*) Laying of Mangalore or corrugated tiles.

(*iii*) Thatch covering.

(*iv*) King post roof truss.

(*v*) Queen post roof truss.

(*vi*) Mansard truss.

12. A hall 8 m. × 16 m. is required to be roofed over with Mangalore tiles on king post truss. The trusses are spaced at 3 m. centre to centre, and are supported on 30 cm., thick walls on either side. Draw detailed sketches for the following :

(*i*) Junction of tie beam with principal rafter.

(*ii*) Arrangement of fixing the truss to the wall supports.

(*iii*) Joints between the principal rafters and the king-post.

(*iv*) Joints between the king-post and the tie beam.

13. Draw to a scale of 1 : 25 of a roof truss over 6 m. span and suggest the scantlings which in your opinion you consider suitable. The side walls are 20 cm. thick in brick and roof is to be covered with Mangalore tiles.

14. A hall 10 m. × 20 m. is required to be roofed over with asbestos cement sheeting on queen post truss. The trusses are spaced at 3 m. centre to centre and are supported on 40 cm. thick brick walls at either end. Sketch the following details :

(*i*) A lay-out plan indicating clearly the position of trusses.

(*ii*) A sectional elevation and section of the queen post truss with suitable sizes of the scantlings.

(*iii*) Joints at the head of queen post.

(*iv*) Joints at the feet of queen post.

15. An assembly hall 10 m. × 30 m. is to be roofed with Mangalore tiled roof over wooden trusses, rafters etc. Sketch the type of truss you would propose, and show in detail with dimensions any three joints in the proposed truss.

16. (*a*) What type of roof will you suggest for a room 4·80 m. by 7·20 m. at a place where rainfall is over 180 cm. a year ? Give reasons for your choice.

Either

(*b*) If you select a pitched roof, draw a cross-section of the truss and purlins etc., showing approximate sizes of the members and joints between members.

Or

If you recommend a flat roof, how will you lay it and what precautions will you take to make it leak-proof.

(*A.M.I.E. May 1967*)

17. (*a*) A queen-post truss of timber is to be made for a span of 12 m. You have 20 cm. × 13 cm. timber, 6·5 m. long only. Draw a neat sketch of the lengthening joint you will provide in making the tie beam.

(*b*) A lean-to roof with Mangalore tiles is to be provided for a verandah 3 m. wide. Draw a neat sketch of the roof showing clearly all the relevant details.

(*A.M.I.E. May 1968*)

18. The roof of a theatre consists of steel trusses of clean span 16 m. placed at 3 m. centres. It is covered over with cement asbestos sheets on angle iron purlins and the celing is of celotex sheets. Draw a section showing the details of the truss, roof cover and ceiling. Give larger scale sketches showing the details of wall supports, ridge and joint of truss. Note the dimensions of all the members.

(*A.M.I.E. Nov., 1968*)

19. Show the construction details of a cycle-stand, for keeping 100 cycles. How will you provide protection from sun, wind and rain ? What factors will have to be taken into consideration if the cost is to be minimum.

21

Structural Steel Work

21·1 Shapes of Structural Steel. The cross-sectional properties of a member are identified by its shape. The various names given to the members of different shapes are Angles ; T-section ; I-section ; Z-section ; Channels ; H-section and so on. Each shape has its particular use in steel structures. The various sections are fabricated from white hot steel by passing it through rolling mills or other machines. An angle section is named by

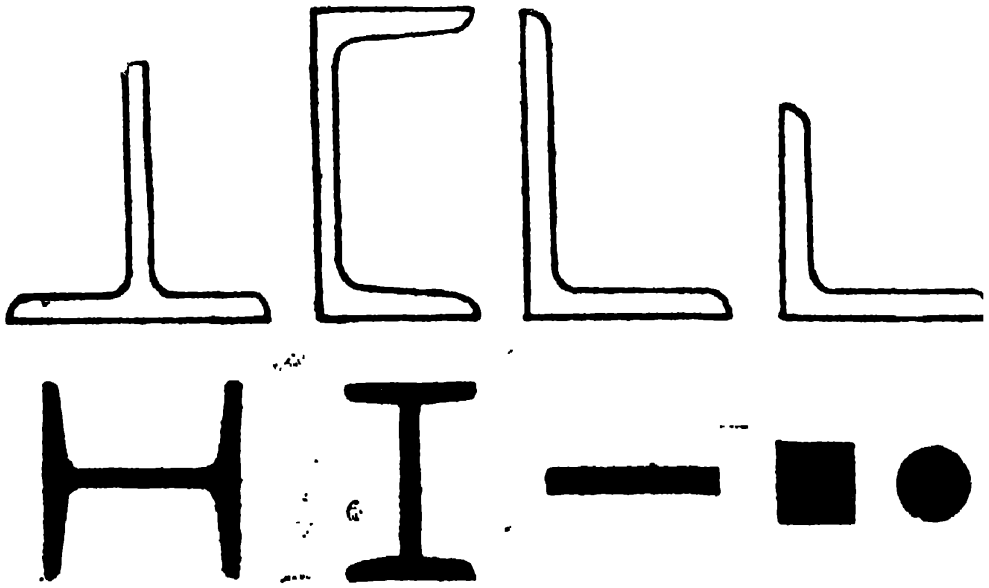


Fig. 21·1
Different shapes of structural steel section

writing the two leg lengths and the thickness of the plate forming the angle. An equal angle-section having length of its each leg as 8 cm. and its thickness equal to 12 mm. will be written thus : $80 \times 80 \times 12$ mm. In case of I-section, the depth of the section is written first. Thus an I-section weighing 34·2 kg/m. and having a depth equal to 200 mm. and flange width 100 mm. will be written as 200 mm. $\times$ 100 mm. $\times$ 34·2 kg./m. Similarly, the other shapes of steel sections are named by writing their dimensions and weights.

21·2 Rivets. The sections used in steel structures are connected to each other by riveting or bolting. Welding is an

alternative method of connecting the structural sections. The various forms of riveted connections are shown in Fig. 21·2. The rivet is rendered soft by heating and then it is placed in the rivet hole. The shank extends out of the prepared rivet hole and

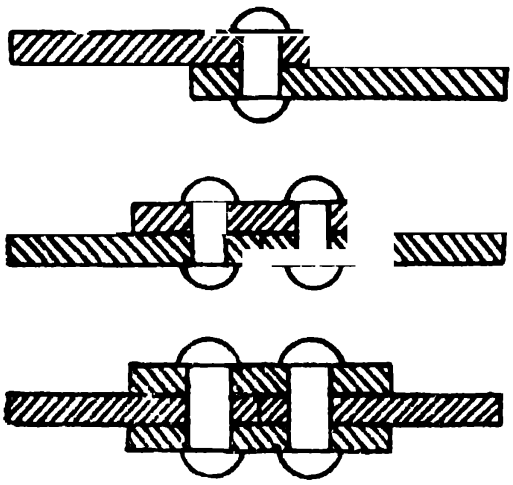


Fig. 21·2

Riveted connections

the extended part of the shank is given the shape of a second head by riveting machine. The usual form of rivet head which is cup-shaped in appearance is termed as snap head. Thus the snap head always extends out from the face of the plate riveted. In case it is desired to have the second head flush with the plate or member to be riveted, counterunk head is employed. The two different types

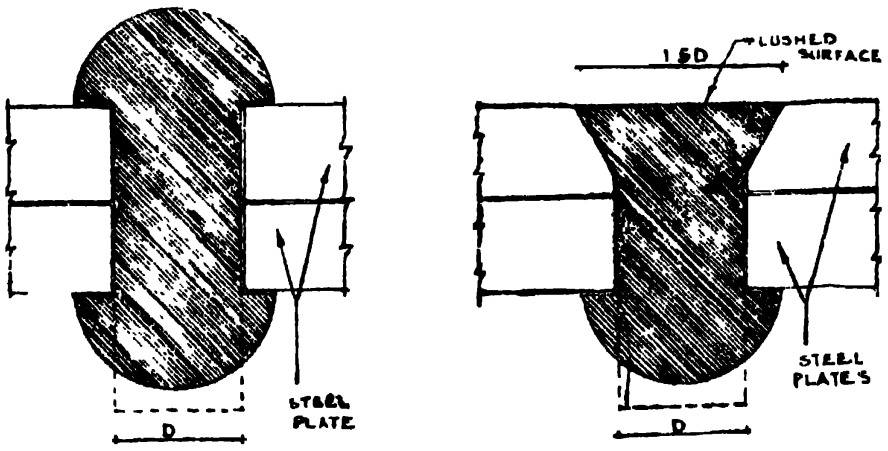


Fig. 21·3

Different forms of rivet heads

of heads are shown in Fig. 21·3. Depending upon the nature of connection, the rivets may be subjected to single shear or double

shear. In single shear, one cross-sectional plane of the rivet is subjected to shearing action while in double shear, two cross-sectional planes of the rivet are subjected to shearing action. The strength of rivets subjected to single shear and for the one, subjected to double shear is given by $\frac{\pi d^2}{4}$ tonne and $\frac{\pi d^2}{2}$ tonne respectively.

Following important rules are observed in designing the riveted connections :

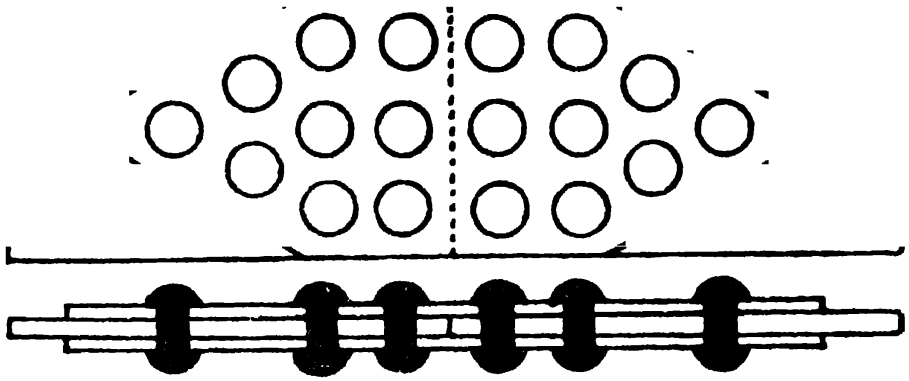


Fig. 21·4

Plan and sectional elevation of a riveted connection

(1) The centre to centre distance between the rivets should never be less than three times the nominal diameter of the rivet.

(2) The maximum centre to centre distance between the rivets should never exceed the following :

(*a*) In case of members subjected to tension : 10 times the thickness of the thinnest outside plate or angle or 20 cm. whichever is less.

(*b*) In case of members subjected to compression : 16 times the thickness of the thinnest outside plate or angle or 15 cm. whichever is less.

(3) The distance between the edge of a rivet and edge of the plate etc., should never be less than the diameter of the rivet.

21·3 Beams. I-sections or rolled steel joists are commonly used as simple beams. They are suitable for moderate loading conditions and spans. But for heavy loads and longer spans, compound beams are used. They are fabricated from one or more rolled steel joists or riveted with plates and angles. In some cases only plate and angles are riveted together to form a compound beam.

Plate girder and box girder are the two examples of compound beams. The various forms of steel beams are shown in Fig. 21·5.

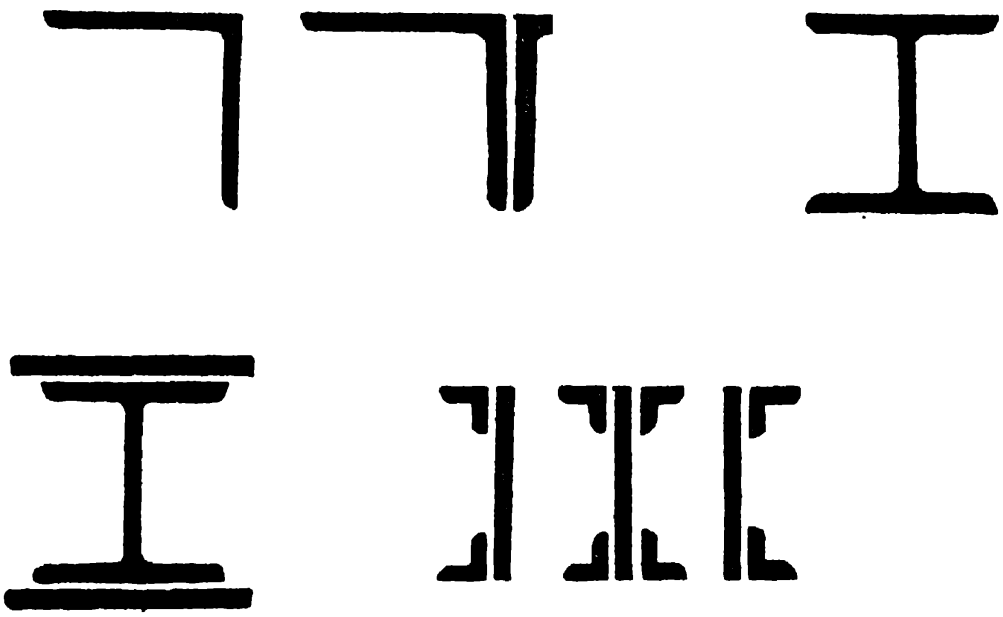


Fig. 21·5

Cross-section of various types of beams

21·4 Steps to be followed in the Design of a Simply Supported Steel Beam

(1) Calculate the loads to be carried by the beam.

(2) Calculate the max. bending moment (M) with regard to the nature of loading conditions.

(3) Calculate the section modulus (Z) of the required section of the beam by the formula :

$$Z = \frac{M}{f}$$, where f is the safe allowable stress in steel in bending.

(4) From the Table on "Properties of sections" select a suitable section having its section modulus slightly greater than the calculated one. In making the selection of the section, deeper sections should be preferred.

(5) Calculate max. shear force in the beam.

(6) Check the section for safe shear stress by the formula :

$$s = \frac{S}{I\,b} A\bar{y}$$

where

s = intensity of shear stress.

S = max. shear force in beam.

$A\bar{y}$ = The moment of the area of the part of the section situated beyond its neutral axis.

In case of a rolled steel joist, this formula may be reduced to $s = \frac{S}{dt}$, where d is the over-all depth of the joist and t is the thickness of the web.

(7) Check the selected section for its safety from consideration of allowable deflection.

21·5 Compression Members. A compression member is one, which is subjected to compression stresses in a direction parallel to its principal axis. The compression stresses tend to buckle the member or shorten it. Hence, in the design of a compression

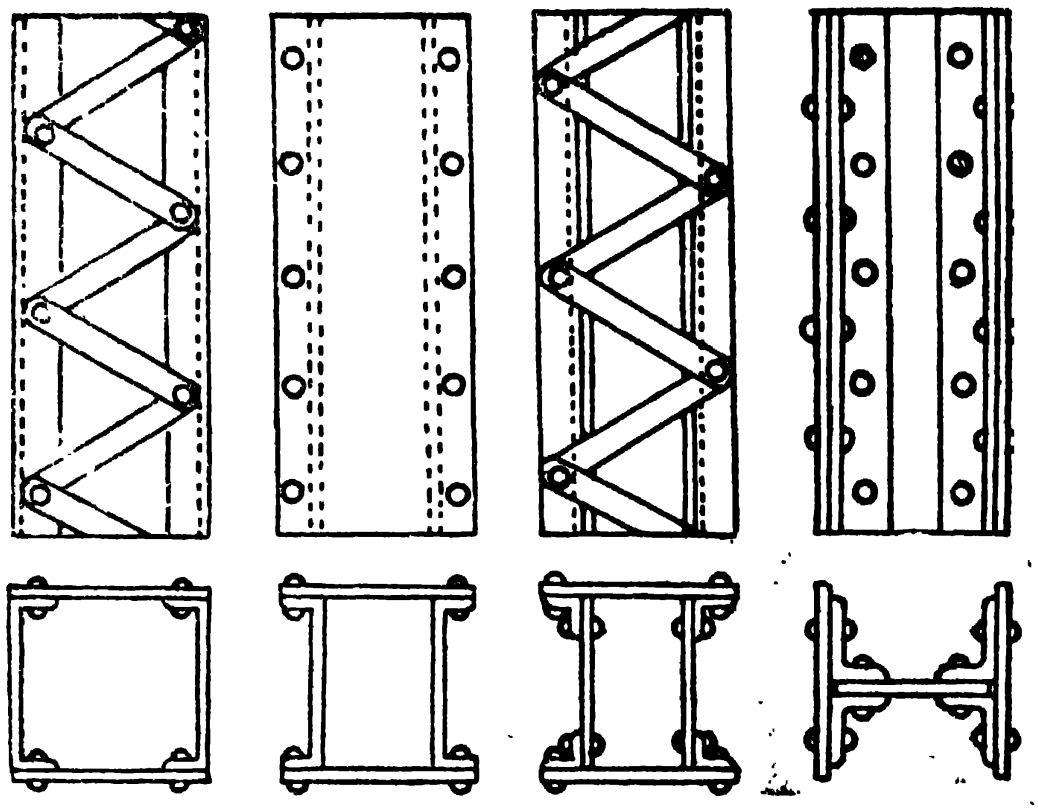


Fig. 21·6

Plan and elevation of various types of stanchions

member, its shape, area of cross-section and its length are of vital importance. Stanchions and columns are the examples of compression members.

21·6 Columns and Stanchions. Column is a vertical compression member which is circular in cross-section. It may be hollow or solid in section. Vertical compression member may be termed as stanchion. Depending upon the height of stanchions, and the loading conditions; they may be fabricated in various shapes. Long column tends to fail in bending and as such, from economical considerations, the column should be so shaped that the variation between the maximum and minimum radii of gyration about its two principal axis and the value of its $\frac{\text{area}}{\text{least radius of gyration}}$ should be as small as possible. Hence, single sections of rolled steel joists, angles or channels etc. are commonly adopted for columns subjected to light loading conditions. For columns required to carry heavy loads, two or more sections of angles, channels, rolled steel joists, etc. are joined to form a compound section. The different types of stanchions are shown in Fig. 23·6.

21·7 Framing of Long Spans. For auditoriums, theatres, hangers, large industrial buildings where greater clear distance is necessary, girders, trusses, arches fabricated from steel sections are used. Girders are used in situations where the depth of framing is limited to 1 m. When the designed depth of the beam works out to a more value, plate girders are employed. But in places where depth of framing is not restricted from architectural considerations, trusses are used.

21·8 Trusses. A truss consists of an assembly of rigid but elastic members jointed in the form of triangles to act as a beam. Because of their greater depths, they provide greater stiffness against deflection. Mild steel angles are commonly used in steel roof construction. They prove economical, and provide facility in jointing. Angles can resist both compressive and tensile stresses and as such they are most suitable for steel trusses. The various forms of trusses used in the modern construction are shown in Fig. 21·7.

Advantages of steel roof truss :

(1) Steel trusses are stronger than timber trusses.

(2) Steel section forming the truss are light in weight and can be fabricated in any desired pattern to suit the architectural requirement.

(3) There is no danger of the material being eaten away by white ants or other insects.

(4) Steel trusses are more fire-resisting than timber trusses.

(5) They do not have span restrictions and as such steel trusses are largely used for large industrial buildings and other such structures.

(6) The sections forming a steel truss are easy in transportation.

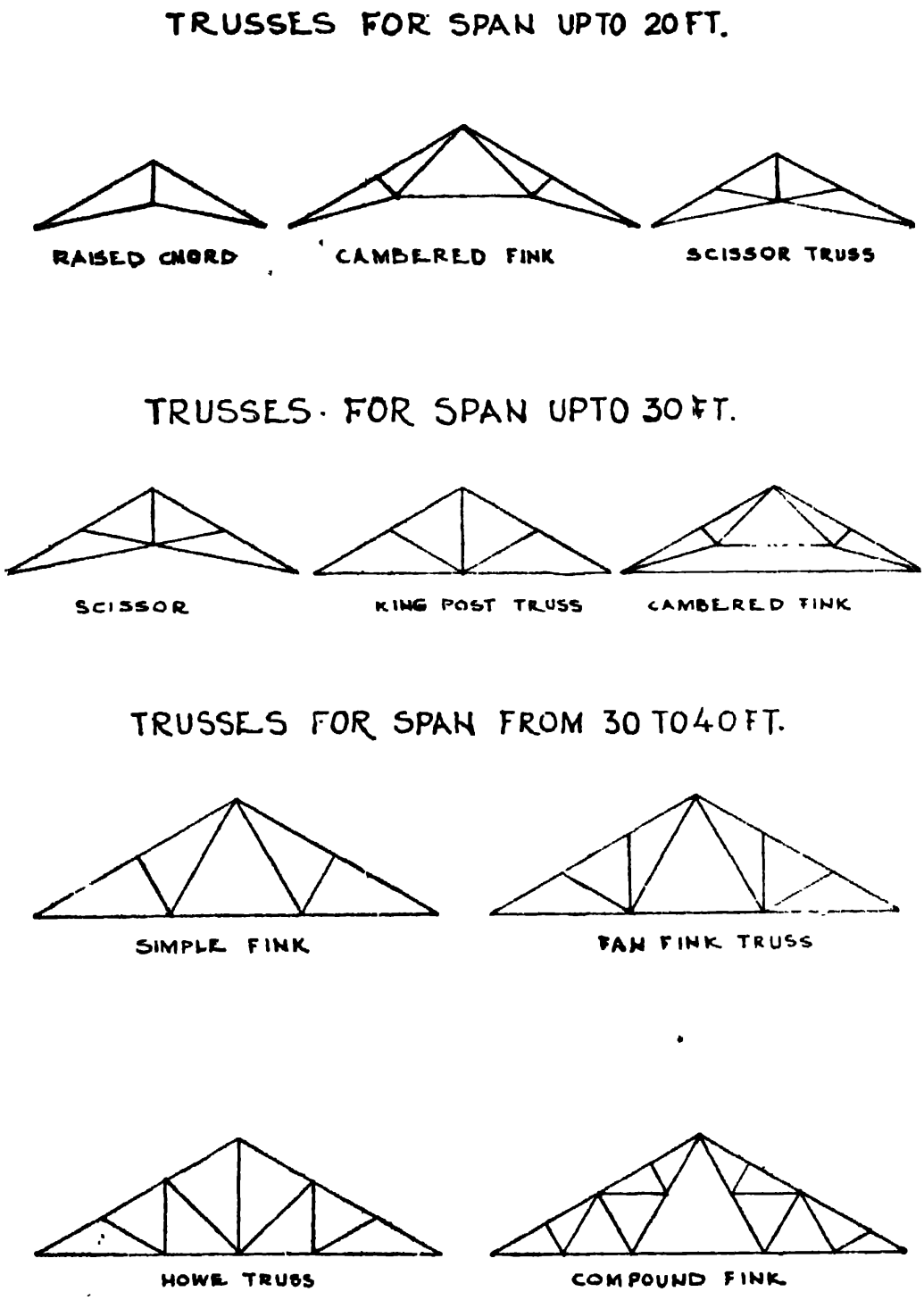


Fig. 21·7

Types of steel trusses suitable for various spans

(7) The sections can be obtained in any desired form or length to suit the requirement and there is not much wastage of the material in cutting, etc.

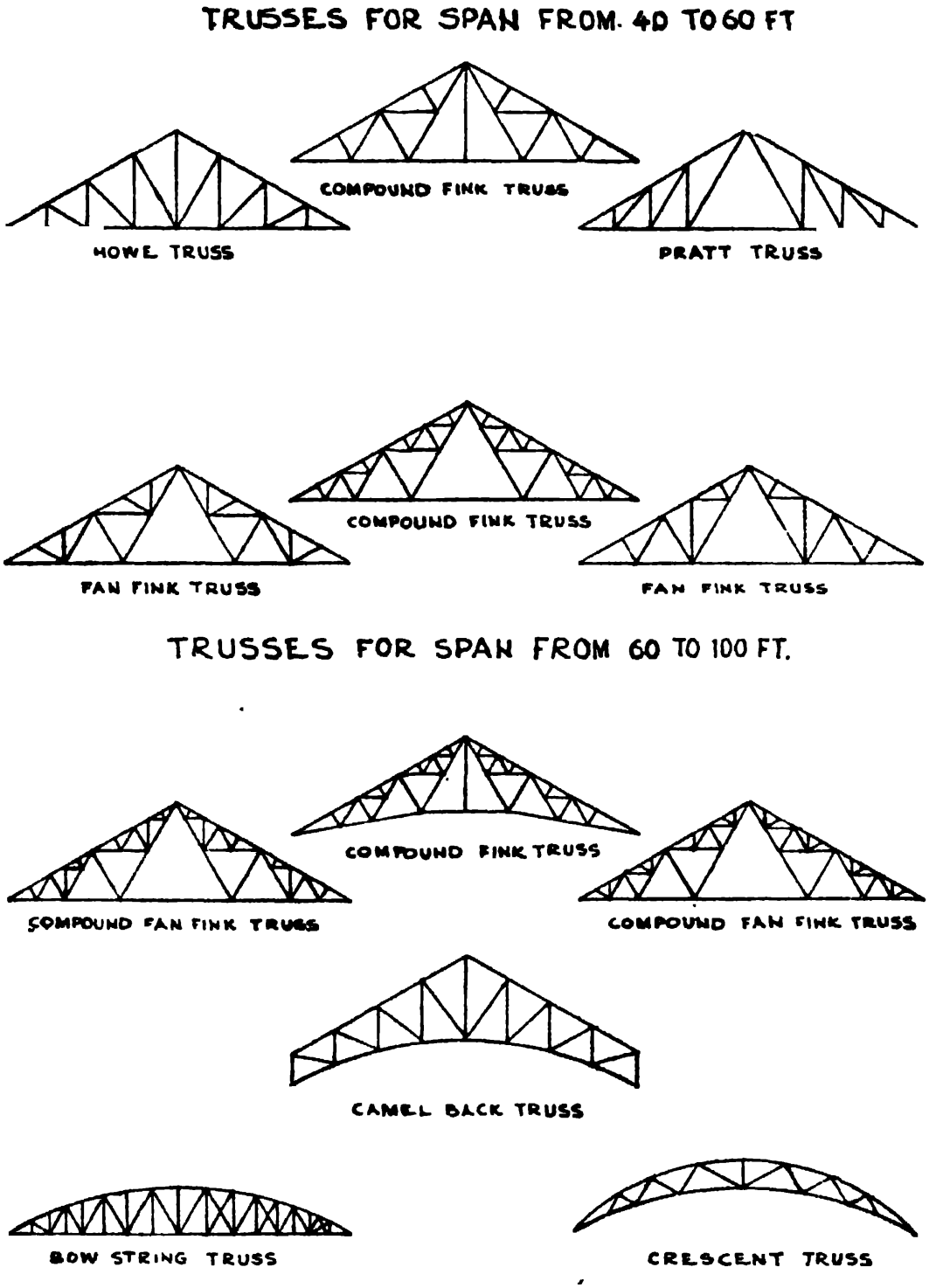


Fig. 21·8

Types of steel trusses suitable for various spans

(8) On account of their easy erection techniques, the progress of work is rapid, which results in great saving of time.

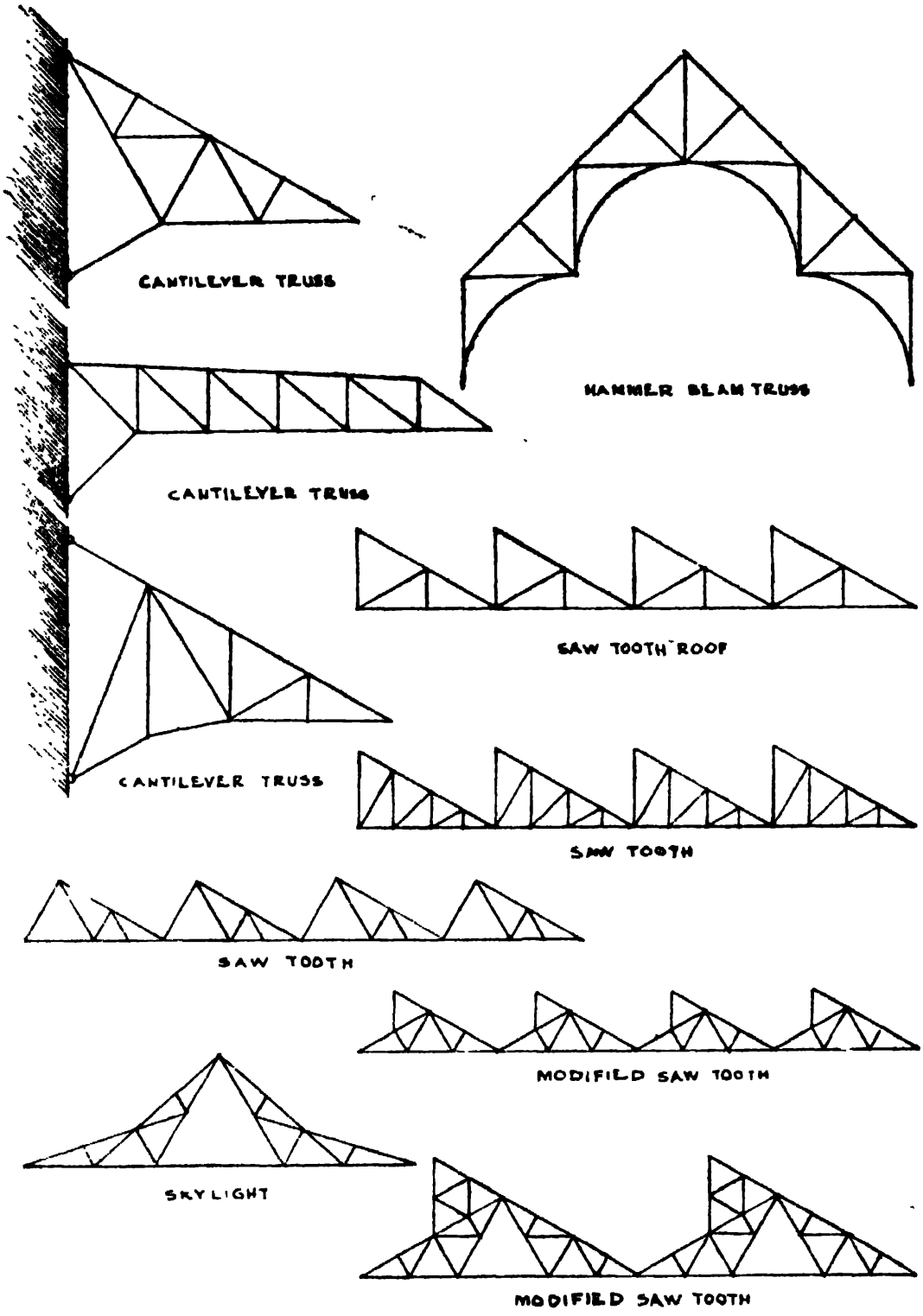


Fig. 21·9

Various types of steel trusses provided in special places

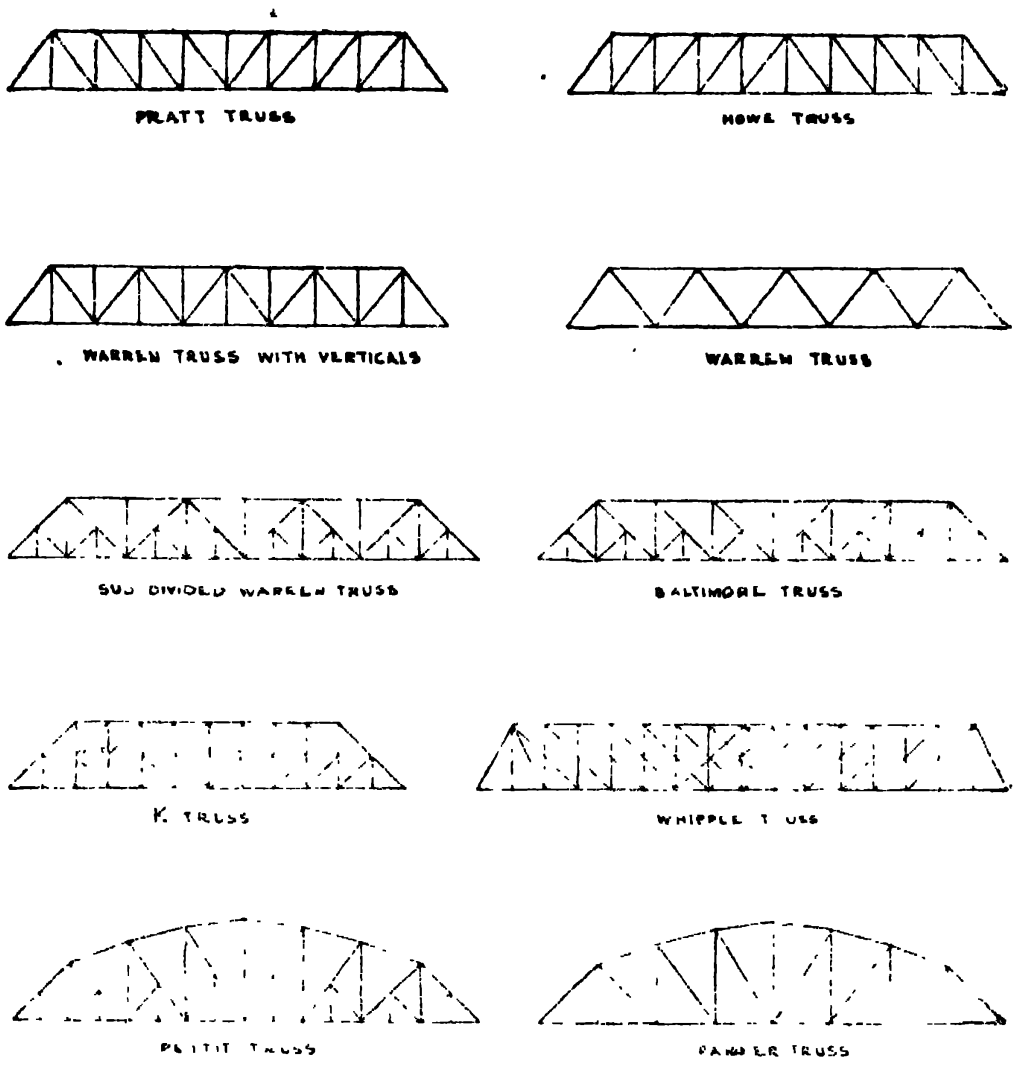


Fig. 21·10

Types of steel framing suitable for longer spans

21·9 Stanchion Base. Stanchions are riveted to specially built bases. The stanchion base consists of an arrangement of base plates, gusset plates, angle cleats, stiffeners, fastenings, etc. The stanchion is fully connected to the base plate with the help of the above fixtures and finally the base plate is fixed to the foundation of stanchion (which may be in most of the cases a simple cement concrete block foundation) through rag bolts. The width of the base plate vary from 2 to 4 times the width of the stanchion and the height of the guest plates vary from $1\frac{1}{2}$ to 2 times the width of the stanchion. To avoid shear and bending, the base plate should not project more than 8 times its thickness.

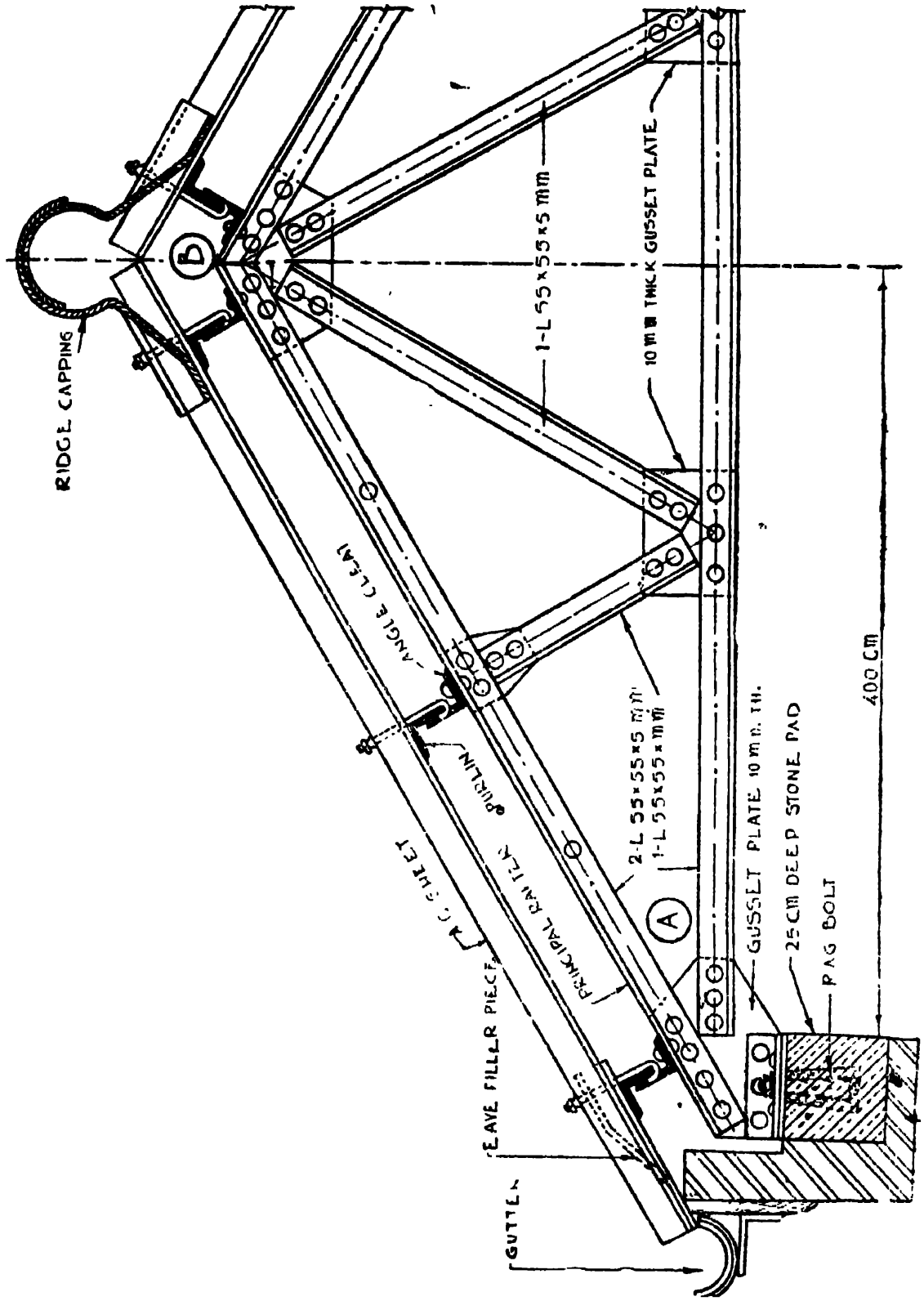
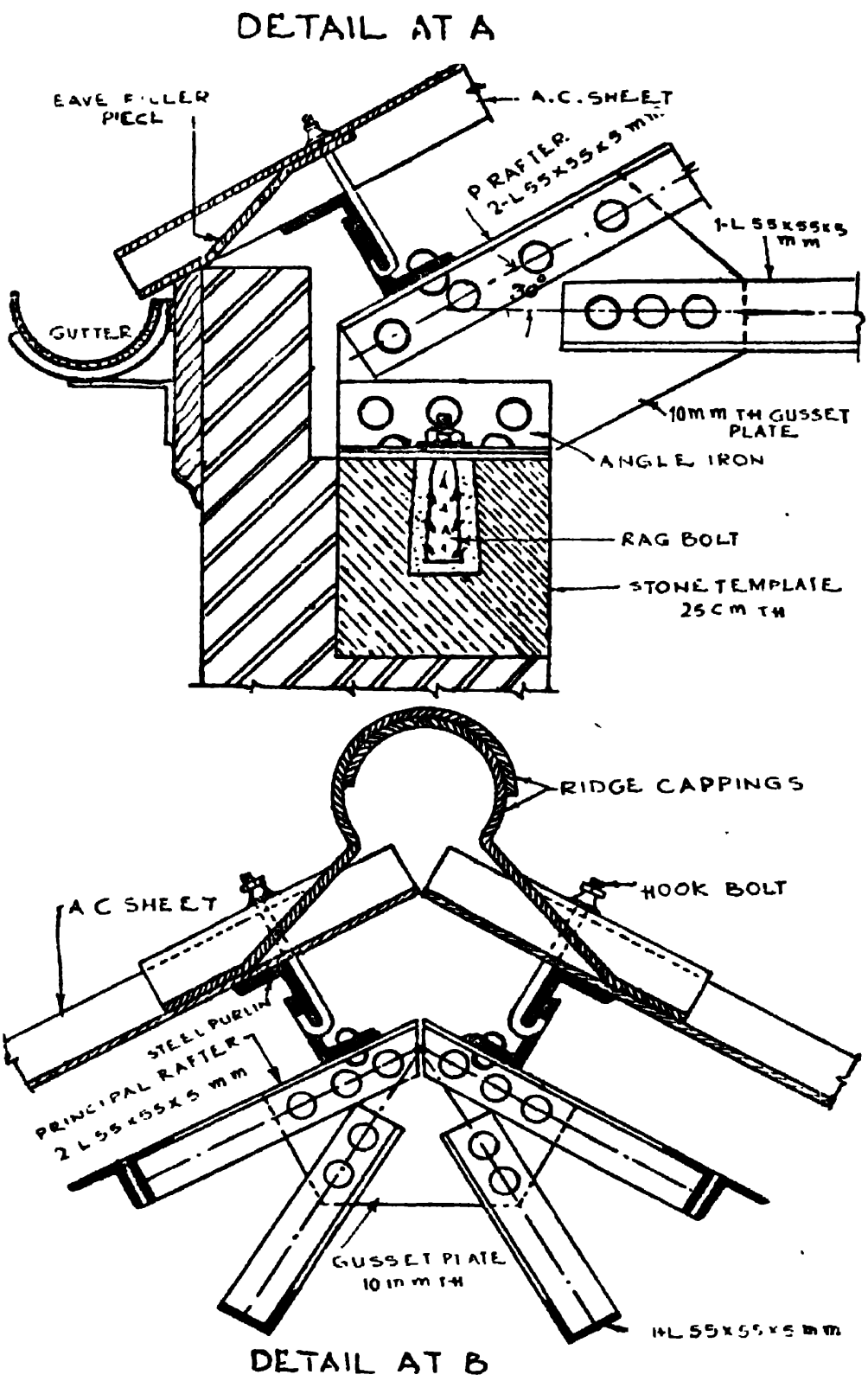


Fig. 21·11

Steel truss suitable for 8 m. span



Figs. 21·12—21·13

Details of the truss shown in Fig. 21·11

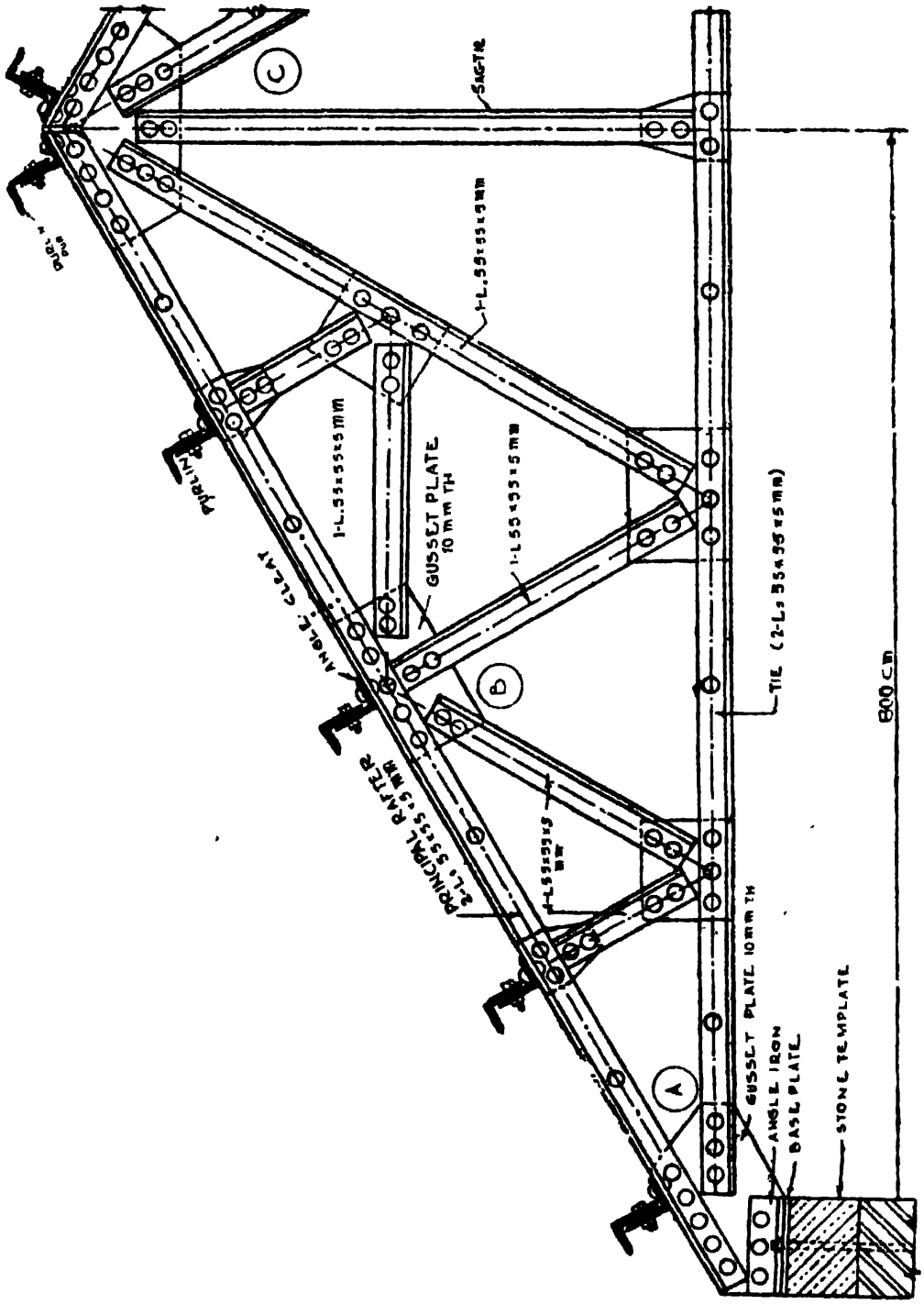
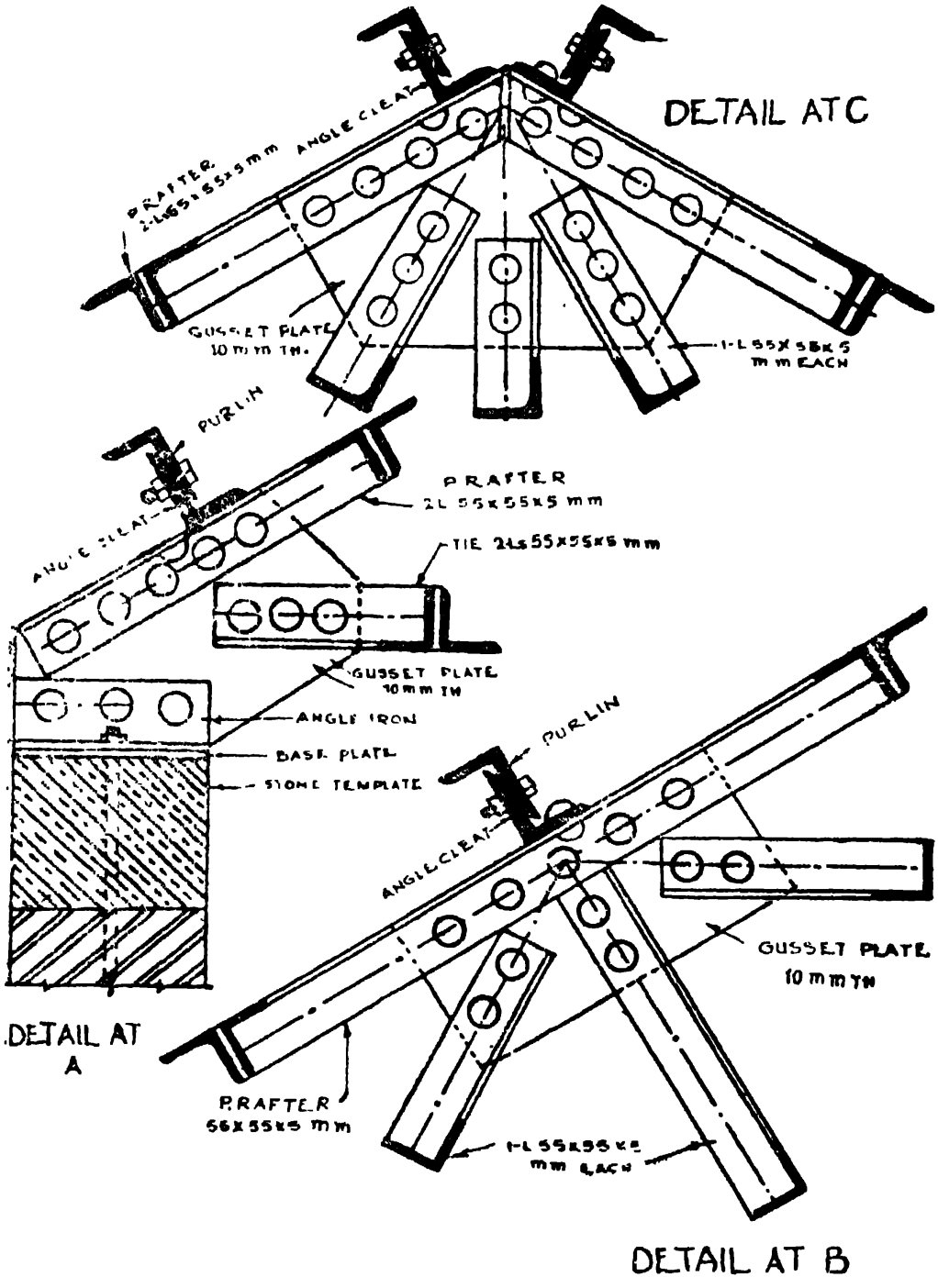


Fig. 21·14
Steel truss suitable for 16 m. span

21·10 Welding. It is a process of joining two or more structural members by introducing fused metal into fillets between them or by raising the temperature of their surfaces or edges to the fusion temperature and applying pressure. It may thus be said to be an alternative method of connecting structural steel sections. With the development of welding it has become possible to rende architectural beauty to steel structures also. Structural me n ::s



Figs. 21-15—21·17

Details of the truss shown in Fig. 21·14

the desired pattern can be joined flush to a smooth and pleasing surface. It has a number of advantages over riveted connection ; some of them are given below :

(1) Rapid execution of work.

(2) Noise produced during the process of riveting is eliminated in welding.

(3) It is economical when used on a large scale.

(4) There is a great saving of material as the angle cleats which are necessary in riveted connection, are eliminated in welding.

(5) In welded connection, the entire section is considered effective for taking up tensile stresses as there is no reduction in sectional areas on account of holes etc.

There are two different methods of welding commonly adopted. (1) Electric arch welding, (2) Oxy-acetylene welding. Electric arch welding is economical and is commonly used in places where electricity is easily available. In case of oxy-acetylene welding, a flame of high temperature is produced by burning a mixture of acetylene and oxygen.

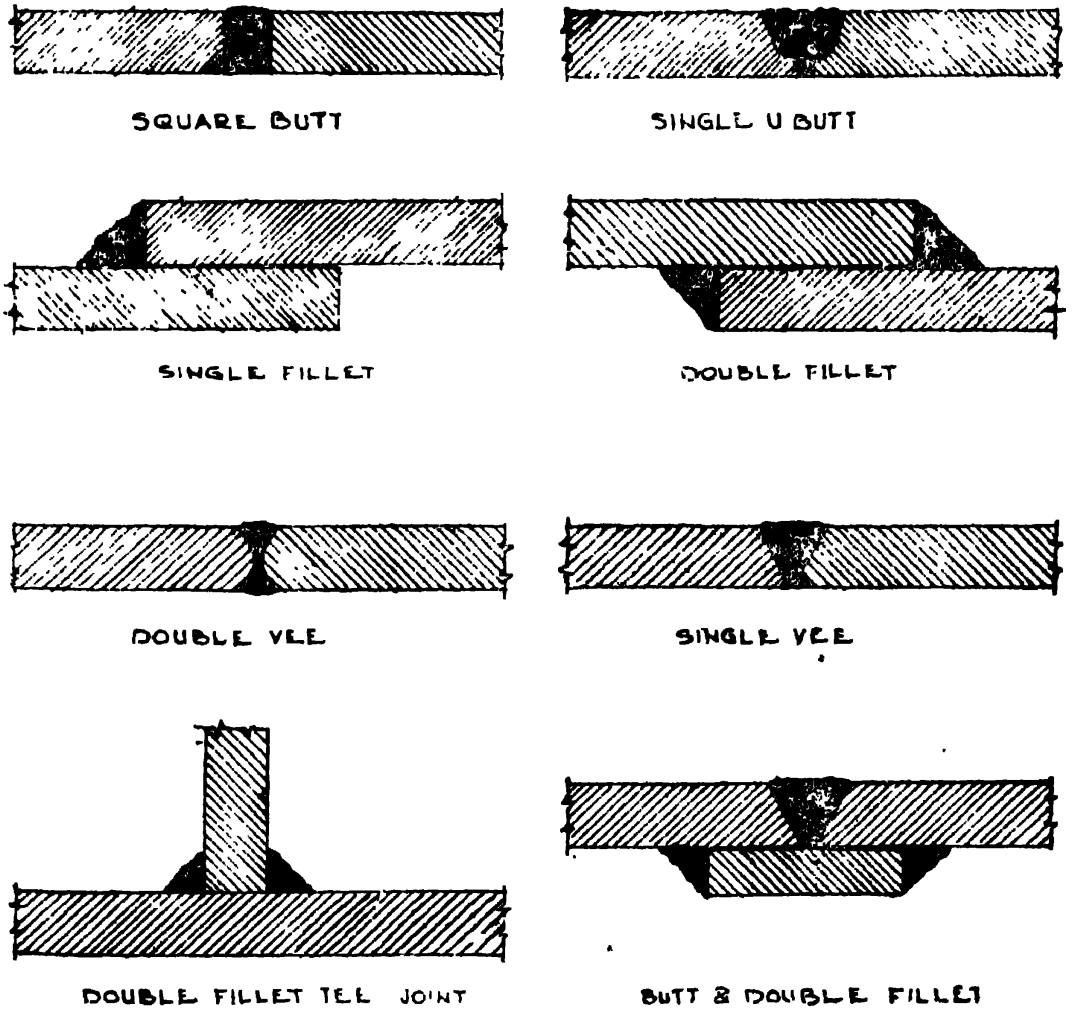


Fig. 21·18

Different types of welded joints

21·11 Types of Weld Joints. There are three different types of welds, namely, Butt welds, Fillet welds and Lap welds.

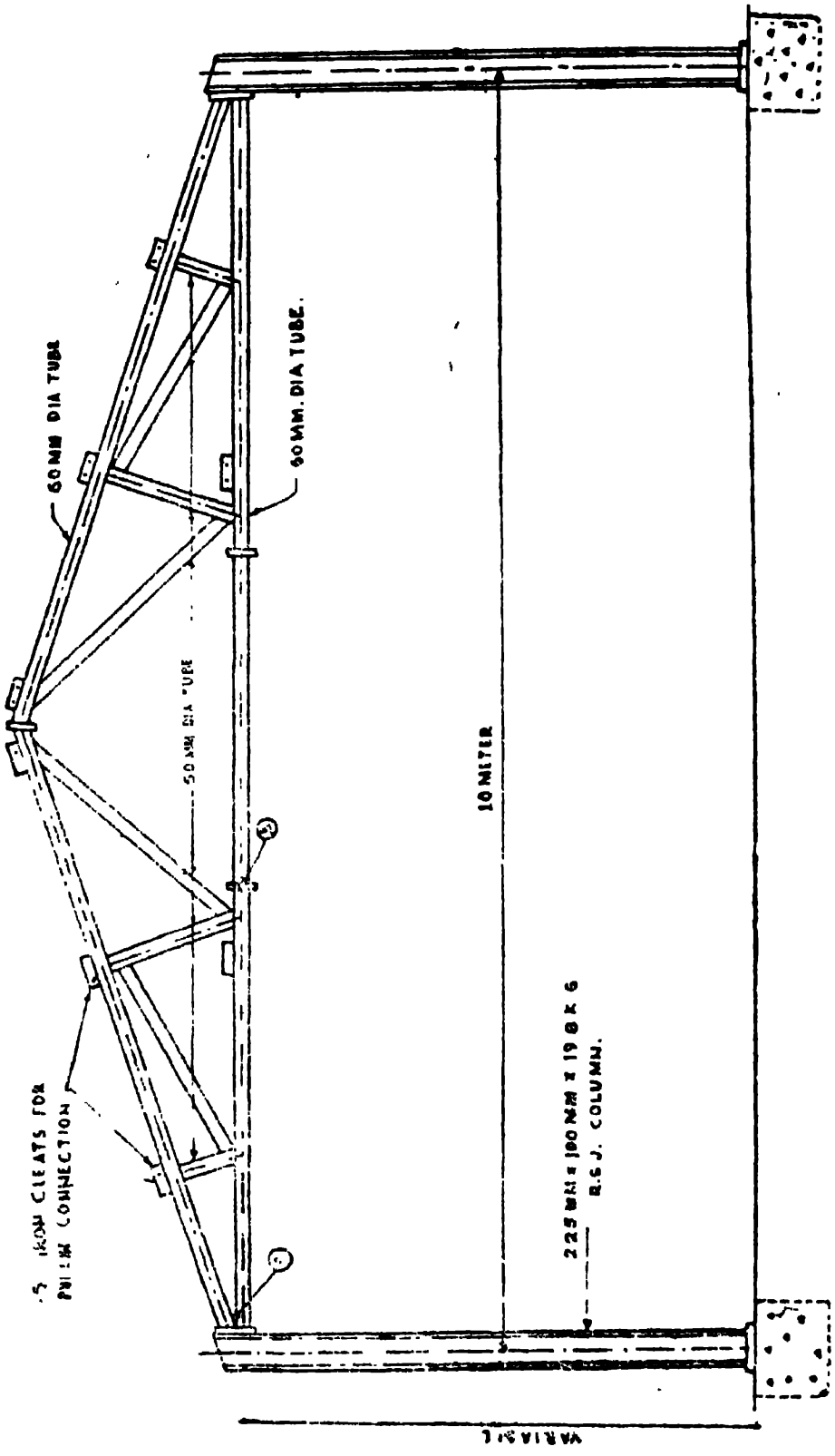
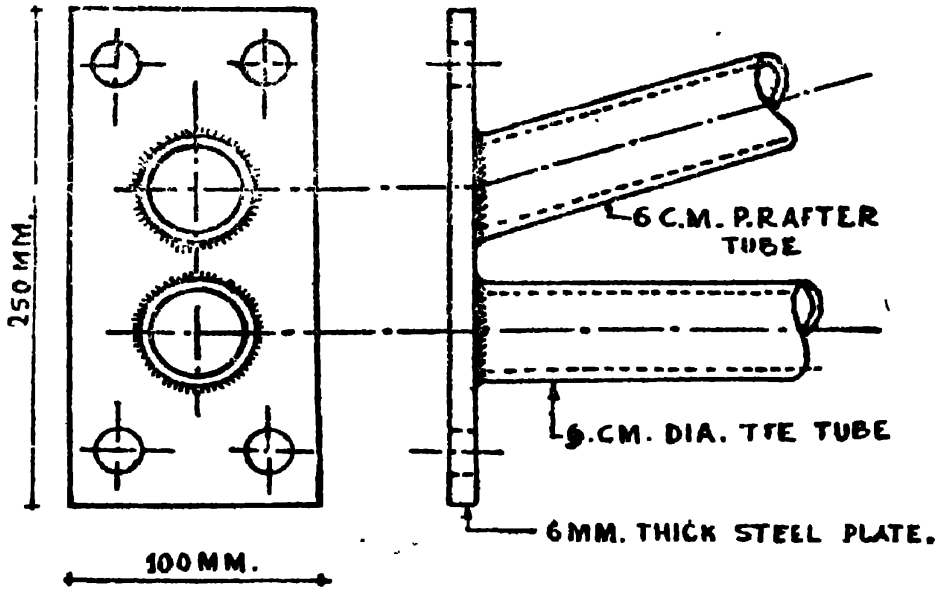
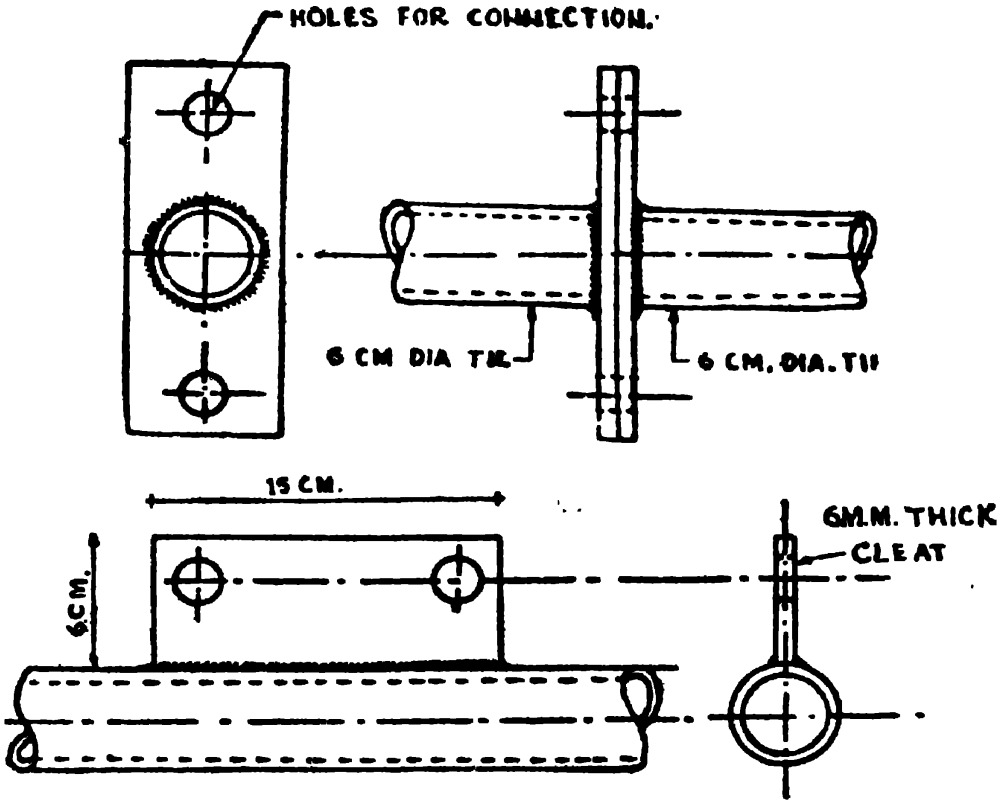


Fig. 21·19
Elevation of a Tubular steel truss 10 metre in span



DETAIL AT "A"

DETAIL AT "A"



DETAIL OF PURLIN CLEAT.

Fig. 21·20

Detail of the tubular truss at various junctions

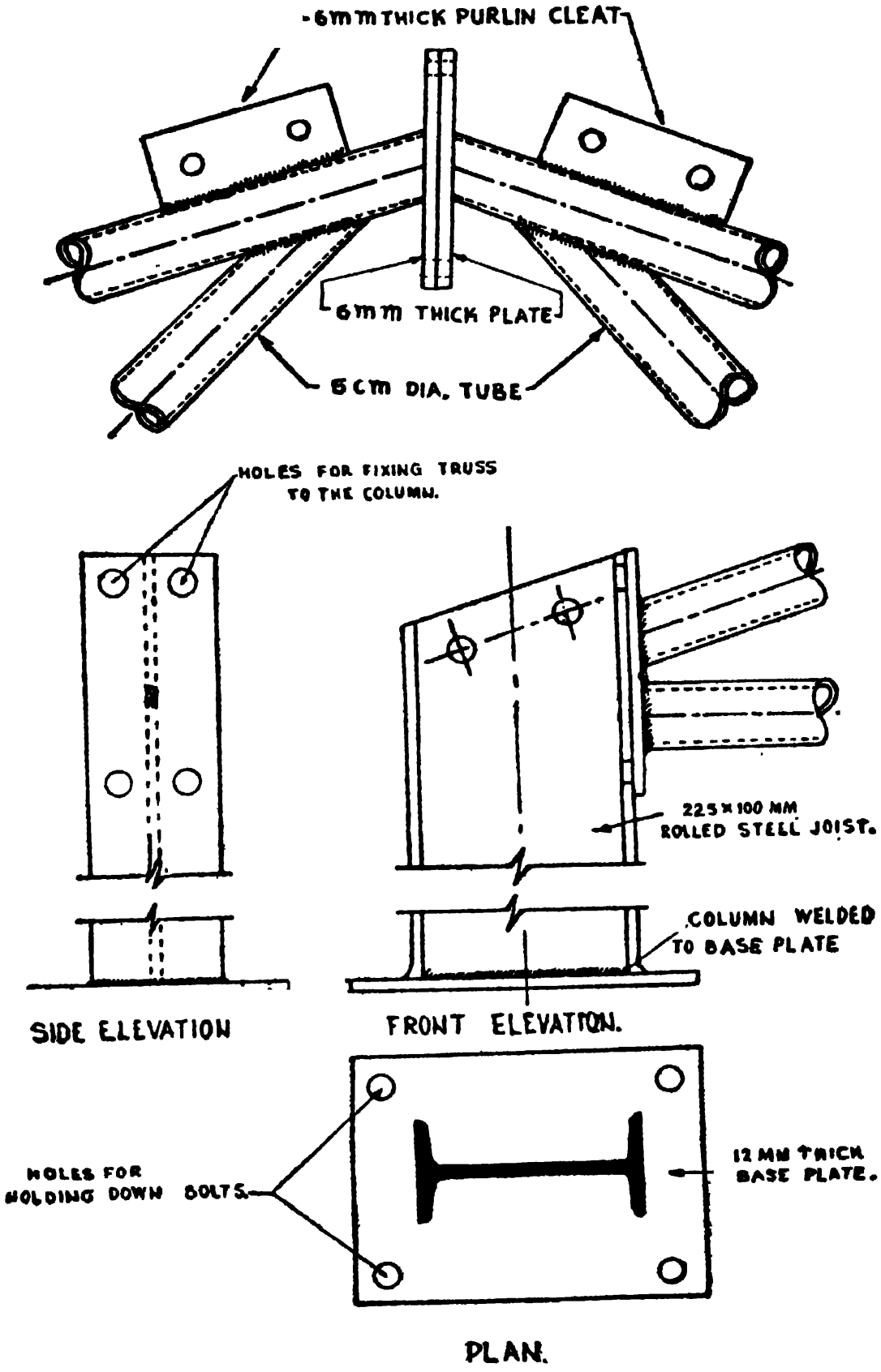


Fig. 21·21
Details of tubular steel truss shown in Fig. 21·19

Butt weld : In this type, the edge of one plate is brought in line with the edge of a second plate and the joint is filled with welding metal or the two edges are heated to their fusion temperatures and pressed together.

Fillet weld : In this type, the edge of one plate is brought against the surface of another (not in the same plane) and welding metal is fused in the corner between the two plates. Thus the joint can be welded on one or both the sides. Different types of butt weld and fillet welds are shown in Fig. (21·18).

Lap weld : In this type, the edges of plates are lapped one over the other and the edge of one plate is welded to the surface of the other.

Questions for Rivision

1. Compare the merits and demerits of structural steel work with reinforced concrete construction.

2. What is the influence of the shape of the steel member upon its position in a steel structure ? Sketch the various shapes of angles, T's channels etc., which are commonly used in steel work.

3. What is the function of rivets in a steel structure ? Describe the various shapes of rivets and the method of riveting in detail giving importance to the general precaution necessary to be observed in the work.

4. What are the various types of beams used in steel frame work ? Describe briefly the important steps which are necessary to be followed in the design of a simply supported beam.

5. Sketch the various types of welding joints. What are the advantages of welding over riveting ?

6. Write a short note on tubular steel roof truss. Sketch the details of a specimen truss at the following junctions :

(*i*) Junction of the beam with principal rafter.

(*ii*) Junction of principal rafter head.

(*iii*) Junction of purlin and principal rafter.

(*iv*) Junction of truss with the steel stanchion.

(*v*) Foundation of the stanchion.

7. Discuss the pros and cons of using the following in a factory building :

(*i*) Cast iron columns.

(*ii*) Built in R.S. stanchions.

(*iii*) R.C.C. columns.

8. What are the main principles to be considered in designing the roof of the assembly hall of a factory measuring 37 m × 152 m ?

The columns are spaced 15 m. centre to centre along the breadth of the building. Indicate by sketches the details of the suitable steel roof truss for the above building, roof cover and ceiling. Give large scale sketches showing the details of the wall supports and the joints of the truss.

9. State the principles governing selection of the members of a steel roof truss :

(*a*) For members in tension.

(*b*) For members in compression.

Show, by suitable sketches, the fixing arrangements you would recommend for the end bearings of a 12 m. span steel roof truss supported on brick walls.

10. Describe several possible types of failures of riveted joints. Draw sketch to illustrate your answer. On what basis are allowable rivet unit stresses usually determined ?

11. Draw enlarged working details to show any two of the following

(*a*) End connections for an angle-iron riveted steel truss of 12 m. span carried on a masonry wall. Rain water gutter and down-take pipe to be also shown.

(*b*) Purlin connection with principal rafter and asbestos sheet roofing to be shown in section and plan.

12. An asbestos cement sheet roof has to be provided for a workshop building 49 m. × 12 m. Sketch the type of truss you would adopt and detail the junction at the head (with gutter) and the crown. Show how the truss is supported on the brick wall. Assume suitable dimensions for all the members.

13. A drawing hall in an office building is to be covered with C.G.I. sheet roofing over tubular steel truss. The clear span of the truss is 10 m. and the trusses are to be supported on stone masonry olumns spaced 3 m. centre to centre. Draw a sectional elevation of the shape of the truss you propose to use and show to a large scale the details of the important junctions of the truss.

14. A factory building 20 m. × 40 m. is to be covered with asbestos cement sheeting fixed on steel truss. The trusses are to be supported on 60 cm. × 60 cm. R.C.C. columns 5·5 m high above the floor level. The columns are spaced at 4·5 m. centre to centre along the length of the building. Draw an elevatian of a truss—suitable for the said span assuming approximate sizes of its various members. Draw details of joint at the following points :

(*i*) Eaves.
(*ii*) Ridge (crown).
(*iii*) Principal rafter and purlin.

Also show the method of fixing A.C. sheeting to the truss.

15. The roof of a workshop building is to consist of C.G.I. sheets on steel trusses. The span of each truss is 15 m. and the truss is supported on 60 cm. (3 brick) thick walls on either side. Show the details of the truss you would propose for the span of 15 m. Draw to a large scale the details of its fixing arrangement with the walls. Adopt suitable sections of the various members of the truss. Draw the details of all the important junctions of the truss.

16. A 6 m. × 6 m. room has to be provided with a jack-arch roofing. Describe, with the help of sketches, the formwork and centering arrangements required for the purpose and state how you would proceed to lay this roof.

You are also required to give a suitable design for the R.S.J.'s and the tie rods, if the roof has to support a live load of 293 kg/m^2. You may assume your own working stresses and any other data required in this connection.

17. An automobile workshops shed of size 40 m. × 8 m. is to be consructed. Suggest a suitable roof for this shed. Sketch the details of the roof you propose giving the approximate size of the members to be used. Will you require any bracing for this roof ? The height at the top of the column on the wall is 6 metres. (*A.M.I.E., May 1969*)

22

Plastering, Painting and White/Colour Washing

22·1 Plastering. This is a process of covering rough surfaces with a plastic material to obtain an even, smooth, regular, clean and durable surface. Plastering conceals defective workmanship and covers up unsound and cheap quality material. Often, plastering is required to provide a satisfactory base for decorating the surface by white-washing, colour washing, distempering or painting. External plastering also termed as 'rendering' is done with the object of improving the resistance of the surface to rain water penetration and other atmospheric influences.

The plastic material or plaster is made by working together a mixture of building materials which may be cement, lime or clay, fine aggregates (usually sand) and water. Certain additives are sometimes added to improve its adhesiveness, durability and lusture. When cement is used as the binding material, the plaster is termed as cement plaster and when lime is used as the binding material it is called lime plaster. Sand forms the greatest proportion of a plaster. Sand controls the shrinkage, porosity, strength and adhesive properties of a plaster. Fine sand is often recommended for plastering and it should be so graded that it should not pass by more than 5% through a sieve of 100 mesh B.S. sieve. Sand used should be clean, sharp and free from deleterious matter. Water used should be clean and fit for drinking purposes. Depending upon the availability of the materials, the choice of plaster for any particular location is governed by the rainfall, weather condition, and the finish desired.

22 2 Preparation of Surface for Plastering. The durability of plaster depends to a great extent upon its adhesion with the background. The preparation of surface is of prime importance. All the projections which extend by more than 13 mm. from the general face of the masonry wall face are knocked off to obtain a uniform surface and to reduce consumption of plaster. In order to obtain a good key of the plaster with the wall surface, all the joints in the masonry are raked out for a depth of at least 13 mm.

Dust and loose mortar is brushed out of the raked joints. The surface is rendered free from oily, greasy spots and efflorescence, if any, is removed by brushing and scrapping. In case of old walls, the smoothness of the surface is destroyed by hacking it with some tool. The surface is then thoroughly washed with water and kept wet before plastering is commenced.

To ensure required thickness and a true surface, patches of plaster 15 cm. × 15 cm. are first of all applied horizontally and vertically at about 1·8 m. apart over the entire surface. The surface of the patches of plaster (also known as screed) serves as gauges for maintaining even thickness of the plaster being applied. Mortar is then applied on the wall between the screed with trowel.

22·3 Lime Plaster. Lime used in plastering may be fat lime or hydraulic lime. Fat limes make best plaster as they yield good putty after slaking. Hydraulic lime on the other hand yields harder and stronger plaster, but it may contain some unslaked particles which may slake slowly (may be in 8 to 12 months) on absorbing moisture from atmosphere and damage the plastering by forming blisters. As a precaution, the hydraulic lime, if used, should be ground dry with sand left for about 2 or 3 weeks and then reground before use.

Mortar for lime plaster is usually prepared by mixing sand and lime in equal proportions. Cement in small quantity is sometimes added to the mixture to improve its strength. Gugal (a kind of fragrant gum) and chopped hemp are sometimes added at the rate of 4·5 kg. and 2·7 kg. to every 2·83 cu.m. of mortar respectively. This treatment prevents the formation of cracks in plaster on drying.

22·4 Application of Plaster. It is usual to provide 13 mm. and 16 mm. thick plaster on plain side and rough side of 20 mm. thick walls respectively. In case of rubble masonry 19 mm. thick plaster is recommended to account for the roughness or uneveness of the surface. Plaster may be applied in one, two or three coats on the prepared wall between the screed with the help of trowel. In the one coat treatment mortar is applied in a uniform surface slightly more than the specified thickness. This is then beaten with thin strips of bamboo to ensure thorough filling of joints and finally brought to a true surface.

During the process of finishing, a solution of lime putty is applied on the surface to make the surface smooth and workable. The finished surface is then cured for at least seven days.

In case it is desired to apply plaster in more than one coat, the first coat, also known as rough coat, is applied on the surface in a layer of 6 to 10 mm. in thickness. The mortar is dashed against the surface to serve as a key to hold the next courses.

Second coat is then applied over the first coat, after the latter has set and roughened. It is well pressed and rubbed with wooden straight edge, to obtain the desired surface. The thickness of layer of mortar in 2nd coat varies between 6 to 10 mm.

The third or finishing coat is applied 5 days after the 2nd coat. This coat does not exceed 3 mm. in thickness and usually consist of a mortar made with cream of white or fat lime (neeru) with fine white sand taken in the ratio of 1 : 2. This is well rubbed with wooden float and then finished with a trowel to a smooth and even surface.

22·5 Cement Plaster. Cement plaster forms an ideal coating for external renderings. It is specially suited for damp conditions (bathrooms, etc.) where non-absorbent wall surface is essential. Cement plaster is usually applied in one coat. Sometimes, when the thickness of plaster is more than 16 mm. or when it is desired to have a finer finish, plaster is applied in two coats.

In case of plastering with one coat, cement plaster is applied on the prepared surface between the screed with mason's trowels. The surface is levelled by means of wooden float and straight edges and finally polished with a trowel.

In case plastering is required to be done in two coats, the first coat is applied as described above with the only difference that the plastered surface is not polished. The surface of the first coat when set (not dry) is roughened with a scratching tool, to form a key for the 2nd or finishing coat. The finishing coat is then applied over the first coat surface (made rough and damp), within 48 hours. This coat is well troweled and the surface finished smooth.

22·6 Mud Plastering. This type of plastering is commonly seen in kuchha construction in villages and in other structures of temporary character. This is the cheapest form of plastering. Mud to be used for plastering should be made from earth free from grass, roots, gravel, stone grit etc. All the clods in the earth should be brooken and reduced to a fine powder. The earth is then mixed with plenty of water in a pit, adding chopped straw, hay or hemp at the rate of 33 kg./cubic metre of earth (1 kg./cu. ft. of earth). This mixture of earth and straw, well flooded with water, is kept for at least 6 days, During this period, the mixture is worked up at intervals with foot or phawras so as to convert it into a homogeneous mass.

The surface to be plastered is prepared exactly in the same manner as that for lime or cement plaster. Mud plaster is generally applied in two coats, the first coat being 13 mm thick while the thickness of the second coat is kept 6 mm. The plaster is dashed against the wall and worked with a straight edge and floats. The second coat is applied only when the first coat has set (not dry).

No curing is done in this case. Cracks formed during drying or any portions which sound hollow when tapped, are repaired by opening such places out and then treating the surface with a mixture of clay and cow-dung.

22·7 Stucco Plastering. Stucco is the name given to a decorative type of plaster which gives an excellent finish. The surface plastered with stucco, compares very much with marble finish both in smoothness and elegance. Stucco plaster can be used for interior as well as exterior surfaces. It is usually laid in three coats making the total thickness of the plaster to about 25 mm. The first coat is called the scratch coat ; the second a finer coat, also known as the brown coat, and the third is called the white coat or finishing coat.

Each coat should be permitted to dry thoroughly before the next coat is applied.

Stucco for interior walls : In this case the scratch coat consists of a coat of lime plaster 12 mm. in thickness. The second coat or the brown coat consists of lime paster which is made richer in lime and is 10 mm. in thickness, and the finishing coat which is 3 mm. thick consists of a mixture of finest lime and well-ground white stone (which may be marble or quartz). The finishing coat is carefully polished with a bag of linen containing moist chalk in the first instance and then oil and chalk. The surface is finally rubbed with oil only and finished smooth and bright.

Stucco for exterior walls : In this case the mortar for the rough coat is prepared by mixing cement and sand in the ratio of 1 : 3 and then adding 10% by weight of hydrated lime to the mixture. The thickness of the first coat in this case is also kept 12 mm. The second coat has the same composition as the rough coat but it is 10 mm. in thickness. The finishing coat which may be 3 to 6 mm. in thickness consists of a mixture of cement and sand taken in proportions of 1 : 2 to 1 : 2½. White or coloured cement may be used in finishing coat to obtain the desired shade.

22·8 Plaster on Lath. Lathing may be either of wood or that of expanded metal. Wooden lath is used for forming a ground for plastering timber partition walls and ceilings of timber floors. Wooden laths are liable to decay or get attacked by white ants and hence they are rarely used. Wooden laths consist of thin strips of well seasoned wood, about 25 mm. in width and 90 to 120 cm. in length. Depending upon the strain due to load of plaster, thickness of the strips vary from 3 mm to 13 mm. The thicker strips are used in the ceilings where the strain is maximum while the thinner ones are used for vertical side of the wall. The strips are nailed in

parallel lines to the wooden frames. 10 mm. gaps are provided between two successive strips for plaster. The strips are fixed so as to break joint at the butt ends. The plastering is then done in the usual manner.

Metal lathing is available in a wide range of designs. They may be classified as (1) Expanded metal ; (2) B.R.C. fabric ; (3) Ribbed expanded—with ribs forming an integral part of the sheets ; (4) Perforated ; (5) Devetailed and so on. Plain or expanded metal lathing is commonly used in residential buildings. The lath is stretched tightly as much as possible and then fixed to the wooden support by G.I. staples. In case of concrete or masonry surface, wooden plugs have to be embedded for fixing the lath. The lath sheets must be over-lapped not less than 25 mm. at the sides and ends and they should be fastened by galvanised lacing wire running through the meshes. The fixing of the lath is so planned that the overlaps do not occur at corners. The lath is always bent at the corners. The lath is plastered in the usual manner.

22·9. Special Types of Finishings. The plastered surfaces may be finished in a variety of finishes. The types of finishing treatments usually adopted for external surfaces are briefiy given below :

(*a*) *Smooth cast* : It is a finish which presents a levelled and smooth surface. The mortar for the finish is made by mixing cement and fine sand in ratio of 1 : 3. The mortar may be applied in one or two coats and finished by working with a wooden float. Steel floats are not recommended for external renderings as they give a very smooth finish which is liable to crack and craze due to exposure to atmospheric conditions.

(*b*) *Rough cast* : It is a finish in which the mortar for the final coat contain a proportion of fairly coarse aggregates. The wet plastic mix is thrown on the surface by means of a scoop or trowel, and is left in the rough condition. The texture desired is regulated by the size of the coarse aggregate which is generally varied between 6 to 12 mm. The mortar for the finish is made by mixing cement, fine sand and coarse aggregate in the ratio of 1 : 1½ : 3. Rough cast finish is water-proof, durable and resistant to cracking and crazing. This type of finish is considered particularly suitable for situations subjected to heavy rainfall and strong winds.

(*c*) *Pebble dash* : It is a finish in which small pebbles or crushed stones of suitable size (usually varying from 10 to 20 mm) are thrown on to a freshly applied final coat of mortar and left exposed. The mortar for the final coat is usually made by mixing cement and coarse sand in the ratio of 1 : 3 and is laid in about 1 mm. thickness. The pebbles used for dashing should be well washed and thrown wet on to the final coat while it is still plastic.

To ensure good bond between the dashing and the final coat, the pebbles may be tightly tapped into the mortar with a wooden float or with the flat of a trowel. This finish possesses all the advantages of the roughcast finish and is recommended in similar conditions.

(*d*) *Scrapped finish* : It is a finish in which the final coat, after being levelled and allowed to stiffen for a few hours, is scrapped with a steel straight edge, old saw blade or other such tool to remove the surface skin. Various types of scrapped finishes can be obtained by using different types of tools in different manners. In this case the final coat is usually 6 to 12 mm. thick of which about 3 mm. is removed in the scrapping process. The scrapping is done after the setting has taken place. In the process of scrapping, the surface skin of the mortar is removed to expose the aggregate and the texture obtained depends upon the grading of aggregates used in the final coat. This type of finish is less liable to crack than plain finishes.

(*e*) *Textured finish* : In this finish, ornamental patterns or textured surfaces are produced by working with various tools on the freshly applied final coat. This type of finish possesses all the advantages of the rough cast finish.

The various finishes described above (smooth cast finish being an exception) require little maintenance except for fungus growth and lodgement of dirt.

22·10 Special Materials used in Plastering

1. *Plaster of Paris* : It is also known a calcium sulphate plaster and is obtained by heating Gypsum. Gypsum occurs in the form of natural rock which is usually composed of one part of calcium sulphate and two parts of chemically combined water of crystallization. When the water of crystallization is driven off from gypsum stone through calcination or heat treatment, the product obtained is called the plaster of Paris. When water is added to this powdery product, it forms a plastic mass, which sets rapidly. Plaster of Paris adheres well to gypsum, wood, metal lath, masonry or other plastering surfaces. The setting time of the plaster of Paris can be controlled by the addition of certain salts. It is mostly used in combination with ordinary lime, for making good, small defects in plastered surfaces. Since gypsum is slightly soluble in water, plaster of Paris is not used for external works.

2. *Keene's Cement* : This is the hardest and densest form of gypsum plaster. It is obtained by calcining selected form of gypsum. It is pure white in colour and takes a high, glasslike polish. It is used for highly decorative plastering work and ornamental work. It is used alone for extra-hard finish or it is mixed with lime putty for medium hard finish.

3. *Barium plaster* : This is essentially made from barium sulphate and is applied in the form of a final coat to serve as a protection around X-ray rooms.

4. *Acoustical Plaster* : It is a gypsum mixture, which is employed as a final coat to serve the purpose of a sound-repellent finish. The minute passages in the form of tiny openings in the plaster coat, absorb sound. The plaster is usually applied in two coats, each 6 mm. in thickness. The surface must be finished uniformly in a manner that promotes porocity, as such, wooden float is preferred to a steel trowel in finishing.

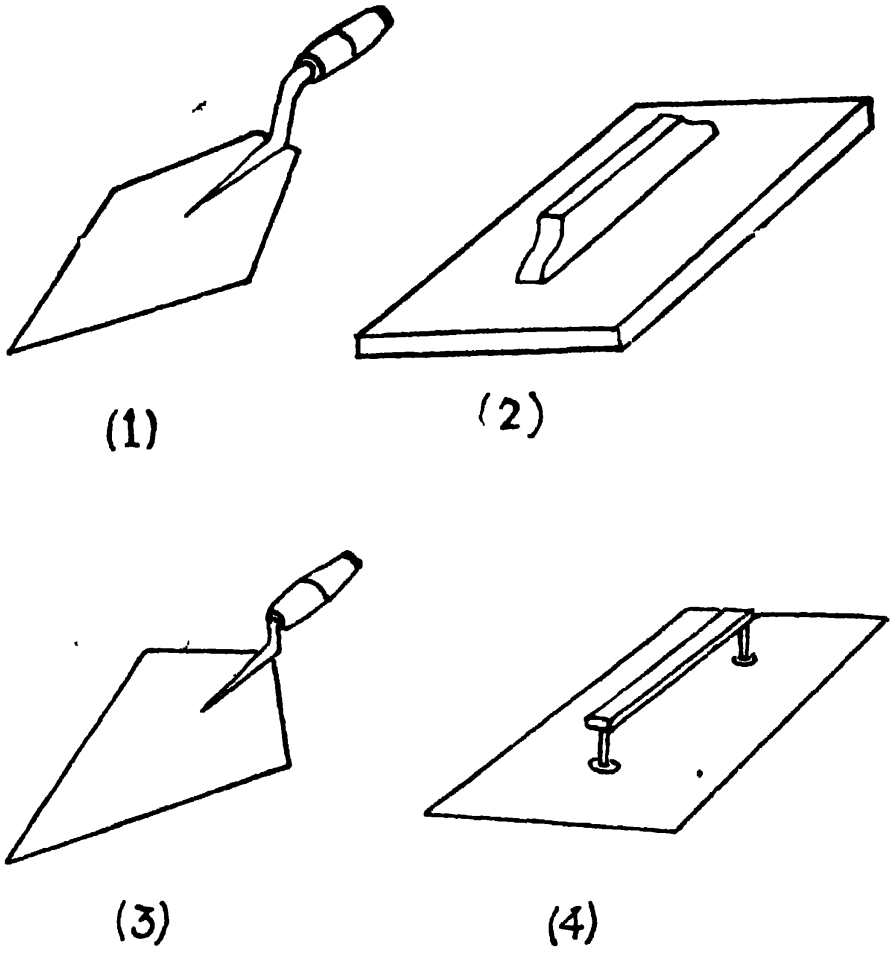


Fig. 22·1

Figs. (1) and (3). Different types of steel trowels.
Fig. (2) Wooden float.
Fig. (4) Metal float.

22·11 Defects in Plaster Work. The following defects may occur in plaster work :

1. *Cracking* : This consists in formation of cracks in plaster work which may be on account of the following :

(*i*) Old surface not being properly prepared.

(*ii*) Movements in the backing either on account of the thermal expansion or due to shrinkage caused by the drying of the backing material. To avoid this the backing surface should be allowed to dry before applying the plaster.

(*iii*) Movement in the plaster itself on account of the expansion (in case of gypsum plaster) or shrinkage of the plaster coat (in case of lime-sand plasters) during drying.

(*iv*) Execessive shrinkage of plaster due to the application of mortar in thick coats.

(*v*) Workmanship and the method of application of the plaster. Rough textured finishes are generally less likely to show cracking than smooth finishes.

2. *Blowing or blistering of plaster* : This consists in formation of small patches of plaster swelling out beyond the plastered surface and are chiefly due to faulty slaking of lime particles in the plaster. After the application of plaster, the unslacked particles in the lime start slaking and thus the defect takes place. Properly slaked lime should be used to prevent blistering.

3. *Falling out of plaster* : This defect may arise due to the following reasons :

(*i*) The adhesion of the plaster to the back-ground may not be perfect.

(*ii*) The suction of the backing material may not be uniform. At the places where the backing material absorbs excessive amount of water, the plaster loses its strength as well as the mechanical bond between the two surfaces.

(*iii*) Excessive thermal changes in plaster or backing.

(*iv*) The bond between the successive coat of plaster may not be perfect.

4. *Efflorescence* : If soluble salts are present in bricks or the mortar they absorb moisture from atmosphere and go into solution which appears on the surface in the form of whitish substance as the

moisture dries out and the salts crystallise. The surface gets disfigured and concentrated strains present an ugly appearance. Efflorescence may occur on brick work or on the surface of plaster.

Efflorescence on the surface is unlikely to cause any real damage to the bricks unless the quantity of soluble salts present is abnormal. However, if the formation of crystal (on drying) of the salt solution takes place within the brick, it can result in the disintegration of the material and cause severe flaking of the plastered surface.

Efflorescence on the surface can be removed to some extent by brushing and washing the surface repeatedly.

In case of brick work, salts can be removed, by applying a solution of zinc sulphate and water and then brushing of the surface when dry.

In another method a solution consisting of one part o hydrochloric or sulphuric acid diluted with 5 parts of water is applied on the surface with the scrubbing brush. The surface is then thoroughly washed and rendered clean and dry.

POINTING

22·12 General. In exposed brick or stone masonry, mortar joints are considered to be weakest spots for giving access to rain water or dampness. Pointing consists in raking out joints in brick or stone masonry to a depth of about 13 mm. and filling the same with mortar of slightly richer mix. This treatment not only protects the joints from the adverse effect of atmosphere but also magnifies the appearance at the surface by exhibiting the pattern of the joints, their thickness, colours and texture.

Preparation of Surface. Pointing should preferably be done whilst the mortar in the joints is still green. This has the advantage of giving a good joint between the soft and wet mortar in the masonry and the mortar used for pointing. The raked joints, both in case of old or new work, are cleaned of all loose mortar or dust by using brushes. The joints as well as the wall surface is well washed and kept wet for a few hours before pointing.

22·13 Mortar. Pointing may be done by using lime or cement mortar. The mortar for lime pointing is made by taking equal parts of fat lime and fine sand and then grinding the mixture thoroughly, in a mortar mill. The mortar for cement pointing is made by mixing cement and sand in proportion of 1 : 2 or 1 : 3.

22·14 Application of Mortar. The mortar is pressed into the raked out joints with a pointing trowel, and rendered flush, sunk or raised according to the type of pointing required. The

desired type of pointing is then made with the proper tool and the surface of the masonry cleaned of all superfluous mortar. The pointing should be kept wet for about a week. The pointing lines should be regular, truly horizontal and vertical. In case of random rubble masonry, where the joints are slanting, the line of joints from different directions should preferably meet at or near the junctions.

22·15 Types of Pointing. The various types of pointing commonly used are described below. The choice of the particular type depends upon the type of masonry, nature of the structure and the nature of the finish desired.

(*1*) *Flush pointing* : In this type of pointing, the mortar is pressed into the raked joints and finished off flush with the edges of the bricks or stones, so as to give a smooth appearance. The edges are then neatly trimmed with a trowel and straight edge. This is the simplest type of pointing and is extensively used in brick work and stone masonry face work.

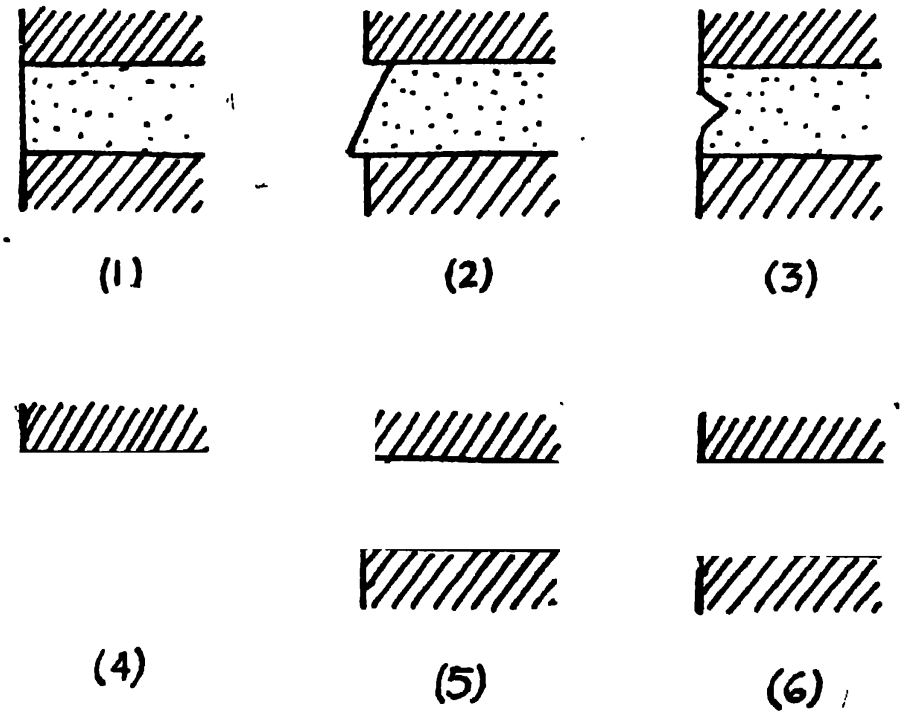


Fig. 22·2

Fig. 1. Flush pointing.
Fig. 2. Cut on weathered or struck pointing.
Fig. 3. V-grooved pointing.
Fig. 4. Keyed—or grooved pointing.
Fig. 5. Tuck-pointing.
Fig. 6. Beaded pointing.

(2) *Cut or weathered or struck pointing* : In this type of pointing, the mortar is first pressed into the raked joints. While the mortar is still-green, the top of the horizontal joints is neatly pressed back by 3 to 6 mm. with the pointing tool. Thus the joint is finished sloping from top of the joint to its bottom.

(3) *V-grooved pointing* : This type of pointing is made similar to keyed or grooved pointing by suitably shaping the end of the steel rod to be used for forming the groove.

(4) *Keyed or grooved pointing* : In this type of pointing, the mortar is pressed into the raked joints and finished off flush with the edge of the bricks or stones. While the pressed mortar is still green, a groove is formed by running the bent end of a small steel rod (6 mm. in diameter) straight along the centre line of the joints. The vertical joints are also finished in the same manner.

(5) *Tuck pointing*. In this type of pointing, the mortar is first pressed in the raked joints and is finished flush with the face of the wall. While the pressed mortar is still green, the top and bottom edges of the joint are cut parallel so as to have a uniformly raised band about 6 mm. raised with 10 mm. width.

(6) *Beaded pointing* : In this type of pointing, the mortar is pressed in the raked joints and finished off flush with the face of the wall. While the pressed mortar is still green, the steel rod having its end suitably shaped, is run straight along the centre line of the joints to form the beading.

WHITE/COLOUR WASHING

22·16 Preparation of White-wash. White-wash is made from pure fat lime (white stone lime) or shell lime. The unslaked lime is dissolved in a tub with a sufficient quantity of water, and the whole is thoroughly stirred with a wooden pole,, until it attains the consistency of thin cream. As a rough guide about 5 litres of water should be added to each kg of lime for making the cream. This mixture is allowed to stand in the tub for a period of about 24 hours and then strained through a clean coarse cloth. Clean gum dissolved in hot water is then added in the proportion of 4 kg of gum per cu. m. of thin cream.

To prevent glare and to obtain pleasing effect, blue (copper sulphate) in proportion of 4 kg. of copper sulphate per cu. m. of thin cream is added. In order that the coat of white-wash may stick well to the surface. Alum or common salt taken in the same proportion as gum, is also sometimes added.

22·17 Preparation of Surface. Before applying white wash on new walls, the wall surface is thoroughly cleaned, brushed and rendered free from mortar droppings and other foreign-matter. If the surface to be coated is sufficiently smooth, it should be rubbed with sand paper to ensure proper adhesion of white wash.

In case of re-white washing an old surface, all loose pieces and scales should be scrapped off. The old loose white-wash is removed by rubbing with sand paper and the holes in wall filled with lime putty. The plaster repairs of the wall should be done well in advance, so that they are dry before white washing. The greasy spots should be given a coat of a mixture of rice water and sand so that the wash may stick to the surface. In kitchens or other places where the walls have been discoloured by smoke or other reasons, the surfaces should be given a coat of a mixture of wood ashes in water before applying white-wash.

22·18 Application of White-wash. White-wash may be applied in specified number of coats until the surface presents a smooth and uniform finish. Three coats are considered necessary for new work and one or two coats for old work. Usually moonj brushes are used for white-washing. Each coat consists of a stroke of the brush applied from the top downwards, another stroke applied from the bottom upwards over the first stroke, and similarly one stroke is applied horizontally from the right and another from the left, before the next one is applied. The finished dry surface should not show any signs of cracking or peeling and it should not readily stain the hand when rubbed. As a measure of protection doors, windows, floors, articles of furniture etc., should be protected from being splashed upon.

22·19 Colour washing. Colour wash is prepared by mineral colours (which are not affected by lime) of the desired shade to the prepared white-wash. The colour wash is applied in the same way as white-wash. The mixture is kept constantly stirred with a bamboo stick, while it is being used. Only colour wash, sufficient for the day's work, should be prepared. Prior to the application of colour-wash on new surfaces, a coat of white wash is applied which acts as a priming coat. In case of old, prepared surface, a coat of colour wash is applied over the patched and repair work. Two or more coats of colour wash are then applied on the entire surface till it presents a uniform finish. The surface should not appear powdery and it should not readily stain the hand when rubbed.

Questions for Rivision

1. What is the object of plastering ? State in brief the different types of plasters adopted for internal and external finishing of wall surfaces.

2. Write short notes on the following :
   (*i*) Stucco plastering,
   (*ii*) Mud plastering.
   (*iii*) Scrapped finish.

3. Differentiate between cement plaster and lime plaster.

4. Write short notes on the following :
   (*i*) Plaster of Paris.
   (*ii*) Keene's cement.
   (*iii*) Barium plaster.
   (*iv*) Acoustical plaster.

5. Write short notes of the following :
   (*i*) Cracking.
   (*ii*) Blistering of plaster.
   (*iii*) Rough cast plaster.
   (*iv*) Pebble-dash.

6. What is the object of pointing brick work ? Describe the operation of pointing giving the preparation of surface, the mortar and its application completely.

7. Writes short notes on the following :
   (*i*) Flush pointing.
   (*i*) Grooved pointing.
   (*iii*) Tuck pointing.
   (*iv*) , Cut or weathered or struck pointing.

8. What is the difference between the terms—colour-washing and white-washing ? Describe in detail the complete operation of white-washing of plastered wall surface.

23

Paints, Varnishes and Distempers

23 1 Paints. Paint is applied on timber, metal, brick or other materials in the form of a liquid which, on drying, forms a thin film on the painted surface. The essential function of the paint film is to provide protection or decoration or both. Paint is indispensable for the proper maintenance and preservation of wooden structures against warping, checking or decay. Most of the metals corrode if not painted at suitable intervals. Painting enables the masonry and concrete work to resist checking and disintegration, thereby extending the life of structure. Decoration, sanitation or improved illumination are the additional factors which often make painting necessary.

Paint is composed of two main components, *viz.*, pigment and organic binder. Pigment is the solid ingredient of the paint and is used in the form of a fine powder while liquid part of the paint is called vehicle. The vehicle varies with the type of paint. It is usually linseed oil for an oil paint, varnish in kalsomine in case of enamel paints and it is water in case of cold water paints.

23·2 Constituents of an Oil Paint. An oil paint is generally made up of six main constituents given below :

(*a*) *A base*

(*b*) *An inert filler or extender*

(*c*) *Colouring pigment*

(*d*) *A vehicle*

(*e*) *A solvent or thinner*

(*f*) *A drier.*

(*a*) **Base :** It is generally a metallic oxide and is used in the form of powder in a paint. Base is essentially a pigment which forms the chief ingredient of a paint. The most important reason for adding base or pigment in a paint is to make an opaque coating to hide the surface to be painted. In addition, it makes the film of coating resistant to abrasion and prevents shrinkage cracks formed in the film, during drying. White lead, red lead, zinc oxide, iron oxide and titanium whites are the bases commonly used.

(*b*) **Inert filler or extender** : It is a cheap pigment added in a paint to reduce its cost. In addition, it modifies the weight of the paint and makes it more durable. With proper formulations, the inert filler pigments may be helpful in contributing useful properties to the paint film. The commonly used inert fillers or extenders are : Barytes (Barium sulphate), lithopone, silica, silicate of magnesia or alumina, whiting, gypsum, charcoal etc.

(*c*) **Colouring pigments** : As the name indicates, it is a white or coloured pigment, mixed in a paint to get the desired colour of the paint.

(*d*) **Vehicle** : It is a liquid which acts as a binder for the various pigments, *viz* , bases, extender and colouring pigment. The vehicle makes the paint in the state of a fluid and thus helps to spread its ingredients uniformly over the surface to be painted. This forms an elastic, resistant to abrasion and reasonably impermeable film on drying. Refined linseed oil is a commonly used vehicle in oil paints. Tung, perilla, soyabean, fish, sunflower, tobacco seeds are also being used as vehicles in various combinations with linseed oil or without linseed oil.

(*e*) **Solvent or thinner** : It is a liquid which thins the consistency of the paint and evaporates after the paint film has been applied. It imparts to the paint film good properties as brushability, smoothness and easy flow. Turpentines, pure oils, petroleum spirit and highly solvent naptha are commonly used as solvent or thinner.

(*f*) **Drier** : These are materials containing metallic compounds and are used in small quantities for accelerating the drying of paint film. They act as catalysts for the oxidation and polymerization of the vehicle used in the paint. Litharge, lead acetate, manganese dioxide and cobalt are the driers commonly used. Not more than 10% (by volume) of the drier should be used in an oil paint. If used in excess, especially in the final coat, they tend to destroy the elasticity of the paint which finally leads to its flaking.

23·3 Characteristics of a Good Paint. A good paint should have the following characteristics :

1. It should stick well to the surface and should be able to seal the porous substrata.
2. Its consistency should provide easy workability.
3. The thickness of the paint film should be adequate for good protection and decoration of the surface.
4. The paint film should dry rapidly.
5. The dried paint film should be able to withstand the adverse weather effect for a long time without losing loss.

6. It should offer resistance to failure by checking, cracking and flaking.
7. It should possess good moisture resistance.
8. Its colour should not fade with the passage of time.

23·4 Bases. The pigments commonly used as the principal constituents for forming the body of various types of paints, are briefly given below.

White lead : This is perhaps the cheapest pigment and is thus extensively used for ordinary painting works. It is sold both in power form as well as in the form of a stiff paste made by mixing it with linseed oil. It has good binding and spreading power. It is very poisonous and is blackened when subjected to an atmosphere contaminated with sulphur compounds. Paints with white lead base can be easily tinted. It is not recommended for painting of iron works as it does not check rusting of iron. White lead paints are best suited for wood work.

Red lead : It is an oxide of lead, bright red in colour and is usually sold in powder form or in the form of paste made by grinding it in linseed oil. Red lead mixed with linseed oil is considered to be the best primer both for wooden surface as well as structural steel work. It forms a tough and durable film which sticks well to the surface.

Lead pigment paints have excellent moisture and mildew-resistance properties. They have good adhesion and paint film fades only on account of checking and cracking.

Zinc white or Zinc oxide : It is a fine white zinc powder which is available both in dry form as well as in the form of paste made by mixing it with linseed oil. This pigment is used as a base for all the zinc paints. Zinc white mixed with linseed oil forms a white paint, which has a good hiding and spreading power. It is not affected by sulphur compound and is not poisonous. It forms a costly paint, less workable and less durable than the white lead paints. It amalgamates readily with the binding oil during the process of drying. It finally gets very hard forming a paint film which is brittle and has a tendency of surface cracks.

Iron oxide : It is a pigment produced from haematite ore. The pigment is obtained by grinding and levigating the red or brown haematite. When mixed with vehicle oil, it forms a cheap and durable paint, which is exclusively used for the priming coat on iron or structural steel.

Titanium white or titanium dioxide : This pigment is chemically inert and is not affected by heat, or light. Due to its high refractive index, titanium white possesses excellent hiding power and as such it

is generally used as an under-coat in all sorts of exterior and interior organic coatings. It may be used with all types of vehicle oils.

Lithopone : This pigment is obtained from the precipitate formed by mixing equal quantities of the solutions of barium sulphide and zinc sulphate under carefully controlled conditions. It is a dense white pigment, having a good covering power, and it tends to turn yellow when exposed to sunlight. The paint made with lithopone as its base is generally used as under-coat. It is also used in cheap enamels. It should not be allowed to come in contact with water.

23·5 Vehicle. The vehicles commonly used in an oil paint are briefly described below :

Linseed oil : This is extensively used as a vehicle in oil paints. It is obtained by pressing crushed flax seed. The drying of the oil takes place not on account of evaporation but when exposed to air it gets oxidised. It may be used either in its raw state or refined state or boiled.

Raw linseed oil : It is a transparent vehicle, yellowish in colour, sweet in taste and has very little smell. It has inferior drying qualities and is generally used for inside painting work. It is normally used for delicate tints. The drying qualities of this vehicle can be improved by adding about one pound of white lead to every gallon of the oil and then allowing it to settle for a period of one week.

Boiled linseed oil : The drawback of slow drying of raw linseed oil is overcome by boiling the raw oil. During the process of boiling, red lead and litharge are added to the oil in proportion of one pound each to one gallon of raw oil. The boiled linseed oil is thicker in consistency and its colour is darker than that of the raw linseed oil. Boiled linseed oil is inferior to raw linseed oil from consideration of elasticity and power of penetration. Being darker in colour, it is not recommended for white or light-coloured paints.

Double boiled linseed oil : Its colour and transparency is exactly similar to that of raw linseed oil but it smells slightly different. It has quick drying qualities and is generally used for painting plastered surfaces.

Poppy oil : It is prepared by pressing poppy seeds. It is used for very delicate colours. It is expensive and is thus used for internal painting of light shades. It is inferior in drying qualities to raw linseed oil.

The raw oil is not suitable for use in paints and as such it is boiled and suitable materials are added to make it an excellent vehicle.

Tury oil : It is extracted by pressing the nuts of tury tree. It is a vehicle better than linseed oil and is largely used for making superior paints and varnishes. It stands well the attack of alkalies.

Nut oil : It is a cheap vehicle and is generally used for painting ordinary works of temporary character. It is colourless, less durable and it dries very quickly. It is used as a vehicle for white or light-coloured paints.

23·6 Thinners. Turpentine is the most common thinner used in the preparation of an oil paint. Turpentine is a spirit obtained by distilling balsam, which is the resin or gum obtained from pine trees. Turpentine thus obtained is termed as spirit of turpentine, sap turpentine or oil of turpentine. Turpentine is an inflammable, volatile, colourless liquid, having a pungent smell. It is used in paints and varnishes to dilute them and to increase their flowing properties. It is added in more quantity in the priming coat on wood-work in order to increase ability of the paints to penetrate into the pores of the woodwork, while in the outer or final coat it is used in much less quantity. If used in excess, it effects the durability of the paint and on evaporation it leaves an excess of colour not mixed in the oil. The usage of turpentine as thinner is adopted only when dull or flat finish without gloss is desired. Weather has adverse effect on turpentine, as such it should normally be recommended for indoor paintwork. Benzene and solvent naptha are the thinners which are cheaper and are sometimes used as substitutes for turpentine.

23·7 Colouring Pigments. Colouring pigments are used to give the desired colour to the paint. In general, for white, black and very dark shades, the base itself is chosen to be a colour pigment. In case of light or bright colour, the desired shade is obtained by mixing pigment to white paint.

The colouring pigments generally used are given below. The desired colour may be obtained by using the pigment, singly or in combination of two of more :

Black pigments : Lamp black ; vegetable black ; ivory black ; graphite.

Brown pigments : Raw umber ; burnt umber ; burnt sienna ; vandyke brown.

Blue pigments : Prussian blue ; indigo ; ultramarine blue ; cobalt blue.

Yellow pigments : Chrome yellow ; yellow ochre ; zinc chromate ; barium chromate ; sienna.

Red pigments : Indian red ; carmine ; red lead ; vermillion ; venetian red ; tuscan red.

Green pigments : Verdigris ; green earth ; chrome green ; emerald green.

23·8 Preparation of Paints. Mostly white lead, oil paint forms the basis of all the paints of light or bright colours. The base which is usually white lead is ground in linseed oil to the consistency of paste. Alternatively the base may be obtained in the form of the paste directly from the market.

The base in the state of stiff paste is then softened or "broken up" by adding linseed oil in a small quantity at a time and then stirring the paste with wooden paddle. If a coloured paint is desired, the proper colouring pigment is ground very fine and mixed with linseed oil to the consistency of paste separately. Driers if used should also be separately ground in linseed oil and the paste mixture of the three, *i.e.* the base, the colouring pigment and the drier, is further thinned into the consistency of cream by adding more linseed oil and stirring it well. The mixture is then strained through a fine canvas or a fine sieve. The paint is thinned to the desired consistency by the addition of oil or turpentine or both, just before it is to be used.

The paint thus prepared should be used and consumed at the earliest. If the prepared paint has to be kept unused for some time, it should be covered with a film of water to protect it from drying or skinning. Ready-mixed paints of varying composition and colour are now produced by many manufacturers such as, Shalimar Paints, Solignum Paints, Holes Paints Ltd , Jenson & Nicolson (India) Ltd. etc. Ready-mixed paints are generally too thick for direct application and as such they are thinned to the desired consistency by adding suitable thinners and stirring it well.

23·9 Types of Paints. The various types of paints commonly used can be broadly divided in the following categories :

(*i*) *Aluminium paints*
(*ii*) *Anti-corrosive paints*
(*iii*) *Asbestos paints*
(*iv*) *Bituminous paints*
(*v*) *Bronze paints*
(*vi*) *Cellulose paints*
(*vii*) *Casein paints*
(*viii*) *Cement-based paints*
(*ix*) *Enamel paints*
(*x*) *Rubber base paints.*

(*i*) **Aluminium Paint.** Alluminium paint is used for painting wood work and metal surfaces. Aluminium powder forms the base

in this paint. In this paint the base is held in suspension and bound by either quick-drying spirit varnish, or slow drying oil varnish to suit the requirements of the surface to be painted. This paint is well established for its good weather-resisting and water-proofing qualities. It is highly heat reflective, resistant to corrosive action of sea water, and stands well the atmosphere contaminated with acidic fumes. Because of its brilliant silvery shining texture, the paint has the advantage of being visible in darkness. Aluminium paint is commonly used for painting metal roofs, silos, machinery, electric and telegraphic poles or towers, oil or gas storage tanks, hot water pipes or tanks, etc.

(*ii*) **Anti-corrosive Paints.** This paint is generally used as a metal protection paint for preserving structural steel work against the adverse effect of fumes, acids, corrosive chemicals and the ravages of rough weather. Several types of anti-corrosive paints are manufactured these days. The pigments used in the various types of paints are dry red lead, sublimed blue lead, zinc oxide and iron oxide, zinc dust, zinc chromate etc. Linseed oil is generally used as the vehicle. Sometimes, driers and inert filters are also added to modify the requirements of the coatings.

(*iii*) **Asbestos Paints.** This type of paint is especially suitable for patch work or stopping leakages in metal roofs. It is also used for painting gutters, spouts, flashings, etc. in order to prevent them from rusting. Asbestos or fibrous coating is sometimes used as a damp-proof cover for the outer face of the basement walls.

(*iv*) **Bituminous Paints.** Bituminous paints are alkali resistant and are chiefly used for painting exterior brick work, and plastered surfaces. They are also used for water-proofing and protection of iron and steel and are commonly applied on iron water mains and structural steel work under water or on fabricated iron and steel products. The paints usually consist of asphalt, bitumen or pitches, dissolved in mineral spirit or naptha. When required, drying oils may also be added to the paint to modify its properties. This type of paint is obtained in black colour but its colour may be modified by incorporating certain pigments like red oxide etc. These paints, however, deteriorate when exposed to the direct rays of the sun.

(*v*) **Bronze Paints.** This type of paint is often used for painting interior or exterior metallic surfaces. On account of its high reflective property, it is commonly applied on radiators. Aluminium powder (or aluminium bronze) or copper powder (or copper bronze) are pigments commonly used in this paint. The vehicle used in the paint is usually nitro-cellulose lacquer.

(*vi*) **Cellulose Paint.** This type of paint is made from celluloid sheets and amyl-acetate substitutes. For making a superior type of paint, Nitro-cotton is used. It dries very quickly and possesses the additional advantages of hardness, flexibility, and

smoothness. It can be cleaned easily and remains unaffected by hot water, smoky or acidic atmosphere and stands well the wear and tear and ravages of rough weather. It is much superior to ordinary house paint and on account of its high cost, its usage is generally restricted to paints of motor cars, aeroplanes or other such situations.

(*vii*) **Casein Paints.** Casein is a protein substance extracted from milk curds which is mixed-up with a base consisting of white pigment like whiting, titanium, lithopone etc. to form the paint which is usually available in powder or pasty form. On account of its high opacity, the paint can be applied on new plaster work without any danger of scaling or alkali burning. The paint can be tinted in any desired shade of colour. It is usually applied on walls, ceiling, wall-board, cement block construction etc. to enhance the appearance of the surface. When used for exterior surfaces of cement, brick or stone masonry, a little quantity of drying oil, or varnish is added to the paint to make it weather well.

(*viii*) **Cement-based Paints.** It is a type of water paint in which white or coloured portland cement forms the base. No oil or other organic matter is used in the making of this paint. The base thinned with water, and the paint when applied on masonry surface forms a strong, durable and water-resisting film on drying. The surface to be painted must be well wetted and the successive coats must be sprayed over with water during the process of drying. It is used for decorating the cement surfaces and is commonly recommended for swimming pools and other such situations.

(*ix*) **Enamel Paints.** Enamel paint is made by adding pigments like white lead or zinc white to a vehicle which is a varnish. Colouring pigments may also be mixed to obtain the enamel paint in any desired colour. On drying, it forms a smooth, glossy, relatively hard and permanent solid thin film. Different types of enamel paints are now manufactured in a variety of colours and are available in readymade form these days. Enamel paints are used both for interior as well as exterior painting. It is not affected by atmosphere and stands well the adverse effects of weather. The enamel paint film presents a glossy surface but, if desired, an eggshell or flat finish may also be obtained by adding turpentine in small or large quantity. It is commonly used for painting porches, decks, stairs, concrete surfaces, etc.

(*x*) **Rubber Base Paints.** This type of paint has excellent acid, alkali and moisture resistant properties. It can be readily used for application on new concrete and lime plastered surfaces. The paint is made from rubber treated with chlorine gas (chlorinated rubber) which is dissolved in suitable solvents and mixed with other pigments. It is commonly used as protective coating on cement concrete floors and interior or exterior masonry surfaces.

PROCESS OF PAINTING DIFFERENT SURFACES

23·10 Process of Painting on New Wood Work. The correct preparation of surface plays an important role in preserving the properties and life of the paint. The process of painting on new wood work can be divided into the following different stages :

1. *Preparation of surface*
2. *Knotting*
3. *Priming*
4. *Stopping*
5. *Second or surface coats or undercoatings*
6. *Finishing coat.*

1. **Preparation of surface.** Wood work to be painted must be properly seasoned, clean, dry and free from dust. The surface should be smoothened by rubbing it with a fine grade sand paper or glass paper used obliquely across the grains and rendered free from grease.

2. **Knotting.** Knots exude resin. Knotting is the process of sealing the knots by suitable means so that the resin from the knots may not destroy the paint films by way of cracking, peeling or brown discoloration. The three different methods of knotting commonly adopted are (*i*) patent knotting, (*ii*) ordinary or size knotting, (*iii*) lime knotting.

(*i*) *Patent knotting* : This consists in sealing the knots by applying one or more coats of shellac or aluminium varnish on the knots.

(*ii*) *Ordinary or size knotting* : This consists in sealing the knots by applying two coats of varying ingredients. The first coat consists of red lead ground in water to which strong glue size is mixed and the fluid is applied hot on the knots. The second coat which consists of red lead ground in oil and thinned with boiled oil and turpentine is applied soon after the first coat is dry.

(*iii*) *Lime knotting* : This consists in keeping the knot covered with hot lime for about 14 hours. After this period, the lime is scrapped off and the knots are treated with the method of ordinary size knotting.

3. **Priming** : This consists in applying first coat or the priming coat on the surface to fill the pores of wood by penetrating inside the wood. The main function of the priming coat or the primer is to serve as the foundation for the subsequent coats. Primers have definite functions to perform and their choice depends on the material being used and hardness or condition of wooden surface to be coated. In general the ingredients of the priming coat should preferably be the same as in the subsequent coats but their proportion

may vary. The composition of primer for interior and exterior woodwork may consist of the following :

(1) *For interior woodwork*

Red lead.....1·5 kg.
White lead.....3·6 kg.
Boiled linseed oil..... 0·57 litre
Raw linseed oil.....0·57 litre
Litharge.....0·045 kg.

(2) *For exterior work*

Red lead..... 0·045 kg.
White lead..... 4·5 kg.
Raw linseed oil..... 2·27 litre
Litharge..... 0·09 kg.

For ordinary works primer can be prepared on site by mixing red lead, raw linseed oil and turpentine in the ratio 0·71 kg. : 0·71 kg : 1 litre.

The priming coat is generally applied before fixing woodwork in position.

4. **Stopping** : This consists in filling up all nail holes, cracks, open joints, dents and other such defects with the putty. Stopping is done soon after the priming coat is dry. Before filling putty, the primed surface is rubbed down with pumice stone or glass paper. After the putty has dried, the surface is once again rubbed with glass paper or pumice stone to level the same. The putty should be made by mixing powdered chalk with pure linseed oil to the consistency of a paste, well kneaded and worked, till smooth and soft. It should be coloured to match the shade of the finished coat.

5. **Second and succeeding coats or under-coatings**. After the primary coat is dry, second coat or under coatings are applied on tne primed surface. The colour of the under-coat should be approximately be of the same shade as that of the desired finish. It should be a thin opaque film, free from brush marks. Two or more under-coatings are sometimes necessary to achieve the object. The final appearance of gloss and durability of the finishing coats depend very much upon the quality of nnder-coating. Sufficient time must be allowed for each coat to dry before applying the succeeding coat. For good results, the dry coating is rubbed down with pumice stone or glass paper and cleaned before applying the succeeding coats.

6. **Finishing coat.** This is the last coat applied on the surface after the under-coat is properly dry. This coat is applied very

carefully in a workmanlike manner, so that the finished surface is free from thin patches and brush marks.

23·11 Painting Old Wood-work. In case the old paint is in good condition but dirty and its removal is not considered necessary, the surface should be cleaned of all dirt and grease by washing it with lime and water. The cleaned surface is rubbed with pumice stone and the holes and cracks, if any, are filled with glazier's putty or wood putty.

If the old painted surface is in bad condition and the paint has badly blistered and flaked, it should be completely removed by use of a blow lamp or one of the patent paint removers. While removing paint with a lamp, care should be taken to see that neither the paint nor the background gets charred and the flame is played upon the surface in such a manner that the paint only gets soft. The softened paint is then removed with a stripping knife following the flame as it is moved up the surface. Paint remover should be used in places where removing the old paint with blow lamp is not considered desirable. The paint remover is applied on the surface with a brush. Under the action of the paint remover, the paint film will lift up and wrinkle and can be easily removed with the help of a sharp instrument.

Old paint can also be removed by applying caustic soda solution (formed by dissolving caustic soda with 48 times its volume of water), on the surface and then stripping it with a sharp instrument. After removing the old paint, the cleaned surface is given two or three coats of the paint to obtain the desired finish.

23·12 Painting Iron and Steel Work. Prevention of rust is one of the importants requirements of painting on metal surfaces. Painting on steel, iron, etc., requires utmost care in the preparation of the surface for painting.

The mill scale and rust is removed by scrapping or brushing with steel wire brushes while the oil, grease and dust may be removed by washing the surface with petrol, benzene or lime water. The clean surface is then given the priming coat which usually consists of an oxide-of-iron paint. Priming coat consisting of red lead is considered to be the best. Two or more coats of the desired paint are then applied over the primed surface with a brush or by spraying. Care should be taken to see that each succeeding coat is applied only after the previous coat has dried completely. For repainting iron or steel, the same procedure as given in repainting old wood work is adopted.

23·13 Painting of Galvanised Iron Work. Galvanised iron is one of the most troublesome metal surfaces to paint. This is on account of the adhesion difficulty the surface offers, when organic

finishes are used. Galvanised iron should not preferably be painted until it has been exposed to weather for a year. This is done because after sufficient weathering the zinc coating on the galvanised surface gets oxidised, forming a thin film of zinc oxide on the surface to which paint easily adheres. If, however, weathering before painting is not possible from consideration of time factor, the new galvanised surface is treated with (*i*) a solution prepared by mixing 6 oz. of copper acetate in a gallon of water (38·2 gm. of copper acetate in a litre of water) or (*ii*) with a solution prepared by mixing 2 oz. of hydrochloric acid in a solution of 2 oz. each of copper chloride, copper nitrate and ammonium chloride dissolved in a gallon of water. The quantity of solution thus formed will be sufficient to cover an area of 233 to 279 sq. m. The galvanised iron surface treated with either of the solutions gets black (due to chemical reaction of copper present in the solution on zinc) and ensures proper adhesion of paint. A priming coat consisting of red lead mixed with linseed oil and turpentine in equal proportions is then applied on the treated surface. When priming coat is dry, the surface can be coated with desired oil paint.

23·14 Painting Plastered Surface. The greatest danger in painting plastered surfaces, particularly if they are relatively fresh, is the free alkalies present in the lime or cement. The free alkalies discolour the paint, destroy its oil and adversely affect the drying properties of the coating. Therefore, preparation of the surface before painting is extremely important. The plastered surfaces should ordinarily be not painted until it has dried completely. If possible leave the walls unpainted for at least first 12 months, so that they may dry out completely. The walls may, however, be white-washed or colour-washed for this duration. In new work, however, the surface should be washed with a dilute solution of zinc sulphate to neutralise the free lime on the walls. Before primer is applied, the holes and undulations should be filled up with plaster of Paris and surface rubbed smooth. Primer for plaster work may be prepared by mixing equal parts of white and red lead in boiled linseed oil. After the primed surface has dried, two or more coats of the desired paint may be applied in the usual way.

With the advent of emulsion paints, new plastered surfaces can be painted quite easily. These paints have good alkali resistance and sealing properties. Being permeable to moisture emulsion paints can be applied on wet surfaces. The emulsion paint dries on the evaporation of the water in the paint and the dried film gets hard. The next coats are then applied to get a flat velvety-smooth finish.

23·15. Painting Damp Walls. Take a mixture consisting of 11·14 litres of parafin, 9 litres of benzoline and 6·4 kg of pale resin in a vessel and shake them well, so that they get completely dissolved. Add 11 kg of whiting (powdered chalk) to the mixture and

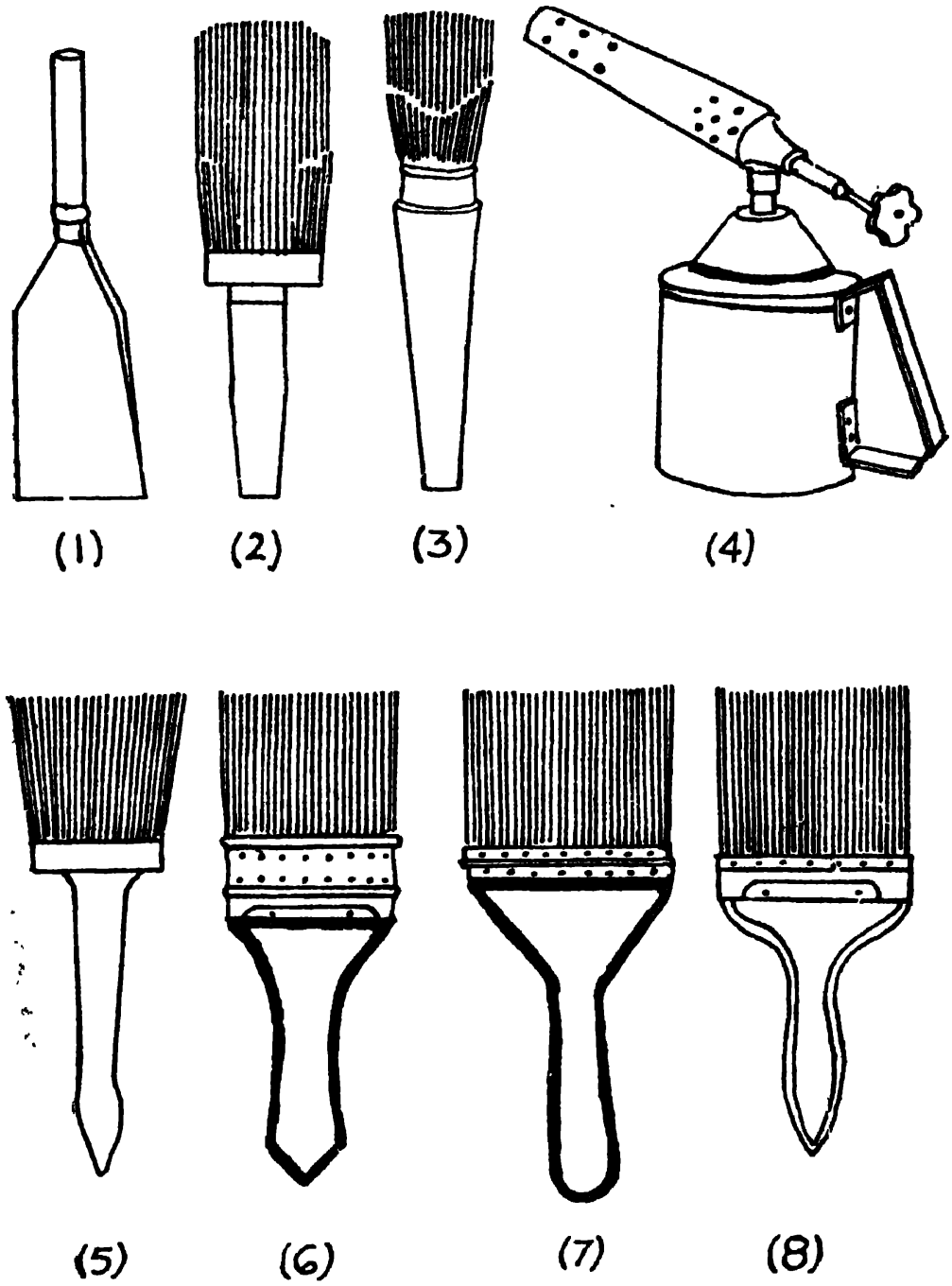


Fig. 23·1

Fig. 1. Scrapping tool.
Fig. 2. Paint brush.
Fig. 3. Sash brush.
Fig. 4. Burning stove.
Fig. 5. Varnish brush.
Fig. 6. Distemper brush.
Fig. 7. White-colour wash brush.
Fig. 8. Wall paint brush.

grind it well. The paint thus formed may be applied in one or more coats on damp walls in the usual manner. On drying, it will form a dry hard film on the surface painted. The mixture is kept air-tight to prevent drying.

23·16. Painting with Brushes. A good brush should have springiness in the bristles. Any new brush may have loose bristles. Prior to painting, the loose bristles should be removed by tapping the brush gently against the palm of hand, twirling it rapidly between the palms of hand and finally putting the loose bristles out. The brush should not be dipped too deeply in the paint, and the excess paint should be removed by gently rubbing the brush against the inside surface of the paint pot. After use, the brushes should be cleaned very thoroughly with kerosene oil. When a brush has been cleaned and is not to be used again, it should be immediately wrapped in an ivory paper or kept in raw linseed oil so that only the bristles are covered by the oil film.

23·17 Spray Painting. Painting with the spray gun is considered to be a highly developed and efficient method of applying all types of protective coatings. It results in rapid execution of work. There is also economy in labour and the consumption of material as only two coats of spray are considered sufficient to obtain the desired finish. For elegance, perfection and durability spray painting is recommended on metal or woodwork. In brief, the operation of the spray machine may be summarised as below.

The paint is put into container and forced by air pressure through a hose to a metal gun. The gun is provided with a spray nozzle and a hose conveying compressed air. When the trigger of the gun is pulled, both the air and the fluid valve gets opened. The compressed air strikes the paint and converts the liquid fluid into atomized paint, which is forced out in the form of a spray, from the nozzle.

In operating the spray gun, care should be taken to see that the spray is at right angles to the surface and at all times the gun is kept at the same distance from the surface to be painted. This distance may vary from 15 to 20 cm.

VARNISH

23·18, General. Varnish is a clear, pale solution of a resinous substance (like amber, common resin, copal, lac or shellac) dissolved in either oil, turpentine or alcohol. The solution on drying forms a hard, transparent, glossy film on the varnish surface. Varnish plays an important role in finishing wooden surfaces of doors, windows, floors etc. Varnish is applied on unpainted furniture and other woodwork to decorate the surface, without hiding the

beautiful grains of wood and to protect the surface against the adverse influence of the atmosphere. Painted surfaces are varnished to enhance the appearance of the paint and to increase the durability of the paint film.

The preparation of varnish is a tedious job and as such as far as possible readymade varnishes should be used for all jobs.

23 19 Types of Varnish. Depending upon the solvent used, varnishes may be classified as below :

Oil varnish. It is a cooked mixture of a drying oil (usually linseed oil) and resin (usually copal) dissolved in a volatile liquid thinner (turpentine or benzine). Oil varnish is used both for interior or exterior works. It takes about 24 hours to dry.

Spar varnish : This derives its name from its utility on spars and other exposed parts of ships. It forms a weather-resistant coating when used on exposed surfaces like rail-road coaches, exterior wood work or metal surfaces. Spar varnish should not be used indoors as it gives a sticky effect in warm weather.

Flat varnish : It is sometimes desired that the varnished surface should present dull appearance. To attain this, manufacturers make varnishes which dry with a reduced gloss by adding such material as wax, metallic soap and finely divided silica.

Asphalt varnish : This is made by dissolving melted hard asphalt in linseed oil and thinned with turpentine or petroleum spirit. The varnish is chiefly used to give a black shop coat to fabricated iron and steel products.

Spirit varnish : This is a solution of a resin or other film-forming material dissolved in a volatile liquid. It dries quickly as the volatile liquid evaporates leaving behind the resin used, in the form of a hard glossy but somewhat brittle film. Spirit varnishes are mostly used for wooden furniture. French polish, Lacquer and Shellac varnishes fall in this category.

23·20. French Polish. It is a spirit varnish. In its simplest form French polish is made by dissolving 0·15 kg. of pure shellac in 1 litre of methylated spirit and straining the solution through a double thickness of coarse muslin. Suitable pigment may be added to get the required shade. It is mostly used for high class furniture and other wood work.

Method of applying French polish : The wooden surface is cleaned of all dirt and dust and all unevennesses rubbed down smooth with sand paper. All the visible knots should be covered with a preparation of red lead and glue size laid on while hot. Holes and indentations on the surface should be stopped with

glaziers putty. The surface is then given a coat of wood filter made by mixing whiting (ground chalk) in methylated spirit at the rate of 1·5 kg. of whiting to 1 litre of spirit. The surface is again rubbed down perfectly smooth with glass paper and wiped clean. On this prepared surface, French polish is applied with a pad of woollen cloth covered by a fine cloth. The pad is moistened with the polish and then rubbed hard on the surface in a sreies of over-lapping circles so that the polish is applied sparingly but uniformly over the entire area. The surface is then allowed to dry. Several coats will be necessary (each succeeding coat being applied in the same way after the previous one has dried) before desired finish is achieved.

Furniture polish : The following mixture will make an excellent furniture polish :

Material	*Qty. required*
Linseed oil	18·2 litre
Methylated spirit	2·2 litre
Vinegar	1·1 litre
Turpentine	1.1 litre
Copal varnish	1·1 litre
Muriatic (Hydrochloric) acid ...	64 litre

The oil should be heated first and then the remaining materials mixed up well.

Lacquer : It is considered to be the fastest drying finish. On drying it gives tough and durable finish which is easy to rub, sand or patch. It can be applied on furniture, floors, linoleum etc. It performs the function of a varnish. Lacquers are available in a variety of colours and can be brushed or sprayed. Since they have low solid contents, the surface requires several coats to attain a film thickness equivalent to varnish or enamel coat.

Stains : It is a liquid preparation which is used to change the colour of various types of cheap quality wood to give them the appearance of wood of superior quality. Dyes are the basis of most stains. Aniline a derivative of coal-tar is the base generally used in stains. The stains are named after the vehicle with which they are applied. Thus when water is used as vehicle it is called water stain and if oil is used, it is called oil stain and if alcohol is used for dissolving the dye, it is called spirit strain.

Water stain is the cheapest and can be applied easily. If applied on wood work water stain causes the fibres of wood to rise and makes the coated surface rough which is not desirable. Spirit stains on the other hand dry very quickly and require skilled painter to apply them satisfactorily. Oil stains are generally prepared by mixing pigments like chrome yellow, burnt sienna, umber etc. to

this oil together with some proportions of turpentine and a drier. Oil stains are considered most suitable, for coating hard wood surfaces.

23·21 Method of Applying Varnish. After knotting and stopping, the prepared wood work should be treated with glue sizing to seal the pores in wood and to prevent absorption of the oil in the varnish by the surface. The treatment consists in applying a hot coat of thin clean glue. When dry, the surface should be rubbed down smooth with sand paper and cleaned. A second coat of thin clean glue size (which is nearly cold) is then applied on the surface. If the wood work is to be strained the colouring pigment should be mixed with second coat of glue size. The sized surface is again rubbed down smooth with a fine sand paper and cleaned. Two or more coats of varnish are then applied on the cleaned surface. Usually the under-coat consists of a flat varnish. This coat, when dry, is rubbed down to produce a smooth surface and then the second coat of varnish is applied.

DISTEMPERS

23·22 General. Distempers may be defined as water paints consisting of whiting (powered chalk), some colouring pigment (if desired) and glue size mixed in water. Distemper may give either a washable or non-washable surface according to the medium used. They are cheaper than paints and varnishes and are easier to work. They act as sealers over porous surfaces and are generally used over plastered surfaces to which a priming coat of whiting has been applied. Distempers for exterior use on cement concrete, stucco and brick surfaces are provided with weather resistant ingredient during the process of manufacturing. They are more durable and present smoother and distinctive appearance than an ordinary colour-white wash. The cost of distempers compares favourbly with that of white-wash in the long run and hence its application should be given preference It should only be used in dry climates as in wet conditions, it gives poor results. Ready mix. washable distempers are now available in a variety of different shades in the form of a stiff plaster or dry power in sealed tins.

23·23 Distempering with Dry Distemper. The new plaster is allowed to dry for at least two months before applying distemper. However, in case of old surfaces, all dust, dent and scales and greasy marks should be removed and all the holes and cracks should be filled with plaster of paris mixed with dry distemper of the colour to be used. A coat of whiting is then applied over the prepared dry-clean surface which acts as the priming coat for the distemper. The dry distemper is then converted into a liquid by mixing it with water and stirring it well. As a rule 0·6 litre of water should be used per kg. of distemper. Distemper is then uniformly

applied over the entire surface with broad stiff distemper brushes in horizontal strokes followed immediately by vertical ones. Second or third coats should only be applied after the previous coat has dried.

On newly-plastered walls, distemper should be applied in at least two coats. When the old unplaned surface is very smooth and is in good condition and priming coat is not felt desirable, a coating of warm glue should be applied prior to the application of distemper.

23·24 Oil Bound Distemper. It is a form of distemper in which the drying oil is rendered mixable with water. The distemper in pasty form is available in different shades in sealed tins. When required, it is diluted or thinned with water. On driving, the oil content of the distemper hardens and forms a durable coating which can be cleaned (when dirty) by washing. However, for oil bound, washable distemper, the surface is given a coat of cement primer or any other primer recommended by the manufactures of the distemper.

23·25 Casein Paints. Casein is a protein substance derived from milk curds. Casein paint is made by working a mixture of finely ground casein (which acts as a binder) with a base of white pigment which is usually slaked lime, and is sold in powdered or paste form in sealed tins. Casein paints, on account of their high opacity, give pleasing results in one coat. They are applied on new plaster without any danger of blistering, scaling or any adverse effect of free alkali. They are manufactured in various colours and are used on plastered surfaces, stucco, fibre board, cement blocks etc.

WAX POLISHING, OILING & GLAZING

23·26 Wax Polishing. Wax-polished surface gives a highly pleasing lustre. It is applied on varnished surface to modify its elegance, and to protect the undercoat. Wax polishing is mostly used for polishing cement concrete, mosaic or terrazzo floors. The polish may be prepared by mixing bees wax, linseed oil, turpentine and varnish in the ratio of $2 : 1\frac{1}{2} : 1 : \frac{1}{2}$ by weight. Bees wax and linseed oil are first heated over a slow fire. When the wax is completely dissolved, the mixture is cooled down slightly and turpentine and varnish are then added and the mixture well stirred.

The polish is applied on the prepared wood-work, with a clean soft pad of cotton cloth and the surface is then rubbed continuously for about half an hour. The second coats are subsequently applied when the coat is dry and rubbed in the similar manner till the desired polished surface is obtained.

23·27 Oiling Wood-Work. Oiling may be done to wood-work to increase its durability and to make it appear more pleasing. The oiling mixture may be prepared as below :

A mixture of 1·35 kg. of double-boiled linseed oil and ·45 kg. of bees-wax is heated over a slow fire till the wax is melted After the mixture has cooled, ·45 kg. of turpentine is added to the mixture. The mixture is applied freely with brushes till the surface can absorb no more of the oil. This mixture when applied in two coats will cover an area of 72 sq. m. of the surface.

A mixture made by using country sweet oil to which equal part of vinegar and turpentine have been added, may also be used for oiling wood-work.

23·28 Coal Tarring. Wood or iron work to be coated is first cleaned of all dust, rust, scales etc. in the similar fashion as is essentially done before painting. The mixture is prepared as described below :

A mixture consisting of 2 lb. of unslaked lime and 1 gallon of tar is heated till it starts boiling. The hot mixture is thinned by addition of ½ pint of country spirit. The mixture is best applied while it is hot. When it is possible to remove iron-work, it should be (if possible), heated to nearly red hot stage and then brushed over with the prepared hot mixture of coal tar. However, if this is not possible, the hot mixture of coal tar is applied with the help of a brush on the prepared wood or iron work.

23·29 Glazing. Glazing consists in fixing glass, to iron, steel or wood-work. Depending upon the size of the opening to be glazed glass panes, weighing not less than 5·5 kg./sq. m. should be used for area of opening upto one square foot. For area greater than 1 sq. foot, the thickness of the glass should be such that its weight is not less than 7·2 kg. per sq. m. The glass panes are so cut (with the help of a glaziers diamond) that they fit slightly loose in the rebates of the sashes.

In wood work, the glass panes are generally fixed with the help of glaziers putty (prepared by mixing one part of white lead with three parts mixture of finely powered chalk and then adding boiled linseed oil to the mixture which is finally kneaded into a stiff paste).

The glazing is done only after the frames have been primed and prepared for painting, so that the wood may not absorb the oil of putty.

A thin layer of putty is first applied along the inner edge of the rebate, for bedding the back of the glass panes. Glass pane is then put in position and secured in position by brads (small nails without head). Putty it then applied in the rebate, uniformly sloping from the inner edge of the rebate. If desired, panes may also be fixed with wooden beading having mitred joints.

23·30 Glazing Steel Frames. In glazing steel doors, windows etc., the glass used should not in any case weigh less than 6·9 kg./sq. m. Special metal sash putty (prepared by adding gold size varnish to glazier's putty for wood work at the rate of 5·64 litres/ 100 kg. of putty), should preferably be used for fixing glass panes. Prior to fixing the glass pane, putty is applied between the glass pane and glazing bars and the glass pane is put in position. Putty is then applied over the glass pane which is stopped 1·5 mm. from the sight line of the back rebate. Putty should normally be painted within 3 weeks to avoid its cracking.

Questions for Revision

1. What are the chief constituents of an oil paint? Explain the functions of each.
2. Name the constituents and state the uses and methods of application of the following :
   (*a*) French polish.
   (*b*) Wax polish.
   (*c*) Distemper.
   (*d*) Painter's brushes.
3. What are varnishes ? Write short notes on the following :
   (*a*) Oil varnish.
   (*b*) Spar varnish.
   (*c*) Flat varnish.
   (*d*) Asphalt.
   (*e*) Spirit varnish.
4. Write short notes on any four of the following :
   (*a*) Anti-corrosive paints.
   (*b*) Bituminous paints.
   (*c*) Double-boiled linseed oil.
   (*d*) White-lead.
   (*e*) Lithopone.
   (*f*) Puppy oil.

24

Plain Cement Concrete

24·1 General. Cement concrete may be defined as a building material obtained by mixing cement, aggregates and water in suitable proportion and then curing this plastic mixture to a hard mass. Plain cement concrete is considerably stronger in compression and is commonly used in the construction of columns foundation, bed blocks, massive gravity dams, heavy foundations, etc. The chief ingredients of concrete have been described in detail below.

24·2 Cement. Portland cement is generally used in all types of concrete works. Cement is manufactured in a variety of forms these days. The selection of a particular type of cement to be used depends upon the type of structure, the conditions under which the construction is to take place and the strength desired. The cements differ in forms on account of their chemical composition and degree of fineness to which they are ground.

24·3 Properties of Cement. The important properties of cement can be classified under the following heads :

(1) Rate of setting.

(2) Rate of hardening.

(3) Heat evolution.

(4) Resistance to chemical action.

(1) *Rate of setting* : Setting is a phenomenon by virtue of which the plastic cement paste changes into a solid mass. Initial set is the term which is applied to that stage of this phenomenon at which any cracks that may appear will not reunite. Final set is the term which relates to the completion of this phenomenon. The rate of setting is the governing factor for the mixing, transportation, placing and compaction of concrete. For ordinary portland cement, the initial setting time should not be more than 10 hours. Similarly, for quick setting cement, the initial setting time should not be less than 5 minutes and the final setting time should not be more than 30 minutes.

(2) *Rate of hardening* : It is a phenomenon by virtue of which, the concrete mix, which is finally set, develops strength. Harden-

ing proceeds at a rapid rate during the first few days and afterwards it continues to increase at a diminishing rate. The rate of hardening governs the time up to which the formwork should be kept in position and the time after which the structure should be loaded.

(3) *Heat evolution* : The setting of cement is the result of a chemical action of cement with water. During the process of setting, cement chemically reacts with water and heat is generated. The evolution of heat affects the rate of hardening. The rate of hardening is directly proportional to the generation of heat. Evolution of heat is an advantage in normal works and it is a disadvantage in works of massive nature.

(4) *Resistance to chemical action* : Concrete may be subjected to chemical action either by its being in contact with ground or water or on account of the spilling of corrosive liquids on its surface during the usage of the structure. The resistance of cement to chemical action varies with the type of cement and as such suitable type of cement should be used where such actions are susceptible.

24·4 Types of Cement. The various types of cement commonly used are given below :

(*a*) Normal setting cement.

(*b*) Rapid hardening cement.

(*c*) Quick-setting cement.

(*d*) High alumina cement.

(*e*) White and coloured cement.

(*a*) *Normal setting cement* : This is the type of cement which is commonly used in all types of structures which require no special consideration.

(*b*) *Rapid hardening cement* : It is the type of cement which acquires its strength at a much rapid rate and as such it is commonly termed as high early strength cement. Its ultimate strength is just the same as that of normal setting cement and its initial and final setting time are a little more than the latter. The advantages of this cement over the normal setting cement are that the formwork can be removed earlier and the structure can be loaded shortly after erection.

(*c*) *Quick-setting cement* : The initial setting time for this type of cement is only 5 minutes and the time for final set is 30 minutes. The quick-setting time of the cement spares very little time for mixing, placing and compacting and as such its use is generally restricted to marine or tidal works.

(*d*) *High alumina cement* : This cement is made by fusing together a mixture of lime stone and bauxite and then grinding the

product to a fine powder. Concrete made with high alumina cement has a high early strength and is resistant to the attack of sulphates. This type of cement is highly resistant to heat, chemicals and other corrosive acids and as such it is particularly used for structures subjected to the action of sea water, chemicals and other such agents.

(*e*) *White or coloured cement* : This is similar to normal Portland cement, the shade of the colour being the only difference. White cement is made from raw materials which do not contain iron oxide. Coloured cements are made by adding suitable mineral pigment to either white or grey cement.

24 5 Aggregate. Aggregate is derived from igneous, sedimentary and metamorphic rock or is manufactured from clays, slags etc. The properties of concrete are directly related to those of its constituents and as such aggregate used in a concrete mix should be hard, strong, durable, free from clay, loam, vegetable and other such foreign matters. The presence of clay, or dirt coating prevents the adhesion of cement on the surface of the aggregate and ultimately retards the setting and hardening of the cement.

Depending upon their size the aggregates are classified as : (*i*) fine aggregate and (*ii*) coarse aggregate.

Fine aggregate. The material below 4·75 mm size is termed as fine aggregate. It should not contain more than 1 to 8% of fine particles, which may pass through I.S. sieve No. 15. Natural sand is the fine aggregate chiefly used in concrete mix. Sand may be obtained from sea, river, lake or pit, but when used in a concrete mix, it should be properly washed and tested to ascertain that it is free from clay, silt, salts and other such organic matter.

Coarse Aggregate. The material whose particles are of such size as are retained on I.S. sieve No. 480 (4 75 mm. is termed as coarse aggregate). The size of the coarse aggregate used depends upon the nature of work. The maximum size may be 20 cm. for mass concrete, such as dams etc. and 6 cm. for plain concrete work For R.C.C. construction the maximum size of the coarse aggregate is limited to 25 mm. although 20 mm. size of aggregate is commonly adopted. The aggregate used in cement concrete work are briefly described below.

Crushed hard stone and gravel are the common materials used as coarse aggregates for struetural concrete. Coarse aggregates are usually obtained by crushing granite, gneiss, crystalline lime stone and good variety of sand stone etc. Broken brick is a cheap aggregate for plain concrete, but it renders the mix, weak in strength. It is not used in R.C.C. work on account of the possibility of the reinforcement getting rusted due to the high porosity of the aggregates. Clinker slag, coal ashes, coke-breeze are also used as aggregates for light weight and insulating concrete where great strength is not desired. Gravel as obtained from pit or river or

crushed stone contains high percentage of fine material and in this state it is only used for unreinforced work.

Sand is commonly used as fine aggregate in R.C.C. work. Sand may be obtained from sea, river. lake or pit. Sea sand should not be used in its natural state for R.C.C. work, as the salts present in the sea water are liable to attack the steel reinforcement. River sand is usually suitable but mostly it is contaminated with mud and thus it is always advisable to wash such sand before use. Pit sand is generally suitable, but it is liable to contain silt or other organic impurities. Hence before using the pit sand in important work, all its impurities must be removed. Sand as obtained from the above sources may be round or angular in grains. Angular grained sand has good interlocking property which results in a strong mortar while rounded grained sand does not afford sufficient interlock in the matrix.

24·6 Bulking of Sand. When dry sand comes in contact with moisture or water, thin film is formed round the particles which causes the particles to get apart from each other. This results in an increase in volume of sand. The volume of damp sand may exceed by more than 30% the volume of the same sand when dry. This phenomenon is known as bulking of sand. Bulking of sand increases with addition of water up to about 5% by weight. Further addition of water causes the films round the particle to break and thus the volume of sand gets reduced. It is important to note that dry and fully saturated sand occupy the same volume.

24·7. Water. Water to be used in the concrete work should have the following properties :

(*i*) It should be free from oils.

(*ii*) It should be free from acids or alkalis or other such organic or inorganic impurities.

(*iii*) It should be free from iron, vegetable matter, or any other substance which is likely to have adverse effect on concrete or reinforcement.

(*iv*) It should be fit for drinking purposes.

Function of water. The function of water in the concrete mix may be summarised as below :

(*i*) It acts as lubricant for the fine and coarse aggregates.

(*ii*) It acts chemically with cement to form the binding paste for the coarse aggregate and reinforcement.

(*iii*) It is necessary to flux the cementing material over the surface of the aggregate.

(*iv*) It is employed to damp the aggregates in order to prevent from them absorbing water vitally necessary for chemical action.

(*v*) It enables the concrete mix to flow into moulds.

24·8 Water Cement Ratio. The ratio of the volume of mixing water to that of cement is termed as water cement ratio. Water cement ratio is a yardstick to obtain a concrete mix of desired strength. The lower the ratio, the greater is the strength of the mix. A rich mix of concrete gives a higher strength than a lean mix, not because more cement is used but it is on account of the fact that concrete can be used with a lower-water cement ratio.

24·9 Properties of concrete. Strength, durability and workability may be considered as the main properties of concrete. In addition, good concrete should be able to resist wear and corrosion and it should be water-tight, compact and economical.

(1) *Strength* ; The concrete must be strong enough to withstand without injury all the imposed stresses with the required factor of safety. When the concrete mix has been designed on the basis of maximum permissible water-cement ratio keeping in view the requirements of durability, it will develop the required strength if properly placed in position and cured. After placing, concrete should not be allowed to dry rapidly because moisture is very much essential for the development of its high strength. Curing temperature also has a great effect on the strength development of concrete. To develop a given strength, longer time of moist curing is required at lower temperatures than is necessary while curing is done at higher temperatures. According to I.S. 456-1964, various concrete mixes should have the following minimum compressive strength when cubes of size 15 cm. made out of the specimen concrete are tested after 28 days of mixing. The strength given in the table is in kg. per sq cm.

TABLE 24·1

Grade of concrete	*Comp. strength at preliminary test*	*Comp. strength at works test*
M 100	135	100
M 150	200	150
M 200	260	200
M 250	320	250
M 300	380	300
M 350	440	350
M 400	500	400

Preliminary test : This is a test conducted in the laboratory on a specimen of the trial concrete mix designed and produced in the laboratory itself.

Works test : This is a test conducted on a specimen, out of the concrete, actually being used on the works. This test may be conducted either in the field or in the laboratory.

(2) *Durability* : It is the property of concrete by virtue of which it is capable of resisting its disintegration and decay which may be caused due to—

(*a*) Use of unsound cement.

(*b*) Use of less durable aggregate.

(*c*) Entry of harmful gases and salts through the pores and voids present in the concrete.

(*d*) Freezing and thawing of water sucked through the crack or crevices by capillary action.

(*e*) Expansion and contraction resulting from temperature changes and alternate drying and wetting.

Thus concrete can be made more durable by using good quality of materials (cement and aggregates), by reducing the extent of voids by proportionating the materials suitably and by ensuring its thorough mixing, desired placing, compaction and curing.

(3) *Workability* : Despite all its importance, workability is the most elusive property of concrete and is quite difficult to define and measure. In the simplest form a concrete is said to be workable if it can be easily mixed, handled, transported, placed in position and compacted.

Lubricating effect of the cement-paste which in turn is solely governed by the degree of dilution, effects the workability of a concrete mix. A workable concrete mix must be fluid enough so that it can be compacted with minimum labour. A workable concrete does not result in bleeding or segregation. Bleeding of concrete takes place when the excess of water in the mix comes up at the surface and segregation is caused when coarse aggregates have a tendency to separate from the fine aggregates. Workability of a concrete mix is appreciably affected by the following :

(*i*) By reducing the proportion of coarse aggregate. It should be well understood that the finer is the grading, the greater will be the workability.

(*ii*) Shape of the aggregates has a great effect on the workability of concrete. Rounded aggregate renders a concrete mix more workable than the angular one.

(*iii*) By increasing the quantity of water to such limits that the water cement ratio is maintained.

(*iv*) By increasing the quantity of cement.

(*v*) By the process of mixing.

Evidently, the requirement of workability varies according to the nature of job and the obstruction to the full flow of concrete caused by the spacing and nature of reinforcement. The workability of concrete is normally measured by the slump test.

24·10 Slump Test. The test is performed with the help of a vessel of the shape of the frustum of a cone and open at both ends. The top and bottom diameter of the vessel should be 10 cm. and 20 cm. respectively and it should be 30 cm. in height. The vessel is placed on a flat non-absorbent surface and then filled with specimen concrete mix in four different layers of equal-thickness. Each layer is tamped 25 times by the point of a 16 mm. ϕ rod 60 cm. in length. The strokes are applied uniformly over the entire area with a force that the rod just penetrates the full depth of the layer being compacted. Immediately after the vessel is completely filled, it is raised vertically, care being taken not to disturb the filling. The concrete filling is allowed to subside or settle. The vertical settlement recorded

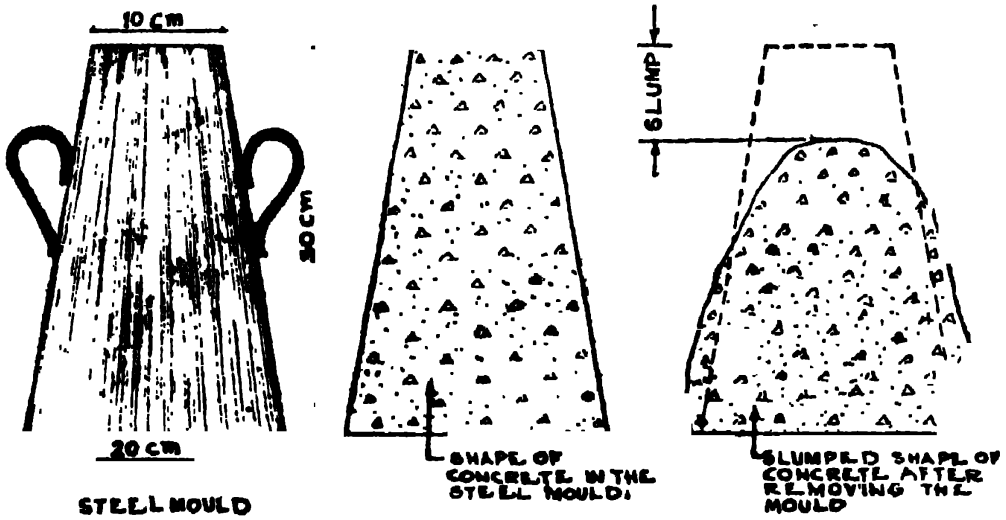


Fig. 24·1
Slump test

in terms of mm. is known as slump. The table below gives the values of slump usually adopted for various type of concrete.

TABLE 24·2
SLUMPS COMMONLY ADOPTED FOR VARIOUS CONCRETE MIX

S. No.	*Type of concrete*	*Slump adopted in mm.*
1	Concrete for road works	20 to 28
2	Ordinary R.C.C. work	0 to 100
3	Columns, retaining walls and thin vertical members, etc.	75 to 175
4	Vibrated concrete	12 to 25
5	Mass concrete.	25 to 50

24·11 Measurement of Materials. In order to obtain the concrete mix of desired consistancy or workability, the components of the mix must be accurately measured.

Measurement of cement : The measurement of cement by volume should never be allowed. It is on account of the fact that

the quantity of cement when loosely filled in a container weighs less than the cement filled tightly in the same container. It has been observed that one cu. m. of loosely filled cement weighs 1120 kg and the same volume weighs 1602 kg. when cement is filled by tamping. Thus cement should always be measured be weight. This can be done either by making one bag of cement weighing 50 kg. as a standard unit or by actually weighing the cement.

Measurement of sand: Due to the bulking of sand, its measurement requires careful consideration. Sand containing about 80 kg. of water per cu. m. may result in an increase in volume upto an extent of 30%. Thus in measuring sand, allowance should be made for its bulking.

Measurement of coarse aggregate: Coarse aggregates may be measured by volume or by weight. In case of wet aggregate, allowance for water should be made while determining the quantity of water to be used in the mix.

Water: It may be measured by volume or by weight. For hand mixing, water may be measured in a can or other suitable container. In large works where mechanical mixers are employed for mixing the concrete, the calculated quantity of water is automatically discharged into the mixer through a syphon system connected to a water tank.

In general practice, however, for small or medium works measurement of material is done by volume as it avoids the use of costly measuring apparatus and prevents loss of time measuring the materials. For large and important works the measurement of materials is done by weight as it obviates the errors in measurement of material by volume.

24·12 Grading of Aggregates. It consists in proportionating the fine and coarse aggregates in such a ratio, so as to get strongest and the densest mix with the least amount of cement. Grading of aggregates requires careful consideration. The aggregates are so graded as to have minimum air voids when mixed. The condition can be satisfied only when the quantity of fine aggregate is just sufficient to fill the voids of coarse aggregates and the quantity of cement is also just sufficient to fill the voids in fine aggregate. The aggregates, when mixed in above proportion with the required quantity of water should render a concrete mass of easy workability. In general the volume of coarse aggregate is taken about twice that of the fine aggregate. This ratio may however be varied to obtain maximum workability with minimum quantity of water. Thus the proportions of ingredients of concrete have to be altered to obtain the concrete of desired strength, durability and workability. The proportions of different aggregates to be adopted in a particular type of concrete mix are usually determined by the following methods :

(*i*) By trial.

(*ii*) By fineness modulus method (Sieve analysis method)

(*iii*) By minimum voids method

(*iv*) By arbitrary standards

(*i*) *By Trial* : This method is based on the fact that a concrete mix which has been formed by so proportionating its aggregates as to give heaviest weight for same volume, yields the densest concrete. Hence in this method a box is filled with varying proportions of the fine and coarse aggregates. The proportion which gives heaviest weight will produce the densest concrete.

(*ii*) *By Fineness modulus methods* : (Sieve analysis method) : In this method the samples of both coarse and fine aggregates are passed through a set of nine standard sieves and the percentage of the sample retained on each of the said sieves is determined. The total of these percentages divided by 100 gives the fineness modulus of the sample. Certain values of fineness modulus for the mixed aggregates have been accepted as giving the best results. Thus if p is the desired fineness modulus for a mix of fine and coarse aggregate and p_1 and p_2 be their respective fineness modulus, then the amount of the aggregate (w) to be mixed with one part of coarse aggregate is given by the equation :

$$w = \frac{p_2 - p}{p - p_1}$$

Example. *To illustrate the above explanation we may consider two samples, one of coarse aggregate and the other of the fine aggregate. It is desired that the aggregates should be so proportioned as to have a fineness modulus of 5·34. The samples are passed through the set of nine standard sieves and the percentage retention on each sieve is recorded in a tabular form given below.*

British Standards Sieve No.	*Percentage Retention of*	
	Sample of Fine Aggregate	*Sample of Coarse Aggregate*
100	100	100
52	87	100
25	51	100
14	29	98
7	14	96
3/16"	7	92
3/8"	—	62
3/4'	—	10
1½"	—	6
Total retention	288	644

Thus the fineness modulus of fine aggregate $\frac{288}{100}$

or $p_1 = 2{\cdot}88$

and the fineness modulus of coarse aggregate $\frac{664}{100}$

or $p_2 = 6{\cdot}64$

As per formula, the amount of fine aggregate (w) to be mixed with one part of coarse aggregate is given by

$$w = \frac{p_2 - p}{p - p_1}$$

$$= \frac{6{\cdot}64 - 5{\cdot}34}{5{\cdot}34 - 2{\cdot}88}$$

$$= \frac{1{\cdot}3}{2{\cdot}46}$$

$$= 0\,528 = 52\,8 \text{ per cent.}$$

$$= 53 \text{ per cent. (say)}$$

$\therefore$ The ratio of the fine aggregate to coarse aggregate

$= 53 : 100.$

(*iii*) *By Minimum voids method* : This method is based on the fact, that to obtain dense concrete the quantity of fine aggregate should be slightly in excess of the voids in the coarse aggregate and the quantity of cement should also be slightly more than the fine aggregates. In this method the voids in the fine and coarse aggregates are separately found out with the help of a graduated cylinder and water. In its simplest form the process of finding the voids consists of partially filling a graduated cylinder with water. Let V_1 be the volume of water filled. To this water a known volume of the specimen aggregate say V_2 is added in the volume of the mixture recorded. Let the volume of the mixture be V. Then, percentage voids in the aggregate (x) is given by the equation :

$$x = \frac{V - V_1}{V_2} \times 100$$

The concrete mix is finally decided by using approximately 10% more sand and about 15% more cement than the percentage voids in coarse and fine aggregates.

(*iv*) *By Arbitrary Standards* : It is commonly adopted method of proportionating the aggregates in a concrete mix for small works of moderate importance. This method is, however; not recommended for large or important works, as the strength of concrete obtained is uncertain. In this method the volumes of cement, sand and coarse aggregate are taken in the proportions of $1 : n : 2n$ respectively. Thus by this method the proportion of aggregates in a concrete mix should be 1 : 2 : 4 ; 1 : $2\frac{1}{2}$: 5 ; 1 : 3 : 6 and so on. The quantity of water to be used is varied to suit the workability desired. The

proportions of materials in concrete mix for various classes of work are given in table 24·3.

TABLE 24·3
CONCRETE MIX FOR VARIOUS TYPES OF WORK

S. No.	*Type of Work*	*Mix recommended*
1.	For rich mix concrete work in columns, beams etc.	M 250 (1 : 1 : 2)
2.	For water retaining structures, piles, precast works or in situations where dense-concrete is desired.	M 200 (1 : 1½ : 3)
3.	Reinforced concrete beams, slabs, columns, roads etc.	M 150 (1 : 2 : 4)
4.	Foundations for buildings; mass reinforced concrete works; machine foundations etc.	M 100 (1 : 3 : 6)
5.	For mass concrete.	1 : 4 : 8

24·13 Mixing of Concrete. During the process of mixing great care is taken to ensure that the materials are maintained in a uniform condition. There are two different types of concrete mixing :

(*a*) Hand mixing.

(*b*) Machine mixing.

(*a*) *Hand mixing* : This method of mixing concrete is resorted to when the quantity of concrete to be used in a work is insufficient to warrant the necessity of machine. This method is used with advantage in places where machinery cannot be used on account of their non-availability or in works near a hospital where noise of machine is not desirable. Hand mixing is done on a clean, hard and impermeable surface. Cement and sand are first mixed with the help of shovels until the mixture attains a uniform colour. Aggregates are then added to this mixture and the whole mixture is then turned by shovels until, the stone pieces are uniformly spread throughout. After this computed quantity of water is poured into the heap from a can fitted with a rose. The mass is then turned until a workable mixture is obtained.

(*b*) *Machine mixing* : The machine used for mixing concrete is termed as concrete mixer. Two types of concrete mixers are in common use :

(*i*) Continuous mixers.

(*ii*) Batch mixers.

Continuous mixers are employed in massive construction where a large and continuous flow of concrete is desired. The process of feeding the mixing plant is more or less automatic. The machine

TABLE 24·4

PERMISSIBLE STRESS IN VARIOUS GRADES OF CONCRETE AS GIVEN BY I.S. 456-1964

(All tabulated values are in kg./sq. cm.)

Grade of Concrete	*Permissible stress in compression*		*Permissible stress in shear*	*Permissible stress in bond*	
	Bending	*Direct*		*Average*	*Local*
M 100	30	25	3	4	7
M 150	50	40	5	6	10
M 200	70	50	7	8	13
M 250	85	60	8	9	15
M 300	100	80	9	10	17
M 350	115	90	10	11	18
M 400	130	100	11	12	19

It may be noted for guidance that M 100, M 150 ; M 200.....of ordinary concrete correspond approximately to 1 : 3 : 6 ; 1 : 2 : 4 : ; 1 : 1½ : 3.....of nominal mixes of ordinary concrete.

requires careful supervision so as to obtain the concrete mix of desired consistency.

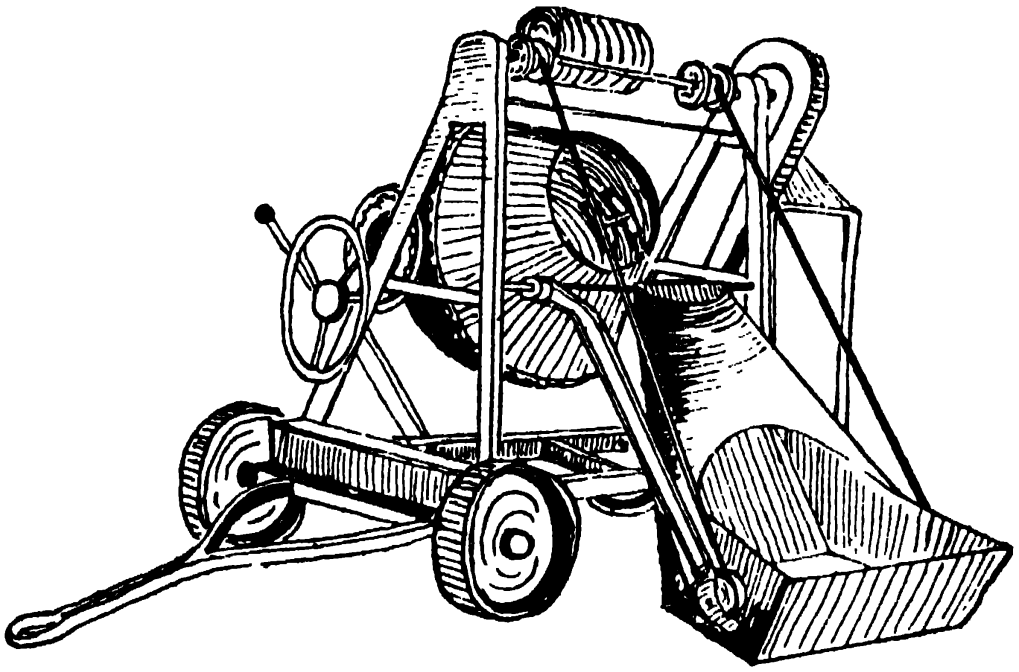


Fig. 24·2
Batch type concrete mixture

In Batch type of concrete mixer, the desired proportions of materials are fed into the hopper of a drum in which the materials get mixed by the series of blades or baffles inside the mixer. Batch mixers are further divided into two main types—*viz.*, tilting drum type and closed drum type. In the first type the components of concrete mix are fed in the revolving drum in a tilting position and after some time the concrete mix is discharged by tilting the drum in the opposite direction. In the latter type the drum remains rotating in one direction and is emptied by means of the hopper which tilts to receive the discharge.

While using the mixer, coarse aggregates should be fed first, sand and then cement should be put afterwards. In this revolving state the components get mixed while water is poured with the help of a can. The concrete should be mixed for at least $1\frac{1}{2}$ to 2 minutes.

24·14 Placing of Concrete. Concrete should be placed and compacted immediately after mixing. The arrangement for the conveyance of the concrete mix should be so planned that the mixed mass is used within 30 to 40 minutes. This is necessary to prevent the danger of concrete getting its initial set. Thus the quantity of concrete prepared in one batch should be such that it can be used within the said period. Before laying concrete the shuttering should be cleaned of all dust or debris. In order to prevent the shuttering

absorbing the water from the concrete or getting stuck to it, a coat of crude oil or grease etc. is usually applied to the shuttering before concreting. In placing concrete, care should be taken to see that it should not be thrown from heights. Concrete should be laid in layers 15 to 30 cm. in thickness, and each layer should be properly compacted before laying the next one.

24·15 Consolidation of Concrete. Consolidation of concrete should proceed immediately after placing The function of consolidation of concrete is to expel the air bubbles in the mass and make it impermeable in addition to its securing desired strength. The concrete mass should be consolidated or compacted till the cream of the cement starts appearing on the surface. Over-compaction may lead to segregation of concrete while under-compaction may leave air-voids in concrete. Consolidation may be done by hand or mechanical device.

Hand compaction may be done by rodding, tamping or hammering. Tamping is usually adopted for compacting concrete for slabs or other such surfaces ; rodding is done for thin vertical members while hammering is done for massive plain concrete works.

Mechanical compaction is done by the use of vibrators. When vibrators are used, concrete mix of lower workability should be used to obtain greater durability and higher strength. Vibrators are of three general types, *viz.*, (*i*) internal ; (*ii*) external ; (*iii*) surface. Internal vibrators are commonly used on large works for flat surface (floor, slabs etc.) compaction. In this case, the vibrator is immersed in the full depth of concrete layer. External vibrators are placed against the formwork and are only adopted for thin sections of members or in place where internal vibrators cannot be used with ease. Surface vibrators are generally employed in concrete road construction.

24·16 Curing of Concrete. Curing of concrete is one of the essential requirements of the process of concreting. Curing is the process of keeping the set concrete continuously damp for some days in order to enable the concrete gain more strength. It has been established that the strength of concrete increases with the age provided it is kept damp. During the process of curing the concrete absorbs the water necessary for its complete chemical action to reach its required strength. The strength of concrete increases more rapidly in the first few days after setting and afterwards the rate of increase in strength goes on retarding. The period for which curing should be continued depends upon atmospheric conditions such as temperature, humidity and wind velocity. In general the process of curing should be continued for 7 to 10 days. In cold weather, however, the concrete should be cured for at the least 14 days, as the rate of hardening of cement, is low in such conditions. Efficient curing increases both impermeability and the durability of concrete, and as such it needs special attention when the concrete is exposed

to water pressure or severe wheather conditions. Correct curing also increases resistance of concrete to abrasion and reduces shrinkage. Curing may be done by adopting the following methods :

(*i*) By covering the exposed surface with moist sand, earth, gunny bags etc. and sprinkling water at intervals to keep the covering wet.

(*ii*) Floors or other horizontal surfaces may be cured by impounding water in earthen or sandy bunds in squares over the entire area, The depth of water in the enclosed squares may be maintained 5 to 8 cm.

(*iii*) Columns, walls or other such vertical surfaces are usually cured by wrapping gunny bags or canvas over the surface and keeping the wrapped material continuously wet by sprinkling water or by some other means.

It has now been discovered that during the process of curing increase in temperature increases the rate of increase in strength of concrete. This property is made use of in curing small precast members by steam. This enables the concrete to gain required strength in less time.

24·17 Concreting Under Water. The deposition of concrete under water is a complicated problem. Concreting under water may be necessary in marine works or in case of deep foundations. As there is a continuous danger of loss of cement and segregation of concrete, placing of concrete under water is usually confined to unreinforced (plain concrete) construction. In case the site is such that the provision of cofferdams, or other such dewatering measures is not practicable, anyone of the methods mentioned below may be selected for concreting under water :

(*i*) *By tremie*

(*ii*) *By skip or bottom opening bucket.*

(*i*) **Tremie** : Tremie is the name given to a steel pipe 15 to 30 cm. in diameter and sufficiently long enough to reach the bed of water shed keeping its one end above the water level. The pipe is fitted with a hopper at its upper end for pourig concrete inside the pipe. The tremie is equipped with a check valve at its lower end. When concrete is poured in the hopper of the pipe, it displaces the air and water from the pipe and reaches the bed. During the process of concreting the tremie is gradually raised, keeping the lower end of the tube submerged in the concrete mass already poured below. In order to compensate the possible loss of cement under water, rich mix of concrete should always be used. Concrete thus laid under water should never be compacted or consolidated.

(*ii*) **Skip or bottom opening buckets** : Cubical hinged bottom bucket or cylindrical bucket equipped with a rolling gate of a skip, is also sometimes used for concreting under water. In either

case it is necessary that the bucket or skip is lowered to the bed of working place before the concrete is discharged. This is necessary to minimise the concrete loss during the process of placing.

24·18 Water-proofing of Concrete. A well designed concrete mix properly laid, compacted and cured is in itself impermeable. As far as possible the addition of water-proofing compounds should be avoided for normal working conditions. A dense concrete having minimum possible air voids shall, therefore, be the essential consideration in the making of damp-proof concrete. The following conditions should be satisfied to achieve the object :

(*i*) Use the best available material.

(*ii*) Proportionate the aggregates by fineness modulus method.

(*iii*) Use only as much quantity of water as is necessary to obtain the desired workability.

(*iv*) Ensure complete mixing of the concrete.

(*v*) Complete supervision during laying and compaction.

(*vi*) Complete curing.

However, in certain cases like water retaining structures ; structures in water logged ground or in damp atmosphere, it may be necessary to take further steps to ensure water-tightness. This includes the addition of certain water-proofing compounds like Permo, Pudlo, Sika etc., in the concrete mix, during the process of

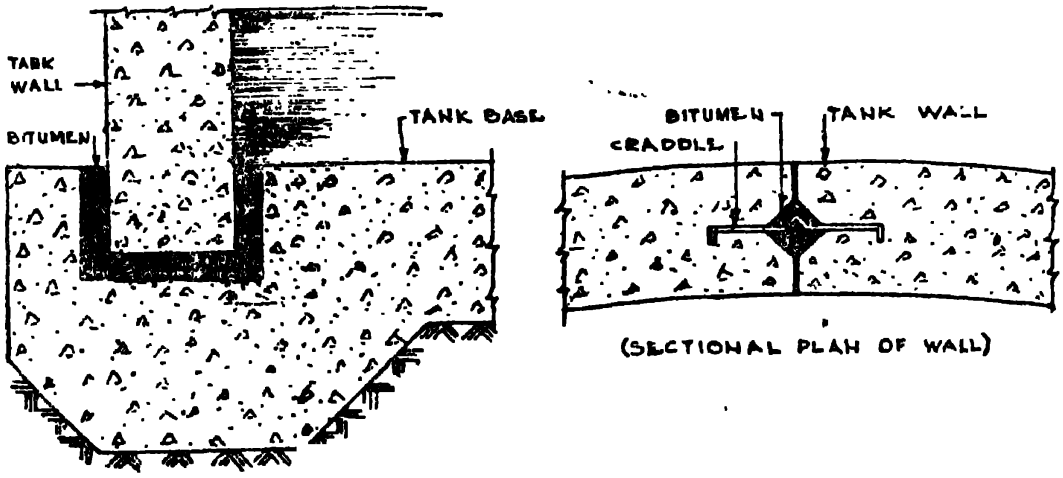


Fig. 24·3
Joints in circular reservoir

mixing. This is termed as integral water-proofing. The various other measures adopted to make the concrete impermeable are described in the chapter on "Damp-proof Course."

24·19 Joints in Concrete. The various types of joints in concrete work may be broadly split up into the following categories:

(*a*) *Construction joints.*

(*b*) *Functional joints (expansion and construction joints).*

(*a*) **Construction joints.** These joints are essentially provided when there is a break in the construction programme. As far as possible, the concreting work should be so planned that the work may be completed in one operation. If, however, the concreting must be stopped before the entire portion is completed and the already laid concrete has started setting or hardening, construction joints are unavoidable. Unplanned spacing of construction joints may lead to the failure of the structure. In general, the position and arrangement of construction joints should be decided before starting concreting. The best location of construction joints is given below :

(*i*) *For beam* : The concereting may be stopped at the mid-span or over the centre of a column along a vertical plane at right angles to the length of beam.

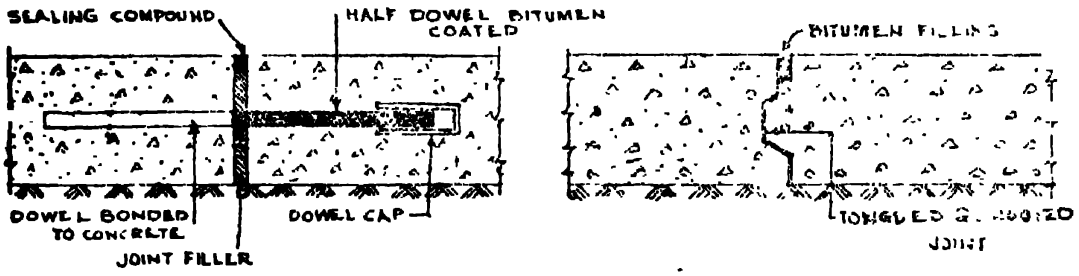


Fig. 24·4—24·5

Fig, 24·4 Transverse expansion and constraction joint.

Fig. 24·5 Longitudinal joint in concrete road.

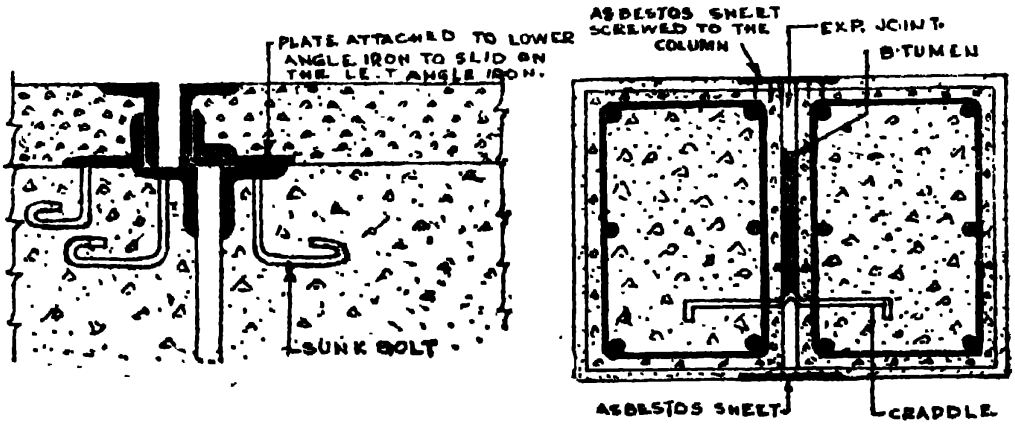


Fig. 24·6—24·7

Fig. 24·6 Joint in deck of bridge.

Fig. 24·7 Expansion joint in column.

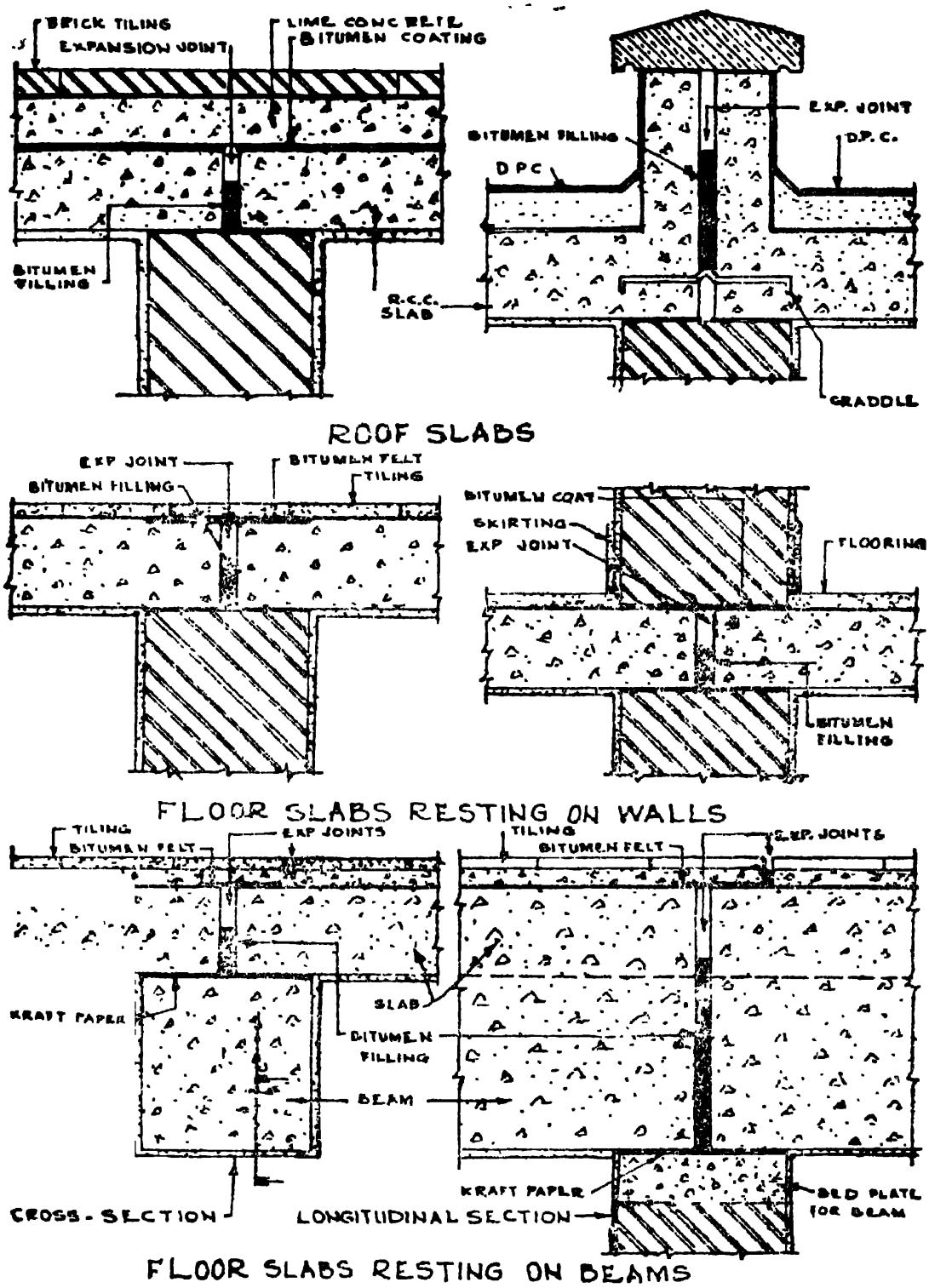


Fig. 24·8

Details showing various methods of providing expansion joints in R.C.C. roof and floor slabs

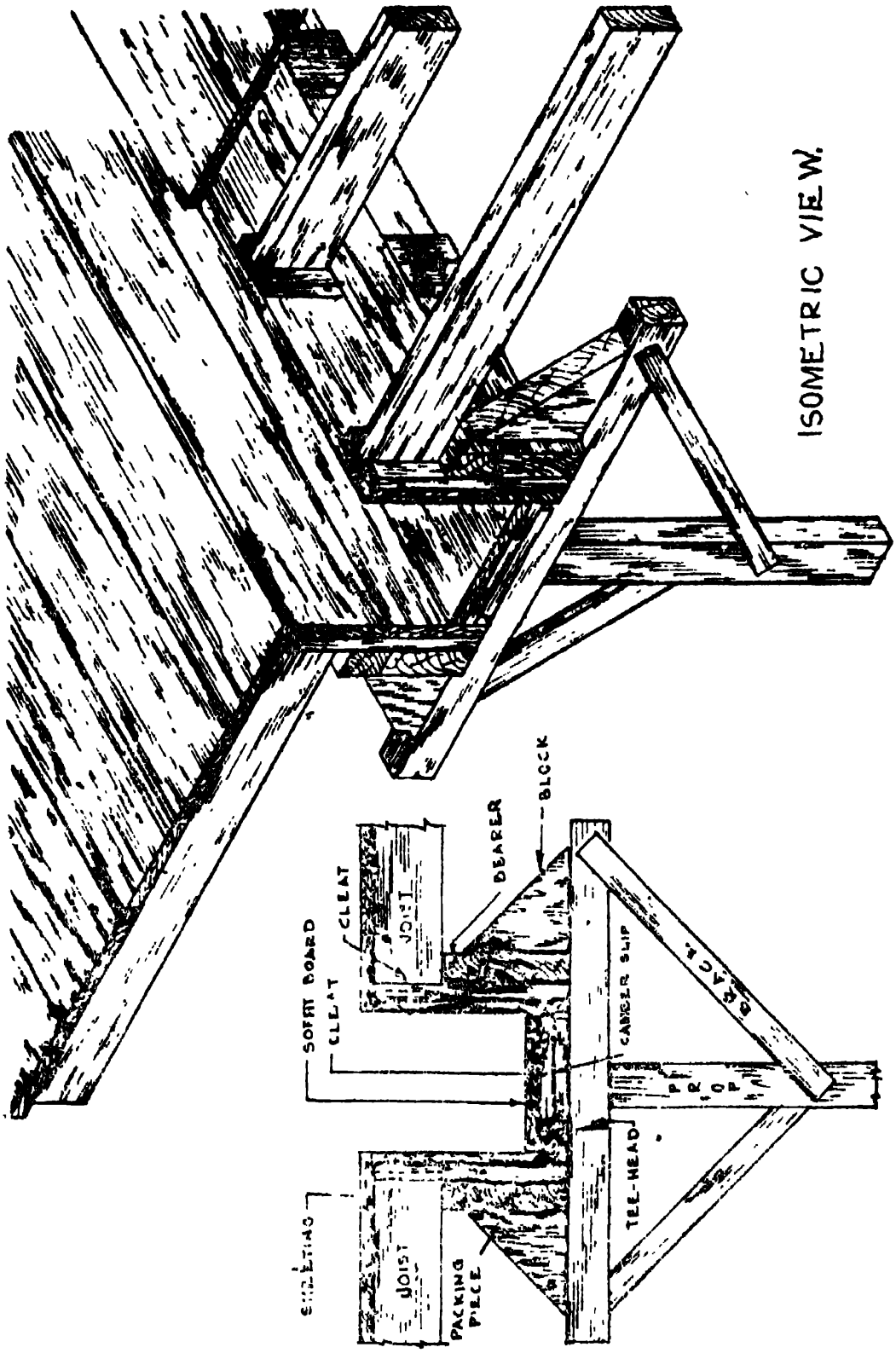
(*ii*) *For slab* : The concreting may be stopped at mid-span of the slab or directly over the centres of the beams making a vertical joint at right angles to the span.

(*iii*) *For column* : The concerting should be stopped a few cm. below its junction with the beam or to the bottom of haunching if any.

In order to have a good bond between the old and the new work, the concrete surface previously cast is cleaned, roughened and thoroughly saturated with water and a coat of neat cement-grout applied. The new concrete is then deposited before the grout attains its initial set.

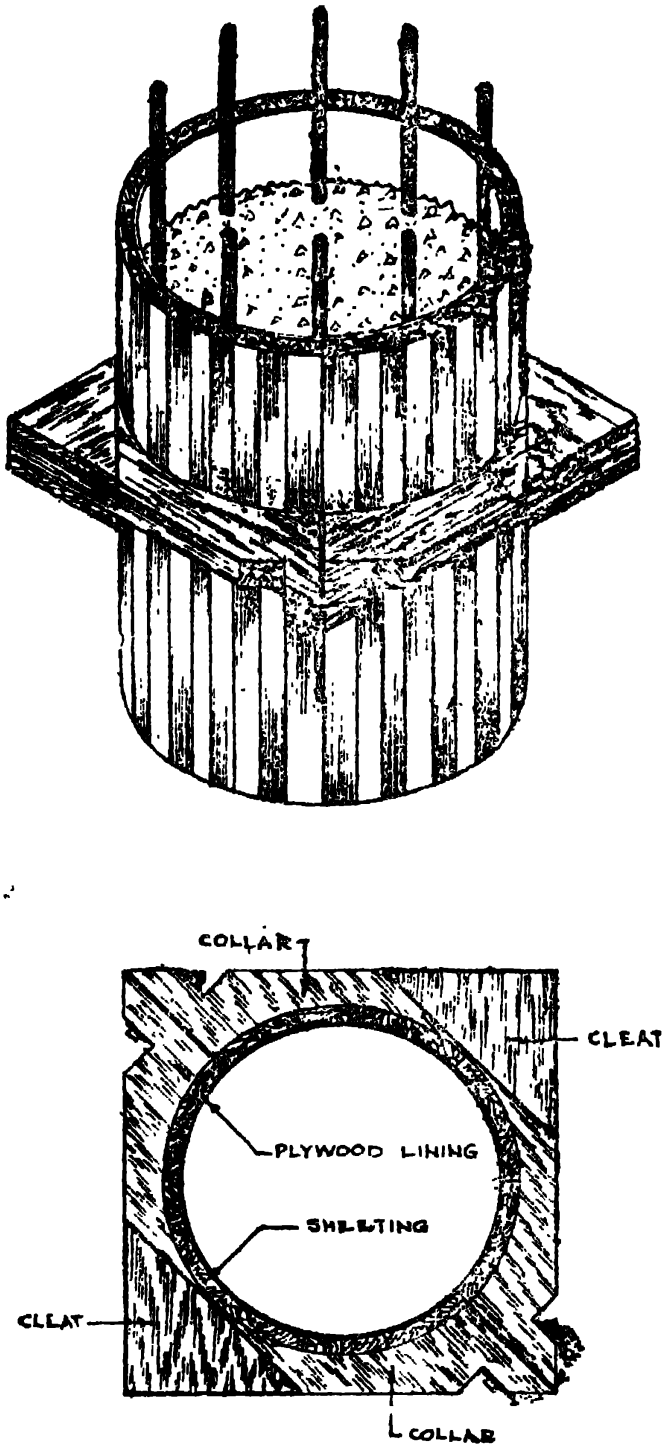
(*b*) **Functional joints** (*expansion and contraction joints*) : Functional joints, also known as expansion and contraction joints, may be necessary to render the structure safe against shrinkage, expansion, sliding and warping of concrete. This type of joints are made by forming continuous breaks in large continuous areas of the structure at suitable distances apart. These breaks permit the concrete to expand or contract freely without distorting the structure. The joints or breaks may be 6 to 38 mm. wide. The design and the centre to centre spacing of the joints depend upon various factors like nature of structure, nature of site, atmospheric conditions and type and quality of materials.

24·20 Form-Work. Centring, shuttering or formwork is a sort of temporary construction in wood or steel, erected to give the concrete its desired shape. The formwork must be strong enough to carry the weight of the wet concrete, impact due to consolidation and the load of workmen, without deflection. It should be rigidly braced so that it will not bulge or sag under the said loads. Timber is commonly used for the formwork on account of its property that it can be easily worked to any desired shape. Partially seasoned soft wood is considered best suitable for formwork. Hard wood is expensive, heavy and difficult to work and hence it is not recommended for such works. The joints of the formwork should preferably be tongued and grooved so as to ensure water tightness and minimise the possibility of the slurry oozing out. If any crack in sheathing is detected after the formwork is ready for taking concrete, it should be remedied by filing it with clay or plaster of paris. Before pouring concrete, all forms should be cleaned of all dust, chips, etc. and rendered perfectly clean. The surface of formwork which is to come in contact with concrete is usually coated with crude oil or soft soap solution, to prevent the possibility or concrete getting stuck to it. The formwok should be removed with great



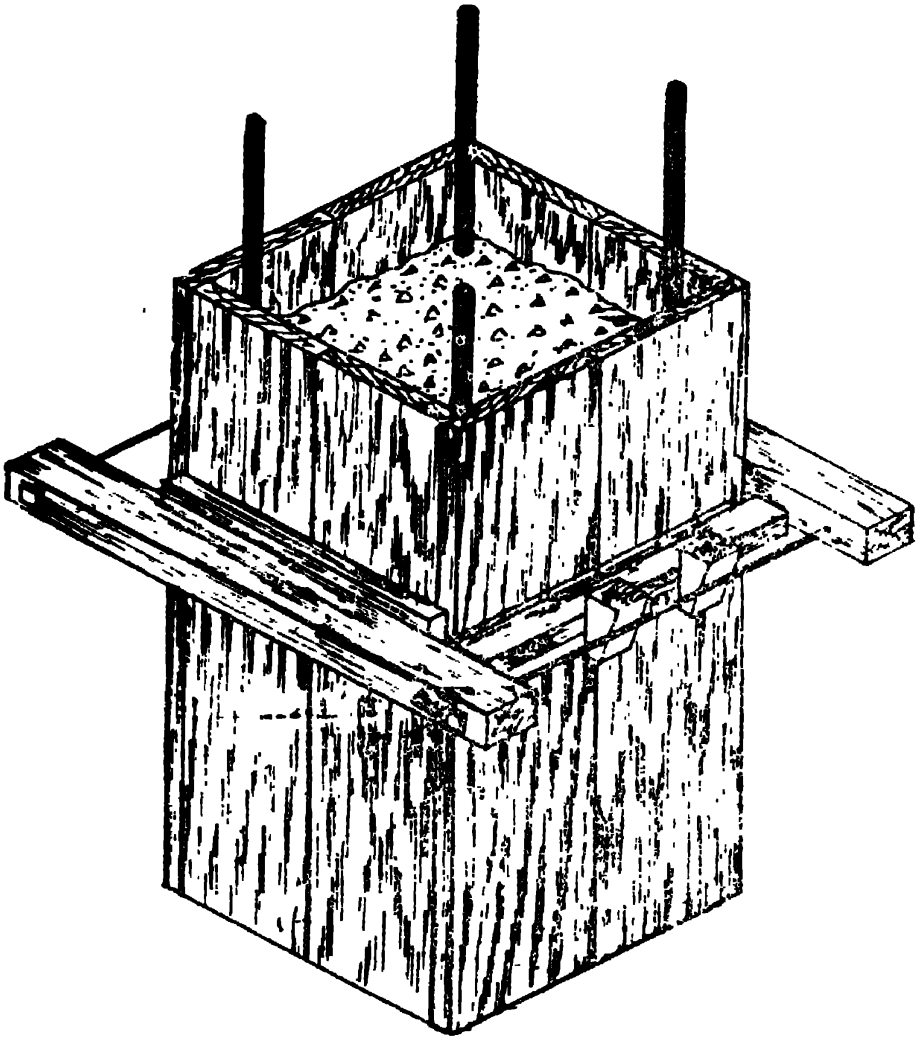
Figs. 24·9—24·10 Sectional elevation and view showing formwork for a beam and slab construction.

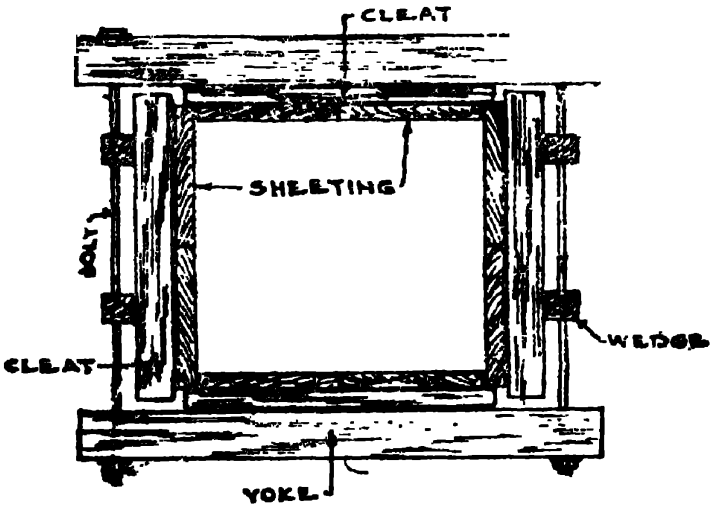
care. It is important to supervise that concrete is not damaged as the formwork is being removed. The planks should be skilfully



Figs. 24·11—24·12

View and sectional plan of formwork for a circular column





Figs. 24·13—24·14

View and sectional plan of formwork for a square-column

removed if possible without damage so that they may be used a number of times and effect saving in cost of formwork. The minimum period after which the formwork can be removed depends upon various factors as type of cement used, richness of the concrete mix, weather conditions etc. In any case, the formwork should only be removed when the supported member attains sufficient strength to support its weight independently. In general, the formwork may be removed after the number of days indicated against various members in the table below. The period mentioned is suitable for normal weather.

TABLE 24·5

NUMBER OF DAYS FOR REMOVAL OF FORMWORK

Description of structural member	*Normal Portland cement*	*Rapid hardening cement*
Beam sides, walls and columns	2 to 3 days	2 days
Slab (props left under)	4 days	3 days
Complete removal of form work for slab	10 days	5 days
Beam soffits (props left under)	days	5 days
Complete removal of formwork for beams	2 (days	8 to 10 days

24·21 Steel Forms. Mostly steel forms are used in large works where the forms have to be used a number of times. In normal practice, steel forms are fabricated from steel sheets strengthened with angle iron and are clipped together by keys and wedges.

Advantages : The steel forms have the following advantages over timber work :

(*i*) They are economical for large works, as there is no damage of any kind.

(*ii*) They afford rapid erection.

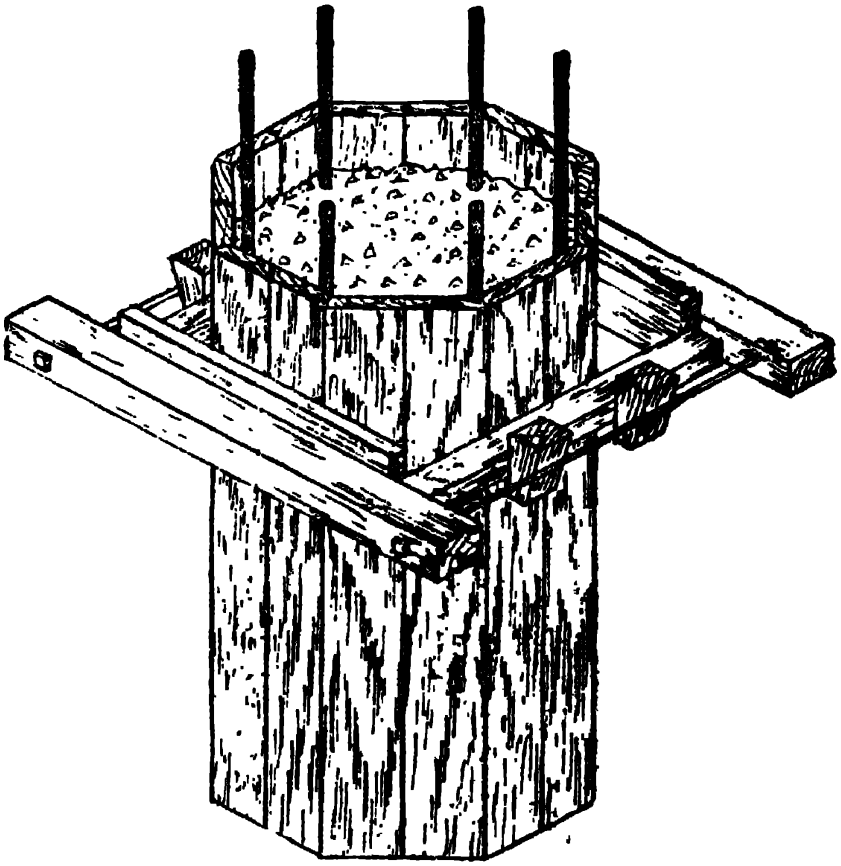
(*iii*) They are not liable to shrinkage or distortion.

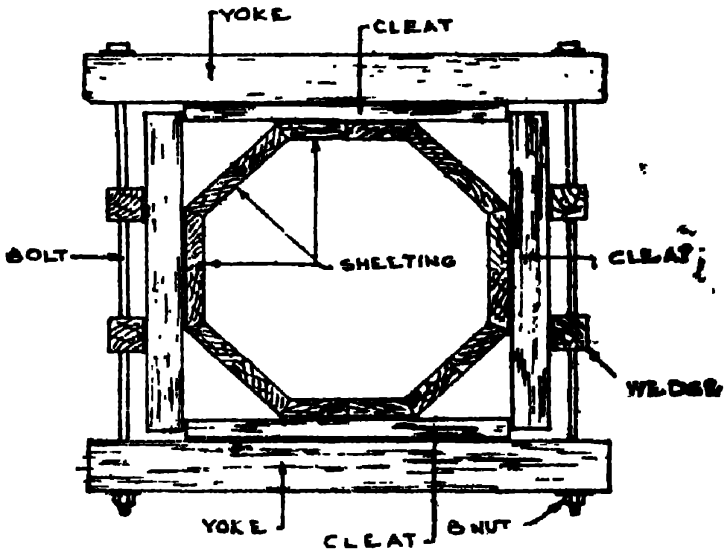
(*iv*) They can he used a number of times.

(*v*) There is no danger of formwork absorbing any moisture from concrete.

(*vi*) They render the surface of concrete, smooth and well finished when removed.

(*vii*) Unskilled labour may be used for their erection.





Figs. 24·15—24·16

View and sectional plan of formwork for a haxagonal column

Questions for Revision

1. What are the chief ingredients of plain cement concrete ? Describe in detail the properties of each.

2. Write short notes on :

(*i*) Rate of setting of cement.

(*ii*) Rate of hardening of cement.

(*iii*) Heat evolution of cement.

(*iv*) Resistance of cement of chemical action.

3. Write short notes on :

(*i*) Normal setting cement.

(*ii*) Rapid hardening cement.

(*iii*) Quick-setting cement.

(*iv*) High-alumina cement.

(*v*) White and coloured cement.

4. What influence do the following have on the strength of cement concrete ?

(*i*) Size of aggregates.

(*ii*) Shape of aggregates.

(*iii*) Proportion of aggregates.

5. What are the functions of water in a concrete mix ? Describe the properties of water which should be used to get good concrete.

6. What do you understand by the term 'bulking of sand' ? Why does it occur ? How do you made allowance for it ?

7. What do you understand by the term, "Water cement ratio" ? Explain how the quantity of water affects the strength of a concrete mix.

8. Write short notes on the following properties of concrete :

(*i*) Strength.

(*ii*) Workability.

9. What do you understand by slump test ? Describe the complete test in detail.

10. How do you measure the following in making a concrete mix ? Justify your mode of measurement :

(*i*) Measurement of cement.

(*ii*) Measurement of sand.

(*iii*) Measurement of water,

11. What effect do the grading of aggregates have upon a concrete mix ? Describe the grading of aggregates by the following methods :

(*i*) By trial.

(*ii*) By fineness modulus method or sieve analysis method.

(*iii*) By minimum void method.

(*iv*) By arbitrary standard.

Write the various methods of mixing concrete.

13. Write short notes on :

(*i*) Workability of concrete.

(*ii*) Water-cement ratio.

(*iii*) Slump test.

(*iv*) Continuous mixers.

(*v*) Batch mixers.

14. What do you understand by the term 'curing' ? Why is it essential to cure concrete ? What are the various methods commonly adopted in curing ?

15. What conditions should be satisfied to get a water-proof concrete ? What are the different methods used in the water-proofing of concrete ?

16. What are the different types of joints commonly provided in cement concrete construction ? Describe them in brief, giving suitable sketches wherever necessary.

17. What do you understand by term 'formwork' ? Describe the following with sketches :

(*i*) Formwork for square and round columns.

(*ii*) Formwork for beam and slab construction,

(*iii*) Formwork for R.C.C. stairs.

18. Write short notes on :

(*i*) Concreting under water.

(*ii*) Proportionating of concrete by weight.

(*iii*) Rapid hardening cement.

(*iv*) Water-cement ratio.

(*v*) Workability of concrete.

(*vi*) Measurement of coarse aggregates.

19. Write an essay on causes of failure of concrete structures.

20. What is the commonly adopted concrete mix for the following:

(*i*) Concrete for water retaining structures.

(*ii*) Concrete for beams, slabs and columns.

(*iii*) Concrete for foundation of heavy machinery.

(*iv*) Concrete for foundation of ordinary building.

(*v*) Mass concrete work.

21. Write the general specifications of following for R.C.C. work :

(*i*) Cement.

(*ii*) Sand.

(*iii*) Water.

22. What do you understand by quality control of concrete ? A R.C.C. 'T' beam roof over a hall 9 m. × 9 m. with beams 3 m. centre to centre has to be laid. Explain how you will plan to lay it giving particular reference to various types of joints necessary. Give list of labour and T & P you would arrange for the purpose. What will you do if your mixer suddeniy fails for that day after doing 25% of the work ?

23. A hall 18 m. × 6 m. with masonry walls will have to be roofed by R.C. beams and slabs. The beams are 3 m. apart. Show by suitable sketches the arrangement of shuttering and formwork required during the construction of the same Assume suitable dimensions of beam and slab and design suitable sections of wooden props, rafters, planking etc. necessary for the formwork.

24. Assuming that you are the architect of a large R.C.C. builiding in which the quality of materials, method of mixing and standard of workmanship are of vital importance. Describe the precautions and investigations you would suggest when the work is in progress.

25. Sketch the plan and sectional elevations, showing staging, centring, shuttering, etc. suitable for casting the roof of an auditorium 6 m. high, R.C. The beams are 75 cm. × 25 cm. wide. 12 m. in spans and resting on brick walls. The beams are spaced 3 m. centres. The roofing slab is 13 cm. thick. Give details of materials you would use showing only one bay.

26. What is understood by "designing of a concrete mix" ? How is it done ?

(*a*) Explain the design of such a mix. for an R.C.C. underground water tank.

(*b*) How is the consistency of concrete determined ? Explain the method.

27. Attempt any two of the following :

(*i*) How would you proceed to work out the proportions of materials for a high grade cement of a particular strength ?

(*ii*) What is "Vibrated concrete" and in what respect is it superior to ordinary concrete ? Describe different types of vibrators commonly used for concrete works of different types.

(*iii*) Describe at least two methods you consider best for rendering concrete of a water-tank leaf roof.

28. Describe the importance of the following in R.C.C. work :

(*a*) Water-cement ratio.

(*b*) Bulking of sand.

(*c*) Slump test.

(*d*) Curing.

29. What do you understand by a concrete of a constant workability and how do you measure the workability ? What are the different agents used in concrete as accelerators and retarders ?

30. Sketch the formwork for R.C. beam and slab construction at a height of about 4 metres from the ground level. The beams are at 3 metres centres and have spans at 6 metres. Mention the size of timber used.

25

Reinforced Cement Concrete

25·1 Definition. Though strong in compression concrete is extremely weak in tension. Its resistance to tension is so low that plain concrete can only be used where the member is in pure compression. Steel is equally strong in compression and tension, but it is apparent that while a long steel bar can develop its full strength in tension, it cannot resist equal amount of compressive force, owing to its buckling due to the slenderness. Thus the combination of concrete and steel has proved to be ideal, as the two materials are used to take up the stresses they are most suitable for. Such a combination of steel and concrete is called 'Reinforced Concrete'.

25·2 Properties of Reinforced Concrete. The combination of steel and concrete becomes practicable or workable for the following three reasons :

(1) The concrete while setting grips very fast the surface of the steel bars. Therefore the concrete is able to transmit to the steel bars those stresses which it cannot resist itself.

(2) The coefficients of linear expansion of concrete and steel are almost the same. Therefore, no internal stresses are set up within reinforced concrete due to variations in temperature.

(3) The coating of cement grout on the surface of steel bars protects them from corrosion and does not produce an adverse chemical effect.

25·3 Advantages of Reinforced Concrete

(1) It is economical in ultimate cost.

(2) Its monolithic character gives much rigidity to the structure.

(3) It is durable and fire-resisting. It does not rot or decay and is not attacked by termites.

(4) It is almost impermeable to moisture.

(5) The cost of maintenance of a reinforced concrete structure is almost nill.

(6) The materials used in the reinforced concrete constructions are easily obtainable.

(7) The flexibility of the reinforcement and the fluidity of the concrete make possible the reinforced concrete members to be moulded in any desired shape. Thus reinforced concrete lends itself to a wide range of architectural expression.

25·4 Basic Assumptions. The following assumptions are made for design purposes :—

(1) A transverse section plain before bending remains plain after bending.

(2) The moduli of elasticity of steel and concrete are constant.

(3) All tensile stresses are taken up by steel reinforcement only and the resistance of concrete to tension is nil.

(4) The bond between concrete and steel is supposed to be sufficient to make them act jointly to resist tensile or compressive forces.

25·5 Why Steel Rods are used for Reinforcement ? The fact which makes it possible to combine steel and concrete is that concrete contracts on setting in air. If a steel rod is embedded in a mass of wet concrete, it will be found that considerable force is necessary to pull it out when the concrete is set. If the steel rod be in the form of a plate, although it will resist removal when the concrete is set, yet it can be knocked off by sharp blows. In the first ease, the concrete grips the steel, while in the second it only adheres. The grip depends upon the quality of the concrete, whether it has been well or badly rammed round the rod. It depends upon the condition of the surface of rod, whether it is rough or smooth. Specially shaped bars have been introduced from time to time with the object of increasing the grip. It is on account of their superior bond value that the steel rods are used in the reinforced concrete construction.

25·6 Causes of Failure of Reinforced Concrete Structures. A reinforced concrete member can fail mostly in the following cases :

(1) When the member is subjected to excessive tension, so as to exceed the permissible stress in steel.

(2) When the loading is such that the compressive stress in concrete exceeds its safe permissible value.

(3) When the concrete is subjected to excessive shear.

(4) On account of the slipping of the steel bars from concrete.

(5) Due to bad quality of material used, shrinkage, creep or thermal effects.

(6) When the member is subjected to extremes of temperature, aggressive liquids or gases.

25·7 General Design Requirements. An efficient design of a reinforced concrete structure requires that the materials be economically selected, proportioned and arranged to carry the required loads without developing stresses which are in excess of the allowable working stresses. Due consideration should be given to the effect of continuity on the distribution of bending moments and shears due to monolithic construction. Correct estimation of all types of loads should be made before taking up the design proper. The design requirements may be summarised to the following general considerations :

(1) Sufficient longitudinal reinforcements should be provided to take care for the direct tensile stresses caused by bending.

(2) The sectional area of concrete should be sufficient to take care for the direct compressive stresses caused by bending moment.

(3) Provision of sufficient anchorage for all reinforcement so that all bond stresses and anchorage requirements are met.

(4) Sufficient shear reinforcements to keep the shearing stresses within permissible limits.

Basic Rules for the Design of Beams and Slabs

Refer pages 333—339 of this book.

Steps to be followed in the design of Slabs

Refer pages 339—351 of this book.

Steps to be followed in the design of Beams or lintels

Refer pages 377—381 of this book.

DOUBLY REINFORCED BEAMS

25·8 General. A doubly reinforced beam is a member which is reinforced both in tension and compression. A beam has to be doubly reinforced in the following cases :

(1) When the depth and breadth of the beam are restricted and it has to resist greater bending moment than a singly reinforced beam of that section.

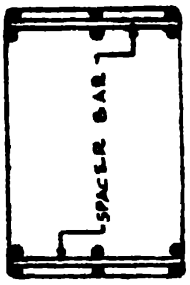


Fig. 25·1

Section of a doubly reinforced beam

(2) When the beam is continuous over several supports, the section of the beam at the supports is usually designed as doubly reinforced section.

(3) When the member is subjected to eccentric loading.

(4) When the bending moment reverses according to loading condition, as in walls of storage reservoir, brackets, etc.

25·9. Steel Beam Theory. When the compression steel resists the whole of the compressive stresses, the maximum permissible stress in compression steel is the same as in tensile steel *i.e.*, 1400 kg/sq. cm. The design of such a beam is done by steel beam theory. According to this theory, equal area of tensile and compressive steel, is provided and the lever arm of the beam is the c/c distance between the tensile and compressive steel. The formula used to calculate the tensile and compressive steel is

$$A_t = A_c = \frac{M}{1400(d-d_c)}$$

Where M = The B.M., the beam has to resist

$d-d_c$ = The c/c distance between the tensile and compressive steel.

25·10 Formulae used in the Design of Doubly Reinforced Beam :

(1) $$A_{t_1} = \frac{M'}{a_1.d.t}$$

where A_{t_1} = the tensile steel required for the singly reinforced section.

M' = the moment of resistance of the singly reinforced beam of the given section.

(2) $$A_{t_2} = \frac{M-M'}{t\,(d-d_c)}$$

where A_{t_2} = extra tensile steel required to resist the balance of B·M.

(3) Total tensile steel required = $A_{t_1}+A_{t_2}$

(4) Total compression steel required

$$A_c = \frac{mA_{t_2}\,(d-n)}{(m-1)(n-d_c)}$$

25·11 Steps to be followed in Design of a Doubly Reinforced beam.

(*a*) Calculate the moment of resistance of the given section of the beam by the formula

$M' = Q.b.d^2$

(*b*) Find A_{t_1}, the area of tensile steel required to resist the above B.M.

$$A_{t_1} = \frac{M'}{a_1.d.t}$$

(*c*) Find $M-M'$

wherd M is the external bending moment the beam is required to resist.

(*d*) Calculate extra tensile steel, A_{t_2} required to resist excess of bending moment by the formula

$$A_{t_2} = \frac{M - M'}{(d - d_c)t}$$

where d_c is the distance of the compression steel from top of them.

(*e*) Find total area of tensile steel required, given by

$$A_t = A_{t_1} + A_{t_2}$$

(*f*) Calculate the compressive steel required by equating the moments of the equivalent areas of compressive steel (A_c) and extra tensile steel (A_{t_2}) about the neutral axis. This is given by

$$A_c = \frac{m.A_{t_2}(d - n)}{(m - 1)(n - d_c)}$$

DESIGN OF T-BEAMS

25·12 General. In T-beam design the slab which is to be supported by the beams is designed first. This gives the thickness of the flange of the T-beam. The breadth of the rib is generally kept $\frac{1}{3}$ to $\frac{1}{2}$ of the assumed depth of the beam. Depending upon the loading conditions and the span, the assumed depth of beam should vary between $\frac{1}{12}$ to $\frac{1}{10}$ of the span. The design of T-beam now consists in calculating the area of steel required and to ascertain that the assumed depth keeps the stresses in concrete and steel within safe permissible limits. The design is, however, checked for shear and bond, similar to a rectangular beam.

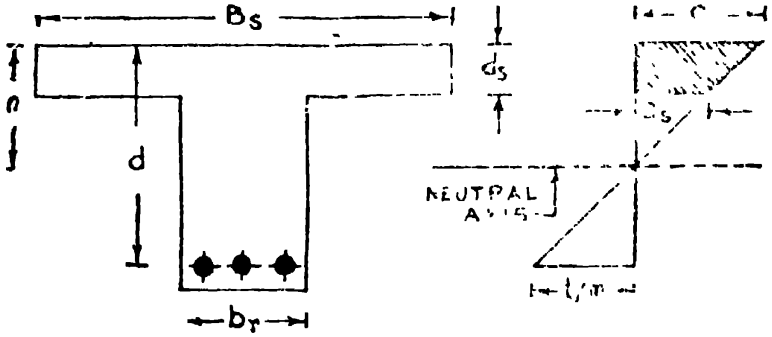


Fig. 25·2

25·13 Dimensions of T-beam

(1) The thickness of flange *i.e.*, d_s is the thickness of the slab spanning over the beams.

(2) The breadth of the rib *i.e.*, b_r. should be sufficient to

accommodate the main bars in the beam. It may be assumed to be between $\frac{1}{8}$ to $\frac{2}{8}$ of the over-all depth.

(3) The value of D, the over-all depth of the beam, is usually assumed as below :

(*a*) For freely supported beams

$D = \frac{1}{12}$ to $\frac{1}{15}$ of the span.

(*b*) For continuous beams

(*i*) D (for light loads, as in case of roof etc.)
$= \frac{1}{15}$ to $\frac{1}{20}$ of the span.

(*ii*) D (for medium loads, as in case of floors etc.)
$= \frac{1}{12}$ to $\frac{1}{15}$ of the span.

(*iii*) D (for heavy loads of the order of 1200 kg./sq. m.)
$= \frac{1}{10}$ to $\frac{1}{12}$ of the span.

(4) The effective breadth of the flange, *i.e.*, B_s, in case of T-beams should not exceed the least of the following values :

(*i*) $\frac{1}{3}$rd of the effective span of the beams.

(*ii*) c/c distance between the beams.

(*iii*) Breadth of the rib + 12 × thickness of slab, *i.e.* $b_r + 12d_s$.

25·14 Steps to be Followed in the Design. The design of T-beam differs in many respects from the design of a rectangular beam. The various steps involved in designing a simply supported T-beam are given below :

(*a*) Fix the depth and breadth of the rib, the thickness of flange being already calculated.

(*b*) Decide the approx. lever arm of the beam, by taking larger of the following values :

(*i*) Effective depth of the T-beam $= d - \frac{d_s}{2}$ or

(*ii*) $0{\cdot}87d$ to $0{\cdot}9d$.

(*c*) Calculate the effective span of the beam.

(*d*) Find (w) the load per metre run on the beam ; w = loads due to slab in kg./m. + wt. of rib in kg./m.

(*e*) Calculate the max. bending moment (M) in the beam.

(*f*) Calculate the area of tensile steel given by the formula

$$A_t = \frac{M}{\text{approx. lever arm} \times t}$$

(*g*) Check the section for maximum stress. This involves the following steps :

(*i*) Calculate neutral axis of the beam, given by the equation

$$B_s d_s \left(n - \frac{}{2} \right) = mA_t(d-n) \qquad ...(i)$$

Depending upon the assumed depth, applied B.M. or the thickness of the flange of the beam, the neutral axis may lie inside the flange or it may lie outside.

If the value of neutral axis as obtained in (*i*) is less than the thickness of slab or d_s, the neural axis lies inside the flange. In such cases the neutral axis is re-calculated by using the equation

$$\frac{B_s n^2}{2} = m.A_t(d-n) \qquad ...(ii)$$

and the exact lever arm of the beam $= d - \frac{n}{3}$

If, on the other hand, the value of n as obtained in (*i*) is more than d_s, the neutral axis lies outside the flange and the exact lever arm is then

$$= d - \bar{y}$$

where $$\bar{y} = \left(\frac{c+2c_s}{c+c_s} \right) \frac{d_s}{3}$$

(*ii*) Find the stress developed in steel by the formula

$$t = \frac{M}{\text{exact lever arm} \times A_t}$$

(*iii*) Find the stress developed in concrete in compression given by the formula

$$c = \frac{nt}{m(d-n)}$$

The values of t and c, as obtained in steps (*ii*) and (*iii*) above, should be less than the safe allowable stresses in steel and concrete.

If the value of t or c as obtained in steps (*ii*) and (*iii*) above is more than their safe permissible values, repeat the design by increasing the assumed depth of the beam.

(*h*) Find the max. shear stress developed in the beam. This is given by the formula

$$s = \frac{S}{\text{exact lever arm} \times b_r}$$

Design for shear reinforcement is similar to that of a rectangular beam

(*i*) Check for bond by the formula

$$S_b = \frac{S}{\text{exact lever arm} \times \Sigma 0}$$

25·15 Design of Continuous T-beams. In case of continuous T-beam, the bending moment at the mid-span is of sagging nature and the slab forming the flange of the T-beam it subjected to compression. Thus the presence of the slab is helpful in increasing the compressive resistance of the beam. Over the supports, the bending moment is of hogging nature and the flange of the beam is subjected to tension. Since the tensile resistance of concrete is totally ignored in our basic assumptions, the availability of slab as flange of the beam over the supports is of no value. Hence the T-beam behaves like a rectangular beam over the supports. Since the depth of the beam is fixed by taking advantage of the compressive resistance of concrete in flange of the T-beam, it is obviously less than that required for a rectangular beam. Thus the section of the beam at the support is restricted in its dimensions and is usually designed as doubly reinforced section.

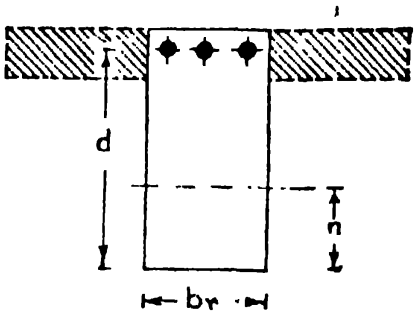


Fig. 25 3

25·16 Flange Reinforcement. The slab forming the flange of the T-beam may be spanning either transverse to the beam or it may be spanning parallel to it. The width of the slab which acts effectively with the T-beam will remain the same in both the cases. However, when the slab spans parallel to the beam, adequate reinforcement should be provided transverse to the beam throughout its length upto a distance of $\frac{l}{4}$ on either side of the rib of the beam, near the top face of the flange as shown in Fig. 25·4. As per Indian Standard Code of Practice, the area of such reinforcement should not be less than 60% of the area of the main reinforment provided at the mid-span of the slab forming the flange of the beam.

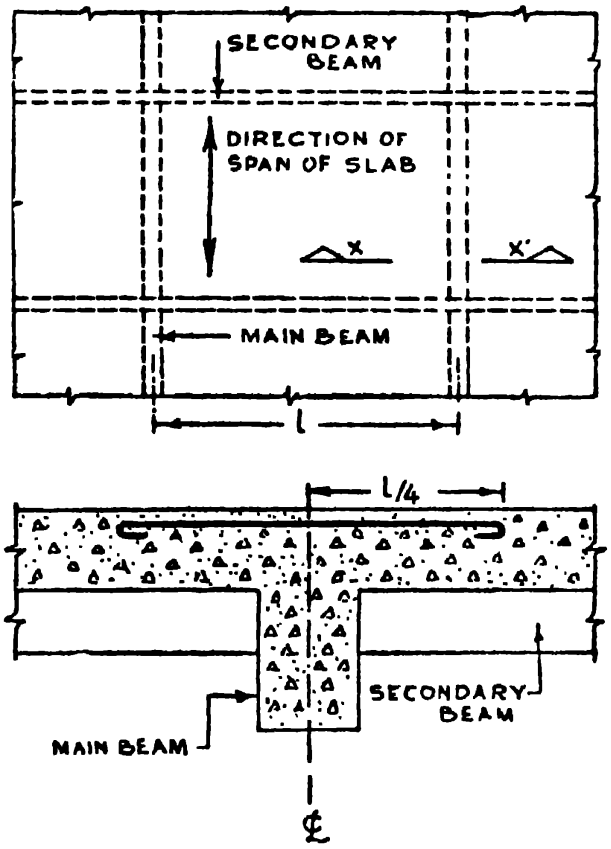


Fig. 25·4

DESIGN OF COLUMNS

25·17 General. A R.C. column is said to be subjected to axial load when the line of the resultant trust of loads supported by the column in coincident with the line of *C.G.* of the column in the longitudinal direction. Depending upon the architectural requirements and the loads to be supported, R.C. columns may be cast in various shapes, *i.e.*, square, rectangular, circular, hexagonal, etc. or tee-sections. The longitudinal bars in the R.C. columns help to bear the load in combination with the concrete. These bars are uniformly spaced along the perimeter of the columns as near the surface as practical. In order to prevent the longitudinal bars from bending, transverse reinforcement known as lateral binders or links are used. The links are spaced at suitable distance apart and every longitudinal bar is tied to them. In case of circular or hexagonal columns, the lateral binders, are generally provided in the form of closely wound spiral or helical reinforcement although separate units may also be used. A reinforced concrete column

having helical reinforcement must have at least six longitudinal bars.

25·18. Permissible Stresses in R.C. Columns. As a result of experiments all the codes recommend reduction of stresses in concrete as well as steel in R.C. columns.

As per the revised Indian Standard Code of Practice, I.S. 456—1964, the permissible stresses for various grades of concrete and for various types of steel reinforcement to be adopted in columns is given below :

Stress in concrete :

Grade of concrete	*Permissible stress in concrete in direct compre sion*
M 150 (1 : 2 : 4	40 kg./sq. cm.
M 200 (1 : ½ : 3)	50 kg./sq. cm.
M 250 (1 : 1 : 2)	60 kg./sq. cm.

Stresses in steel :

(*i*) For column bars in compression = t_c = 1300 kg /sq. cm.

(*ii*) For helical reinforcement in column

= t_c = 1000 kg./sq. cm.

25·19. Effective Length or Height of a Column. From practical considerations, the actual height or length of a column is usually taken as the clear distance between the floor and the lower extremity of the capital, drop or slab, whichever is smaller while in a beam and slab construction the actual length (L) is taken as the clear distance between the floor and the underside of the shallower beam framing into the column.

Effective length or height of a column depends upon the conditions of its ends.

For the design purposes, only the effective length of a column is used. The table below gives the effective length (l) of a column in terms of its actual length (L) for various end conditions.

S. No.	*End condition of the column*	*Effective length (l)*
1.	Both ends hinged (*i.e.* fixed in position but not in (direction).	L
2.	Both ends fixed in position as well as in direction.	$0{\cdot}75\,L$
3.	One end fixed in position and direction while the other end free.	$2L$
4.	One end properly fixed in position and direction while the other end is imperfectly fixed in both position and direction.	The value intermediate between L and $2L$ depending upon the efficiency of the imperfect restraint.

25·20 Types of Columns. In general columns may be divided into two different types, namely, short columns and long columns. A column is considered to be short when the ratio of its effective length of its least lateral dimension does not exceed 15 or the ratio to its effective length to the minimum radius of gyration does not exceed 50. If the said limits of the ratio exceed 15 and 50 respectively, the column is considered to be a slender or long column. Depending upon the type of lateral reinforcement used, the short columns are further sub-divided into the following two categories :

(*i*) Short column with separate links or binders.

(*ii*) Short column with helical binders.

25·21 Strength of Columns. The safe load carrying capacity for different types of columns is given below.

(*i*) *Short columns with separate binders* : The permissible load (P) for a short column with separate binders or lateral ties is given by the formula

$$P = c_d(A - A_c) + t_c.A_c$$

where c_d = permissible stress in concrete in direct compression,

A = the gross cross-sectional area of the column.

A_c = the cross-sectional area of the longitudinal steel.

t_c = permissible compressive stress for column bars.

$\therefore A - A_c$ = net area of concrete section conluding any finishing material and reinforced steel.

(*ii*) *Short column with helical binders* : The permissible load (P) for a short column in which helical binders are used as transverse reinforcement is given by the following formulae

(1) $P = c_d.A_k + t_c.A_c + 2t_e.A_e$

where.

A_k = cross-sectional are of concrete in the column core excluding the area of longitudinal reinforcement. The column core is considered to be the portion of the concrete enclosed inside the helical reinforcement upto the centre line of the helix.

t_e = permissible stress in helical reinforcement.

A_e = equivalent area of helical reinforcement which is taken as the volume of helical reinforcement per unit length of the column.

The above formula will hold good provided that the sum of the terms $c_d.A_k + 2t_e.A_e$ does not exceed.

$$0{\cdot}5\ \sigma cu.\ (A - A_c)$$

where σcu is the crushing strength of concrete cube (works test) after 28 days. Its value for M 150 grade of concrete (1 : 2 : 4) being 150 kg./sq. cm.

(2) $P = c_d(A - A_s) + t_c.A_c$

In this formula only nominal circular ties are provided and the presence of the transverse reinforcement is not supposed to contribute to the strength of the column.

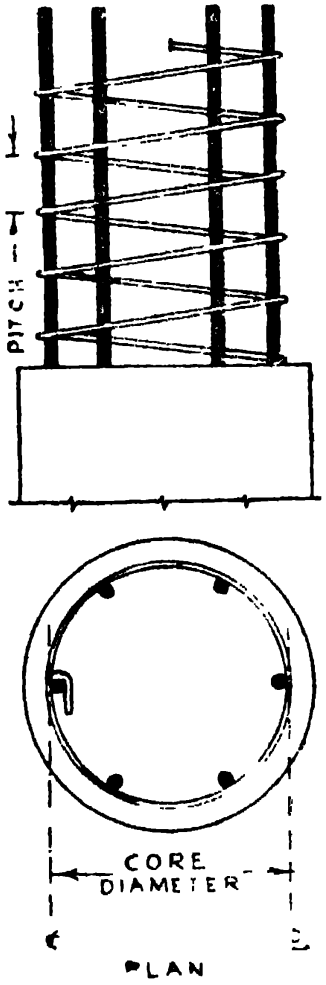


Fig. 25·5

25·22 Strength of Long Columns. A long column (*i.e.* a column having $\frac{l}{d} > 15$ or $\frac{l}{k} > 50$, where d is the least lateral dimension of the column and k is the minimum radius of gyration) on account of its buckling tendency has less strength than a short column of the same sectional area. To safeguard the long column against the buckling effect, the permissible values of the working stresses in steel and concrete are reduced by multiplying the respective stresses by a reduction coefficient given by the formula

$$R = \left(1{\cdot}5 - \frac{l}{30d}\right) \qquad \ldots(i)$$

or $$R = \left(1{\cdot}5 - \frac{l}{100k}\right) \qquad (ii)$$

where l = effective length of the column

d = least lateral dimension of the column

k = least radius of gyration.

Hence, the safe load that a long column can carry is obtained by multiplying the load, which a short column of same sectional area can carry, by the reduction coefficient R.

25·23. Basic Rules for the Design of Columns

Longitudinal reinforcement. (*i*) The cross-sectional area of longitudinal reinforcement in a column shall not be less than 0·8% and not more than 8% of the gross-sectional area of the column. In places where bars from a column below have to be lapped with those in the column to be designed, the maximum percentage of steel should preferably not exceed 4%.

(*ii*) The minimum diameter of the longitudinal bar shall not be less than 12 mm. and the maximum diameter should preferably not exceed 5 cm.

(*iii*) The minimum cover of the outside of longitudinal bars shall be 40 mm. or the diameter of the bar whichever is more. In case where the minimum dimension of a column does not exceed 20 cm. and the diameter of the longitudinal bars does not exceed 13 mm. the cover of 25 mm. may be used. This is as per the recommendation of revised I.S. 4456—1964.

(*iv*) Where it is necessary to splice the longitudinal reinforcement, the bars shall over-lap for a distance of not less than 24 times the diameter of the smallest bar.

Transverse reinforcement. To safeguard the longitudinal reinforcement against buckling, the transverse reinforcement may be provided either in the form of ties or helical reinforcement (spiral).

(*i*) The minimum diameter of the ties or helical reinforcement (spiral) shall not be less than $\frac{1}{4}$th of the diameter of the largest longitudinal bars or 5 mm. whichever is more.

(*ii*) The maximum diameter of the ties and helical reinforcement (spiral) should preferably be not more than 13 mm. and 25 mm. respectively.

(*iii*) The pitch of the ties should not be more than the least of the following distances :

(*a*) The least lateral dimension of the column.

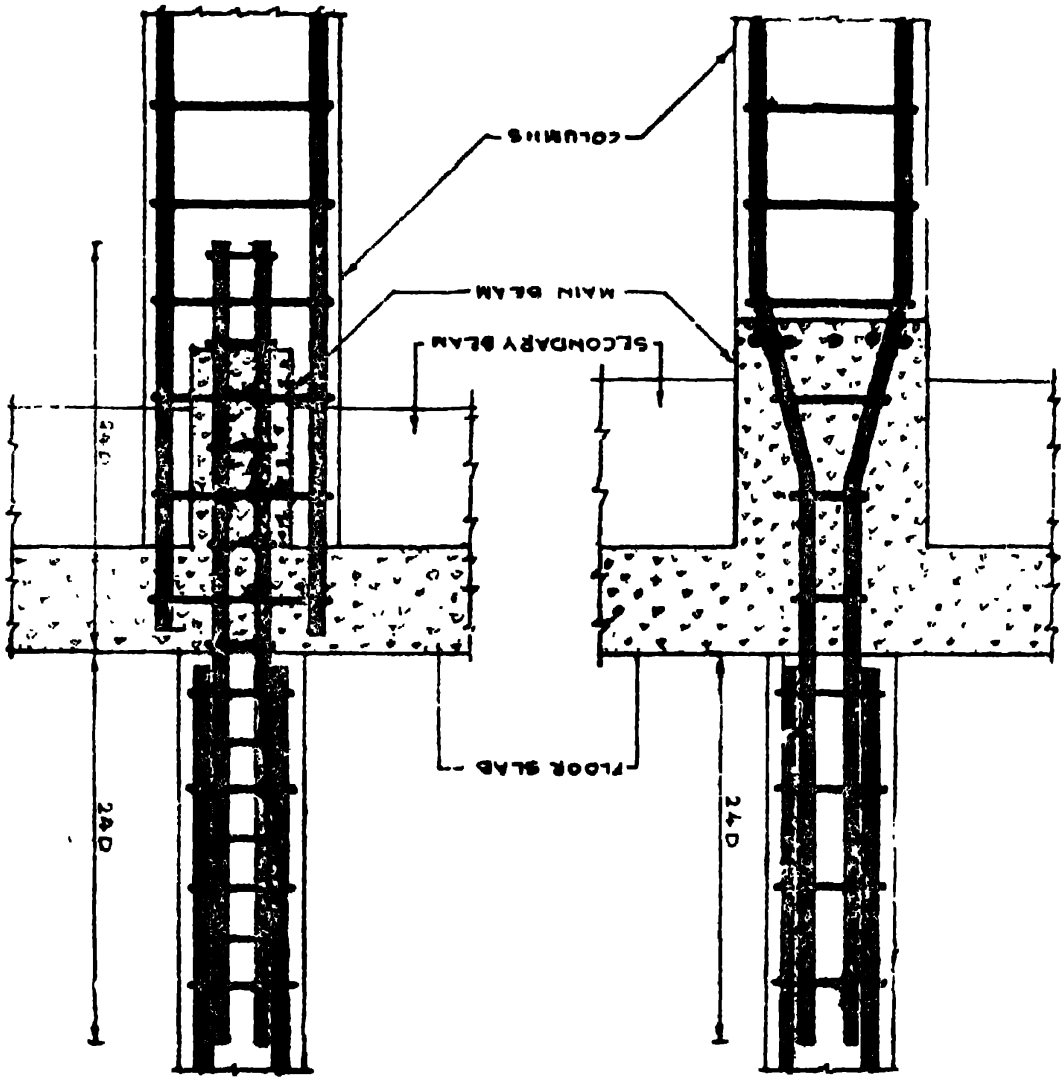


Fig. 25·6

Alternative details of column joints

(*b*) 12 times the diameter of the smallest longitudinal bar.

(*c*) 30 cm.

(*d*) 48 times the diameter of tie.

In cases where the column is assumed to take increased load on account of the continuous binding or spiral reinforcement, the following requirement in respect of the pitch of the spiral should be strictly followed.

(*iv*) The pitch of the spiral should not be more than the least of the following distances :

(*a*) $\frac{1}{6}$th of the diameter of the concrete core.

(*b*) 75 mm.

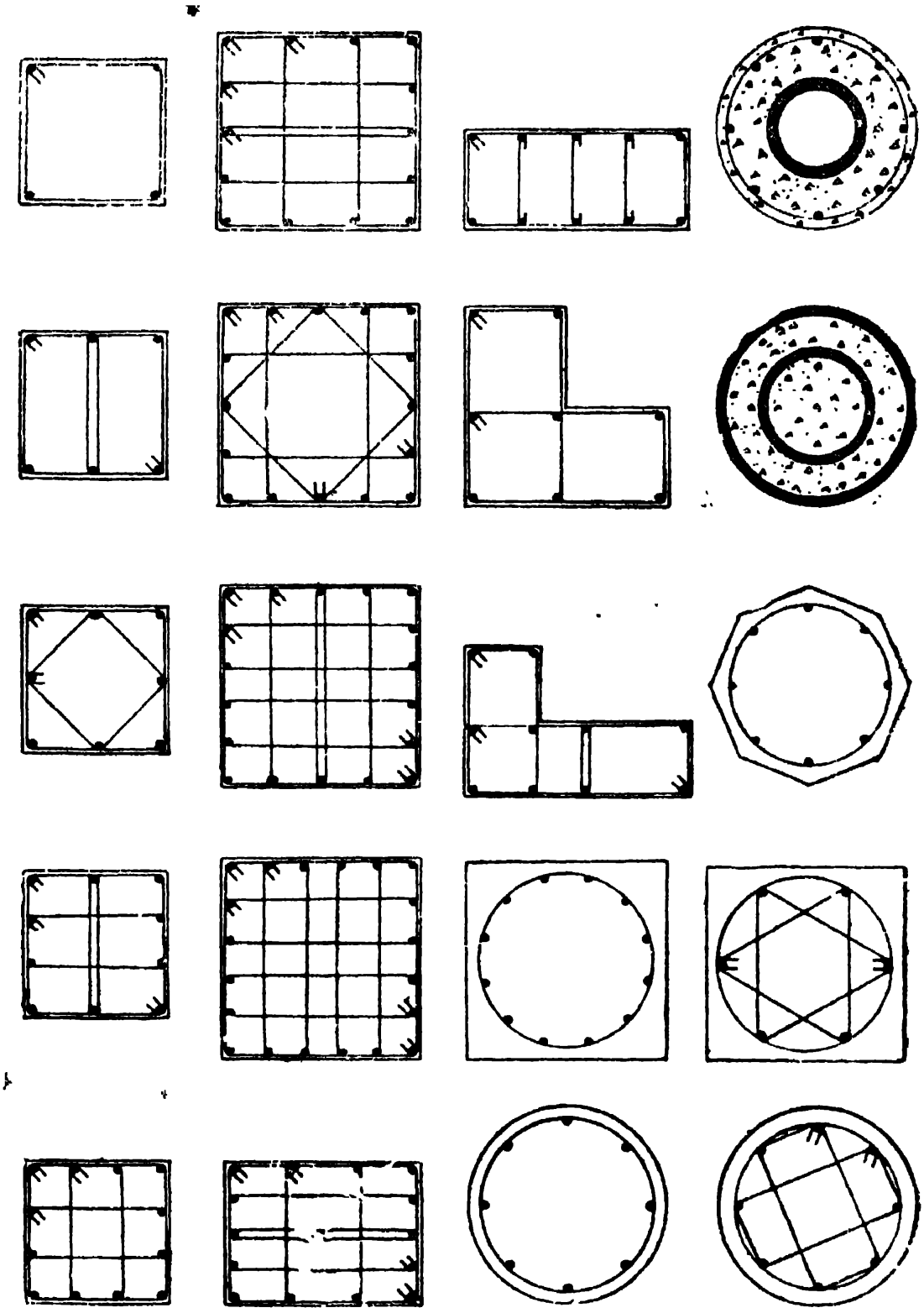


Fig. 25·7

Sketches showing arrangement of ties for various numbers of column bars

(*v*) The least spacing of the lateral ties may be 15 cm. and for the spirals, the minimum pitch shall be 25 mm. or 3 times the diameter of the spiral with head whichever is greater.

25·24 Steps to be Followed in the Design. The various steps involved in the design of a column with independent or separate links are given below :

(*a*) Find the load the column is required to carry. Add the self weight of column to get the total load at the column base.

(*b*) Decide the mix of concrete and hence the stress in concrete to be adopted in the design.

(*c*) Depending upon the load, assume, A_c=1 to 2% of A and calculate the approximate area of the column by the formula

$$P = c_d(A - A_c) + t_c . A_c$$

If A_c assumed $= 1\%\ A = 0{\cdot}01\ A$

then $$P = c_d\ (A - 0{\cdot}01\ A) + t_c \times {\cdot}01A$$

(*d*) Having found the value of A from the above equation, find out the least lateral dimension (d) of the column. In case it is desired to have a square column, $d = \sqrt{A}$, while if a circular column is desired

$$d = \sqrt{\frac{4A}{\pi}}.$$

(*e*) Find the effective length of the column from the given end conditions. If $\frac{l}{d} < 15$, drop the steps (*f*) and (*g*) given below and then proceed.

(*f*) If $\frac{l}{d} > 15$, or $= 15$, find the reduction coefficient R given by

$$R = \left(1{\cdot}5 - \frac{l}{30d}\right).$$

(*g*) Calculate the load P' for which a short column should be designed.

$$\therefore \qquad P' = \frac{P}{R}.$$

Now substitute this value of load, in the step (*c*) and calculate the final area of column.

(*h*) Choose suitable diameter of longitudinal reinforcement so that it may not be less than the assumed area of steel.

(*i*) Find the diameter of the stirrups and fix their pitch in accordance with the rules.

Questions for Revision

1. (*a*) What are doubly reinforced beams ? Why and where are these used ? Is their design economical ?

(*b*) An office floor has intermediate spans of R.C.C. slab supported on steel beams 3 m. centres. The span of steel beams is 6·1 m. If the slab is required to carry a live load of 300 kg./m.^{2}, design and detail the reinforcement in the slab.

2. Design a R.C.C. T-beam and a R.C.C. balcony for a lecture theatre having the following data :

(*i*) Size of the lecture theatre	12·2 m.×7·6 m.×6·1 m. height.
(*ii*) Size of the balcony	2·22 m. wide clear with 0·75 m. high and 10 cm. thick R.C.C. railing.
(*iii*) Height of the balcony	4·22 m. from floor.
(*iv*) Thickness of the brick wall	45 cm.
(*v*) Live-load for roof	146 kg/m.
(*vi*) Live-load for balcony	390 kg./m.^{2}

Stresses :

(*a*) Safe tensile stress in steel	1400 kg./cm.^{2}
(*b*) Safe compressive stress in bending in concrete	50 kg./cm.^{2}
(*c*) Modular ratio	15
(*d*) Bond stress	49 kg./cm.^{2}
(*e*) Shear stress	5 kg./cm.^{2}

Draw out necessary drawings to show the reinforcement and lay out.

3. Design a rectangular R.C.C. column, required to carry a load of 101 tonnes including its own weight. The design should be based on I.S.I. specifications.

4. A tee-beam of 12·2 m. effective span is required to be designed from the following data :

Live load on floor	...	490 kg./m.^{2}
Slab thickness	...	13 cm.
The over-all depth of beam	...	60 cm.
Width of rib	...	25 cm.
Spacing of T-beams	...	3·66 m. c/c.

Allowable stresses are :

C=56 kg./cm^2

t=1400 kg./cm^2

m=18

Allowable shear stress = 5·6 kg./sq. cm. In addition to the load from the slab the beam carries a brick partition wall 15 cm. thick and 3 m. high having the density of 1920 kg./m^2.

Determine the area of steel for moments and shear and give a neat dimensioned sketch of the design.

5. A R.C.C. T-beam and slab over a room 7·32×4·88 m. between centres of walls consist of two beams at 2·44 m. centres. The slab is 15 cm. thick and the size of the beam stem is 38 cm ×23 cm. The beam reinforcement will be 4 bar of 20 mm. diameter and two-legged stirrups of 6 mm. diameter. The slab reinforcement is 10 cm. rounds at 10 cm. centre to centre with 6 cm. rounds at 20 cm. centre to centre as temperature reinforcement. Draw a dimensioned cross-section through all the beams showing clearly the arrangement of reinforcement in beams and slab.

6. (*a*) What are permissible direct compressive stresses in M 150 (1 : 2 : 4) cement concrete mix allowed in the design of plain cement concrete columns of short length and in the design of R.C.C. column ? State the reasons for the difference in the two permissible stresses.

(*b*) A R.C.C. column 3·65 metres long 38 cm. square is reinforced with four longitudinal bars 25 mm. diameter. If the compressive stresses in M 150 (1 : 2 : 4) cement concrete are not to exceed 42·13 kg./cm.^{2} and $m = 15$, calculate the safe axial load on the column. Calculate the dimensions of the square footing of the column for the safe load you have calculated. The bearing capacity of soil is 22 tonne/sq. m.

7. The ground floor R.C.C. column of a residential building 60 cm. diameter carries a load of 243 tonnes. The height of the column is 380 cm. Design the column and its footing, if the permissible soil pressure is 8·3 tonne/m^2. Assume the weight of the footing suitably.

Permissible stresses are :

(*i*)	Concrete	70·30 kg. per sq. cm.
(*ii*)	Tensile stress in reinforcing bars	1400 kg. per sq. cm.
(*iii*)	Punching shear	8·40 kg. per sq. cm.
(*iv*)	Adhesive stresses	7·00 kg. per sq. cm.
(*v*)	Modular ratio—15.	

8. A simply supported R.C.C. beam rectangular in section is required to carry a uniformly distributed load of 1·66 metric tonnes per metre run exclusive of its own weight over a span of 9·14 metres. There are also two concentrated loads of 3·05 metric tonnes each acting on the beam at a distance of 3·05 metres from each end support.

Calculate the effective depth of the R.C.C. beam and the area of tensile reinforcement ; given the following :

(*i*) Width of beam = 36 cm.

(*ii*) $m = 15$

(*iii*) $f_c = 50$ kg./cm^2

(*iv*) $f_t = 1400$ kg./cm.^{2}

Draw neat sketch to show the finished section of the beam and the tensile reinforcement in the beam and its arrangements with shear reinforcement. Mark all dimensions and sizes of reinforcement bars.

26

Fire Protection

26·1 General. It is the growing tendency of the modern architect and engineer, that the structures should be so designed, planned or oriented, that the safety of the occupants is fully assured in the advent of outbreak of fire in the structure. This object is achieved by using fire-resistive materials for constructional purposes ; providing suitable means of quick escape of the occupants : dividing the building into small compartments, so as to minimise the spread of fire. The compartments should be so treated that the fire is localised. Once the fire starts, it tends to ignite all the combustible materials in the surrounding areas, and then, if not checked, it may spread to other parts of the building. If it is not controlled within the reasonable period, the entire structure may collapse.

The selection of the type of material to be used for the construction of walls, floors, roofs, partitions etc. deserves careful consideration. Thus, in order to make a judicial selection, the knowledge about the effect of heat on various materials is of vital importance. The fire-resistive properties of various building materials are given blow.

26·2 Timber. Timber construction is made fire resistant by taking advantage of the self-insulating and slow burning properties of the material. Additional fire resistance is achieved through impregnation of timber with large quantities of fire-retarding chemicals. The commonly used chemicals for the purpose are ammonium phosphate and sulphate, borax and boric acid, zinc chloride etc. This treatment retards increase in temperature during fire ; decreases rate of flame spread and enables easy fire control. Usually 32 to 48 kg of chemical per cubic metre of wood are used for moderate protection and 80 to 96 kg per cubic metre for high protection. During the recent years, a number of fire resistant paints have also been introduced for rendering the timber fire-resistant. Paints of asbestos, magnesium sulphate, ferrous-oxide etc. have been found to be very much effective.

26·3 Brick. First-class bricks moulded from good clay can stand exposure to fire for a considerable length of time. The properties of bricks which render them fire resistant are the size of bricks ; the method of construction, the components of fire-resistive

materials in bricks clay etc. It has been well established that brick masonry construction is most suitable for safeguarding the structure against fire hazards.

26·4 Stone. The usage of stone in a fire resistive construction should be strictly restricted to the minimum. Granite, when exposed to severe fire, explodes and disintegrates. Lime stone is least recommended as it crumbles and gets ruined by an ordinary fire. Only compact sand-stone having fine grains may be used for it can stand the exposure to moderate fire without serious cracks.

26·5 Steel. Steel although incombustible has a very low fire resistance value. With the increase in temperature, the co-efficient of elasticity of the metal falls appreciably rendering the member soft and free to expand. When the members in this state come in contact with water, used for extinguishing the fire, they tend to contact, twist or distort and thus the stability of the entire structure is endangered. It has been noticed that unprotected steel when subjected to fire causes the collapse of the structure. Thus in a fire resistive construction, structural steel members must be suitably protected.

26·6 Concrete. The influence of fire on concrete varies with the nature of its coarse aggregate and its density. It has been found that aggregates obtained from igneous rocks containing higher calcerous content, tend to crack when subjected to fire. Coarse aggregates like foamed slag, cinder and brick are best suited for a concrete which has to be fire-resistive. It has been noticed that in an average fire, the concrete surface gets disintegrated for a depth of about 25 mm. This is due to the dehydration of mortar in concrete by the fire. Hence in a reinforced concrete fire resistive construction, the thickness of clear cover should be more.

26·7 Glass. Glass conducts heat faster than metal. Because of its low thermal conductivity, the change in volume on account of expansion or contraction is very small and as such it may be considered to be a good fire resisting material. But when subjected to sudden and extreme variation of temperatures it fractures or cracks By the use of glass reinforced with steel wire netting such cracks can be minimised. Even when the cracks are formed, the fractured glass remains in its original position, as the embedded wire holds the cracked portion and does not allow it to fall. The reinforced glass has a higher melting point than the ordinary glass, and as such it is commonly used for fire-resisting doors, windows, sky-lights etc.

26·8 Asbestos. Asbestos is a fibrous mineral which is combined with portland cement to form a material having great fire-resistive value. Asbestos cement products are largely used for the construction of fire-resistive partitions, roofs etc. On account of its

low co-efficient of expansion and property of incombustibility, the structural members blended with asbestos cement possess great resistance to cracking, swelling or disintegration when exposed to fire.

26·9 Plaster or Mortar. Plaster or mortar is incombustible and as such, by suitable choice of the type of mortar, the walls or ceilings of a building can be made better fire resistant. Cement mortar is better than lime mortar, as the latter is liable to calcine. The resistance of the plaster to fire hazards can be increased by using it in thicker layer or reinforcing the plaster with metal laths. Gypsum plaster when applied over structural members like steel columns etc., makes the latter have good fire-resistive qualities.

26·10 Fire Resistant Canstruction. In a fire-resistive construction, the maximum use of non-combustible material should be encouraged. All the structural elements such as beams, columns, lintels, arches, floors and roofs, load-bearing walls or partition walls, should be constructed in such a way that they should continue to function as structural membars at least for the period which may be sufficient for the occupants to escape. The following additional points should be kept in view while designing a fire-resistant structure :

(1) The load-bearing walls or columns of masonry should be thicker in section so that they may successfully act as fire barrier for a considerable time.

(2) As far as possible fire resisting material should be used in the construction of flooring. If the usage of material which is likely to be damaged cannot be avoided either due to financial or practical considerations, the following precautions should be observed :

(*i*) In case of wooden floors, thicker joists spaced at greater distance apart should be used.

(*ii*) Fire stops should be provided in wooden floors at suitable intervals.

(*iii*) In case, cast iron or wrought iron has to be used in the work, it should be protected with clay tiles, terracotta, or plaster.

(3) Reinforced concrete framed structures should be preferred to steel structures. As steel is liable to twist, sag or distort under heavy fire, the metal should be protected by using concrete hollow clay tiles, bricks, metal lath and plaster, etc. The treatment given to steel columns is shown in Fig. 26·1. The cover of the protected material like tiles or bricks etc. all round the steel member should be at least 10 cm. from all sides. In any case, the metal flanges should be protected with not less than 5 cm. layer of concrete etc. The cover of concrete for reinforced concrete members, like beams

or columns should be sufficient to enable the members function satisfactorily, under fire for a maximum time. The concrete cover outside the main reinforcement should be atleast 5 cm. for very important structural members, like columns, girders, trusses etc., 38 mm. for ordinary beam, or long span slabs, arches etc. and 25 mm for partition walls, short span slabs, etc.

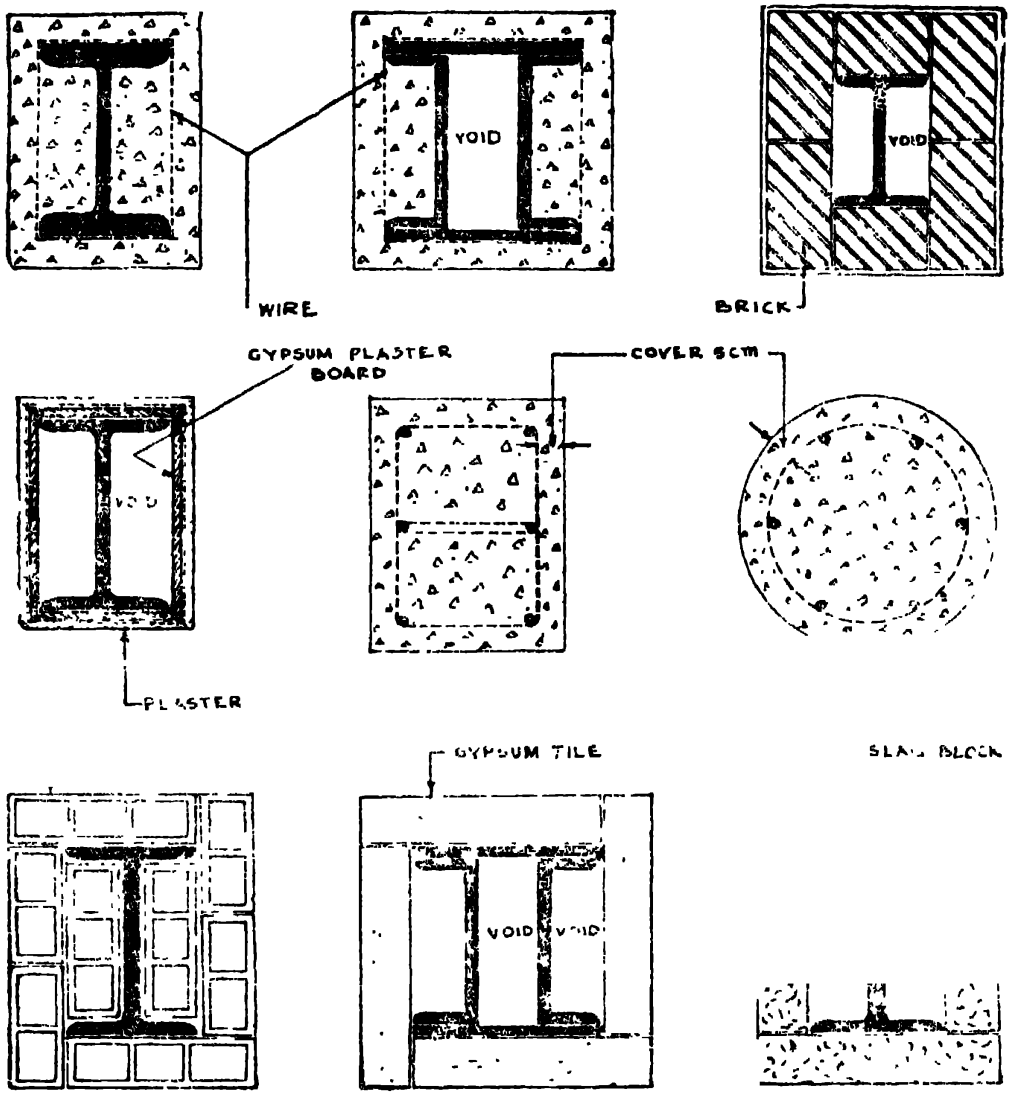


Fig. 26·1

Various types of fire-proofing treatments given to steel and concrete columns

4. The partition walls should similarly be of fire-resistant material. In general, R.C.C., R.B.C., metal lath and plaster, asbestos cement board ; hollow concrete or clay tiles should be used in the construction of partition walls. In case, wooden partition has to be made fire resistant, it should be covered with metal lath and plaster.

5. The load-bearing walls, as well as non-load bearing walls, should be plastered with fire-resistive mortar.

6. The ceiling should be directly attached or suspended from the floor joists and it should be made fire-resistant by fixing asbestos cement boards, fibre boards, metal lath and plaster to its framework.

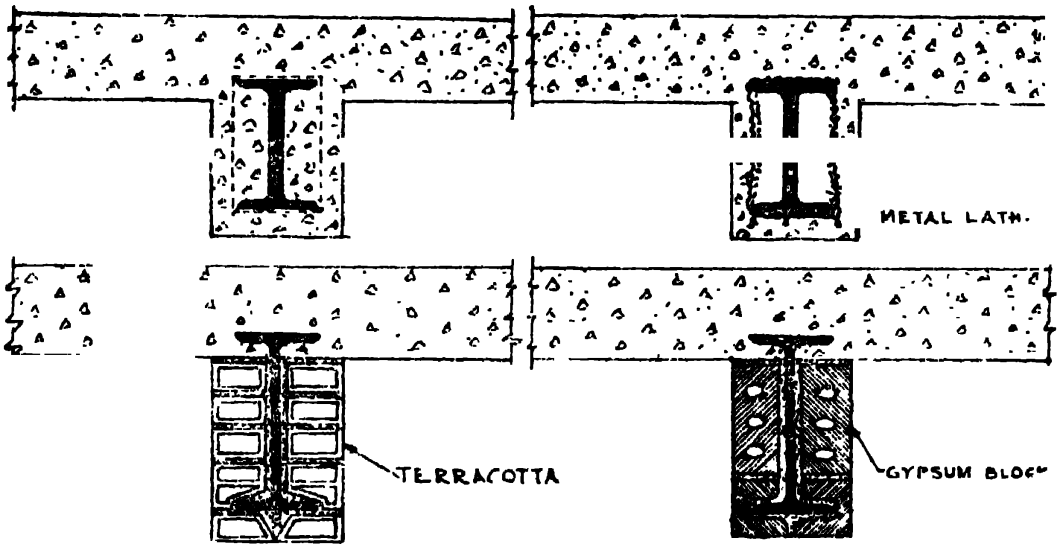


Fig. 26·2
Various types of fire-proofing treatment given to beams

7. The doors, windows or exposed sides should be glazed type and fitted with reinforced glass panels.

8. As far as possible, use metal frames for doors with steel shutters.

9. Due consideration should be made for providing suitable means of escape for the occupants of the structure. In single storey building, the provision of an accessible window, large enough to permit the occupants to get out through the opening, should be ensured. In case of multi-storeyed structures, the situation of staircase should meet a wise decision. For stairs of important buildings, a higher standard of the fire resistance is required. R.C.C. stairs are considered best from all considerations. The staircase hall which acts like a vertical shaft connecting the various floors should be surrounded with the enclosure walls made up of fire-resistive materials. The lift halls should also be similarly treated. All the doors or windows of the staircase hall or lift wall should preferably be of metal frame with steel shutters.

10. As far as possible flat roof should be encouraged. In case, the sloping roof is necessary either due to site conditions or architectural reasons, the ceilings of the sloped roofs should be made up of fire-resistive material.

Questions for Revision

1. What do you understand by the term 'fire-proof construction '? Describe the fire-proofing properties of the following materials :

(*i*) Timber
(*ii*) Stone.
(*iii*) Steel.
(*iv*) Brick.
(*v*) Concrete.
(*vi*) Glass.
(*vii*) Asbestos.
(*viii*) Plaster or mortar.

2. What are the guiding factors that should be kept in view while deciding the structural and architectural requirements of a fire-resistive structure ? Describe the fire-resistive properties of the following :

(*i*) Asbestos.
(*ii*) Concrete.
(*iii*) Steel.

3. How will you render a steel column fire-resistant ? Draw different sketches using the various types of material you can use to achieve the object.

4. Write an essay on a fire-proof building.

27

Acoustics and Sound Insulation

27·1 General. The sound which causes annoyance, interference with speech, damage to hearing and results in reduction in efficiency of work performance is called noise. Noise may also be defined as a disturbance in an elastic medium which includes solid, liquid and gases. It is a form of wave motion created by a vibrating body and is transmitted in all directions in the form of spherical waves consisting of alternate compressions and rarefactions. The procedure of obtaining an acceptable noise environment at a particular point is called noise control.

27·2 Classification of Sound. Depending upon the position of source, sound can be broadly divided in two classes :

(*i*) Airborne sound

(*ii*) Impact sound.

(*i*) *Airborne sound* : An airborne sound is one which is transmitted through air and travels direct to the ear of the person. This type of sound travels from one part of the building to another or from outside of the building to the inside, through open doors, windows or other openings or through small gaps around doors and windows etc.

(*ii*) *Impact sound* : The sound which is transmitted first through the structure is called impact sound. The noise of the footsteps, furniture, movement, dropping of utensils on the floor under this category. Impact sounds are troublesome and are often very sharp.

27·3 Measurement of Sound. Ear is an incredibly a sensitive instrument. It can react to the rustle of the wind in a leaf in the silent night as well as to the noise of a rock drill, later being 10,000,000,000 times stronger than the former. Sound is usually measured and expressed in terms of sound pressure levels or *decibles* (d_B).

The formula for writing down the two sound pressures

$$= 20 \log \frac{p_1}{p_2} \text{ decibles}$$

where p_1 = the pressure of the sound wave at source
and p_2 = the pressure of the sound wave at recipient.

Decible is therefore used as a convenient unit to measure the magnitude of sound, sound levels or sound insulation (noise reduction achieved by sound absorbing materials). 0·002 dynes/sq. cm. is the lowest value of sound pressure that an average human ear can perceive and hence this value is taken as zero on the d_B scale. The noise at the threshold of pain in the ear is considered to have a sound pressure of 130 d_B.

Table given below gives an idea about the magnitude of noise levels from some common noisy sources.

S. No.	*Type of source of noise*	*Noise levels in* d_B
1.	Light road traffic (side street)	60—70
2.	Medium road traffic (main streets)	70—80
3.	Heavy road traffic (highways)	80—90
4.	Rail traffic	90—110
5.	Air traffic (at 300 m)	90—110

27·4 Transmission of Sound. When sound in produced in a room it proceeds outward in spherical waves until it strikes the boundaries of the room. Thereafter, the sound waves are reflected, transmitted and absorbed in varying amounts depending upon the characteristics of the walls of the room (thickness, weight, material of wall and nature of its surface) and the frequency of the sound.

27·5 Transmission Loss. The reduction in the intensity of airborne sound, that takes place during its transmission from the source to the recipient is called transmission loss. Transmission loss or T.L. is numerically equivalent to the loss in the intensity of sound expressed is decibles. Hence if $100d_B$ and $60d_B$ are the sound levels measured on either side of a partition wall, the transmission loss or sound insulation of the partition wall is equal to $100d_B - 60d_B = 40d_B$.

27·6 Defects Due to Reflected Sound. The behaviour of the reflected sound plays an important role in sound insulation or acoustical design of a room/hall. The main defects which reflected sound waves may cause in a room are :

(*i*) Echoes

(*ii*) Reverberation

(*i*) *Echoes* : When a reflecting surface is so far away from the source that the sound is reflected back as a distinct repetition of the direct sound, the reflected sound is called an echo. Echoes are produced, when the time interval between the direct and the

reflected sound waves is about $\frac{1}{15}$th of a second. This defect is particularly common when the reflecting surface is curved in shape. To minimise this defect in curved walls, the walls are covered with highly absorbent material or grills are provided on the face work.

(*ii*) *Reverberation* : When the sound waves get reflected (on striking the walls), a part of the sound energy is converted into heat energy by friction and is absorbed by the walls. Subsequently the reflected waves get inter-reflected from one surface to another until they gradually fade and become inaudible. This phenomenon of undue prolongation of sound by successive reflections from surrounding surfaces, after the source sound has ceased is termed as reverberation. A certain amount of reverberation is necessary to enhance the sound. However, excessive reverberation is damaging to clarity.

Reverberation Time : The reverberation period is the time taken for the sound energy to decay by $60 d_B$, after the sound source has stopped. The reverberation time depends principally on the volume and absorption of the room.

Prof. Sabine of Harvard University developed a formula for calculating the time of reverberation which is given by

$$t = \frac{0{\cdot}16\,V}{a_1 s_1 + a_2 s_2 + a_3 s_3 \ldots}$$

$$= \frac{0{\cdot}16\,V}{\text{Sum of the absorption of various absorption components}}$$

where $a_1, a_2, a_3 \ldots$ = coefficient of absorption

$s_1, s_2, s_3 \ldots$ = area of absorbing surface.

The time of reverberation plays a significant role in achieving desired acoustical condition. If the time of reverberation is too long, it results in overlapping of speech and loss of intelligibility ; and if it is too short, it produces the effect of deadness and loss of brillance of sound. If the time of reverberation works out to a value greater than 3 seconds, it is considered bad ; between 3 to 2 seconds as fairly good and between 2 to $\frac{1}{2}$ second as very good. The time of reverberation to be allowed varies with the purpose for which the enclosure is to be used. If the enclosure or auditorium is to be used as a sound film theatre or for public address system, the time of reverberation selected should be short, whereas for concert halls and churches, it should be longer. For enclosures to be used for both speech and music, a value midway between the two should be adopted.

The selection of the correct time of reverberation is called *optimum time of reverberation.*

It is noted that presence of audience in a room, reduces the time of reverberation. This is on account of the absorption provided by the audience (being due to the clothing worn by the persons). This shows that a theatre will have a greater time of reverberation, when it is empty, than, when it is full with audience. To make allowance for this aspect in deciding the time of reverberation, the strength of audience contributing towards the absorption of sound is taken as $\frac{1}{4}$, $\frac{2}{3}$, or full depending upon the type of hall, The desirable optimum time of reverberation worked out after considering the indicated audience strength, is shown in the table below :

TABLE 27·1

S. No.	*Description of building*	*Optimum reverberation by sabine formula*	*Audience factor to be considered in design*
1.	Cinema theatres	1·3 seconds	Two-thirds
2.	Churches	1·8 to 3 „	Two-thirds
3.	Law courts, committee rooms, Conference halls etc. ...	1 to 1·5 „	One-third
4.	Large halls	2 to 3 „	Full
5.	Music concert hall	1·6 to 2 „	Full
6.	Parliament house, Assembly hall, Council chamber ...	1 to 1·5 „	Quorum
7.	Public lecture hall	1·5 to 2 „	One third

27·7 Sound Absorbent. Broadly speaking, the material having hard, rigid and non-porous surface, provide the least absorption, whereas those which are flexible, soft porous 'and can vibrate, absorb more sound. The efficiency of the sound absorption, however, depends more upon the porosity of the material used as sound absorbent. The term used to express the percentage of the incident sound that can be absorbed by a material is known as *absorption coefficient* of the material. Thus if the absorption co-efficient of a material is 0·75, this would mean that the material is capable of absorbing 75% of the incident sound. The absorption co-efficient differs with the frequency of the incident sound. In general, low density materials have higher absorption co-efficient at the higher frequencies than at low frequencies. Table No. 27·2 lists the sound absorption coefficient of commonly used acoustical materials

27·8 Classification of Absorbents. Sound absorbents can be broadly classified into the following four categories ;

(*i*) *Porous absorbents*
(*ii*) *Resonant absorbents*
(*iii*) *Cavity resonators*
(*iv*) *Composite type of absorbents.*

(*i*) *Porous absorbents* : When sound waves strike the surface of porous material, a part of the waves get reflected while a part enters the pores of the material and is thought to be dissipated into heat energy (produced on account of the friction developed between the sound waves in motion in the restricted pores of the material). The efficiency of this type of absorbent increases with the increase in the resistance offered by the material to air flow, its thickness and the porosity. Slagwool, glasswool, woodwool, asbestos fibre spray, foamed plastics, and perforated fibreboards are some of the examples of porous absorbent. In general, porous materials are selected mainly to absorb sound having high frequency.

(*ii*) *Resonant absorbents* ; In this system, the absorbent material is fixed on sound framing (usually timber) with an air space left out between it and the wall at the back. Such an arrangement works most efficiently for absorbing sound waves at low frequency. The principal of sound absorption in this method is that sound waves of the appropriate frequency cause sympathetic vibrations in the panel, which acts as a diaphram. The absorption of sound takes place by virtue of the dampening of the sympathetic vibration in the panel by means of the air space behind the panel. Dampening effect of this system can be improved appreciably by placing a porous material in the air space.

(*iii*) *Cavity resonators* : Cavity resonators essentially consist of a chamber with a narrow opening (entrance) in which absorption takes place by resonance of the air in the chamber which gives loss of sound energy. Such an arrangement can act effectively over a single selected frequency. Application of cavity resonator is normally restricted to absorption from individual machine or in similar cases.

(*iv*) *Composite Type of absorbents* : They consist of perforated panels mounted on battens so as to leave a cavity between panels and wall at the back. The panels may be metal wood (plywood) hard board, plaster board etc. The area of holes in the panel should vary between 10 to 20% of the total area of the panel. When the sound strikes the panel, the sound waves pass through the holes and get damped by the resonance of the air in the cavity. The effectiveness of this system can be increased by placing a porous material like mineral wood etc. in the cavity. This type of absorbent is commonly used as it is easy to install, economical and can accommodate wide range of frequencies.

TABLE 27·2

SOUND ABSORPTION CO-EFFICIENTS OF ACOUSTICAL MATERIAL

S. No.	Material	Application Coefficients		
		Frequency of sound in cycle/sec		
		125	500	2000
1.	Brick wall painted	0·012	0 017	0·023
2.	Brick wall unpainted	0 024	0·03	0·049
3.	6 mm. thick carpet or felt on solid concrete floor	0·07	0 5	0·65
4.	Carpet unlined	0·09	0·20	0 27
5.	Capet felt lined	0·11	0·37	0 37
6.	Curtains—light (3 kg,/sq. m.)	0·04	0·11	0·30
7.	Curtains—medium	0·06	0·13	0·40
8.	Curtains—heavy (5·5 kg./sq. m.)	0·10	0·50	0·82
9.	Chairs, metal or wooden	0·014	0 016	0·019
10.	Chair with wood veneer seat and back	—	0 023	—
11.	Chair with leather cushion	—	0·18	0·07
12.	Chair heavily upholstered	—	0·24 to 0·28	—
13.	Compressed paper board	—	0·11	0·11
14.	Floor (concrete)	0·01	0·015	0·02
15.	Floor (timber)	0·05	0·03	0·05
16.	Linoleum, or asphalt laid on concrete floor	0·05	0·03 to 0·08	0·03
17.	Fibre board (12 mm. thick) on battens keeping about 25 mm. air space between the boards and the solid wall	0·3	0·3	0 3
18.	Formed concrete 19 mm thick	—	0·12	0·20
19.	G ass (upto 32 oz.)	0·035	0 ·027	0·04
20.	Glass wool, or slag wool (50 mm. thick) fixed on batten secured to solid wall	0·35	0·91	0 95
21.	Plaster, gypsum or lime smooth finish on brick wall	0·013	0·025	0·04
22.	Plaster, gypsum or llme on lath over solid backing	0 02	0·03	0·04
23.	Perforated fire board tiles (18 mm. thick) badded solidly	0·2	0·65	0·8
24.	Plywood panelling fixed on battens keeping about 25 mm. air gap between the panelling and the solid wa l	0·3	0·15	0·1

27·9 Sound Insulation of Buildings. Control of noise transmission is essentially to minimise the disturbing effect of sound passing from one room to another, through walls, partitions, and floors or ceilings. Good planning in respect of the location of building as well as the placement of quiet and noisy areas in the building itself play an important role in controlling noise transmission. The constructional measure to be adopted for noise control and sound insulation are briefly discussed below.

27·10 Wall Construction. The sound insulation rating of a wall is generally governed by the net sound transmission loss it provides and also the efficiency with which it serves as a barrier for speech sound. Weight of the wall is the governing factor in wall insulation. It is seen that a solid one brick thick wall plastered on both sides, proves quite effective as a sound insulating partition wall. It has an average reduction of $50d_B$. It is now, however, possible to have walls made up from a suitable combination of materials which are light is weight and yet have high insulation value.

A cavity wall type of construction can be made to have increased insulation value by filling the cavity with some resilient material. In this type of construction, the cavity should be at least 5 cm. in width and the two wall leaves should be tied by use of only light

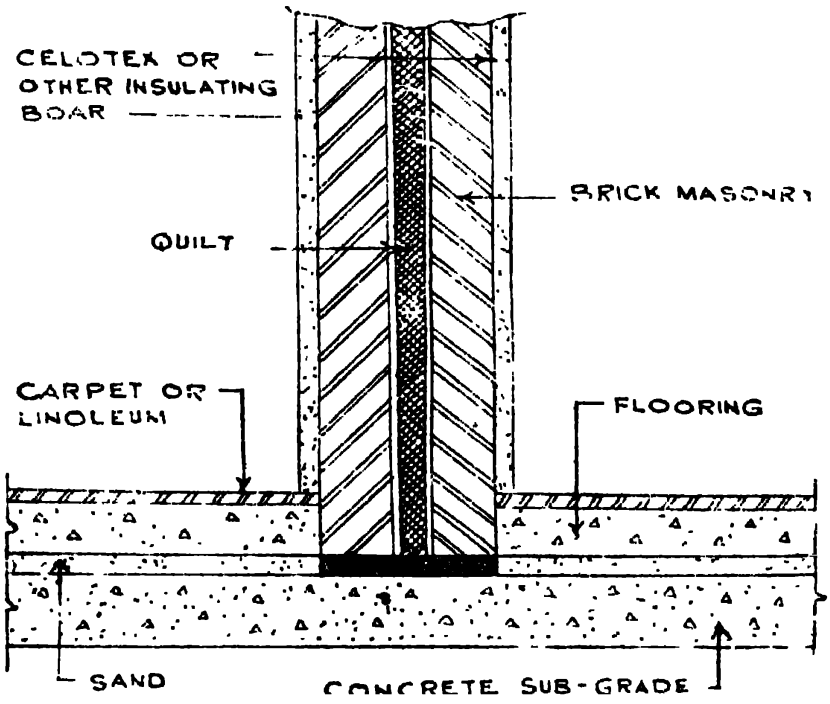


Fig. 27·1

Details of the junction of cavity type partition wall and floor for a sound proof construction

butterfly wall ties. The insulation value of different types of partition walls is given in Table 27·3. Partion walls having the value of transmission loss of $45d_B$ or less are considered adequate for separating critical areas of adjacent dwellings.

TABLE 27·3

TYPICAL INSULATION VALUES OF WALLS

S, No.	*Type of construction*	*Approx. weight in kg./sq. m.*	*Average T.L. in dB*
1.	One brick thick wall	488	50
2.	One and a half brick thick wall	708	53
3.	Cavity wall having two leaves each of half brick thickness with 5 cm. cavity	488	50 to 53
4.	Cavity wall having two 10 cm. thick leaves of clinker block with 5 cm. cavity	312	50
5.	Half brick wall with 13 mm. thick plaster on both sides	268	45
6.	20 cm. thick hollow dense concrete block wall with 13 mm. thick plaster on both sides	185	45
7.	Partition wall made with gypsum wall board fixed on timber frame work	67	45
8.	76 mm. thick hollow clay block wall with 13 mm. thick plaster on both sides	108	36

27·11 Floors. Transmission of sound takes place more easily through floors. This is on account of the fact, that invariably the sound producing source has actual contact with the floor. Hence the floor serves as the most common path for the transmission of impact noise. The ordinary R.C.C. floor weighing less than 220 kg./sq. m. has a sound reduction of only $45d_B$. Thus bare concrete and timber floors do not function effectively as barriers against impact sound. A floating floor resting on a resilient material like glass wool, material wool, quilt, hairfelt corck, rubber etc., has an increased rating for impact sound insulation. The principle underlaying the design of a floating floor is its insulation from any other part of structure. To achieve this, the resilient layer on which the floor rests is turned up at all edges which abut the walls, partitions or other parts of the structure. The partition should be

built off the structural floor so that the floating screed is self-contained with each room.

The various types of floating floor construction are shown in Fig. 27·2.

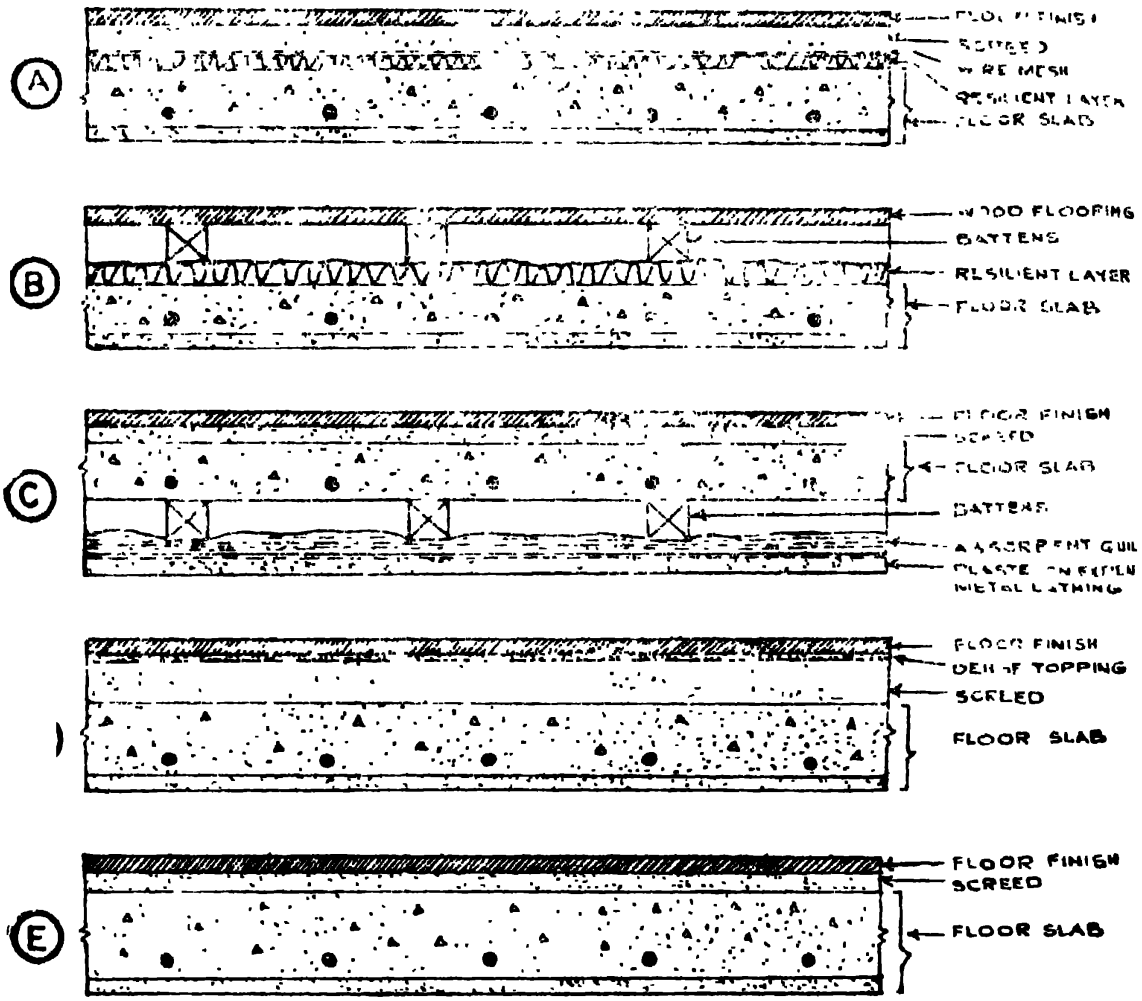


Fig. 27·2
Figures showing different methods of sound insulation of floors

The wood raft floating floor as shown in [Fig. 27·2 (*B*)] consist of 50 mm. deep × 50 mm. side wooden battens, on which 20 mm. thick resilient quilt laid over the structural floor slab.

The concrete screed floating floor as shown in [Fig. 27·2 (*A*)] consist of a 70 mm. thick layer of 1 : 1½ : 3 concrete screed laid on a 25 mm. thick resilient layer of mineral wool quilt. The quilt is covered with waterproof paper to prevent the moisture from concrete screed travelling below on to the structural floor slab.

Floors with suspended ceilings have an added advantage of insulation against air borne sound, provided a soft floor finish is provided on top to give necessary insulation against impact sound [Refer Fig. 27·2 (*C*)].

Wood joist floors : The performance of wood joist floors is greatly influenced by the amount of indirect or flanking sound, transmitted via the walls. This factor is not important in concrete floors, since the concrete floors are considered heavy, rigid and stiff enough to restrain the vibration of the walls. In timber floor, this factor can be taken care of by increasing the stiffness and thickness of the wall below the floor. Alternatively the floor should be made heavy and stiff enough to reduce the vibrations of the walls. The two different types of wooden joist floors which give adequate sound insulation are shown in Fig. 27·3. A noteworthy feature in the insulation of these floors is the floating floor effect achieved by using a 25 mm. thick mineral wool or glass wool quilt which is dropped over the joist and turned up at the edges of the boards. The efficiency of the flooring system is improved by increasing its weight with pugging between the joists.

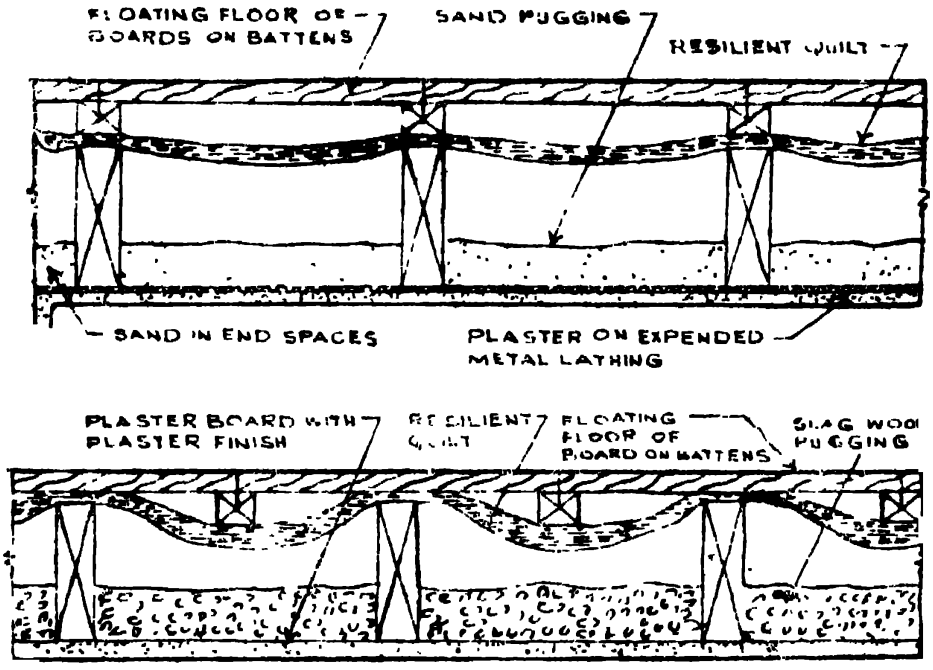


Fig. 27·3

Figures showing different methods of sound insulation of timber floors

27·12 Acoustical Design of Auditorium. The important factors which influence the acoustical design of an auditorium are the volume, the shape and the sound absorption.

The volume of the auditorium should be in proportion to the intensity of the sound that is expected to be generated in the hall.

In deciding the volume of the hall, its height plays a significant role than its length or breadth. This is on account of the fact that a small increase in height increases the volume considerably. The volume required for musical concert halls is larger than that required for halls to be used for speech alone. This is necessary from the point of view of proper distribution of musical sound. In case, however, the auditorium is to be used for both musical concerts as well as speech, the volume of the auditorium should be so chosen as to have a value intermediate between the two. The following data may be used as a rough guide for deciding the volume of an auditorium.

(*i*) For cinema theatres=3·7 to 4·2 cu. m. per person.

(*ii*) For public lecture halls=2·8 to 3·7 cu. m. per person.

(*iii*) For concert halls=4·2 to 5·6 cu. m. per person.

The shape of the auditorium is the governing factor in avoiding the defects like echoes or other types of reflections of sound waves. On account of the introduction of sound amplifiers, this aspect of planning has become still more important. Since the behaviour of sound in a hall is different from that in the open, it is rather easier to create desirable acoustic conditions in an auditorium rather than in an open air theatre. Rectangular, fan, horse shoe, circular or oval are the typical possible shapes of the floor plan of an auditorium.

The side walls and ceiling are advantageously used to provide favourable reflections. The walls of the hall are so shaped and placed as to minimise the possibilities of echoes. Plain walls are normally found suitable. The convex shaped walls are, however,

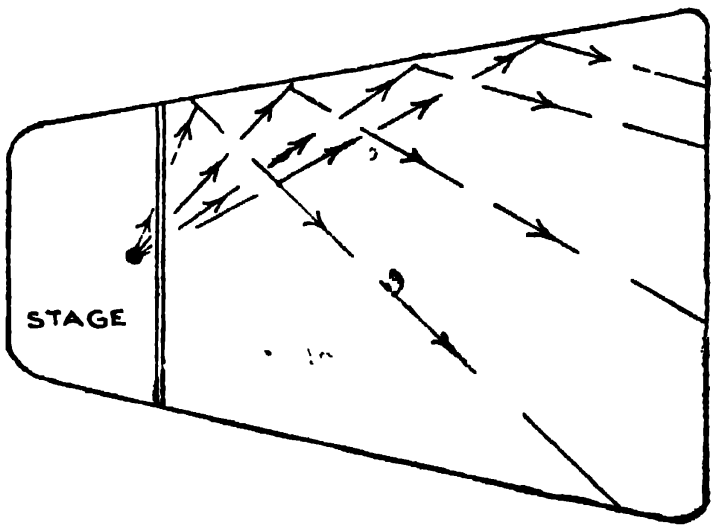


Fig. 27·4

Fan shaped floor plan of an auditorium showing favourable reflections from side walls

considered best to reduce echoes to a great extent. In general, the ceiling height of the hall should be about $\frac{1}{2}$ to $\frac{2}{3}$rd of the width. For reducing the focussing effect of a curved ceiling, the radius of curvature of the ceiling should be made at least twice the height or less than half the ceiling height. Ceilings play a significant role in reflecting the sound to the rear areas of the auditorium. A

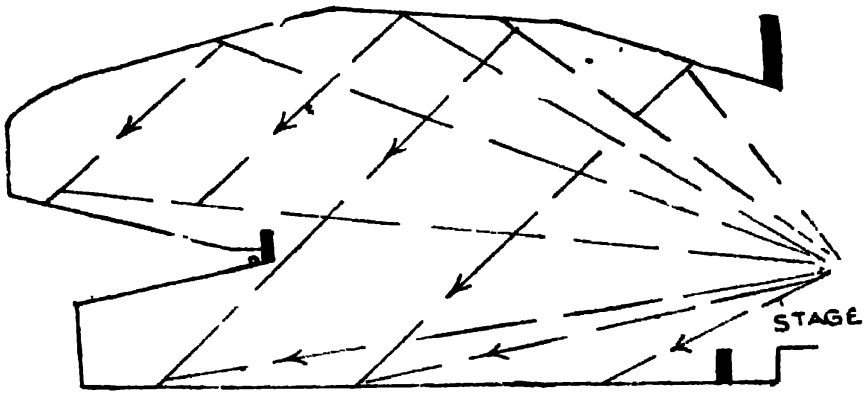


Fig. 27·5

Typical section showing favourable reflection from the ceiling of an auditorium

noteworthy point in the selection and installation of the ceiling is that it should be ensured that the sound waves get reflected either directly or via the walls to the audience in such a manner that the waves do not concentrate at certain spots.

Sound absorbing materials are also used to minimise objectionable reflection of sound. However, to ensure effectiveness of the sound absorbing material, the zones of installations have to be decided very carefully. A variety of acoustical materials are manufactured these days and while making a selection, the consideration that weigh heavily on the choice include their appearance, light reflection, flame resistance, workability, durability and cost.

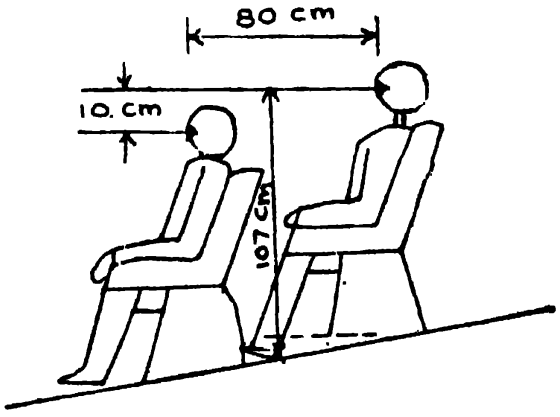


Fig. 27·6

In addition, the furnishings and the audience contribute to a great extent to the absorption present in the room. In fact the audience may be the largest contributors to the absorption in any auditorium. With a view to ensure optimum absorption from the audience, the seats in the hall are raked so that the heads in one row do not intercept the passage of direct sound to the persons in the row immediately behind them. A typical raking arrangement of the seats in an auditorium is shown in Fig. 27·6.

Questions for Revision

1. What is meant by the term reverberation ? Explain what do you understand by optimum line of reverberation ?

2. Write a short essay on the acoustical design of auditorium.

3. Show by sketches the method of sound insulation of a cavity wall and a wooden joist floor.

4. Write short notes on :

   (*i*) Air borne sound

   (*ii*) Echoes

   (*iii*) Transmission loss

   (*iv*) Resonant absorbents.

28

Anti-Termite Treatment

28·1 Introduction. Insects could be defined as ancient race of animals which have been in existence for millions of years. They are capable of survival under most adverse conditions and environments. Man is affected in a multiplicity of way by insects. Insect can attack his body, his food, crops, fruits, other agricultural products including his stored possession and even the house in which he lives.

The type of insects known as subterranean termites or white ants are most harmful and cause maximum damage to buildings. Termites eat wood, cellulosic materials and also attack non-cellulosic materials like leather, plastics, etc. They require moisture for their existence. Termite build underground colonies and tunnels or covered earthen runways (tubes) which serve as protected shelter for their movements. It is through these tubes that they maintain direct contact with the soil for meeting their moisture requirements essentially needed for their survival. White ants infiltrate into the buildings through cracks and crevices in masonry, joints or cracks in floors and through runways built over surface of structure in contact with ground, pipes, conduits, etc. and immediately attack upon the wooden portion of the building, textile, paper, etc. In the absence of adequate data it is rather difficult to estimate the exact loss due to termites attack, the total figure could, however, be assumed to run into several millions of rupees. White ants breed and spread so fast that they can damage a building in 3 to 5 years time.

It is very difficult to control and eradicate termites after they have gained entry into the building, as the cost involved in the process may be exorbitantly high. It is, therefore, desirable to take preventive measures against termites attack in buildings right from the stage of the starting up of construction works.

Anti-termite treatment in buildings may be broadly divided into following two categories :

(*i*) *Pre-constructional treatment.*

(*ii*) *Post-construction treatment.*

28·2 Pre-constructional treatment. This treatment is carried out at the early stages of the starting up of construction of building. This process essentially consists in creating as chemical barrier between the ground and the part of the building in contact with the ground. The various operations involved in this treatment could be summarised as under :

(*a*) Site preparation

(*b*) Soil treatment

(*a*) *Site preparation.* This consists in removing stumps, roots, waste wood, etc. from the site where the building is to be constructed. In case termite mounds are discovered within the plinth area of the building, they should be destroyed by use of insecticides. For this treatment, holes should be made into the mound at several places by use of a crow-bar and the insecticide taken in the form of water suspension or emulsion should be poured into the holes. The quantity of insecticide solution to be used will depend on the size of the mound. As per Indian Standard Code of Practice, for a mound volume of one cubic metre, 4 litres of an emulsion in water of one of the following chemicals may be used :

(*i*) 5% DDT

(*ii*) 0·5% of Dieldrin

(*iii*) 0·25% of Aldrin

(*b*) *Soil treatment.* This operation consists in poisoning, the soil underneath and around the foundation of the building with insecticide solution consisting of any one of the following chemical in water emulsion :

(*i*) Dieldrin	...	0·5%
(*ii*) Aldrin	...	0·5%
(*iii*) Heptachlor	...	0·5%
(*iv*) Chlordane	...	1%

In order that the soil treatment may be fully effective, the chemical water emulsion should be applied continuously and completely over the various areas in the following steps.

(*i*) The bottom surface and the sides (to a height of about 300 mm) of the foundation trench pits and basement should be treated by applying chemical water emulsion at the rate of 5 litres per square metre of the surface area.

(*ii*) The foundation concrete should thereafter be laid over the treated trench surface and after the concrete has set, the upper surface of the foundation concrete should be poisoned with chemical emulsion taken at the rate of 5 litre per square metre.

(*iii*) After the foundation of wall, pier, etc. have been constructed over the treated foundation concrete surface, treat the back fill earth in immediate contact with the foundation with the chemical emulsion at the rate of 15 litres per square metre of the vertical surface of the foundation masonry on each side. In case of R.C.C. column footings, it is not necessary to start the soil treatment from the bottom of excavation and in such cases it may start from 500 mm below ground level.

(*iv*) Prior to laying of sand bed or sub-grade for floors, the top surface of the earth filling within walls should be levelled and treated with chemical emulsion at the rate of 5 litres per square metre of the surface.

(*v*) The junction of walls and the floors (before laying sub-grade) require special attention to ensure effective soil treatment. For this it is important to establish vertical continuity of the poisoned soil on inner wall surface upto earth filling in plinth. This is achieved by making 30 mm wide and 30 mm deep channels at all junction of walls and columns with the earth filling in plinth and then filling the channels with chemical emulsion at the rate of 15 litres per square metre of the vertical wall or column surface.

(*vi*) The termites are also liable to gain access in the building from ground surface around the external perimeter of the building. To check this about 300 mm deep holes at 150 mm centre to centre are dug all along the external perimeter of the building and filled with chemical emulsion.

28·3 Post Construction Treatment. This treatment is applied to existing buildings which have already been attacked by termites. It is observed that even after their entry in buildings, the termite maintains regular contact with its nest in the ground. This important symptom is gainfully utilized in eradicating termite from buildings. The various operations involved under the treatment could be briefly summarised as under.

(*i*) *Inspection.* Inspection is essentially carried out to estimate the magnitude of the spread of the termite infestation in the building and also to detect the route of entry of termite and the zones which

are attacked. Thereafter the mud walked tubes are removed whenever possible and oil or kerosene base chemical emulsion is injected over the attacked areas of woodwork and masonry. At times structural additions and alteration may become necessary to make sure that all direct contact between the soil and the effected portions of the structure are broken.

(*ii*) *Soil treatment for foundation.* In this operation about 300 to 500 mm deep trenches are made along the external wall all along the periphery of the building with the help of a shovel (width of the trench being equal to the width of the shovel) and 12 mmϕ to 18 mmϕ holes at 150 mm apart are then made in the trench close to the wall face, with the help of a bar. The holes should preferably extend upto the top of the foundation concrete. The trench as well as the holes are then filled with chemical emulsion. In addition the soil used for back filling the trench should be mixed with chemicals at the rate of 6 litres of the chemical emulsion per metre length of the trench per 30 cm. depth. The poisoned back fill earth is filled in layers and consolidated.

(*iii*) *Soil treatment underfloors.* Cracks in concrete floor are the weak spots which permit the entry of the termites from earth below the floor sub-grade. The cracks usually occur at the junction of the floor and walls and at joints between slabs when the floor is cast in sections. Cracks may also result due to use of unsound material and defective workmanship. In such cases eradication of of termites is achieved by poisoning the soil underneath the floor. This operation is generally carried out by drilling 12 mmϕ holes at 300 mm centre to centre all along the cracks in the floor and then injecting chemical emulsion into the holes till the soil below gets fully saturated. The holes are then sealed with concrete.

(*iv*) *Treatment to voids in masonary.* To prevent the entry of termites through voids in masonry 12 mm. ϕ holes at 300 mm centre to centre are drilled at an angle of 45° from both side of wall at plinth level and then chemical emulsion is pumped until the zones gets fully saturated with the chemical. The holes are then sealed properly.

(*v*) *Treatment to woodwork.* Timber which is badly damaged by termites should be replaced by new timber which is properly brushed or dipped in kerosene oil based chemical emulsion. The existing woodwork which is not attacked by termites should be sprayed over with chemical emulsion to check its destruction.

APPENDIX I

USEFUL DATA FOR R.C.C. DESIGN

Properties of Round Bars

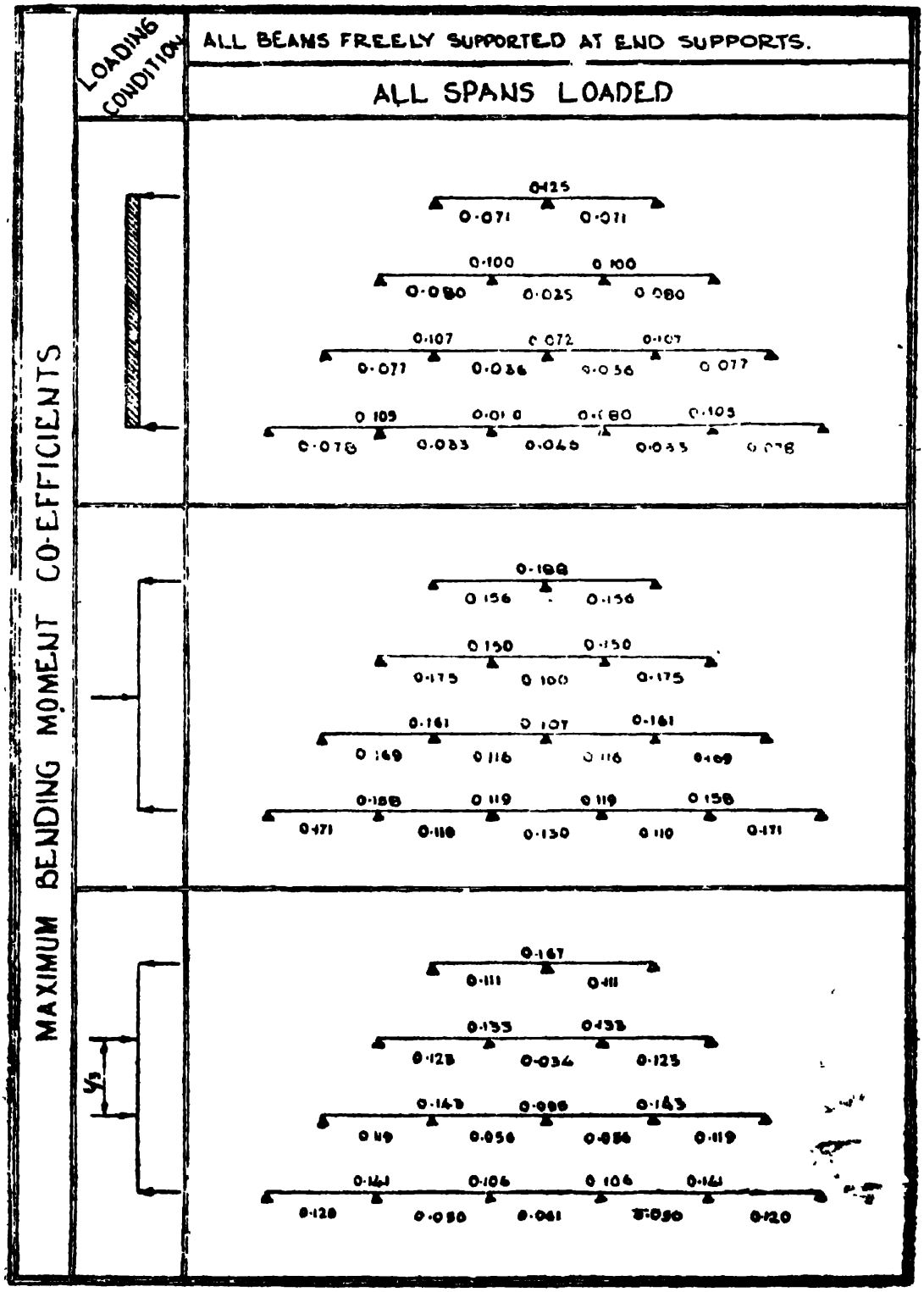
Diameter in cm.	*Area in sq. cm.*	*Perimeter in cm.*	*Weight in kg/metre*
5	0·20	1·57	0·15
6	0·28	1·89	0·22
8	0·50	2·51	0·39
10	0·79	3·14	0·62
12	1·13	3·77	0·89
14	1·54	4·40	1·21
16	2·01	5 03	1·58
18	2·54	5·65	2·00
20	3·14	6·28	2·46
22	3·80	6·91	2·98
24	4·52	7·54	3·55
25	4·91	7·85	3·85
28	6·16	8·80	4·83
32	8·04	10 05	6·31
36	10·18	11·33	7·99
40	12·57	12·57	9 87

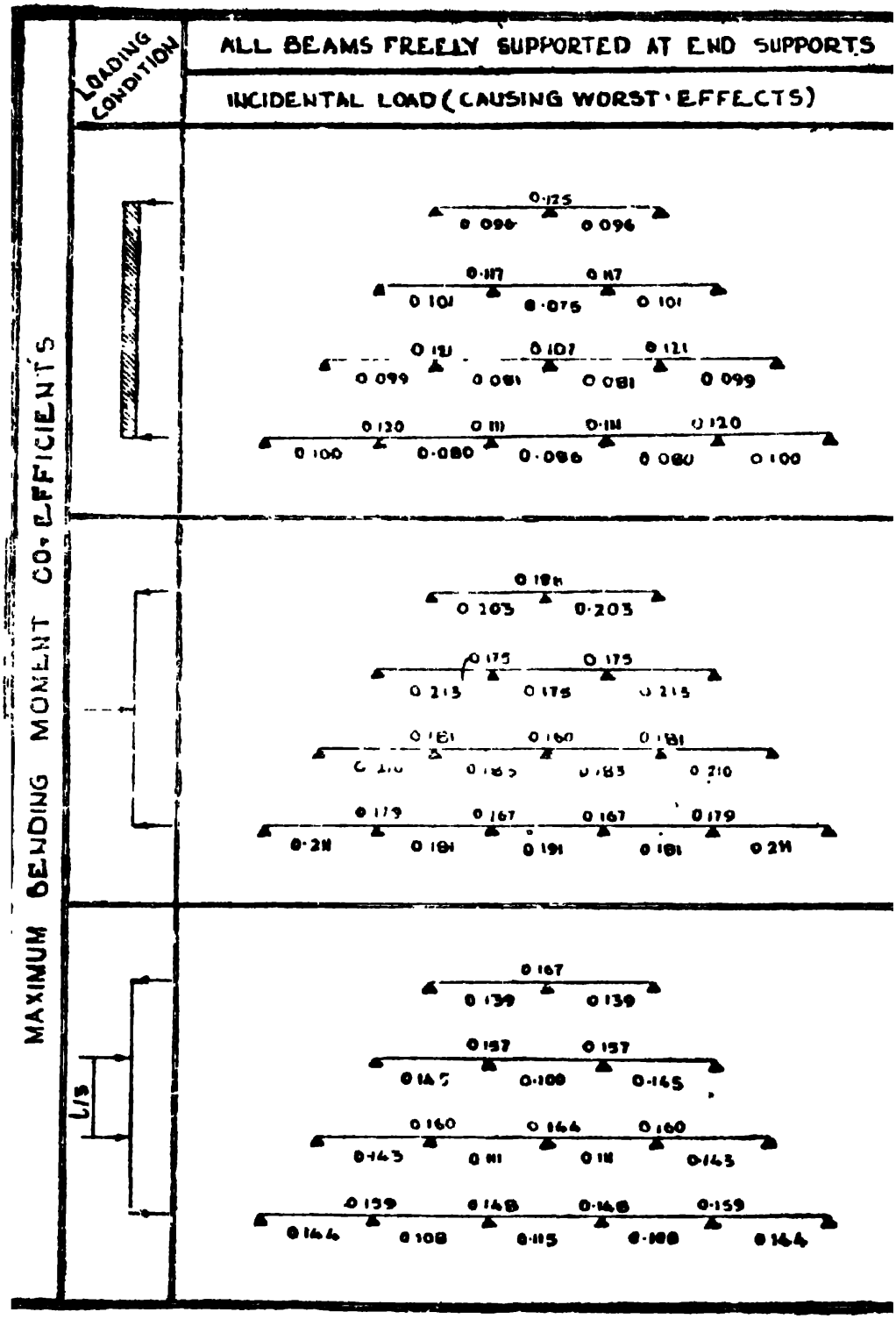
Sectiona Areas of Groups of Stee Round Ba

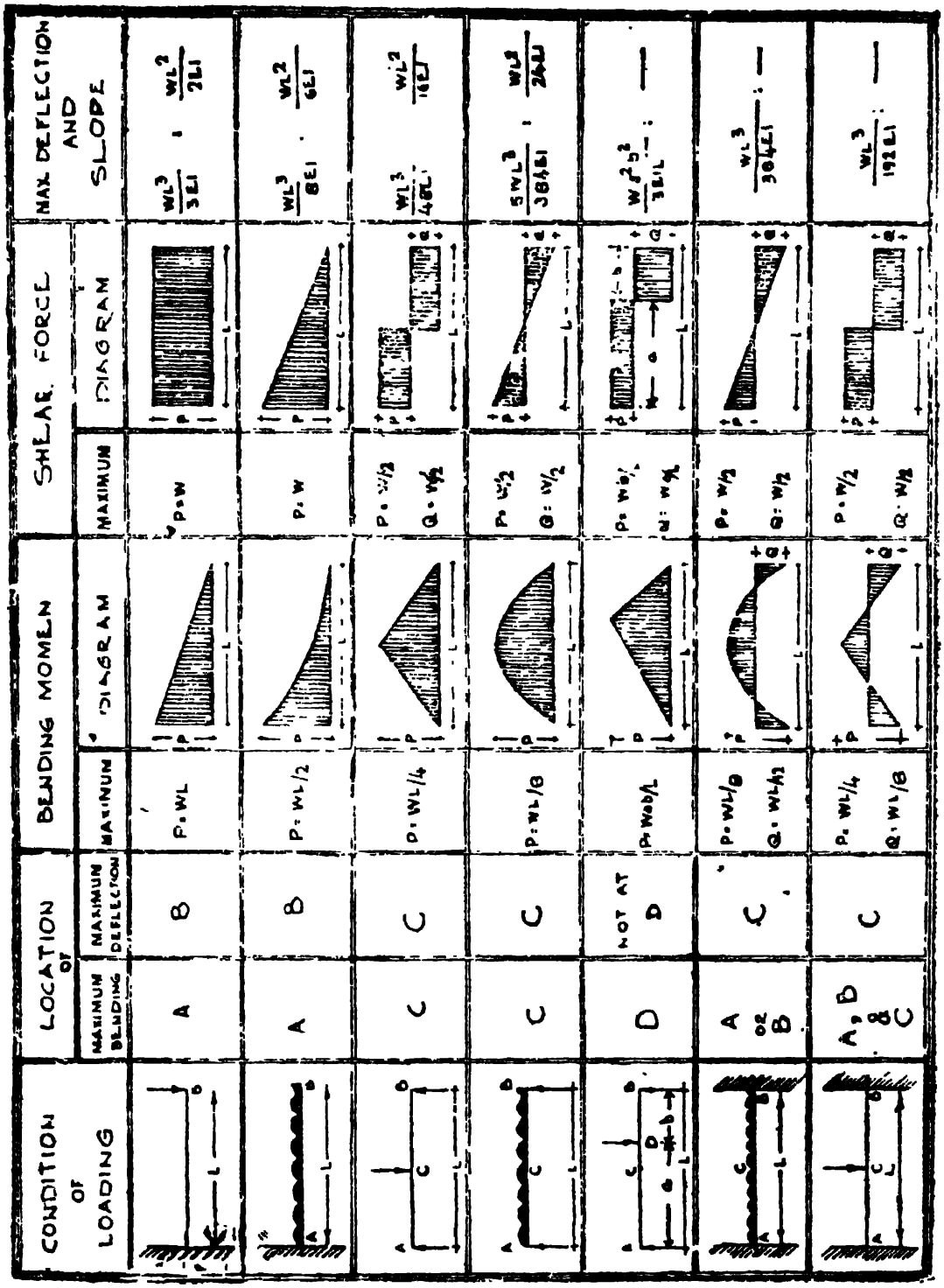
Rar dia-meter in (mm)	Area in cm² for various number of bars											
	1	2	3	4	5	6	7	8	9	10	11	12
5	0·20	0·39	0·59	0·78		1·18	1·37	1·57	1·77	1·96	2·26	2·35
6	0·28	0·56	0·85	1·13	1·41	1·70	1·98	2·26	2·54	2·83	3 11	3 40
8	0·50	1·00	1·51	2·01	2·51	3 01	3·52	4 02	4·52	5·03	5·53	6·04
10	0·79	1·57	2·36	3·14	3·53	4·71	5·50	6 28	7·07	7·85	8·64	9·42
12	1·13	2 26	3·39	4·52	5·65	6·78	7·91	9·05	10·18	11·31	12·44	13 57
14	1·54	3·08	4·62	6·16	7·70	9·24	10 77	12 32	13 86	15 39	16 94	18·48
16	2·01	4 02	6 03	8 04	10·05	12·06	14 07	16 08	18·09	20 11	22·12	24·13
18	2·54	5·09	7·63	10 18	12·72	15·26	17·81	20 36	22 90	25·45	27·99	30 54
20	3·14	6·28	9 42	12 57	15·71	18·84	21·99	25·14	28·28	31·42	34·56	37 70
22	3 80	7·60	11·40	15 21	19·01	22 81	26·61	30 41	34 21	38 01	41·81	45·62
24	4 52	9·05	13·57	18·10	22·62	27·14	31·67	36·39	40·71	45·24	49 66	54·29
25	4·91	9·82	14·73	19 63	24·54	29·45	34·36	39·27	44·18	49·09	54 00	58·91
28	6·16	12·31	18 47	24·63	36·79	36·94	43·10	49 26	55·42	61·58	67·73	73·89
32	80·40	16·08	24·13	32·17	40·21	48 26	56·30	64·34	72·38	80·42	88 47	96·51
36	10·18	20·36	30·54	40 72	50·90	61·07	71·26	81·83	91·61	101·79	111·97	122·15
40	57·57	25·13	37 70	50·26	63·83	75·40	87·96	100·53	113 09	125·66	138·23	150·80

Area of Reinforcement Per Metre Width of Slab for Various Spacings

Spacing of bars in (cm)	*Area in cm² per metre width of slab*										
	5 mm.	*6 m*	*8 mm.*	*10 mm.*	*12 mm.*	*14 mm.*	*16 mm.*	*18 mm.*	*20 mm.*	*22 mm.*	*24 mm.*
6	3·27	4 71	8·38	13·09	18 85	25·66	33·52	42 41	52 36	63·36	75 40
7	2·81	4·04	7 18	11·22	16·16	21·99	28·73	36·36	44 87	54·30	64·63
8	2·46	3·53	6·28	9·82	14 14	19 24	25·14	31·18	39 26	47 51	56·55
9	2·18	3·14	5·59	8 73	12·57	17·10	22 34	28 28	34 90	42 23	50 27
10	1·96	2 83	5 03	7 85	11·31	15·39	20 11	25·45	31 41	38·01	45 24
11	1·78	2·57	4·57	7·14	10·28	13·99	18·28	23·14	28·55	34·55	41·13
12	1·63	2·36	4·19	6·54	9 42	12·83	16·76	21·21	26·17	31 67	37·70
13	1·51	2·17	3·87	6 04	8 70	11 84	15·47	19·58	24·16	29·24	34 80
14	1·40	2 02	3·59	5 61	8 08	11·00	14·36	18·18	22·44	27·15	32 31
15	1 31	1·89	3 35	5·24	7·54	10 26	13·41	16 97	20 94	25·34	30 16
16	1·23	1·77	3 14	4 91	7·07	9·62	12·57	15 90	19·64	23·76	28·28
17	1·16	1·66	2 96	4 62	6·65	9·05	11 83	14 97	18·48	22·36	26 61
18	1·09	1·57	2·79	4 36	6·28	8·55	11·17	14·14	17·46	21·12	25 13
19	1·03	1·49	2 65	4·13	5 95	8·10	10·58	13 39	16 54	20·01	23·81
20	0 98	1 41	2·51	3 93	5·65	7 69	10 05	12 72	15·72	10 01	22·62


MAXIMUM BENDING MOMENT CO-EFFICIENTS
LOADING CONDITION
ALL BEAMS FREELY SUPPORTED AT END SUPPORTS.
ALL SPANS LOADED
0·125
0·071
0·071
0·100
0·100
0·080
0·025
0·080
0·107
0·072
0·107
0·077
0·036
0·036
0·077
0·105
0·078
0·033
0·046
0·033
0·078
0·156
0·156
0·150
0·150
0·175
0·100
0·175
0·161
0·107
0·161
0·169
0·116
0·116
0·169
0·188
0·119
0·119
0·150
0·171
0·110
0·130
0·110
0·171
0·167
0·111
0·111
0·133
0·133
0·125
0·034
0·125
0·143
0·095
0·143
0·119
0·056
0·056
0·119
0·161
0·106
0·106
0·161
0·120
0·050
0·061
0·050
0·120


MAXIMUM BENDING MOMENT CO-EFFICIENTS
LOADING CONDITION
ALL BEAMS FREELY SUPPORTED AT END SUPPORTS
INCIDENTAL LOAD (CAUSING WORST EFFECTS)
0·125
0 096
0 096
0·117
0 117
0 101
0·075
0 101
0 121
0 107
0 121
0 099
0 081
0 081
0 099
0 120
0 111
0·111
0 120
0 100
0·080
0·096
0 080
0 100
0 188
0 165
0·203
0 175
0 175
0 213
0 175
0 213
0 181
0 160
0 181
0 210
0 185
0 185
0 210
0 179
0 167
0 167
0 179
0·211
0 191
0 191
0 181
0 211
0 167
0 139
0 139
0 157
0 157
0 145
0·100
0·145
0 160
0 144
0 160
0·143
0 111
0 111
0·143
0 159
0 148
0·148
0·159
0 144
0 108
0·115
0·108
0 144
L/5


CONDITION OF LOADING
LOCATION OF
MAXIMUM BENDING
MAXIMUM DEFLECTION
BENDING MOMENT
MAXIMUM
DIAGRAM
SHEAR FORCE
MAXIMUM
DIAGRAM
MAX DEFLECTION AND SLOPE
P = W
P = WL
P = WL/2
P = WL/4
P = WL/8
P = Wab/L
P = W/2
Q = W/2
P = 5/8 W
Q = 3/8 W
P = Wb/L
Q = Wa/L
P = 3/8 W
Q = 5/8 W
P = W/2
Q = W/2
P = W/2
Q = W/2
NOT AT D

APPENDIX II

Useful Data for Retaining Walls

(Weights and angles of repose of various backing materials)

Material	*Weight in kg./m³*	*Angle of repose in degrees*
Dry sand	1540 to 1600	30 to 35
Damp sand	1600 to 1760	35
Wet sand	1760 to 2000	25 to 26
Sand dry and consolidated	1920	35
Vegetable earth dry	1600	20 to 30
Vegetable earth moist	1600 to 1760	45 to 49
Vegetable earth wet	1760 to 1920	15 to 17
Vegetable earth consolidated and dry	1600	49
Clean gravel	1440	40
Gravel and sand	1600 to 1760	26 to 30
Rubble stone	1600 to 1760	45
Day clay	1920 to 2240	30
Damp clay	1920 to 2560	45
Wet clay	1920 to 2560	15
Mud	1600 to 1920	0
Ashes	640	40

Co-efficient of friction between concrete and different surfaces

Surfaces	*Co-efficient of friction*
Dry clay, gravel or sand	0·2 to 0·4
Moist clay or sand	0·3 to 0·35
Wet clay	0·1 to 0·3
Rock	0·5 to 0·6

Functions of Soil Angles

Degree ϕ	$\cos\phi$	$\sin\phi$	$\frac{1-\sin\phi}{1+\sin\phi}$	$\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$	$\cos^2\phi$
15	·966	·259	·589	·348	·933
17	·956	·292	·548	·300	·914
20	·940	·342	·490	·240	·883
22	·927	·375	·455	·207	·859
25	·906	·423	·408	·166	·821
26	·899	·438	·390	·150	·810
27	·891	·454	·376	·141	·794
30	·860	·500	·333	·111	·740
31	·857	·515	·322	·104	·735
32	·848	·530	·308	·094	·720
33	·839	·545	·295	·087	·704
34	·829	·559	·283	·080	·688
35	·819	·574	·271	·073	·671
36	·809	·588	·260	·068	·655
37	·709	·602	·250	·060	·638
38	·788	·616	·238	·057	·621
39	·777	·625	·220	·050	·603
40	·766	·643	·218	·048	·588
41	·755	·656	·210	·040	·570
42	·743	·670	·199	·040	·522
43	·731	·681	·190	·040	·552
44	·719	·695	·180	·032	·509
45	·707	·707	·174	·030	·500

APPENDIX III

Mensuration

Areas

Parallelogram	= base × perpendicular height
Triangle	= base × $\frac{1}{2}$ perpendicular height
Trapezium	= $\frac{1}{2}$ sum of parallel sides × perpendicular ht.
Circle	= 0·7854 × square of diameter
Sector of circle	= length of arc × $\frac{1}{2}$ radius
Parabola	= base × $\frac{2}{3}$ height
Ellipse	= longer diameter × short diameter × 0·7854
Regular polygon	= sum of sides × $\frac{1}{2}$ perpendicular distance from centre of sides
Surface of sphere	= π × square of diameter
Surface of cone	= area of base + (circumference of base × $\frac{1}{2}$ slant height)

Volume

Prism	= area of base × height
Pyramid or cone	= area of base × $\frac{1}{3}$ height
Sphere	= 4·188 × radius^3

Position of centre of gravity

Triangle	= $\frac{1}{3}$ perpendicular height from base
Parabola	= $\frac{2}{3}$ height from base
Semi-Parabola	= $\frac{3}{5}$ length of the axis from the vertex, and $\frac{3}{8}$ of the semi-base from the axis
Parallelogram	= At the intersection of the diagonals
Prism or cylinder	= At the middle point of the line joining the centre of gravity of the bases

APPENDIX IV

Properties of Indian Standard Beams

Size in mm.	*Weight per metre (kg.)*	*Sectional area*	*Thickness of Web*	*Thickness of flange*	*Moment of Inertia*		*Radii of Gyration*		*Section Moduli*	
					I_{xx}	I_{yy}	V_{xx}	V_{yy}	Z_{xx}	Z_{yy}
75×50	6·1	7·71	3·7	6·0	72·7	10·0	3·07	1·14	19 4	4·0
100×50	8·0	10 21	4·0	6·4	168·0	12·7	4·06	1·21	33·6	5·1
125×75	11·9	15·12	4 4	6·5	408 8	43·4	5·19	1·69	65·1	11·6
150×80	14·2	18 08	4·8	6 8	688 8	55·2	6·17	1·75	91·8	13·8
175×90	16·7	21·30	5·1	6 9	1096·2	79·6	7·17	1·93	125·3	17·7
200×100	19·8	25·27	5·4	7·3	1096·6	115·4	8·19	2·13	169·7	23·1
225×100	23·5	29·92	5·8	8·6	2501·9	112·7	9·15	1 94	222 4	22·5
250×125	27·9	35 53	6·1	8·2	3717·8	193·4	10·23	2·33	297·4	30·9
275×140	33·0	42·02	6·4	8·8	5375·3	287·0	11·31	2·61	392·4	41·0
300×150	37·7	48·08	6·7	9·4	7332·9	376·2	12·35	2·80	488·9	50·2
325×165	43 1	54 90	7 0	9·8	9874·5	510·8	13·41	3·05	607·7	61·9
350×165	49·5	63·01	7·4	11·4	13158 3	631·6	14·45	3·17	751·0	76·6
400×165	56 9	72·43	8·0	12·5	14306·3	716·4	16·33	3·15	965·3	86·8
450×170	65·3	83·14	8·6	13·4	27536·1	853 0	18·20	3·20	1223·8	100·4
500×180	75 0	95·50	9·2	14·1	38579·0	1063·9	20·10	3·34	543·2	118 2
550×190	86·3	109·9	9 9	15 0	53161·6	1335·1	21·99	3 48	1933·2	140·5
600×210	99·5	126·69	10·5	15·5	72867 0	1821·9	23·98	3·79	2428·9	173·5

APPENDIX V

The Metric System

Length

10 millimetres	= 1 centimetre.
10 centimetres	= 1 decimetre.
10 decimetres	= 1 metre.
10 metres	= 1 dekametre.
10 dekametres	= 1 hectometre.
10 hectometres	= 1 kilometre

Weight

10 milligrams	= 1 centigram.
10 centigrams	= 1 decigrams.
10 decigrams	= 1 gram.
10 grams	= 1dekagram.
10 dekagrams	= 1 hectogram.
10 hectograms	= 1 kilogram
100 kilograms	= 1 quintal.
1000 kilograms	= 1 metric tonne.
200 milligrams	= 1 caret

Area

100 sq. millimetres	= 1 sq. centimetre.
100 sq. centimetres	= 1 sq. decimetre.
100 sq. decimetres	= 1 sq. metre.
100 sq. metres	= 1 sq. dekametre.
100 sq. decametres	= 1 sq. hectometre.
100 sq. hectometres	= 1 sq. kilometre.

Capacity

10 millilitres	= 1 centilitre.
10 centilitres	= 1 decilitre.
10 decilitres	= 1 litre.
10 litres	= 1 dekalitre.
10 deka litres	= 1 hectolitre.
10 hectolitres	= 1 kilolitre.

Volume

1000 cu. millimetres	= 1 cu. centimetre.
1000 cu. centimetres	= 1 cu. decimetre.
1000 cu. decimetres	= 1 cu. metre.

APPENDIX VI

Common Conversion Factors

Linear Measure

Multiply by	*To convert*	*To*
25·4	inch	millimetres.
0·305	foot	metres.
0·9144	yard	metres.
201·168	furlong	metres.
1·609	mile	kilometres

Square Measure

Multiply by	*To convert*	*To*
6·45	sq. inch	sq. centimetres.
0·093	sq. foot	sq. metres.
0·836	sq. yard	sq. metres.
40·447	acre	sq. decametres
2·588	sq. mile	sq. kilometre.

Cubic Measure

Multiply by	*To convert*	*To*
16·39	cubic inch	cubic centimetres
28·32	cubic ft.	cubic decimetres.
0·756	cubic yards	cubic metres.

Liquid Measure

Multiply by	*To convert*	*To*
0·142	gill	litres
0·568	pint	litres
1·136	Quart	litres
4·546	gallons	litres

General Conversion

Multiply by	*To convert*	*To*
70·3	lb./sq. inch	gram./sq. cm.
4·883	lb./sq. ft.	kgm./sq. metre.
0·593	lb./cubic yard	kgm./cubic metre.
16·02	lb./cubic ft.	,, ,, ,,
0·0998	lb /gallon	kgm./litre.
0·1383	foot pounds	kgm. metres.
0·33	foot tons	tonne metres.
746	horse power	watts.
33000	,, ,,	ft. lb./minute.
76	,, ,,	kgm. m./second.
44	watts	ft. lb./minute.
0·1	,,	kgm. m./second.
88	miles/hour	ft./minute.
197	metres/sec.	,, ,,
1·488	lb./ft.	kgm./metre.
0·496	lb./yard	,, ,,
3333 33	tons/ft.	,, ,,
1111 11	tons/yard	,, ,,
0·2818	lbs./mile	kgm./k. metre.
10 916	tons/sq. ft.	tons/sq. metre.
1·215	tons/sq. yard	,, ,, ,,
1·329	tons/cubic yard	tons/cubic metre
48 905	gallons/sq. ft.	litres/sq. metre.
50·80	cwt.	kilograms.
1016·3	tonne	..

LOGARITHM TABLES

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1 2 3	4 5 6	7 8 9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	5 9 13 4 8 12	17 21 26 16 20 24	30 34 38 28 32 36
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4 8 12 4 7 11	16 20 23 15 18 22	27 31 35 26 29 33
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3 7 11 3 7 10	14 18 21 14 17 20	25 28 32 24 27 31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3 6 10 3 7 10	13 16 19 13 16 19	23 26 29 22 25 29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3 6 9 3 6 9	12 15 19 12 14 17	22 25 28 20 23 26
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3 6 9 3 6 8	11 14 17 11 14 17	20 23 26 19 22 25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3 6 8 3 5 8	11 14 16 10 13 16	19 22 24 18 21 23
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	3 5 8 3 5 8	10 13 15 10 12 15	18 20 23 17 20 22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2 5 7 2 4 7	9 12 14 9 11 14	17 19 21 16 18 21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2 4 7 2 4 6	9 11 13 8 11 13	16 18 20 15 17 19
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2 4 6	8 11 13	15 17 19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2 4 6	8 10 12	14 16 18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2 4 6	8 10 12	14 15 17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2 4 6	7 9 11	13 15 17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2 4 5	7 9 11	12 14 16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2 3 5	7 9 10	12 14 15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2 3 5	7 8 10	11 13 15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2 3 5	6 8 9	11 13 14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2 3 5	6 8 9	11 12 14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1 3 4	6 7 9	10 12 13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1 3 4	6 7 9	10 11 13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1 3 4	6 7 8	10 11 12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1 3 4	5 7 8	9 11 12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1 3 4	5 6 8	9 10 12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1 3 4	5 6 8	9 10 11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1 2 4	5 6 7	9 10 11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1 2 4	5 6 7	8 10 11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1 2 3	5 6 7	8 9 10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1 2 3	5 6 7	8 9 10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1 2 3	4 5 7	8 9 10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1 2 3	4 5 6	8 9 10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1 2 3	4 5 6	7 8 9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1 2 3	4 5 6	7 8 9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1 2 3	4 5 6	7 8 9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1 2 3	4 5 6	7 8 9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1 2 3	4 5 6	7 8 9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1 2 3	4 5 6	7 7 8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1 2 3	4 5 5	6 7 8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1 2 3	4 4 5	6 7 8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1 2 3	4 4 5	6 7 8

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	123	456	789
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1 2 3	3 4 5	6 7 8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1 2 3	3 4 5	6 7 8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1 2 2	3 4 5	6 7 7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1 2 2	3 4 5	6 6 7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1 2 2	3 4 5	6 6 7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1 2 2	3 4 5	5 6 7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1 2 2	3 4 5	5 6 7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1 2 2	3 4 5	5 6 7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1 1 2	3 4 4	5 6 7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1 1 2	3 4 4	5 6 7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1 1 2	3 4 4	5 6 6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1 1 2	3 4 4	5 6 6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1 1 2	3 3 4	5 6 6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1 1 2	3 3 4	5 5 6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1 1 2	3 3 4	5 5 6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1 1 2	3 3 4	5 5 6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1 1 2	3 3 4	5 5 6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1 1 2	3 3 4	5 5 6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1 1 2	3 3 4	4 5 6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1 1 2	2 3 4	4 5 6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1 1 2	2 3 4	4 5 6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1 1 2	2 3 4	4 5 5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1 1 2	2 3 4	4 5 5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1 1 2	2 3 4	4 5 5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1 1 2	2 3 4	4 5 5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1 1 2	2 3 3	4 5 5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1 1 2	2 3 3	4 5 5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1 1 2	2 3 3	4 4 5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1 1 2	2 3 3	4 4 5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1 1 2	2 3 3	4 4 5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1 1 2	2 3 3	4 4 5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1 1 2	2 3 3	4 4 5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1 1 2	2 3 3	4 4 5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1 1 2	2 3 3	4 4 5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1 1 2	2 3 3	4 4 5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1 1 2	2 3 3	4 4 5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1 1 2	2 3 3	4 4 5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0 1 1	2 2 3	3 4 4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0 1 1	2 2 3	3 4 4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0 1 1	2 2 3	3 4 4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0 1 1	2 2 3	3 4 4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0 1 1	2 2 3	3 4 4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0 1 1	2 2 3	3 4 4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0 1 1	2 2 3	3 4 4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0 1 1	2 2 3	3 4 4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0 1 1	2 2 3	3 4 4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0 1 1	2 2 3	3 4 4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0 1 1	2 2 3	3 4 4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0 1 1	2 2 3	3 4 4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0 1 1	2 2 3	3 3 4

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1 2 3	4 5 6	7 8 9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0 0 1	1 1 1	2 2 2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0 0 1	1 1 1	2 2 2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0 0 1	1 1 1	2 2 2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0 0 1	1 1 1	2 2 2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0 1 1	1 1 2	2 2 2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0 1 1	1 1 2	2 2 2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0 1 1	1 1 2	2 2 2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0 1 1	1 1 2	2 2 2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0 1 1	1 1 2	2 2 3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0 1 1	1 1 2	2 2 3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0 1 1	1 1 2	2 2 3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0 1 1	1 2 2	2 2 3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0 1 1	1 2 2	2 2 3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0 1 1	1 2 2	2 3 3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0 1 1	1 2 2	2 3 3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0 1 1	1 2 2	2 3 3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0 1 1	1 2 2	2 3 3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0 1 1	1 2 2	2 3 3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0 1 1	1 2 2	2 3 3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0 1 1	1 2 2	3 3 3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0 1 1	1 2 2	3 3 3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0 1 1	2 2 2	3 3 3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0 1 1	2 2 2	3 3 3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0 1 1	2 2 2	3 3 4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0 1 1	2 2 2	3 3 4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0 1 1	2 2 2	3 3 4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0 1 1	2 2 3	3 3 4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0 1 1	2 2 3	3 3 4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0 1 1	2 2 3	3 4 4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0 1 1	2 2 3	3 4 4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0 1 1	2 2 3	3 4 4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0 1 1	2 2 3	3 4 4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0 1 1	2 2 3	3 4 4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0 1 1	2 2 3	3 4 4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1 1 2	2 3 3	4 4 5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1 1 2	2 3 3	4 4 5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1 1 2	2 3 3	4 4 5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1 1 2	2 3 3	4 4 5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1 1 2	2 3 3	4 4 5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1 1 2	2 3 3	4 5 5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1 1 2	2 3 4	4 5 5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1 1 2	2 3 4	4 5 5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1 1 2	2 3 4	4 5 6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1 1 2	3 3 4	4 5 6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1 1 2	3 3 4	4 5 6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1 1 2	3 3 4	5 5 6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1 1 2	3 3 4	5 5 6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1 1 2	3 3 4	5 5 6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1 1 2	3 4 4	5 6 6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1 1 2	3 4 4	5 6 6

ANTILOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1 2 3	4 5 6	7 8 9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1 1 2	3 4 4	5 6 7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1 2 2	3 4 5	5 6 7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1 2 2	3 4 5	5 6 7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1 2 2	3 4 5	6 6 7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1 2 2	3 4 5	6 6 7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1 2 2	3 4 5	6 7 7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1 2 3	3 4 5	6 7 8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1 2 3	3 4 5	6 7 8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1 2 3	4 4 5	6 7 8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1 2 3	4 5 5	6 7 8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1 2 3	4 5 6	6 7 8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1 2 3	4 5 6	7 8 9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1 2 3	4 5 6	7 8 9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1 2 3	4 5 6	7 8 9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1 2 3	4 5 6	7 8 9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1 2 3	4 5 6	7 8 9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1 2 3	4 5 6	7 9 10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1 2 3	4 5 7	8 9 10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1 2 3	4 6 7	8 9 10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1 2 3	5 6 7	8 9 10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1 2 4	5 6 7	8 9 11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1 2 4	5 6 7	8 10 11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1 2 4	5 6 7	9 10 11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1 3 4	5 6 8	9 10 11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1 3 4	5 6 8	9 10 12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1 3 4	5 7 8	9 10 12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1 3 4	5 7 8	9 11 12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1 3 4	5 7 8	10 11 12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1 3 4	6 7 8	10 11 13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1 3 4	6 7 9	10 11 13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1 3 4	6 7 9	10 12 13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2 3 5	6 8 9	11 12 14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2 3 5	6 8 9	11 12 14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2 3 5	6 8 9	11 13 14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2 3 5	6 8 10	11 13 15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2 3 5	7 8 10	12 13 15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2 3 5	7 8 10	12 13 15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2 3 5	7 9 10	12 14 16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2 4 5	7 9 11	12 14 16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2 4 5	7 9 11	13 14 16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2 4 6	7 9 11	13 15 17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2 4 6	8 9 11	13 15 17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2 4 6	8 10 12	14 15 17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2 4 6	8 10 12	14 16 18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2 4 6	8 10 12	14 16 18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2 4 6	8 10 12	15 17 19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2 4 6	8 11 13	15 17 19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2 4 7	9 11 13	15 17 20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2 4 7	9 11 13	16 18 20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2 5 7	9 11 14	16 18 20

NATURAL SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	12	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	10	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10

NATURAL SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2 4 6	8 10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2 4 6	8 10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2 4 6	8 10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2 4 6	8 10
49	·7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2 4 6	8 9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2 4 6	7 9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2 4 5	7 9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2 4 5	7 9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2 3 5	7 9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2 3 5	7 8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2 3 5	7 8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2 3 5	6 8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2 3 5	6 8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2 3 5	6 8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1 3 4	6 7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1 3 4	6 7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1 3 4	6 7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1 3 4	5 7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1 3 4	5 6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1 3 4	5 6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1 2 4	5 6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1 2 3	5 6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1 2 3	4 6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1 2 3	4 5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1 2 3	4 5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1 2 3	4 5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1 2 3	4 5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1 2 2	3 4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1 2 3	3 4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1 2 2	3 4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1 1 2	3 4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1 1 2	3 3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1 1 2	3 3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1 1 2	2 3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1 1 2	2 3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0 1 1	2 2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0 1 1	2 2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0 1 1	2 2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0 1 1	1 2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0 1 1	1 2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0 0 1	1 1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0 0 1	1 1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0 0 0	1 1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0 0 0	0 0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0 0 0	0 0
90	1·000											

NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
0	1·000	1·000	1·000	1·000	1·000	1·000	·9999	9999	9999	9999	0 0 0	0 0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0 0 0	0 0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0 0 0	1 1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0 0 1	1 1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0 0 1	1 1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0 1 1	1 2
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0 1 1	1 2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0 1 1	2 2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0 1 1	2 2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0 1 1	2 2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1 1 2	2 3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1 1 2	2 3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1 1 2	3 3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1 1 2	3 3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1 1 2	3 4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1 2 2	3 4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1 2 2	3 4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1 2 3	3 4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1 2 3	4 5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1 2 3	4 5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1 2 3	4 5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1 2 3	4 5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1 2 3	4 6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1 2 3	5 6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1 2 4	5 6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1 3 4	5 6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1 3 4	5 6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1 3 4	5 7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1 3 4	6 7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1 3 4	6 7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1 3 4	6 7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2 3 5	6 8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2 3 5	6 8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2 3 5	6 8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2 3 5	7 8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2 3 5	7 8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2 3 5	7 9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2 4 5	7 9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2 4 5	7 9
39	·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2 4 6	7 9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2 4 6	8 9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2 4 6	8 10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2 4 6	8 10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2 4 6	8 10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2 4 6	8 10

NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2 4 6	8 10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2 4 6	8 11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2 4 6	9 11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2 4 7	9 11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2 4 7	9 11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2 4 7	9 11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2 5 7	9 11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2 5 7	9 12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2 5 7	9 12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2 5 7	9 12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2 5 7	10 12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2 5 7	10 12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2 5 7	10 12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2 5 7	10 12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3 5 8	10 13
60	·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3 5 8	10 13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3 5 8	10 13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3 5 8	10 13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3 5 8	10 13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3 5 8	11 13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3 5 8	11 13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3 5 8	11 14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3 5 8	11 14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3 5 8	11 14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3 5 8	11 14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3 5 8	11 14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3 6 8	11 14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3 6 8	11 14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3 6 8	11 14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3 6 8	11 14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3 6 8	11 14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3 6 8	11 14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3 6 9	11 14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3 6 9	11 14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3 6 9	11 14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3 6 9	12 14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3 6 9	12 14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3 6 9	12 14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3 6 9	12 14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3 6 9	12 14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3 6 9	12 15
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3 6 9	12 15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3 6 9	12 15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3 6 9	12 15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3 6 9	12 15
90	·0000											

NATURAL TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29

NATURAL TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	2·0057	2·0145	2·0233	2·0323	2·0413	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	104	131
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53	107	160	213	267
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970					
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285					
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95					
86	14·30	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46					
87	19·08	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27					
88	28·64	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08					
89	57·29	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0					
90	∞														

Mean differences cease to be sufficiently accurate.

LOGARITHMS OF SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
0	−∞	$\bar{3}$·2419	$\bar{3}$·5429	7190	8439	9408	$\bar{2}$·0200	$\bar{2}$·0870	$\bar{2}$·1450	$\bar{2}$·1961		
1	$\bar{2}$·2419	2832	3210	3558	3880	4179	4459	4723	4971	5206		
2	$\bar{2}$·5428	5640	5842	6035	6220	6397	6567	6731	6889	7041		
3	$\bar{2}$·7188	7330	7468	7602	7731	7857	7979	8098	8213	8326		
4	$\bar{2}$·8436	8543	8647	8749	8849	8946	9042	9135	9226	9315	16 32 48	64 80
5	$\bar{2}$·9403	9489	9573	9655	9736	9816	9894	9970	$\bar{1}$·0046	$\bar{1}$·0120	13 26 39	52 65
6	$\bar{1}$·0192	0264	0334	0403	0472	0539	0605	0670	0734	0797	11 22 33	44 55
7	$\bar{1}$·0859	0920	0981	1040	1099	1157	1214	1271	1326	1381	10 19 29	38 48
8	$\bar{1}$·1436	1489	1542	1594	1646	1697	1747	1797	1847	1895	8 17 25	34 42
9	$\bar{1}$·1943	1991	2038	2085	2131	2176	2221	2266	2310	2353	8 15 23	30 38
10	$\bar{1}$·2397	2439	2482	2524	2565	2606	2647	2687	2727	2767	7 14 20	27 34
11	$\bar{1}$·2806	2845	2883	2921	2959	2997	3034	3070	3107	3143	6 12 19	25 31
12	$\bar{1}$·3179	3214	3250	3284	3319	3353	3387	3421	3455	3488	6 11 17	23 28
13	$\bar{1}$·3521	3554	3586	3618	3650	3682	3713	3745	3775	3806	5 11 16	21 26
14	$\bar{1}$·3837	3867	3897	3927	3957	3986	4015	4044	4073	4102	5 10 15	20 24
15	$\bar{1}$·4130	4158	4186	4214	4242	4269	4296	4323	4350	4377	5 9 14	18 23
16	$\bar{1}$·4403	4430	4456	4482	4508	4533	4559	4584	4609	4634	4 9 13	17 21
17	$\bar{1}$·4659	4684	4709	4733	4757	4781	4805	4829	4853	4876	4 8 12	16 20
18	$\bar{1}$·4900	4923	4946	4969	4992	5015	5037	5060	5082	5104	4 8 11	15 19
19	$\bar{1}$·5126	5148	5170	5192	5213	5235	5256	5278	5299	5320	4 7 11	14 18
20	$\bar{1}$·5341	5361	5382	5402	5423	5443	5463	5484	5504	5523	3 7 10	14 17
21	$\bar{1}$·5543	5563	5583	5602	5621	5641	5660	5679	5698	5717	3 6 10	13 16
22	$\bar{1}$·5736	5754	5773	5792	5810	5828	5847	5865	5883	5901	3 6 9	12 15
23	$\bar{1}$·5919	5937	5954	5972	5990	6007	6024	6042	6059	6076	3 6 9	12 15
24	$\bar{1}$·6093	6110	6127	6144	6161	6177	6194	6210	6227	6243	3 6 8	11 14
25	$\bar{1}$·6259	6276	6292	6308	6324	6340	6356	6371	6387	6403	3 5 8	11 13
26	$\bar{1}$·6418	6434	6449	6465	6480	6495	6510	6526	6541	6556	3 5 8	10 13
27	$\bar{1}$·6570	6585	6600	6615	6629	6644	6659	6673	6687	6702	2 5 7	10 12
28	$\bar{1}$·6716	6730	6744	6759	6773	6787	6801	6814	6828	6842	2 5 7	9 12
29	$\bar{1}$·6856	6869	6883	6896	6910	6923	6937	6950	6963	6977	2 4 7	9 11
30	$\bar{1}$·6990	7003	7016	7029	7042	7055	7068	7080	7093	7106	2 4 6	9 11
31	$\bar{1}$·7118	7131	7144	7156	7168	7181	7193	7205	7218	7230	2 4 6	8 10
32	$\bar{1}$·7242	7254	7266	7278	7290	7302	7314	7326	7338	7349	2 4 6	8 10
33	$\bar{1}$·7361	7373	7384	7396	7407	7419	7430	7442	7453	7464	2 4 6	8 10
34	$\bar{1}$·7476	7487	7498	7509	7520	7531	7542	7553	7564	7575	2 4 6	7 9
35	$\bar{1}$·7586	7597	7607	7618	7629	7640	7650	7661	7671	7682	2 4 5	7 9
36	$\bar{1}$·7692	7703	7713	7723	7734	7744	7754	7764	7774	7785	2 3 5	7 9
37	$\bar{1}$·7795	7805	7815	7825	7835	7844	7854	7864	7874	7884	2 3 5	7 8
38	$\bar{1}$·7893	7903	7913	7922	7932	7941	7951	7960	7970	7979	2 3 5	6 8
39	$\bar{1}$·7989	7998	8007	8017	8026	8035	8044	8053	8063	8072	2 3 5	6 8
40	$\bar{1}$·8081	8090	8099	8108	8117	8125	8134	8143	8152	8161	1 3 4	6 7
41	$\bar{1}$·8169	8178	8187	8195	8204	8213	8221	8230	8238	8247	1 3 4	6 7
42	$\bar{1}$·8255	8264	8272	8280	8289	8297	8305	8313	8322	8330	1 3 4	6 7
43	$\bar{1}$·8338	8346	8354	8362	8370	8378	8386	8394	8402	8410	1 3 4	5 7
44	$\bar{1}$·8418	8426	8433	8441	8449	8457	8464	8472	8480	8487	1 3 4	5 6

LOGARITHMS OF SINES

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1	2	3	4	5
45	$\bar{1}$·8495	8502	8510	8517	8525	8532	8540	8547	8555	8562	1	2	4	5	6
46	$\bar{1}$·8569	8577	8584	8591	8598	8606	8613	8620	8627	8634	1	2	4	5	6
47	$\bar{1}$·8641	8648	8655	8662	8669	8676	8683	8690	8697	8704	1	2	3	5	6
48	$\bar{1}$·8711	8718	8724	8731	8738	8745	8751	8758	8765	8771	1	2	3	4	6
49	$\bar{1}$·8778	8784	8791	8797	8804	8810	8817	8823	8830	8836	1	2	3	4	5
50	$\bar{1}$·8843	8849	8855	8862	8868	8874	8880	8887	8893	8899	1	2	3	4	5
51	$\bar{1}$·8905	8911	8917	8923	8929	8935	8941	8947	8953	8959	1	2	3	4	5
52	$\bar{1}$·8965	8971	8977	8983	8989	8995	9000	9006	9012	9018	1	2	3	4	5
53	$\bar{1}$·9023	9029	9035	9041	9046	9052	9057	9063	9069	9074	1	2	3	4	5
54	$\bar{1}$·9080	9085	9091	9096	9101	9107	9112	9118	9123	9128	1	2	3	4	5
55	$\bar{1}$·9134	9139	9144	9149	9155	9160	9165	9170	9175	9181	1	2	3	3	4
56	$\bar{1}$·9186	9191	9196	9201	9206	9211	9216	9221	9226	9231	1	2	3	3	4
57	$\bar{1}$·9236	9241	9246	9251	9255	9260	9265	9270	9275	9279	1	2	2	3	4
58	$\bar{1}$·9284	9289	9294	9298	9303	9308	9312	9317	9322	9326	1	2	2	3	4
59	$\bar{1}$·9331	9335	9340	9344	9349	9353	9358	9362	9367	9371	1	1	2	3	4
60	$\bar{1}$·9375	9380	9384	9388	9393	9397	9401	9406	9410	9414	1	1	2	3	4
61	$\bar{1}$·9418	9422	9427	9431	9435	9439	9443	9447	9451	9455	1	1	2	3	3
62	$\bar{1}$·9459	9463	9467	9471	9475	9479	9483	9487	9491	9495	1	1	2	3	3
63	$\bar{1}$·9499	9503	9506	9510	9514	9518	9522	9525	9529	9533	1	1	2	3	3
64	$\bar{1}$·9537	9540	9544	9548	9551	9555	9558	9562	9566	9569	1	1	2	2	3
65	$\bar{1}$·9573	9576	9580	9583	9587	9590	9594	9597	9601	9604	1	1	2	2	3
66	$\bar{1}$·9607	9611	9614	9617	9621	9624	9627	9631	9634	9637	1	1	2	2	3
67	$\bar{1}$·9640	9643	9647	9650	9653	9656	9659	9662	9666	9669	1	1	2	2	3
68	$\bar{1}$·9672	9675	9678	9681	9684	9687	9690	9693	9696	9699	0	1	1	2	2
69	$\bar{1}$·9702	9704	9707	9710	9713	9716	9719	9722	9724	9727	0	1	1	2	2
70	$\bar{1}$·9730	9733	9735	9738	9741	9743	9746	9749	9751	9754	0	1	1	2	2
71	$\bar{1}$·9757	9759	9762	9764	9767	9770	9772	9775	9777	9780	0	1	1	2	2
72	$\bar{1}$·9782	9785	9787	9789	9792	9794	9797	9799	9801	9804	0	1	1	2	2
73	$\bar{1}$·9806	9808	9811	9813	9815	9817	9820	9822	9824	9826	0	1	1	2	2
74	$\bar{1}$·9828	9831	9833	9835	9837	9839	9841	9843	9845	9847	0	1	1	1	2
75	$\bar{1}$·9849	9851	9853	9855	9857	9859	9861	9863	9865	9867	0	1	1	1	2
76	$\bar{1}$·9869	9871	9873	9875	9876	9878	9880	9882	9884	9885	0	1	1	1	2
77	$\bar{1}$·9887	9889	9891	9892	9894	9896	9897	9899	9901	9902	0	1	1	1	1
78	$\bar{1}$·9904	9906	9907	9909	9910	9912	9913	9915	9916	9918	0	1	1	1	1
79	$\bar{1}$·9919	9921	9922	9924	9925	9927	9928	9929	9931	9932	0	0	1	1	1
80	$\bar{1}$·9934	9935	9936	9937	9939	9940	9941	9943	9944	9945	0	0	1	1	1
81	$\bar{1}$·9946	9947	9949	9950	9951	9952	9953	9954	9955	9956	0	0	1	1	1
82	$\bar{1}$·9958	9959	9960	9961	9962	9963	9964	9965	9966	9967	0	0	1	1	1
83	$\bar{1}$·9968	9968	9969	9970	9971	9972	9973	9974	9975	9975	0	0	0	1	1
84	$\bar{1}$·9976	9977	9978	9978	9979	9980	9981	9981	9982	9983	0	0	0	0	1
85	$\bar{1}$·9983	9984	9985	9985	9986	9987	9987	9988	9988	9989	0	0	0	0	0
86	$\bar{1}$·9989	9990	9990	9991	9991	9992	9992	9993	9993	9994	0	0	0	0	0
87	$\bar{1}$·9994	9994	9995	9995	9996	9996	9996	9996	9997	9997	0	0	0	0	0
88	$\bar{1}$·9997	9998	9998	9998	9998	9999	9999	9999	9999	9999	0	0	0	0	0
89	$\bar{1}$·9999	9999	0·0000	0000	0000	0000	0000	0000	0000	0000					
90	0·0000														

LOGARITHMS OF COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
0	0·0000	0000	0000	0000	0000	0000	0000	0000	0000	$\bar{1}$·9999	0 0 0	0 0
1	$\bar{1}$·9999	9999	9999	9999	9999	9999	9998	9998	9998	9998	0 0 0	0 0
2	$\bar{1}$·9997	9997	9997	9996	9996	9996	9996	9995	9995	9994	0 0 0	0 0
3	$\bar{1}$·9994	9994	9993	9993	9992	9992	9991	9991	9990	9990	0 0 0	0 0
4	$\bar{1}$·9989	9989	9988	9988	9987	9987	9986	9985	9985	9984	0 0 0	0 0
5	$\bar{1}$·9983	9983	9982	9981	9981	9980	9979	9978	9978	9977	0 0 0	0 1
6	$\bar{1}$·9976	9975	9975	9974	9973	9972	9971	9970	9969	9968	0 0 0	1 1
7	$\bar{1}$·9968	9967	9966	9965	9964	9963	9962	9961	9960	9959	0 0 1	1 1
8	$\bar{1}$·9958	9956	9955	9954	9953	9952	9951	9950	9949	9947	0 0 1	1 1
9	$\bar{1}$·9946	9945	9944	9943	9941	9940	9939	9937	9936	9935	0 0 1	1 1
10	$\bar{1}$·9934	9932	9931	9929	9928	9927	9925	9924	9922	9921	0 0 1	1 1
11	$\bar{1}$·9919	9918	9916	9915	9913	9912	9910	9909	9907	9906	0 1 1	1 1
12	$\bar{1}$·9904	9902	9901	9899	9897	9896	9894	9892	9891	9889	0 1 1	1 1
13	$\bar{1}$·9887	9885	9884	9882	9880	9878	9876	9875	9873	9871	0 1 1	1 2
14	$\bar{1}$·9869	9867	9865	9863	0861	9859	9857	9855	9853	9851	0 1 1	1 2
15	$\bar{1}$·9849	9847	9845	9843	9841	9839	9837	9835	9833	9831	0 1 1	1 2
16	$\bar{1}$·9828	9826	9824	9822	9820	9817	9815	9813	9811	9808	0 1 1	2 2
17	$\bar{1}$·9806	9804	9801	9799	9797	9794	9792	9789	9787	9785	0 1 1	2 2
18	$\bar{1}$·9782	9780	9777	9775	9772	9770	9767	9764	9762	9759	0 1 1	2 2
19	$\bar{1}$·9757	9754	9751	9749	9746	9743	9741	9738	9735	9733	0 1 1	2 2
20	$\bar{1}$·9730	9727	9724	9722	9719	9716	9713	9710	9707	9704	0 1 1	2 2
21	$\bar{1}$·9702	9699	9696	9693	9690	9687	9684	9681	9678	9675	0 1 1	2 2
22	$\bar{1}$·9672	9669	9666	9662	9659	9656	9653	9650	9647	9643	1 1 2	2 3
23	$\bar{1}$·9640	9637	9634	9631	9627	9624	9621	9617	9614	9611	1 1 2	2 3
24	$\bar{1}$·9607	9604	9601	9597	9594	9590	9587	9583	9580	9576	1 1 2	2 3
25	$\bar{1}$·9573	9569	9566	9562	9558	9555	9551	9548	9544	9540	1 1 2	2 3
26	$\bar{1}$·9537	9533	9529	9525	9522	9518	9514	9510	9506	9503	1 1 2	3 3
27	$\bar{1}$·9499	9495	9491	9487	9483	9479	9475	9471	9467	9463	1 1 2	3 3
28	$\bar{1}$·9459	9455	9451	9447	9443	9439	9435	9431	9427	9422	1 1 2	3 3
29	$\bar{1}$·9418	9414	9410	9406	9401	9397	9393	9388	9384	9380	1 1 2	3 4
30	$\bar{1}$·9375	9371	9367	9362	9358	9353	9349	9344	9340	9335	1 1 2	3 4
31	$\bar{1}$·9331	9326	9322	9317	9312	9308	9303	9298	9294	9289	1 2 2	3 4
32	$\bar{1}$·9284	9279	9275	9270	9265	9260	9255	9251	9246	9241	1 2 2	3 4
33	$\bar{1}$·9236	9231	9226	9221	9216	9211	9206	9201	9196	9191	1 2 3	3 4
34	$\bar{1}$·9186	9181	9175	9170	9165	9160	9155	9149	9144	9139	1 2 3	3 4
35	$\bar{1}$·9134	9128	9123	9118	9112	9107	9101	9096	9091	9085	1 2 3	4 5
36	$\bar{1}$·9080	9074	9069	9063	9057	9052	9046	9041	9035	9029	1 2 3	4 5
37	$\bar{1}$·9023	9018	9012	9006	9000	8995	8989	8983	8977	8971	1 2 3	4 5
38	$\bar{1}$·8965	8959	8953	8947	8941	8935	8929	8923	8917	8911	1 2 3	4 5
39	$\bar{1}$·8905	8899	8893	8887	8880	8874	8868	8862	8855	8849	1 2 3	4 5
40	$\bar{1}$·8843	8836	8830	8823	8817	8810	8804	8797	8791	8784	1 2 3	4 5
41	$\bar{1}$·8778	8771	8765	8758	8751	8745	8738	8731	8724	8718	1 2 3	5 6
42	$\bar{1}$·8711	8704	8697	8690	8683	8676	8669	8662	8655	8648	1 2 3	5 6
43	$\bar{1}$·8641	8634	8627	8620	8613	8606	8598	8591	8584	8577	1 2 4	5 6
44	$\bar{1}$·8569	8562	8555	8547	8540	8532	8525	8517	8510	8502	1 2 4	5 6

LOGARITHMS OF COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
45	$\bar{1}$·8495	8487	8480	8472	8464	8457	8449	8441	8433	8426	1 3 4	5 6
46	$\bar{1}$·8418	8410	8402	8394	8386	8378	8370	8362	8354	8346	1 3 4	5 7
47	$\bar{1}$·8338	8330	8322	8313	8305	8297	8289	8280	8272	8264	1 3 4	6 7
48	$\bar{1}$·8255	8247	8238	8230	8221	8213	8204	8195	8187	8178	1 3 4	6 7
49	$\bar{1}$·8169	8161	8152	8143	8134	8125	8117	8108	8099	8090	1 3 4	6 7
50	$\bar{1}$·8081	8072	8063	8053	8044	8035	8026	8017	8007	7998	2 3 5	6 8
51	$\bar{1}$·7989	7979	7970	7960	7951	7941	7932	7922	7913	7903	2 3 5	6 8
52	$\bar{1}$·7893	7884	7874	7864	7854	7844	7835	7825	7815	7805	2 3 5	7 8
53	$\bar{1}$·7795	7785	7774	7764	7754	7744	7734	7723	7713	7703	2 3 5	7 9
54	$\bar{1}$·7692	7682	7671	7661	7650	7640	7629	7618	7607	7597	2 4 5	7 9
55	$\bar{1}$·7586	7575	7564	7553	7542	7531	7520	7509	7498	7487	2 4 5	7 9
56	$\bar{1}$·7476	7464	7453	7442	7430	7419	7407	7396	7384	7373	2 4 6	8 10
57	$\bar{1}$·7361	7349	7338	7326	7314	7302	7290	7278	7266	7254	2 4 6	8 10
58	$\bar{1}$·7242	7230	7218	7205	7193	7181	7168	7156	7144	7131	2 4 6	8 10
59	$\bar{1}$·7118	7106	7093	7080	7068	7055	7042	7029	7016	7003	2 4 6	9 11
60	$\bar{1}$·6990	6977	6965	6950	6937	6923	6910	6896	6883	6869	2 4 7	9 11
61	$\bar{1}$·6856	6842	6828	6814	6801	6787	6773	6759	6744	6730	2 5 7	9 12
62	$\bar{1}$·6716	6702	6687	6673	6659	6644	6629	6615	6600	6585	2 5 7	10 12
63	$\bar{1}$·6570	6556	6541	6526	6510	6495	6480	6465	6449	6434	3 5 8	10 13
64	$\bar{1}$·6418	6403	6387	6371	6355	6340	6324	6308	6292	6276	3 5 8	11 13
65	$\bar{1}$·6259	6243	6227	6210	6194	6177	6161	6144	6127	6110	3 6 8	11 14
66	$\bar{1}$·6093	6076	6059	6042	6024	6007	5990	5972	5954	5937	3 6 9	12 15
67	$\bar{1}$·5919	5901	5883	5865	5847	5828	5810	5792	5773	5754	3 6 9	12 15
68	$\bar{1}$·5736	5717	5698	5679	5660	5641	5621	5602	5583	5563	3 6 10	13 16
69	$\bar{1}$·5543	5523	5504	5484	5463	5443	5423	5402	5382	5361	3 7 10	13 17
70	$\bar{1}$·5341	5320	5299	5278	5256	5235	5213	5192	5170	5148	4 7 11	14 18
71	$\bar{1}$·5126	5104	5082	5060	5037	5015	4992	4969	4946	4923	4 8 11	15 19
72	$\bar{1}$·4900	4876	4853	4829	4805	4781	4757	4733	4709	4684	4 8 12	16 20
73	$\bar{1}$·4659	4634	4609	4584	4559	4533	4508	4482	4456	4430	4 9 13	17 21
74	$\bar{1}$·4403	4377	4350	4323	4296	4269	4242	4214	4186	4158	5 9 14	18 23
75	$\bar{1}$·4130	4102	4073	4044	4015	3986	3957	3927	3897	3867	5 10 15	20 24
76	$\bar{1}$·3837	3806	3775	3745	3713	3682	3650	3618	3586	3554	5 11 16	21 26
77	$\bar{1}$·3521	3488	3455	3421	3387	3353	3319	3284	3250	3214	6 11 17	23 28
78	$\bar{1}$·3179	3143	3107	3070	3034	2997	2959	2921	2883	2845	6 12 19	25 31
79	$\bar{1}$·2806	2767	2727	2687	2647	2606	2565	2524	2482	2439	7 13 20	27 34
80	$\bar{1}$·2397	2353	2310	2266	2221	2176	2131	2085	2038	1991	8 15 23	30 38
81	$\bar{1}$·1943	1895	1847	1797	1747	1697	1646	1594	1542	1489	8 17 25	33 42
82	$\bar{1}$·1436	1381	1326	1271	1214	1157	1099	1040	0981	0920	10 19 29	38 48
83	$\bar{1}$·0859	0797	0734	0669	0605	0539	0472	0403	0334	0264	11 22 33	44 55
84	$\bar{1}$·0192	0120	0046	$\bar{2}$·9970	$\bar{2}$·9894	$\bar{2}$·9816	$\bar{2}$·9736	$\bar{2}$·9655	$\bar{2}$·9573	$\bar{2}$·9489	13 26 39	52 65
85	$\bar{2}$·9403	9315	9226	9135	9042	8946	8849	8749	8647	8543	16 32 48	64 80
86	$\bar{2}$·8436	8326	8213	8098	7979	7857	7731	7602	7468	7330		
87	$\bar{2}$·7188	7041	6889	6731	6567	6397	6220	6035	5842	5640		
88	$\bar{2}$·5428	5206	4971	4723	4459	4179	3880	3558	3210	2832		
89	$\bar{2}$·2419	1961	1450	0870	0200	$\bar{3}$·9408	$\bar{3}$·8439	$\bar{3}$·7190	$\bar{3}$·5429	$\bar{3}$·2419		
90	$-\infty$											

LOGARITHMS OF TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	Mean Differences 4 5
0	−∞	$\bar{3}$·2419	$\bar{3}$·5429	$\bar{3}$·7190	3·8439	$\bar{3}$·9409	$\bar{2}$·0200	$\bar{2}$·0870	$\bar{2}$·1450	$\bar{2}$·1962		
1	$\bar{2}$·2419	2833	3211	3559	3881	4181	4461	4725	4973	5208		
2	$\bar{2}$·5431	5643	5845	6038	6223	6401	6571	6736	6894	7046		
3	$\bar{2}$·7194	7337	7475	7609	7739	7865	7988	8107	8223	8336		
4	$\bar{2}$·8446	8554	8659	8762	8862	8960	9056	9150	9241	9331	16 32 48	64 81
5	$\bar{2}$·9420	9506	9591	9674	9756	9836	9915	9992	$\bar{1}$·0068	$\bar{1}$·0143	13 26 40	53 66
6	$\bar{1}$·0216	0289	0360	0430	0499	0567	0633	0699	0764	0828	11 22 34	45 56
7	$\bar{1}$·0891	0954	1015	1076	1135	1194	1252	1310	1367	1423	10 20 29	39 49
8	$\bar{1}$·1478	1533	1587	1640	1693	1745	1797	1848	1898	1948	9 17 26	35 43
9	$\bar{1}$·1997	2046	2094	2142	2189	2236	2282	2328	2374	2419	8 16 23	31 39
10	$\bar{1}$·2463	2507	2551	2594	2637	2680	2722	2764	2805	2846	7 14 21	28 35
11	$\bar{1}$·2887	2927	2967	3006	3046	3085	3123	3162	3200	3237	6 13 19	26 32
12	$\bar{1}$·3275	3312	3349	3385	3422	3458	3493	3529	3564	3599	6 12 18	24 30
13	$\bar{1}$·3634	3668	3702	3736	3770	3804	3837	3870	3903	3935	6 11 17	22 28
14	$\bar{1}$·3968	4000	4032	4064	4095	4127	4158	4189	4220	4250	5 10 16	21 26
15	$\bar{1}$·4281	4311	4341	4371	4400	4430	4459	4488	4517	4546	5 10 15	20 25
16	$\bar{1}$·4575	4603	4632	4660	4688	4716	4744	4771	4799	4826	5 9 14	19 23
17	$\bar{1}$·4853	4880	4907	4934	4961	4987	5014	5040	5066	5092	4 9 13	18 22
18	$\bar{1}$·5118	5143	5169	5195	5220	5245	5270	5295	5320	5345	4 8 13	17 21
19	$\bar{1}$·5370	5394	5419	5443	5467	5491	5516	5539	5563	5587	4 8 12	16 20
20	$\bar{1}$·5611	5634	5658	5681	5704	5727	5750	5773	5796	5819	4 8 12	15 19
21	$\bar{1}$·5842	5864	5887	5909	5932	5954	5976	5998	6020	6042	4 7 11	15 19
22	$\bar{1}$·6064	6086	6108	6129	6151	6172	6194	6215	6236	6257	4 7 11	14 18
23	$\bar{1}$·6279	6300	6321	6341	6362	6383	6404	6424	6445	6465	3 7 10	14 17
24	$\bar{1}$·6486	6506	6527	6547	6567	6587	6607	6627	6647	6667	3 7 10	13 17
25	$\bar{1}$·6687	6706	6726	6746	6765	6785	6804	6824	6843	6863	3 7 10	13 16
26	$\bar{1}$·6882	6901	6920	6939	6958	6977	6996	7015	7034	7053	3 6 9	13 16
27	$\bar{1}$·7072	7090	7109	7128	7146	7165	7183	7202	7220	7238	3 6 9	12 15
28	$\bar{1}$·7257	7275	7293	7311	7330	7348	7366	7384	7402	7420	3 6 9	12 15
29	$\bar{1}$·7438	7455	7473	7491	7509	7526	7544	7562	7579	7597	3 6 9	12 15
30	$\bar{1}$·7614	7632	7649	7667	7684	7701	7719	7736	7753	7771	3 6 9	12 14
31	$\bar{1}$·7788	7805	7822	7839	7856	7873	7890	7907	7924	7941	3 6 9	11 14
32	$\bar{1}$·7958	7975	7992	8008	8025	8042	8059	8075	8092	8109	3 6 8	11 14
33	$\bar{1}$·8125	8142	8158	8175	8191	8208	8224	8241	8257	8274	3 5 8	11 14
34	$\bar{1}$·8290	8306	8323	8339	8355	8371	8388	8404	8420	8436	3 5 8	11 14
35	$\bar{1}$·8452	8468	8484	8501	8517	8533	8549	8565	8581	8597	3 5 8	11 13
36	$\bar{1}$·8613	8629	8644	8660	8676	8692	8708	8724	8740	8755	3 5 8	11 13
37	$\bar{1}$·8771	8787	8803	8818	8834	8850	8865	8881	8897	8912	3 5 8	10 13
38	$\bar{1}$·8928	8944	8959	8975	8990	9006	9022	9037	9053	9068	3 5 8	10 13
39	$\bar{1}$·9084	9099	9115	9130	9146	9161	9176	9192	9207	9223	3 5 8	10 13
40	$\bar{1}$·9238	9254	9269	9284	9300	9315	9330	9346	9361	9376	3 5 8	10 13
41	$\bar{1}$·9392	9407	9422	9438	9453	9468	9483	9499	9514	9529	3 5 8	10 13
42	$\bar{1}$·9544	9560	9575	9590	9605	9621	9636	9651	9666	9681	3 5 8	10 13
43	$\bar{1}$·9697	9712	9727	9742	9757	9772	9788	9803	9818	9833	3 5 8	10 13
44	$\bar{1}$·9848	9864	9879	9894	9909	9924	9939	9955	9970	9985	3 5 8	10 13

LOGARITHMS OF TANGENTS

Degrees	0′ 0°·0	6′ 0°·1	12′ 0°·2	18′ 0°·3	24′ 0°·4	30′ 0°·5	36′ 0°·6	42′ 0°·7	48′ 0°·8	54′ 0°·9	Mean Differences 1 2 3	4 5
45	·0000	0015	0030	0045	0061	0076	0091	0106	0121	0136	3 5 8	10 13
46	·0152	0167	0182	0197	0212	0228	0243	0258	0273	0288	3 5 8	10 13
47	·0303	0319	0334	0349	0364	0379	0395	0410	0425	0440	3 5 8	10 13
48	·0459	0471	0486	0501	0517	0532	0547	0562	0578	0593	3 5 8	10 13
49	·0608	0624	0639	0654	0670	0685	0700	0716	0731	0746	3 5 8	10 13
50	·0762	0777	0793	0808	0824	0839	0854	0870	0885	0901	3 5 8	10 13
51	·0916	0932	0947	0963	0978	0994	1010	1025	1041	1056	3 5 8	10 13
52	·1072	1088	1103	1119	1135	1150	1166	1182	1197	1213	3 5 8	10 13
53	·1229	1245	1260	1276	1292	1308	1324	1340	1356	1371	3 5 8	11 13
54	·1387	1403	1419	1435	1451	1467	1483	1499	1516	1532	3 5 8	11 13
55	·1548	1564	1580	1596	1612	1629	1645	1661	1677	1694	3 5 8	11 14
56	·1710	1726	1743	1759	1776	1792	1809	1825	1842	1858	3 5 8	11 14
57	·1875	1891	1908	1925	1941	1958	1975	1992	2008	2025	3 6 8	11 14
58	·2042	2059	2076	2093	2110	2127	2144	2161	2178	2195	3 6 9	11 14
59	·2212	2229	2247	2264	2281	2299	2316	2333	2351	2368	3 6 9	12 14
60	·2386	2403	2421	2438	2456	2474	2491	2509	2527	2545	3 6 9	12 15
61	·2562	2580	2598	2616	2634	2652	2670	2689	2707	2725	3 6 9	12 15
62	·2743	2762	2780	2798	2817	2835	2854	2872	2891	2910	3 6 9	12 15
63	·2928	2947	2966	2985	3004	3023	3042	3061	3080	3099	3 6 9	13 16
64	·3118	3137	3157	3176	3196	3215	3235	3254	3274	3294	3 6 10	13 16
65	·3313	3333	3353	3373	3393	3413	3433	3453	3473	3494	3 7 10	13 17
66	·3514	3535	3555	3576	3596	3617	3638	3659	3679	3700	3 7 10	14 17
67	·3721	3743	3764	3785	3806	3828	3849	3871	3892	3914	4 7 11	14 18
68	·3936	3958	3980	4002	4024	4046	4068	4091	4113	4136	4 7 11	15 19
69	·4158	4181	4204	4227	4250	4273	4296	4319	4342	4366	4 8 12	15 19
70	·4389	4413	4437	4461	4484	4509	4533	4557	4581	4606	4 8 12	16 20
71	·4630	4655	4680	4705	4730	4755	4780	4805	4831	4857	4 8 13	17 21
72	·4882	4908	4934	4960	4986	5013	5039	5066	5093	5120	4 9 13	18 22
73	·5147	5174	5201	5229	5256	5284	5312	5340	5368	5397	5 9 14	19 23
74	·5425	5454	5483	5512	5541	5570	5600	5629	5659	5689	5 10 15	20 25
75	·5719	5750	5780	5811	5842	5873	5905	5936	5968	6000	5 10 16	21 26
76	·6032	6065	6097	6130	6163	6196	6230	6264	6298	6332	6 11 17	22 28
77	·6366	6401	6436	6471	6507	6542	6578	6615	6651	6688	6 12 18	24 30
78	·6725	6763	6800	6838	6877	6915	6954	6994	7033	7073	6 13 19	26 32
79	·7113	7154	7195	7236	7278	7320	7363	7406	7449	7493	7 14 21	28 35
80	·7537	7581	7626	7672	7718	7764	7811	7858	7906	7954	8 16 23	31 39
81	·8003	8052	8102	8152	8203	8255	8307	8360	8413	8467	9 17 26	35 43
82	·8522	8577	8633	8690	8748	8806	8865	8924	8985	9046	10 20 29	39 49
83	·9109	9172	9236	9301	9367	9433	9501	9570	9640	9711	11 22 34	45 56
84	·9784	9857	9932	1·0008	1·0085	1·0164	1·0244	1·0326	1·0409	1·0494	13 26 40	53 66
85	1·0580	0669	0759	0850	0944	1040	1138	1238	1341	1446	16 32 48	64 81
86	1·1554	1664	1777	1893	2012	2135	2261	2391	2525	2663		
87	1·2806	2954	3106	3264	3429	3599	3777	3962	4155	4357		
88	1·4569	4792	5027	5275	5539	5819	6119	6441	6789	7167		
89	1·7581	8038	8550	9130	9800	2·0591	2·1561	2·2810	2·4571	2·7581		

SQUARE ROOTS. FROM 1 TO 10

0	0	1	2	3	4	5	6	7	8	9	Mean Differences		
											1 2 3	4 5 6	7 8 9
1·0	1·000	1·005	1·010	1·015	1·020	1·025	1·030	1·034	1·039	1·044	0 1 1	2 2 3	3 4 4
1·1	1·049	1·054	1·058	1·063	1·068	1·072	1·077	1·082	1·086	1·091	0 1 1	2 2 3	3 4 4
1·2	1·095	1·100	1·105	1·109	1·114	1·118	1·122	1·127	1·131	1·136	0 1 1	2 2 3	3 4 4
1·3	1·140	1·145	1·149	1·153	1·158	1·162	1·166	1·170	1·175	1·179	0 1 1	2 2 3	3 3 4
1·4	1·183	1·187	1·192	1·196	1·200	1·204	1·208	1·212	1·217	1·221	0 1 1	2 2 2	3 3 4
1·5	1·225	1·229	1·233	1·237	1·241	1·245	1·249	1·253	1·257	1·261	0 1 1	2 2 2	3 3 4
1·6	1·265	1·269	1·273	1·277	1·281	1·285	1·288	1·292	1·296	1·300	0 1 1	2 2 2	3 3 3
1·7	1·304	1·308	1·311	1·315	1·319	1·323	1·327	1·330	1·334	1·338	0 1 1	2 2 2	3 3 3
1·8	1·342	1·345	1·349	1·353	1·356	1·360	1·364	1·367	1·371	1·375	0 1 1	1 2 2	3 3 3
1·9	1·378	1·382	1·386	1·389	1·393	1·396	1·400	1·404	1·407	1·411	0 1 1	1 2 2	3 3 3
2·0	1·414	1·418	1·421	1·425	1·428	1·432	1·435	1·439	1·442	1·446	0 1 1	1 2 2	2 3 3
2·1	1·449	1·453	1·456	1·459	1·463	1·466	1·470	1·473	1·476	1·480	0 1 1	1 2 2	2 3 3
2·2	1·483	1·487	1·490	1·493	1·497	1·500	1·503	1·507	1·510	1·513	0 1 1	1 2 2	2 3 3
2·3	1·517	1·520	1·523	1·526	1·530	1·533	1·536	1·539	1·543	1·546	0 1 1	1 2 2	2 3 3
2·4	1·549	1·552	1·556	1·559	1·562	1·565	1·568	1·572	1·575	1·578	0 1 1	1 2 2	2 3 3
2·5	1·581	1·584	1·587	1·591	1·594	1·597	1·600	1·603	1·606	1·609	0 1 1	1 2 2	2 3 3
2·6	1·612	1·616	1·619	1·622	1·625	1·628	1·631	1·634	1·637	1·640	0 1 1	1 2 2	2 2 3
2·7	1·643	1·646	1·649	1·652	1·655	1·658	1·661	1·664	1·667	1·670	0 1 1	1 2 2	2 2 3
2·8	1·673	1·676	1·679	1·682	1·685	1·688	1·691	1·694	1·697	1·700	0 1 1	1 1 2	2 2 3
2·9	1·703	1·706	1·709	1·712	1·715	1·718	1·720	1·723	1·726	1·729	0 1 1	1 1 2	2 2 3
3·0	1·732	1·735	1·738	1·741	1·744	1·746	1·749	1·752	1·755	1·758	0 1 1	1 1 2	2 2 3
3·1	1·761	1·764	1·766	1·769	1·772	1·775	1·778	1·780	1·783	1·786	0 1 1	1 1 2	2 2 3
3·2	1·789	1·792	1·794	1·797	1·800	1·803	1·806	1·808	1·811	1·814	0 1 1	1 1 2	2 2 2
3·3	1·817	1·819	1·822	1·825	1·828	1·830	1·833	1·836	1·838	1·841	0 1 1	1 1 2	2 2 2
3·4	1·844	1·847	1·849	1·852	1·855	1·857	1·860	1·863	1·865	1·868	0 1 1	1 1 2	2 2 2
3·5	1·871	1·873	1·876	1·879	1·881	1·884	1·887	1·889	1·892	1·895	0 1 1	1 1 2	2 2 2
3·6	1·897	1·900	1·903	1·905	1·908	1·910	1·913	1·916	1·918	1·921	0 1 1	1 1 2	2 2 2
3·7	1·924	1·926	1·929	1·931	1·934	1·936	1·939	1·942	1·944	1·947	0 1 1	1 1 2	2 2 2
3·8	1·949	1·952	1·954	1·957	1·960	1·962	1·965	1·967	1·970	1·972	0 1 1	1 1 2	2 2 2
3·9	1·975	1·977	1·980	1·982	1·985	1·987	1·990	1·992	1·995	1·997	0 1 1	1 1 2	2 2 2
4·0	2·000	2·002	2·005	2·007	2·010	2·012	2·015	2·017	2·020	2·022	0 0 1	1 1 1	2 2 2
4·1	2·025	2·027	2·030	2·032	2·035	2·037	2·040	2·042	2·045	2·047	0 0 1	1 1 1	2 2 2
4·2	2·049	2·052	2·054	2·057	2·059	2·062	2·064	2·066	2·069	2·071	0 0 1	1 1 1	2 2 2
4·3	2·074	2·076	2·078	2·081	2·083	2·086	2·088	2·090	2·093	2·095	0 0 1	1 1 1	2 2 2
4·4	2·098	2·100	2·102	2·105	2·107	2·110	2·112	2·114	2·117	2·119	0 0 1	1 1 1	2 2 2
4·5	2·121	2·124	2·126	2·128	2·131	2·133	2·135	2·138	2·140	2·142	0 0 1	1 1 1	2 2 2
4·6	2·145	2·147	2·149	2·152	2·154	2·156	2·159	2·161	2·163	2·166	0 0 1	1 1 1	2 2 2
4·7	2·168	2·170	2·173	2·175	2·177	2·179	2·182	2·184	2·186	2·189	0 0 1	1 1 1	2 2 2
4·8	2·191	2·193	2·195	2·198	2·200	2·202	2·205	2·207	2·209	2·211	0 0 1	1 1 1	2 2 2
4·9	2·214	2·216	2·218	2·220	2·223	2·225	2·227	2·229	2·232	2·234	0 0 1	1 1 1	2 2 2
5·0	2·236	2·238	2·241	2·243	2·245	2·247	2·249	2·252	2·254	2·256	0 0 1	1 1 1	2 2 2
5·1	2·258	2·261	2·263	2·265	2·267	2·269	2·272	2·274	2·276	2·278	0 0 1	1 1 1	2 2 2
5·2	2·280	2·283	2·285	2·287	2·289	2·291	2·293	2·296	2·298	2·300	0 0 1	1 1 1	2 2 2
5·3	2·302	2·304	2·307	2·309	2·311	2·313	2·315	2·317	2·319	2·322	0 0 1	1 1 1	2 2 2
5·4	2·324	2·326	2·328	2·330	2·332	2·335	2·337	2·339	2·341	2·343	0 0 1	1 1 1	1 2 2

SQUARE ROOTS. From 1 to 10.

	0	1	2	3	4	5	6	7	8	9	Mean Differences.		
											1 2 3	4 5 6	7 8 9
5·5	2·345	2·347	2·349	2·352	2·354	2·356	2·358	2·360	2·362	2·364	0 0 1	1 1 1	1 2 2
5·6	2·366	2·369	2·371	2·373	2·375	2·377	2·379	2·381	2·383	2·385	0 0 1	1 1 1	1 2 2
5·7	2·387	2·390	2·392	2·394	2·396	2·398	2·400	2·402	2·404	2·406	0 0 1	1 1 1	1 2 2
5·8	2·408	2·410	2·412	2·415	2·417	2·419	2·421	2·423	2·425	2·427	0 0 1	1 1 1	1 2 2
5·9	2·429	2·431	2·433	2·435	2·437	2·439	2·441	2·443	2·445	2·447	0 0 1	1 1 1	1 2 2
6·0	2·449	2·452	2·454	2·456	2·458	2·460	2·462	2·464	2·466	2·468	0 0 1	1 1 1	1 2 2
6·1	2·470	2·472	2·474	2·476	2·478	2·480	2·482	2·484	2·486	2·488	0 0 1	1 1 1	1 2 2
6·2	2·4900	2·492	2·494	2·496	2·498	2·500	2·502	2·504	2 506	2·508	0 0 1	1 1 1	1 2 2
6·3	2·510	2·512	2·514	2·516	2·518	2·520	2·522	2·524	2·526	2·528	0 0 1	1 1 1	1 2 2
6·4	2·530	2·532	2·534	2·536	2·538	2·540	2·542	2·544	2·546	2·548	0 0 1	1 1 1	1 2 2
6·5	2·550	2·551	2·553	2·555	2·557	2·559	2·561	2·563	2·565	2·567	0 0 1	1 1 1	1 2 2
6·6	2·569	2·571	2·573	2·575	2·577	2·579	2·581	2·583	2·585	2·587	0 0 1	1 1 1	1 2 2
6·7	2·588	2·590	2·592	2·594	2·596	2·598	2·600	2·602	2·604	2·606	0 0 1	1 1 1	1 2 2
6·8	2·608	2·610	2·612	2·613	2·615	2·617	2·619	2·621	2·623	2·625	0 0 1	1 1 1	1 2 2
6·9	2·627	2·629	2·631	2·632	2·634	2·636	2·638	2·640	2·642	2·644	0 0 1	1 1 1	1 2 2
7·0	2·646	2·648	2·650	2·651	2·653	2·655	2·657	2·659	2·661	2·663	0 0 1	1 1 1	1 2 2
7·1	2·665	2·666	2·668	2·670	2·672	2·674	2·676	2·678	2·680	2·681	0 0 1	1 1 1	1 1 2
7·2	2·683	2·685	2·687	2·689	2·691	2·693	2·694	2·696	2·698	2·700	0 0 1	1 1 1	1 1 2
7·3	2·702	2·704	2·706	2·707	2·709	2·711	2·713	2·715	2·717	2·718	0 0 1	1 1 1	1 1 2
7·4	2·720	2·722	2·724	2·726	2·728	2·729	2·731	2·733	2·735	2·737	0 0 1	1 1 1	1 1 2
7·5	2·739	2·741	2·742	2·744	2·746	2·748	2·750	2·751	2·753	2·755	0 0 1	1 1 1	1 1 2
7·6	2·757	2·759	2·760	2·762	2·764	2·766	2·768	2·769	2·771	2·773	0 0 1	1 1 1	1 1 2
7·7	2·775	2·777	2·778	2·780	2·782	2·784	2·786	2·787	2·789	2·791	0 0 1	1 1 1	1 1 2
7·8	2·793	2·795	2·796	2·798	2·800	2·802	2·804	2·805	2·807	2·809	0 0 1	1 1 1	1 1 2
7·9	2·811	2·812	2·814	2·816	2·818	2·820	2·821	2·823	2·825	2·827	0 0 1	1 1 1	1 1 2
8·0	2·828	2·830	2·832	2·834	2·835	2·837	2·839	2·841	2·843	2·844	0 0 1	1 1 1	1 1 2
8·1	2·846	2·848	2·850	2·851	2·853	2·855	2·857	2·858	2·860	2·862	0 0 1	1 1 1	1 1 2
8·2	2·864	2·865	2·867	2·869	2·871	2·872	2·874	2·876	2·877	2·879	0 0 1	1 1 1	1 1 2
8·3	2·881	2·883	2·884	2·886	2·888	2·890	2·891	2·893	2·895	2·897	0 0 1	1 1 1	1 1 2
8·4	2·898	2·900	2·902	2·903	2·905	2·907	2·909	2·910	2·912	2·914	0 0 1	1 1 1	1 1 2
8·5	2·915	2·917	2·919	2·921	2·922	2·924	2·926	2·927	2·929	2·931	0 0 1	1 1 1	1 1 2
8·6	2·933	2·934	2·936	2·938	2·939	2·941	2·943	2·944	2·946	2·948	0 0 1	1 1 1	1 1 2
8·7	2·950	2·951	2·953	2·955	2·956	2·958	2·960	2·961	2·963	2·965	0 0 1	1 1 1	1 1 2
8·8	2·967	2·968	2·970	2·972	2·973	2·975	2·977	2·978	2·980	2·982	0 0 1	1 1 1	1 1 2
8·9	2·983	2·985	2·987	2·988	2·990	2·992	2·993	2·995	2·997	2·998	0 0 1	1 1 1	1 1 2
9·0	3·000	3·002	3·003	3·005	3·007	3·008	3·010	3·012	3·013	3·015	0 0 0	1 1 1	1 1 1
9·1	3·017	3·018	3·020	3·022	3·023	3·025	3·027	3·028	3·030	3·032	0 0 0	1 1 1	1 1 1
9·2	3·033	3·035	3·036	3·038	3·040	3·041	3·043	3·045	3·046	3·048	0 0 0	1 1 1	1 1 1
9·3	3·050	3·051	3·053	3·055	3·056	3·058	3·059	3·061	3·063	3·064	0 0 0	1 1 1	1 1 1
9·4	3·066	3·068	3·069	3·071	3·072	3·074	3·076	3·077	3·079	3·081	0 0 0	1 1 1	1 1 1
9·5	3·082	3·084	3·085	3·087	3·089	3·090	3·092	3·094	3·095	3·097	0 0 0	1 1 1	1 1 1
9·6	3·098	3·100	3·102	3·103	3·105	3·106	3·108	3·110	3·111	3·113	0 0 0	1 1 1	1 1 1
9·7	3·114	3·116	3·118	3·119	3·121	3·122	3·124	3·126	3·127	3·129	0 0 0	1 1 1	1 1 1
9·8	3·130	3·132	3·134	3·135	3·137	3·138	3·140	3·142	3·143	3·145	0 0 0	1 1 1	1 1 1
9·9	3·146	3·148	3·150	3·151	3·153	3·154	3·156	3·158	3·159	3·161	0 0 0	1 1 1	1 1 1

SQUARE ROOTS. From 10 to 100

	0	1	2	3	4	5	6	7	8	9	Mean Differences		
											1 2 3	4 5 6	7 8 9
10	3·162	3·178	3·194	3·209	3·225	3·240	3·256	3·271	3·286	3·302	2 3 5	6 8 9	11 12 14
11	3·317	3·332	3·347	3·362	3·376	3·391	3·406	3·421	3·435	3·450	1 3 4	6 7 9	10 12 13
12	3·464	3·479	3·493	3·507	3·521	3·536	3·550	3·564	3·578	3·592	1 3 4	6 7 8	10 11 13
13	3·606	3·619	3·633	3·647	3·661	3·674	3·688	3·701	3·715	3·728	1 3 4	5 7 8	10 11 12
14	3·742	3·755	3·768	3·782	3·795	3·808	3·821	3·834	3·847	3·860	1 3 4	5 7 8	9 11 12
15	3·873	3·886	3·899	3·912	3·924	3·937	3·950	3·962	3·975	3·987	1 3 4	5 6 8	9 10 11
16	4·000	4·012	4·025	4·037	4·050	4·062	4·074	4·087	4·099	4·111	1 2 4	5 6 7	9 10 11
17	4·123	4·135	4·147	4·159	4·171	4·183	4·195	4·207	4·219	4·231	1 2 4	5 6 7	8 10 11
18	4·243	4·254	4·266	4·278	4·290	4·301	4·313	4·324	4·336	4·347	1 2 3	5 6 7	8 9 10
19	4·359	4·370	4·382	4·393	4·405	4·416	4·427	4·438	4·450	4·461	1 2 3	5 6 7	8 9 10
20	4·472	4·483	4·494	4·506	4·517	4·528	4·539	4·550	4·561	4·572	1 2 3	4 6 7	8 9 10
21	4·583	4·593	4·604	4·615	4·626	4·637	4·648	4·658	4·669	4·680	1 2 3	4 5 6	8 9 10
22	4·690	4·701	4·712	4·722	4·733	4·743	4·754	4·764	4·775	4·785	1 2 3	4 5 6	7 8 9
23	4·796	4·806	4·817	4·827	4·837	4·848	4·858	4·868	4·879	4·889	1 2 3	4 5 6	7 8 9
24	4·899	4·909	4·919	4·930	4·940	4·950	4·960	4·970	4·980	4·990	1 2 3	4 5 6	7 8 9
25	5·000	5·010	5·020	5·030	5·040	5·050	5·060	5·070	5·079	5·089	1 2 3	4 5 6	7 8 9
26	5·099	5·109	5·119	5·128	5·138	5·148	5·158	5·167	5·177	5·187	1 2 3	4 5 6	7 8 9
27	5·196	5·206	5·215	5·225	5·235	5·244	5·254	5·263	5·273	5·282	1 2 3	4 5 6	7 8 9
28	5·292	5·301	5·310	5·320	5·329	5·339	5·348	5·357	5·367	5·376	1 2 3	4 5 6	7 7 8
29	5·385	5·394	5·404	5·413	5·422	5·431	5·441	5·450	5·459	5·468	1 2 3	4 5 5	6 7 8
30	5·477	5·486	5·495	5·505	5·514	5·523	5·532	5·541	5·550	5·559	1 2 3	4 4 5	6 7 8
31	5·568	5·577	5·586	5·595	5·604	5·612	5·621	5·630	5·639	5·648	1 2 3	3 4 5	6 7 8
32	5·657	5·666	5·675	5·683	5·692	5·701	5·710	5·718	5·727	5·736	1 2 3	3 4 5	6 7 8
33	5·745	5·753	5·762	5·771	5·779	5·788	5·797	5·805	5·814	5·822	1 2 3	3 4 5	6 7 8
34	5·831	5·840	5·848	5·857	5·865	5·874	5·882	5·891	5·899	5·908	1 2 3	3 4 5	6 7 8
35	5·916	5·925	5·933	5·941	5·950	5·958	5·967	5·975	5·983	5·992	1 2 2	3 4 5	6 7 8
36	6·000	6·008	6·017	6·025	6·033	6·042	6·050	6·058	6·066	6·075	1 2 2	3 4 5	6 7 7
37	6·083	6·091	6·099	6·107	6·116	6·124	6·132	6·140	6·148	6·156	1 2 2	3 4 5	6 7 7
38	6·164	6·173	6·181	6·189	6·197	6·205	6·213	6·221	6·229	6·237	1 2 2	3 4 5	6 6 7
39	6·245	6·253	6·261	6·269	6·277	6·285	6·293	6·301	6·309	6·317	1 2 2	3 4 5	6 6 7
40	6·325	6·332	6·340	6·348	6·356	6·364	6·372	6·380	6·387	6·395	1 2 2	3 4 5	6 6 7
41	6·403	6·411	6·419	6·427	6·434	6·442	6·450	6·458	6·465	6·473	1 2 2	3 4 5	5 6 7
42	6·481	6·488	6·496	6·504	6·512	6·519	6·527	6·535	6·542	6·550	1 2 2	3 4 5	5 6 7
43	6·557	6·565	6·573	6·580	6·588	6·595	6·603	6·611	6·618	6·626	1 2 2	3 4 5	5 6 7
44	6·633	6·641	6·648	6·656	6·663	6·671	6·678	6·686	6·693	6·701	1 2 2	3 4 5	5 6 7
45	6·708	6·716	6·723	6·731	6·738	6·745	6·753	6·760	6·768	6·775	1 1 2	3 4 4	5 6 7
46	6·782	6·790	6·797	6·804	6·812	6·819	6·826	6·834	6·841	6·848	1 1 2	3 4 4	5 6 7
47	6·856	6·863	6·870	6·877	6·885	6·892	6·899	6·907	6·914	6·921	1 1 2	3 4 4	5 6 7
48	6·928	6·935	6·943	6·950	6·957	6·964	6·971	6·979	6·986	6·993	1 1 2	3 4 4	5 6 6
49	7·000	7·007	7·014	7·021	7·029	7·036	7·043	7·050	7·057	7·064	1 1 2	3 4 4	5 6 6
50	7·071	7·078	7·085	7·092	7·099	7·106	7·113	7·120	7·127	7·134	1 1 2	3 4 4	5 6 6
51	7·141	7·148	7·155	7·162	7·169	7·176	7·183	7·190	7·197	7·204	1 1 2	3 4 4	5 6 6
52	7·211	7·218	7·225	7·232	7·239	7·246	7·253	7·259	7·266	7·273	1 1 2	3 3 4	5 6 6
53	7·280	7·287	7·294	7·301	7·308	7·314	7·321	7·328	7·335	7·342	1 1 2	3 3 4	5 5 6
54	7·348	7·355	7·362	7·369	7·376	7·382	7·389	7·396	7·403	7·409	1 1 2	3 3 4	5 5 6

SQUARE ROOTS. From 10 to 100

	0	1	2	3	4	5	6	7	8	9	Mean Differences		
											123	456	789
55	7·416	7·423	7·430	7·436	7·443	7·450	7·457	7·463	7·470	7·477	1 1 2	3 3 4	5 5 6
56	7·483	7·490	7·497	7·503	7·510	7·517	7·523	7·530	7·537	7·543	1 1 2	3 3 4	5 5 6
57	7·550	7·556	7·563	7·570	7·576	7·583	7·589	7·596	7·603	7·609	1 1 2	3 3 4	5 5 6
58	7·616	7·622	7·629	7·635	7·642	7·649	7·655	7·662	7·668	7·675	1 1 2	3 3 4	5 5 6
59	7·681	7·688	7·694	7·701	7·707	7·714	7·720	7·727	7·733	7·740	1 1 2	3 3 4	4 5 6
60	7·746	7·752	7·759	7·765	7·772	7·778	7·785	7·791	7·797	7·804	1 1 2	3 3 4	4 5 6
61	7·810	7·817	7·823	7·829	7·836	7·842	7·849	7·855	7·861	7·868	1 1 2	3 3 4	4 5 6
62	7·874	7·880	7·887	7·893	7·899	7·906	7·912	7·918	7·925	7·931	1 1 2	3 3 4	4 5 6
63	7·937	7·944	7·950	7·956	7·962	7·969	7·975	7·981	7·987	7·994	1 1 2	3 3 4	4 5 6
64	8·000	8·006	8·012	8·019	8·025	8·031	8·037	8·044	8·050	8·056	1 1 2	2 3 4	4 5 6
65	8·062	8·068	8·075	8·081	8·087	8·093	8·099	8·106	8·112	8·118	1 1 2	2 3 4	4 5 6
66	8·124	8·130	8·136	8·142	8·149	8·155	8·161	8·167	8·173	8·179	1 1 2	2 3 4	4 5 5
67	8·185	8·191	8·198	8·204	8·210	8·216	8·222	8·228	8·234	8·240	1 1 2	2 3 4	4 5 5
68	8·246	8·252	8·258	8·264	8·270	8·276	8·283	8·289	8·295	8·301	1 1 2	2 3 4	4 5 5
69	8·307	8·313	8·319	8·325	8·331	8·337	8·343	8·349	8·355	8·361	1 1 2	2 3 4	4 5 5
70	8·367	8·373	8·379	8·385	8·390	8·396	8·402	8·408	8·414	8·420	1 1 2	2 3 4	4 5 5
71	8·426	8·432	8·438	8·444	8·450	8·456	8·462	8·468	8·473	8·479	1 1 2	2 3 4	4 5 5
72	8·485	8·491	8·497	8·503	8·509	8·515	8·521	8·526	8·532	8·538	1 1 2	2 3 3	4 5 5
73	8·544	8·550	8·556	8·562	8·567	8·573	8·579	8·585	8·591	8·597	1 1 2	2 3 3	4 5 5
74	8·602	8·608	8·614	8·620	8·626	8·631	8·637	8·643	8·649	8·654	1 1 2	2 3 3	4 5 5
75	8·660	8·666	8·672	8·678	8·683	8·689	8·695	8·701	8·706	8·712	1 1 2	2 3 3	4 5 5
76	8·718	8·724	8·729	8·735	8·741	8·746	8·752	8·758	8·764	8·769	1 1 2	2 3 3	4 5 5
77	8·775	8·781	8·786	8·792	8·798	8·803	8·809	8·815	8·820	8·826	1 1 2	2 3 3	4 4 5
78	8·832	8·837	8·843	8·849	8·854	8·860	8·866	8·871	8·877	8·883	1 1 2	2 3 3	4 4 5
79	8·888	8·894	8·899	8·905	8·911	8·916	8·922	8·927	8·933	8·939	1 1 2	2 3 3	4 4 5
80	8·944	8·950	8·955	8·961	8·967	8·972	8·978	8·983	8·989	8·994	1 1 2	2 3 3	4 4 5
81	9·000	9·006	9·011	9·017	9·022	9·028	9·033	9·039	9·044	9·050	1 1 2	2 3 3	4 4 5
82	9·055	9·061	9·066	9·072	9·077	9·083	9·088	9·094	9·099	9·105	1 1 2	2 3 3	4 4 5
83	9·110	9·116	9·121	9·127	9·132	9·138	9·143	9·149	9·154	9·160	1 1 2	2 3 3	4 4 5
84	9·165	9·171	9·176	9·182	9·187	9·192	9·198	9·203	9·209	9·214	1 1 2	2 3 3	4 4 5
85	9·220	9·225	9·230	9·236	9·241	9·247	9·252	9·257	9·263	9·268	1 1 2	2 3 3	4 4 5
86	9·274	9·279	9·284	9·290	9·295	9·301	9·306	9·311	9·317	9·322	1 1 2	2 3 3	4 4 5
87	9·327	9·333	9·338	9·343	9·349	9·354	9·359	9·365	9·370	9·375	1 1 2	2 3 3	4 4 5
88	9·381	9·386	9·391	9·397	9·402	9·407	9·413	9·418	9·423	9·429	1 1 2	2 3 3	4 4 5
89	9·434	9·439	9·445	9·450	9·455	9·460	9·466	9·471	9·476	9·482	1 1 2	2 3 3	4 4 5
90	9·487	9·492	9·497	9·503	9·508	9·513	9·518	9·524	9·529	9·534	1 1 2	2 3 3	4 4 5
91	9·539	9·545	9·550	9·555	9·560	9·566	9·571	9·576	9·581	9·586	1 1 2	2 3 3	4 4 5
92	9·592	9·597	9·602	9·607	9·612	9·618	9·623	9·628	9·633	9·638	1 1 2	2 3 3	4 4 5
93	9·644	9·649	9·654	9·659	9·664	9·670	9·675	9·680	9·685	9·690	1 1 2	2 3 3	4 4 5
94	9·695	9·701	9·706	9·711	9·716	9·721	9·726	9·731	9·737	9·742	1 1 2	2 3 3	4 4 5
95	9·747	9·752	9·757	9·762	9·767	9·772	9·778	9·783	9·788	9·793	1 1 2	2 3 3	4 4 5
96	9·798	9·803	9·808	9·813	9·818	9·823	9·829	9·834	9·839	9·844	1 1 2	2 3 3	4 4 5
97	9·849	9·854	9·859	9·864	9·869	9·874	9·879	9·884	9·889	9·894	1 1 1	2 3 3	4 4 5
98	9·899	9·905	9·910	9·915	9·920	9·925	9·930	9·935	9·940	9·945	0 1 1	2 2 3	3 4 4
99	9·950	9·955	9·960	9·965	9·970	9·975	9·980	9·985	9·990	9·995	0 1 1	2 2 3	3 4 4

POWERS, ROOTS, AND RECIPROCALS.

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
1	1	1	1	1	3·1623	2·1544	4·6416	1
2	4	8	1·4142	1·2599	4·4721	2·7144	5·8480	·50000
3	9	27	1·7321	1·4422	5·4772	3·1072	6·6943	·33333
4	16	64	2·000	1·5874	6·3246	3·4200	7·3681	·25000
5	25	125	2·2361	1·7100	7·0711	3·6840	7·9370	·20000
6	36	216	2·4495	1·8171	7·7460	3·9149	8·4343	·16667
7	49	343	2·6458	1·9129	8·3666	4·1213	8·8790	·14286
8	64	512	2·8284	2·000	8·9443	4·3089	9·2832	·12500
9	81	729	3·000	2·0801	9·4868	4·4814	9·6549	·11111
10	100	1000	3·1623	2·1544	10·000	4·6416	10·0000	·10000
11	121	1331	3·3166	2·2240	10·4881	4·7914	10·3228	·090909
12	144	1728	3·4641	2·2894	10·9545	4·9324	10·6266	·083333
13	169	2197	3·6056	2·3513	11·4018	5·0658	10·9139	·076923
14	196	2744	3·7417	2·4101	11·8322	5·1925	11·1869	·071429
15	225	3375	3·8730	2·4662	12·2474	5·3133	11·4471	·066667
16	256	4096	4·000	2·5198	12·6491	5·4288	11·6961	·062500
17	289	4913	4·1231	2·5713	13·0384	5·5397	11·9348	·058824
18	324	5832	4·2426	2·6207	13·4164	5·6462	12·1644	·055556
19	361	6859	4·3589	2·6684	13·7840	5·7489	12·3856	·052632
20	400	8000	4·4721	2·7144	14·1421	5·8480	12·5992	·05000
21	441	9261	4·5826	2·7589	14·4914	5·9439	12·8058	·047619
22	484	10648	4·6904	2·8020	14·8324	6·0368	13·0059	·045455
23	529	12167	4·7958	2·8439	15·1658	6·1269	13·2001	·043478
24	576	13824	4·8990	2·8845	15·4919	6·2145	13·3887	·041667
25	625	15625	5·000	2·9240	15·8114	6·2996	13·5721	·04000
26	676	17576	5·0990	2·9625	16·1245	6·3825	13·7507	·038402
27	729	19683	5·1962	3·0000	16·4317	6·4633	13·9248	·037037
28	784	21952	5·2915	3·0366	16·7332	6·5421	14·0946	·035714
29	841	24389	5·3852	3·0723	17·0294	6·6191	14·2604	·034483
30	900	27000	5·4772	3·1072	17·3205	6·6943	14·4225	·033333
31	961	29791	5·5678	3·1414	17·6068	6·7679	14·5810	·032258
32	1024	32768	5·6569	3·1748	17·8885	6·8399	14·7361	·031250
33	1089	35937	5·7446	3·2075	18·1659	6·9104	14·8881	·030303
34	1156	39304	5·8310	3·2396	18·4391	6·9795	15·0369	·029412
35	1225	42875	5·9161	3·2711	18·7083	7·0473	15·1829	·028571
36	1296	46656	6·000	3·3019	18·9737	7·1138	15·3262	·027778
37	1369	50653	6·0828	3·3322	19·2354	7·1791	15·4668	·027027
38	1444	54872	6·1644	3·3620	19·4936	7·2432	15·6049	·026316
39	1521	59319	6·2450	3·3912	19·7484	7·3061	15·7406	·025641
40	1600	64000	6·3246	3·4200	20·000	7·3681	15·8740	·02500
41	1681	68921	6·4031	3·4482	20·2485	7·4290	16·0052	·024390
42	1764	74088	6·4807	3·4760	20·4939	7·4889	16·1343	·023810
43	1849	79507	6·5574	3·5034	20·7364	7·5478	16·2613	·023256
44	1936	85184	6·6332	3·5303	20·9762	7·6059	16·3864	·022727
45	2025	91125	6·7082	3·5569	21·2132	7·6631	16·5096	·022222
46	2116	97336	6·7823	3·5830	21·4476	7·7194	16·6310	·021739
47	2209	103823	6·8557	3·6088	21·6795	7·7750	16·7507	·021277
48	2304	110592	6·9282	3·6342	21·9089	7·8297	16·8687	·020833
49	2401	117649	7·000	3·6593	22·1359	7·8837	16·9850	·020408
50	2500	125000	7·0711	3·6840	22·3607	7·9370	17·0998	·02000

POWERS, ROOTS, AND RECIPROCALS.

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
51	2601	132651	7·1414	3·7084	22·5832	7·9896	17·2130	·019608
52	2704	140608	7·2111	3·7325	22·8035	8·0415	17·3248	·019231
53	2809	148877	7·2801	3·7563	23·0217	8·0927	17·4351	·018868
54	2916	157464	7·3485	3·7798	23·2379	8·1433	17·5441	·018519
55	3025	166375	7·4162	3·8030	23·4521	8·1932	17·6517	·018182
56	3136	175616	7·4833	3·8259	23·6643	8·2426	17·7581	·017857
57	3249	185193	7·5498	3·8485	23·8747	8·2913	17·8632	·017544
58	3364	195112	7·6158	3·8709	24·0832	8·3396	17·9670	·017241
59	3481	205379	7·6811	3·8930	24·2899	8·3872	18·0697	·016949
60	3600	216000	7·7460	3·9149	24·4949	8·4343	18·1712	·016667
61	3721	226981	7·8102	3·9365	24·6982	8·4809	18·2716	·016393
62	3844	238328	7·8740	3·9579	24·8998	8·5270	18·3709	·016129
63	3969	250047	7·9373	3·9791	25·0998	8·5726	18·4691	·015873
64	4096	262144	8·000	4·000	25·2982	8·6177	18·5664	·015625
65	4225	274625	8·0623	4·0207	25·4951	8·0624	18·6626	·015385
66	4356	287496	8·1240	4·0412	25·6905	8·7066	18·7578	·015152
67	4489	300763	8·1854	4·0615	25·8844	8·7503	18·8520	·014925
68	4624	314432	8·2462	4·0817	26·0768	8·7937	18·9454	·014706
69	4761	328509	8·3066	4·1016	26·2679	8·8366	19·0378	·014493
70	4900	343000	8·3666	4·1213	26·4575	8·8790	19·1293	·014286
71	5041	357911	8·4261	4·1408	26·6458	8·9211	19·2200	·014085
72	5184	373248	8·4853	4·1602	26·8328	8·9628	19·3098	·013889
73	5329	389017	8·5440	4·1793	27·0185	9·0041	19·3988	·013699
74	5476	405224	8·6023	4·1983	27·2029	9·0450	19·4870	·013514
75	5625	421875	8·6603	4·2172	27·3861	9·0856	19·5743	·013333
76	5776	438976	8·7178	4·2358	27·5681	9·1258	19·6610	·013158
77	5929	456533	8·7750	4·2543	27·7489	9·1657	19·7468	·012987
78	6084	474552	8·8318	4·2727	27·9285	9·2052	19·8319	·012821
79	6241	493039	8·8882	4·2908	28·1069	9·2443	19·9163	·012658
80	6400	512000	8·9443	4·3089	28·2843	9·2832	20·0000	·012500
81	6561	531441	9·0000	4·3267	28·4605	9·3217	20·0830	·012346
82	6724	551368	9·0554	4·3445	28·6356	9·3599	20·1653	·012195
83	6889	571787	9·1104	4·3621	28·8097	9·3978	20·2469	·012048
84	7056	592704	9·1652	4·3795	28·9828	9·4354	20·3279	·011905
85	7225	614125	9·2195	4·3968	29·1548	9·4727	20·4083	·011765
86	7396	636056	9·2736	4·4140	29·3258	9·5097	20·4880	·011628
87	7569	658503	9·3274	4·4310	29·4958	9·5464	20·5671	·011494
88	7744	681472	9·3808	4·4480	29·6648	9·5828	20·6456	·011304
89	7921	704969	9·4340	4·4647	29·8329	9·6190	20·7235	·011236
90	8100	729000	9·4868	4·4814	30·000	9·6549	20·8008	·011111
91	8281	753571	9·5394	4·4979	30·1662	9·6905	20·8776	·010989
92	8464	778688	9·5917	4·5144	30·3315	9·7259	20·9538	·010870
93	8649	804357	9·6437	4·5307	30·4959	9·7610	21·0294	·010753
94	8836	830584	9·6954	4·5468	30·6594	9·7959	21·1045	·010638
95	9025	857375	9·7468	4·5629	30·8221	9·8305	21·1791	·010526
96	9216	884736	9·7980	4·5789	30·9839	9·8648	21·2532	·010417
97	9409	912673	9·8489	4·5947	31·1448	9·8990	21·3267	·010309
98	9604	941192	9·8995	4·6104	31·3050	9·9329	21·3997	·010204
99	9801	970299	9·9499	4·6261	31·4643	9·9666	21·4723	·010101
100	10000	1000000	10·000	4·6416	31·6228	10·000	21·5443	·0100

SQUARES. From 1 to 10.

	0	1	2	3	4	5	6	7	8	9	Mean Differences.								
											1	2	3	4	5	6	7	8	9
10	1·0000	1·0201	1·0404	1·0609	1·0816	1·1025	1·1236	1·1449	1·1664	1·1881	21	42	63	84	105	126	147	168	189
11	1·2100	1·2321	1·2544	1·2769	1·2996	1·3225	1·3456	1·3689	1·3924	1·4161	23	46	69	92	115	138	161	184	207
12	1·4400	1·4641	1·4884	1·5129	1·5376	1·5625	1·5876	1·6129	1·6384	1·6641	25	50	75	100	125	150	175	200	225
13	1·6900	1·7161	1·7424	1·7689	1·7956	1·8225	1·8496	1·8769	1·9044	1·9321	27	54	81	108	135	162	189	216	243
14	1·9600	1·9881	2·0164	2·0449	2·0736	2·1025	2·1316	2·1609	2·1904	2·2201	29	58	87	116	145	174	203	232	261
15	2·2500	2·2801	2·3104	2·3409	2·3716	2·4025	2·4336	2·4649	2·4964	2·5281	31	62	93	124	155	186	217	248	279
16	2·5600	2·5921	2·6244	2·6569	2·6896	2·7225	2·7556	2·7889	2·8224	2·8561	33	66	99	132	165	198	231	264	297
17	2·8900	2·9241	2·9584	2·9929	3·0276	3·0625	3·0976	3·1329	3·1684	3·2041	35	70	105	140	175	210	245	280	315
18	3·2400	3·2761	3·3124	3·3489	3·3856	3·4225	3·4596	3·4969	3·5344	3·5721	37	74	111	148	185	222	259	296	333
19	3·6100	3·6481	3·6864	3·7249	3·7636	3·8025	3·8416	3·8809	3·9204	3·9601	39	78	117	156	195	234	274	312	351
20	4·0000	4·0401	4·0804	4·1209	4·1616	4·2025	4·2436	4·2849	4·3264	4·3681	41	82	123	164	205	246	287	328	369
21	4·4100	4·4521	4·4944	4·5369	4·5796	4·6225	4·6656	4·7089	4·7524	4·7961	43	86	129	172	215	258	301	344	387
22	4·8400	4·8841	4·9284	4·9729	5·0176	5·0625	5·1076	5·1529	5·1984	5·2441	45	90	135	180	225	270	315	360	405
23	5·2900	5·3361	5·3824	5·4289	5·4756	5·5225	5·5696	5·6169	5·6644	5·7121	47	94	141	188	235	282	329	376	423
24	5·7600	5·8081	5·8564	5·9049	5·9536	6·0025	6·0516	6·1009	6·1504	6·2001	49	98	147	196	245	294	343	392	441
25	6·2500	6·3001	6·3504	6·4009	6·4516	6·5025	6·5536	6·6049	6·6564	6·7081	51	102	153	204	255	306	357	408	459
26	6·7600	6·8121	6·8644	6·9169	6·9696	7·0225	7·0756	7·1289	7·1824	7·2361	53	106	159	212	265	318	371	424	477
27	7·2900	7·3441	7·3984	7·4529	7·5076	7·5625	7·6176	7·6729	7·7284	7·7841	55	110	165	220	275	330	385	440	495
28	7·8400	7·8961	7·9524	8·0089	8·0656	8·1225	8·1796	8·2369	8·2944	8·3521	57	114	171	228	285	342	399	456	513
29	8·4100	8·4681	8·5264	8·5849	8·6436	8·7025	8·7616	8·8209	8·8804	8·9401	59	118	177	236	295	354	413	472	531
30	9·0000	9·0601	9·1204	9·1809	9·2416	9·3025	9·3636	9·4249	9·4864	9·5481	61	122	183	244	305	366	427	488	549
31	9·6100	9·6721	9·7344	9·7969	9·8596	9·9225	9·9856	10·0489	10·1124	10·1761	63	126	188	251	313	376	439	502	564
32	10·2400	10·3041	10·3684	10·4329	10·4976	10·5625	10·6276	10·6929	10·7584	10·8241	7	13	20	26	33	39	46	52	59
33	10·8900	10·9561	11·0224	11·0889	11·1556	11·2225	11·2896	11·3569	11·4244	11·4921	7	13	20	27	34	40	47	54	60
34	11·5600	11·6281	11·6964	11·7649	11·8336	11·9025	11·9716	12·0409	12·1104	12·1801	7	14	21	28	35	41	48	55	62
35	12·2500	12·3201	12·3904	12·4609	12·5316	12·6025	12·6736	12·7449	12·8164	12·8881	7	15	21	28	36	43	50	57	64
36	12·9600	13·0321	13·1044	13·1769	13·2496	13·3225	13·3956	13·4689	13·5424	13·6161	7	15	22	29	37	44	51	58	66
37	13·6900	13·7641	13·8384	13·9129	13·9876	14·0625	14·1376	14·2129	14·2884	14·3641	8	15	23	30	38	45	53	60	68
38	14·4400	14·5161	14·5924	14·6689	14·7456	14·8225	14·8996	14·9769	15·0544	15·1321	8	15	23	31	39	46	54	62	69
39	15·2100	15·2881	15·3664	15·4449	15·5236	15·6025	15·6816	15·7609	15·8404	15·9201	8	16	24	32	40	47	55	63	71
40	16·0000	16·0801	16·1604	16·2409	16·3216	16·4025	16·4836	16·5649	16·6464	16·7281	8	16	24	32	41	49	57	65	73
41	16·8100	16·8921	16·9744	17·0569	17·1396	17·2225	17·3056	17·3889	17·4724	17·5561	8	17	25	33	42	50	58	66	75
42	17·6400	17·7241	17·8084	17·8929	17·9776	18·0625	18·1476	18·2329	18·3184	18·4041	9	17	26	34	43	51	60	68	77
43	18·4900	18·5761	18·6624	18·7489	18·8356	18·9225	19·0096	19·0969	19·1844	19·2721	9	17	26	35	43	52	61	70	78
44	19·3600	19·4481	19·5364	19·6249	19·7136	19·8025	19·8916	19·9809	20·0704	20·1601	9	18	27	36	45	53	62	71	80
45	20·2500	20·3401	20·4304	20·5209	20·6116	20·7025	20·7936	20·8849	20·9764	21·0681	9	18	27	36	46	55	64	73	82
46	21·1600	21·2521	21·3444	21·4369	21·5296	21·6225	21·7156	21·8089	21·9024	21·9961	9	19	28	37	47	56	65	74	84
47	22·0900	22·1841	22·2784	22·3729	22·4676	22·5625	22·6576	22·7529	22·8484	22·9441	10	19	29	38	48	57	67	76	86
48	23·0400	23·1361	23·2324	23·3289	23·4256	23·5225	23·6196	23·7169	23·8144	23·9121	10	19	29	39	49	58	68	78	87
49	24·0100	24·1081	24·2064	24·3049	24·4036	24·5025	24·6016	24·7009	24·8004	24·9001	10	20	30	40	50	59	69	79	89
50	25·0000	25·1001	25·2004	25·3009	25·4016	25·5025	25·6036	25·7049	25·8064	25·9081	10	20	30	40	51	61	71	81	91
51	26·0100	26·1121	26·2144	26·3169	26·4196	26·5225	26·6256	26·7289	26·8324	26·9361	10	21	31	41	52	62	72	82	93
52	27·0400	27·1441	27·2484	27·3529	27·4576	27·5625	27·6676	27·7729	27·8784	27·9841	11	21	32	42	53	63	74	84	95
53	28·0900	28·1961	28·3024	28·4089	28·5156	28·6225	28·7296	28·8369	28·9444	29·0521	11	21	32	43	54	64	75	86	96
54	29·1600	29·2681	29·3764	29·4849	29·5936	29·7025	29·8116	29·9209	30·0304	30·1401	11	22	33	44	55	65	76	87	98

SQUARES. From 1 to 10.

	0	1	2	3	4	5	6	7	8	9	Mean Differences								
											1	2	3	4	5	6	7	8	9
5·5	30·250	30·360	30·470	30·581	30·692	30·803	30·914	31·025	31·136	31·248	11	22	33	44	56	67	78	89	100
5·6	31·360	31·472	31·584	31·697	31·810	31·923	32·036	32·149	32·262	32·376	11	23	34	45	57	68	79	90	102
5·7	32·490	32·604	32·718	32·833	32·948	33·063	33·178	33·293	33·408	33·524	12	23	35	46	58	69	81	92	104
5·8	33·640	33·756	33·872	33·989	34·106	34·223	34·340	34·457	34·574	34·692	12	23	35	47	59	70	82	94	105
5·9	34·810	34·928	35·046	35·165	35·284	35·403	35·522	35·641	35·760	35·880	12	24	36	48	60	71	83	95	107
6·0	36·000	36·120	36·240	36·361	36·482	36·603	36·724	36·845	36·966	37·088	12	24	36	48	61	73	85	97	109
6·1	37·210	37·332	37·454	37·577	37·700	37·823	37·946	38·069	38·192	38·316	12	25	37	49	62	74	86	98	111
6·2	38·440	38·564	38·688	38·813	38·938	39·063	39·188	39·313	39·438	39·564	13	25	38	50	63	75	88	100	113
6·3	39·690	39·816	39·942	40·069	40·196	40·323	40·450	40·577	40·704	40·832	13	25	38	51	64	76	89	102	114
6·4	40·960	41·088	41·216	41·345	41·474	41·603	41·732	41·861	41·990	42·120	13	26	39	52	65	77	90	103	116
6·5	42·250	42·380	42·510	42·641	42·772	42·903	43·034	43·165	43·296	43·428	13	26	39	52	66	79	92	105	118
6·6	43·560	43·692	43·824	43·957	44·090	44·223	44·356	44·489	44·622	44·756	13	27	40	53	67	80	93	106	120
6·7	44·890	45·024	45·158	45·293	45·428	45·563	45·698	45·833	45·968	46·104	14	27	41	54	68	81	95	109	122
6·8	46·240	46·376	46·512	46·649	46·786	46·923	47·060	47·197	47·334	47·472	14	27	41	55	69	82	96	110	123
6·9	47·610	47·748	47·886	48·025	48·164	48·303	48·442	48·581	48·720	48·860	14	28	42	56	70	83	97	111	125
7·0	49·000	49·140	49·280	49·421	49·562	49·703	49·844	49·985	50·126	50·268	14	28	42	56	71	85	99	113	127
7·1	50·410	50·552	50·694	50·837	50·980	51·123	51·266	51·409	51·552	51·696	14	29	43	57	72	86	100	114	129
7·2	51·840	51·984	52·128	52·273	52·418	52·563	52·708	52·853	52·998	53·144	15	29	44	58	73	87	102	116	131
7·3	53·290	53·436	53·582	53·729	53·876	54·023	54·170	54·317	54·464	54·612	15	29	44	59	74	88	103	118	132
7·4	54·760	54·908	55·056	55·205	55·354	55·503	55·652	55·801	55·950	56·100	15	30	45	60	75	89	104	119	134
7·5	56·250	56·400	56·550	56·701	56·852	57·003	57·154	57·305	57·456	57·608	15	30	45	60	76	91	106	121	136
7·6	57·760	57·912	58·064	58·217	58·370	58·523	58·676	58·829	58·982	59·136	15	31	46	61	77	92	107	122	138
7·7	59·290	59·444	59·598	59·753	59·908	60·063	60·218	60·373	60·528	60·684	16	31	47	62	78	93	109	124	140
7·8	60·840	60·996	61·152	61·309	61·466	61·623	61·780	61·937	62·094	62·252	16	31	47	63	79	94	110	126	141
7·9	62·410	62·568	62·726	62·885	63·044	63·203	63·362	63·521	63·680	63·840	16	32	48	64	80	95	111	127	143
8·0	64·000	64·160	64·320	64·481	64·642	64·803	64·964	65·125	65·286	65·448	16	32	48	64	81	97	113	129	145
8·1	65·610	65·772	65·934	66·097	66·260	66·423	66·586	66·749	66·912	67·076	16	33	49	65	82	98	114	130	147
8·2	67·240	67·404	67·568	67·733	67·898	68·063	68·228	68·393	68·558	68·724	17	33	50	66	83	99	116	132	149
8·3	68·890	69·056	69·222	69·389	69·556	69·723	69·890	70·057	70·224	70·392	17	33	50	67	84	100	117	134	150
8·4	70·560	70·728	70·896	71·065	71·234	71·403	71·572	71·741	71·910	72·080	17	34	51	68	85	101	118	135	152
8·5	72·250	72·420	72·590	72·761	72·932	73·103	73·274	73·445	73·616	73·788	17	34	51	68	86	103	120	137	154
8·6	73·960	74·132	74·304	74·477	74·650	74·823	74·996	75·169	75·342	75·516	17	35	52	69	87	104	121	138	156
8·7	75·690	75·864	76·038	76·213	76·388	76·563	76·738	76·913	77·088	77·264	18	35	53	70	88	105	123	140	158
8·8	77·440	77·616	77·792	77·969	78·146	78·323	78·500	78·677	78·854	79·032	18	35	53	71	89	106	124	142	159
8·9	79·210	79·388	79·566	79·745	79·924	80·103	80·282	80·461	80·640	80·820	18	36	54	72	90	107	125	143	161
9·0	81·000	81·180	81·360	81·541	81·722	81·903	82·084	82·265	82·446	82·628	18	36	54	72	91	109	127	145	163
9·1	82·810	82·992	83·174	83·357	83·540	83·723	83·906	84·089	84·272	84·456	18	37	55	73	92	110	128	146	165
9·2	84·640	84·824	85·008	85·193	85·378	85·563	85·748	85·933	86·118	86·304	19	37	56	74	93	111	130	148	167
9·3	86·490	86·676	86·862	87·049	87·236	87·423	87·610	87·797	87·984	88·172	19	37	56	75	94	112	131	150	168
9·4	88·360	88·548	88·736	88·925	89·114	89·303	89·492	89·681	89·870	90·060	19	38	57	76	95	113	132	151	170
9·5	90·250	90·440	90·630	90·821	91·012	91·203	91·394	91·585	91·776	91·968	19	38	57	76	96	115	134	153	172
9·6	92·160	92·352	92·544	92·737	92·930	93·123	93·316	93·509	93·702	93·896	19	39	58	77	97	116	135	154	174
9·7	94·090	94·284	94·478	94·673	94·868	95·063	95·258	95·453	95·648	95·844	20	39	59	78	98	117	137	156	176
9·8	96·040	96·236	96·432	96·629	96·826	97·023	97·220	97·417	97·614	97·812	20	39	59	79	99	118	138	158	177
9·9	98·010	98·208	98·406	98·605	98·804	99·003	99·202	99·401	99·600	99·800	20	40	60	80	100	119	139	159	179

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