A Note on

Transportation Engineering II

CE 4105

by **Farhad Hossain**

MD FARHAD HOSSAIN

CE'15 1500045

Never give up hope of Allah's Mercy (Quran: 12:87)

Special THANKS to-

My friend

SAYEM AHAMEED

CE'15 1500119

INDEX

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Road Construction

* Follow Abdus Sobhan Sir's Sheet

Define the following Terms:

1. Road 2. Street 3. Boulevard 4. Bypass Road

Define Highway. *** Explain needs of Highway classification.

Discuss different types of road based construction materials.

2015
Define soil stabilization.

Soil stabilization may be defined as the combination and manipulation of soils with or without admixtures to produce a firm mass that is capable of supporting traffic in all weather condition.

2005
What are the basic principle of soil stabilization?

1. Eavaluation of the properties of the avaiable soil.
2. Estimating the lacking properties of the avaiable soil.
3. Deciding the method of supplimenting the lacing property through economical method of stabilization.
4. considering the construction procedure by adequately compacting the stabilized layers.

2018, 2010, 2008
Discuss the purposes / scopes / objectives of soil stabilization.

2014, 2013, 2012, 2011, 2010, 2008
Discuss the methods / techniques of soil stabilization.

2018, 2017, 2016, 2012
Write short notes on: Soil stabilized road.

2018, 2017, 2016, 2015, 2012
Write short notes on: WBM Road.

2017, 2013, 2011, 2010, 2009
What are the method / precaution of Rolling?

2018, 2017, 2013, 2011, 2010, 2009
Discuss bad effects of defective Rolling.

(1) Develops corrugation (2) over compaction or under compaction.
(3) wavy road surface (4) Increases vehicle operation cost
(5). Ingress of water through voids and cracks etc.

2016, 2014

Briefly discuss the construction of steps of WBM Road.

2015, 2012

Write short note on: Bituminous road.

Write short note on: Cement Concrete Road.

2015, 2013, 2011, 2010, 2009

Define low cost Roads. Why are low class-road preferred on developing countries.

Low cost road: The roads which require very little cost in their construction which serve the needs of the light traffic are called low cost roads.

Some low-cost roads are:

1. Earth road 2. Gravel Road 3. Brick road 4. Soil stabilized road 5. W.B.M Road.

Why these are preferred:

Due to the development of economy and urbanization, traffic increases on the road. So the existing roads may be improved to serve the needs of the increased traffic.

Making improvement of the existing roads according to traffic needs is called stage construction. Low cost roads are fit into a scheme of stage construction.

construction of low cost roads are preferred now a days in developing countries where large length of roads are to be constructed in the rural areas with the limited available funds.

For following reasons low-cost roads are

(i) paucity (অভাব) of fund.
(ii) Non-availability of cement.
(iii) To serve light traffic.
(iv) Maintenance cost is not so high.
(v) Roads can be used by all sorts of vehicle. etc.

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ROAD CONSTRUCTION

Road: is a structural track constructed to facilitate the movement of persons and goods from one place to another by any sorts of vehicle.
Street: is a road within the town, which has defined by buildings constructed along one or both of its sides.
Highway: is a roadway of standard width, meant for all sorts of vehicles and include all public roads & streets.
Bypass road: is an arrangement for diverting a traffic flow to avoid congested areas of towns or cities.
Boulevard (Avenue): is a very wide road in a city with trees on either side and used as processional roads.
Needs of highway classification: (i) For a designer, it enables him to relate the geometric and structural design standards. (ii) For a planner, this provides a basis for long-term planning. (iii) Also it serves various administrative needs. Two broad categories of road are: (i) Urban – falling within the municipalities and (ii) Non-urban (Rural) – located in areas other than urban.
Based on construction materials, different types of road are discussed below:
(1) Earth Road: Top soil (with 15% clay) of the embankment is compacted adequately with proper camber.
(2) Gravel Road: Well graded crushed stones or gravels are compacted with proper camber for carriageway.
(3) Brick Road: Bricks are laid either flat in one layer or in two layers or on edge on a prepared sub grade or sub-base with sand cushion. Patterns of arrangement of bricks are Header & stretcher or Herring bone bond.
(4) Stabilized Road: Strength of poor soils is improved by soil stabilization techniques to support wheel loads. Purpose of soil stabilization: (a) to improve the strength (b) to control dust (c) to use of local soil for economy.
Types of stabilization technique are discussed below:
(I) Mechanical stabilization: Stability of the soil is increased by blending the available soil with imported soil or aggregate to obtain a desired particle-size distribution and by compacting the mixture to a desired density. Mechanical strength of the mass is due to the internal friction by coarser particles and the cohesion by clay.
Applications: Soil-aggregate mixtures, Sand-clay mixtures, Sand-gravel mixtures, Soil-soft aggregate mixtures.
(II) Stabilization by additives: Stability of the soil is increased by additives – lime, cement, bitumen, resins etc. The strength of the mass is due to the binding and cohesion properties of additives.
Applications: (a) Soil-Lime stabilization, (b) Soil-Cement stabilization and (c) Soil-Bitumen stabilization.
(III) Chemical stabilization: Stability of the soil is increased by the use of chemicals – $CaCl_2$, $NaCl_2$, molasses.
The strength of the mass is due to the moisture content in the soil provided by chemicals from atmosphere.

(5) Water Bound Macadam (WBM) Road: In 1858, Mc Adam was a Scottish engineer who introduced the idea of constructing roads "composed of small size stones held together by means of binding materials". This type road is then named Macadam Road. It is low cost road. The term macadam was qualified by
(i) "Water-bound" macadam if the stone materials are held together by the addition of water and filler.
(ii) "Dry-bound" macadam if the stone materials are held together by mechanical interlock.
(iii) "Wet-mix" macadam if graded stones are mixed with water and compacted.
(iv) "Penetration" macadam if a bituminous material is sprayed over the stones and allowed to penetration.
(v) "Premix" macadam if the bituminous material is mixed with the aggregates prior to laying.

WBM road is a dense and compact course of a road pavement in which coarse aggregates are kept bounded by the action of rolling and voids are filled with screening and binding materials with the help of water.
The strength of a WBM course is thus primarily due to (i) the mechanical interlock in the aggregate particles and (ii) the cohesion between the aggregate particles (stone chips or brick chips) due to soil-moisture binder.
Method of Rolling: (i) Started from the edges and slowly proceeded towards the centre. (ii) Move slowly, because jerk develops corrugation (iii) Forward to backward changing are not at the same place (iv) Low spots filled with additional materials (v) Subsequent pass overlap at least 1/3 of width (vi) Roller always kept damp.
Construction Steps
(1) Preparation of foundation: Foundation layer (sub-grade) is prepared with proper camber and the loose materials are cleaned. For correct alignment & lateral confinement bricks on edge are laid along the road edges.
(2) Spreading of coarse aggregate: After spreading of coarse aggregates, proper compaction is done by roller.
(3) Application of screenings: Dry screenings are applied over the compacted surface & rolled to fill the voids.
(4) Application of binding materials: After application of soil, water is sprinkled over & rolled to fill the voids.
(5) Finishing of the surface: Road surface is allowed to dry over night and next day. Sand or earth layer(6 mm) is spread on the surface and rolled after lightly sprinkling water. Road may be open to traffic after a day or two.

(6) Bituminous Road: in which the surface of low cost roads are treated with some bituminous materials.
(7) Cement Concrete Road: in which cement is used as a binding materials.

General Properties of Road Pavement Design

Define Road Pavement. What are the desirable characterestics of Road Pavement.

classify the road pavement based on structural performance.

2014, 2008

Write down the difference between Rigid pavement and flexible pavement.

2015, 2010

Draw a net sketch of flexible pavement cross-section and show its diffenent components.

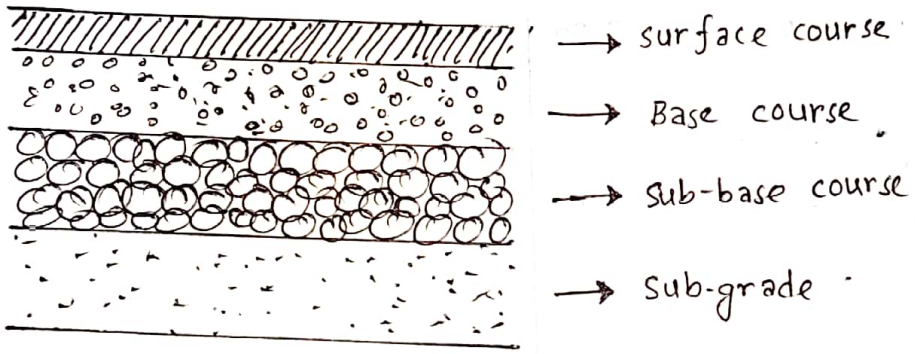


Fig. components of Flexible Pavement

2017

Write the name of materials that used in different course of Flexible pavement.

Materials used - in Subgrade: Native Soil

- in Sub-base course: Granular soil, stabilized soil, Broken stones, Broken bricks etc.
- in Base course: crushed stone, crushed gravel, crushed Bricks etc.
- in surface course: Bituminous mixes, As alt mixes.

2016

Briefly discuss the functions of pavement courses in flexible pavement.

2018, 2015, 2013

Write down the functions of subgrade course and surface course of a flexible pavement.

General Principles of Road Pavement Design

Road pavement is a stable layer constructed over the natural soil to support & distribute the heavy wheel loads.

Desirable Characteristics of Road Pavement:
(1) Should be strong to withstand the stresses (2) Sufficient thick (3) Hard surface (4) Dust proof (5) Good riding quality (6) Adequate roughness (7) Impervious surface (8) Long life (9) Minimum maintenance cost.

Based on structural performance, road pavements can be classified as:
(1) Flexible Pavement: is one which has low flexural strength. The pavement deflects if the subgrade deflects.
(2) Rigid Pavement: is one which withstand loads from the flexural or beam strength over irregular subgrade.
(3) Semi-rigid Pavement: is intermediate state between **(1) & (2)**. Lower flexural strength but derives support.
(4) Composite Pavement: is one which comprises structurally significant layer of different composition.

Comparison of Rigid and Flexible Pavements

Sl.	Factors	Rigid Pavement	Flexible Pavement
1	Design precision	More precise due to flexural strength	Less precise because design is empirical
2	Life of pavement	Long life about 40 years	Life varies from10 to 20 years with repair
3	Maintenance	Needs actually very little maintenance	Needs great inputs in maintenance
4	Initial cost	More costly than a flexible pavement	Cost is lower than a rigid pavement
5	Stage construction	Do not fit for stage construction	Fit into a scheme of stage construction
6	Surface character	Smooth and free from rutting, potholes	Rough and with rutting, waves, potholes
7	Water penetration	Practically impervious, except at joints	Not impervious due to cracks and pores
8	Temp. variation	Induce heavy stresses	Not produce stresses

Pavement Courses: A pavement consists of one or more layers. The simplest classification is given below:
(1) Indian Practice: From bottom (i) Sub-grade (ii) Sub-base course (iii) Base course (iv) Surfacing.
(2) American Practice: (i) Sub-grade (ii) Sub-base course (iii) Base course (iv) Binder course (v) Surface course.
(3) British Practice: (i) Sub-grade (ii) Sub-base (iii) Road base (iv) Surfacing (Base course + Wearing course).
In rigid pavement, concrete slab (surface course) directly placed on the sub-grade or on sub-base for weak soil.

Function of Sub-grade: (i) Receive the other layers (ii) Support the loads and dispersed to earth mass below. Sub-grade soil posses the properties: Strength, drainage, ease of compaction, permanency of compaction etc. Strength of the sub-grade is a basic factor in determining the thickness of pavement and is evaluated by means of CBR tests. Thickness of improved sub-grade = 300 mm for CBR ≤ 2% and that of 200 mm for CBR = 3 & 4%.
The use of geo-textiles is popular because: (i) it separates the granular layer from sub-grade & thereby prevent intrusion of the soil into the stone matrix (ii) it reinforced the granular layer and help in reducing its thickness.

Function of Sub-base: (i) Provides additional help to the base and surfacing in distributing the loads (ii) Prevent intrusion of fine-grained road-bed soils into base courses (iii) Minimize the damaging effects of frost action (iv) Facilitate drainage of free water that might get accumulated below the pavement.
Materials are granular soil, stabilized soil, broken stones & broken bricks. Local materials used for economy. The ratio of khoa, sand and soil is 1:1:1. For very low trafficked rural roads, minimum soaked CBR is 20 %. Brick aggregates shall be made of picket brick. The LAA value < 50 %, AIV< 40 % & water absorption <18 %.

Function of Base course: (i) Act as the main load spreading layer (ii) Prevent intrusion of sub-grade soil when constructed directly over the sub-grade (iii) The life of the pavement is dependent on the strength of this layer. Base course should have sufficient (i) thickness (ii) structural stability (iii) density (iv) resistance to weathering.
Function of base course under rigid pavements are: (i) to prevent pumping (ii) to protect frost action (iii) to check volume changes (iv) to increase structural stability (v) to form a working surface on silts and clays.

Function of Surface course: (i) Perform as a structural portion of the pavement (ii) Resist the abrasive forces of traffic (iii) Offers resistance to the infiltration of water (iv) Provide a uniform and skid-resistance surface.
In case of bituminous concrete, the performance of Sylhet stones will be better than Pakur stone but a slightly higher bitumen will be necessary. LAA value < 40%, AIV< 30%, soundness < 18 % & water absorption < 1.2%.

Factors to be considered in Design of a Pavement

2018, 2016, 2013, 2012

Discuss the traffic factors that affect the stability of a flexible pavement.

2014, 2008

Differentiate Between Contact pressure and tyre pressure.

Contact Pressure	Tyre pressure
1. Stress on contact area of wheel and road surface is known as Contact pressure.	1. Air pressure inside the pneumatic tyre is known as Tyre pressure.
2. It is considered circular in shape	2. It is considered elliptical in shape.
3. High contact pressure requires thick pavement thickness.	3. High inflation pressure requires high quality surfacing material
4. contact pressure = $\frac{\text{Wheel load}}{\text{contact area}}$	5. Tyre pressure = $\frac{0.9 \times \text{wheel Load}}{\text{contact area}}$

2017, 2015, 2014.

Write short note on: ESWL

Write short note on: *** EWLF

2015

Discuss the moisture factors and soil factors considered for the design of flexible pavement.

2017, 2015, 2014, 2013, 2012, 2011, 2010, 2009

Write short note on: Frost Action

Discuss the climate factors considered for design of flexible pavement.

Factors to be considered in Design of Pavement

The various factors to be considered for the design of pavement thickness are:

I. Traffic (Design Wheel Load) Factors: Higher wheel loads obviously need thicker pavement, provided other design factors are same. While considering the design wheel load, the following terms are included:

(i) Maximum wheel load: For highways the maximum legal axle load = 18000 lb with a max. equivalent single wheel load = 9000 lb (4085 kg), 10000 lb, 11000 lb and 12000 lb specified by IRC, AASHTO,UK and USA respectively. Based on the Boussinesq's theory: Vertical stress at depth z, $\delta z = p[1 - \{z^3 \div (a^2 + z^2)^{3/2}\}]$ where, p = surface pressure & a = radius of loaded area. Vertical stress distribution according to the above equation is shown in Fig.2. The magnitude of vertical stress at any depth of pavement mass depends upon the surface pressure as well as on the total load. At constant tyre pressure, total load influences the thickness requirements of pavements. Vertical stress influences the quality of surface course. Higher tyre pressures require high quality of surfacing material in upper layers of the pavement, without affecting the total depth of the pavement.

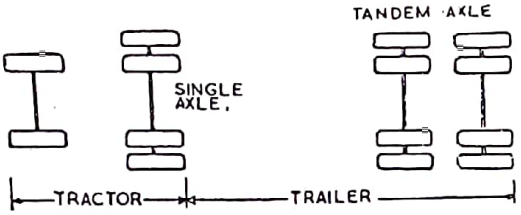


Fig.1 Wheel Configuration of tractor Trailer Unit

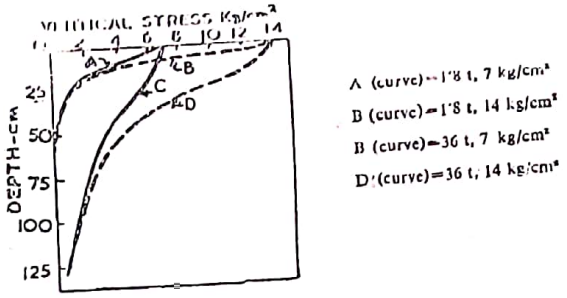


Fig. 2 Vertical Stress Distribution

(ii) Load Contact Pressure: Stress on contact (imprint) area is known as contact pressure. Experimentally established that contact pressure is more than the tyre (inflation) pressure when the tyre pressure is less than 7 kg/cm^2 and it is, otherwise if tyre pressure is more than 7 kg/cm^2.
Rigidity Factor = (Contact pressure ÷ Tyre pressure) is ≥1 for pavement design.

(iii) Dual or Multiple wheel loads and Equivalent Single Wheel Load (ESWL): In order to carry greater loads and at the same time to maintain the maximum wheel load within the legal prescribed limit, it is essential to provide dual wheel assembly to the rear axles. In doing so it is necessary to find out the effect of dual assembly on the pavement. From the Fig.3 it is clear that effect of dual wheel assembly is not twice the effect of one wheel but less than this. The effect is in between the single load and two times the load carried by the wheel. Up to depth d/2, both the wheel loads are dispersed independently but below this point they start overlapping. Total stresses, at any depth, greater than 2S may be considered to be equivalent to a single wheel load carrying 2P load. *An ESWL is defined as the load on a single tyre that will cause an equal magnitude of a pre selected parameter (deflection, stress, strain, distress) at a given location within a specific pavement system to that resulting from a multiple-wheel load at the same location within the pavement structure.*
For assumed design thickness of pavement, value of ESWL is read from graph (Fig. 4) and this ESWL is used for design computations. If computed thickness is equal to the assumed thickness then the ESWL calculations are considered correct. If not, repeated trials are made by assuming different thickness of the pavement every time. In case of trailers and heavy trucks, the load on each wheel can be reduced adopting tandem axles.

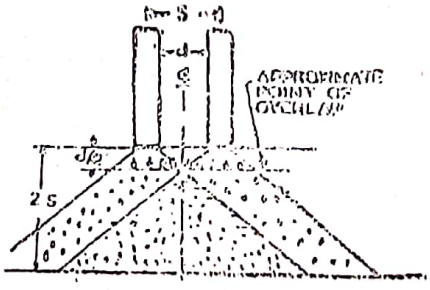


Fig.3 Dual wheel distribution of stress

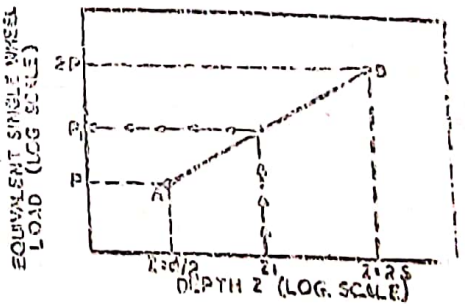


Fig.4 ESWL by graphical method

2014

(iv) Repetition of Loads: Single application of wheel load may cause very little deformation but the repeated application of same wheel load cause appreciable permanent deformation and may cause of road failure. For mix traffic conditions, it is important to convert the effect of repetition of each type of vehicle in terms of the effect of a standard single wheel load which is known as Equivalent Wheel Load Factor (EWLF).

McLeod assumed that the design thickness will support 10^6 repetitions of the design load in 25 years and for one repetition of the design load will require only 25 % thickness of designed thickness required for 10^6 repetitions. One fourth of design thickness were plotted for various wheel loads on vertical axis against one load application and total thickness (100 %) were plotted on vertical axis drawn at 10^6 repetitions. If the wheel load of 2268 kg (5000 lb) and the failure number of repetitions for 25 cm thick pavement are taken as standard, the number of failure repetitions for higher wheel loads may be obtained from Fig.5.

Table: EWLF for various wheel load repetitions

Wheel load, kg	Repetition to failure, No.	Equivalent to 2268 kg	EWLF
2268	105000	1.0	1
2722	50000	2.1	2
3175	24500	4.3	4
3629	13000	8.2	8
4085	6500	16.3	16
4536	3300	32.0	32
4990	1700	62.0	64
5443	1000	105.0	128

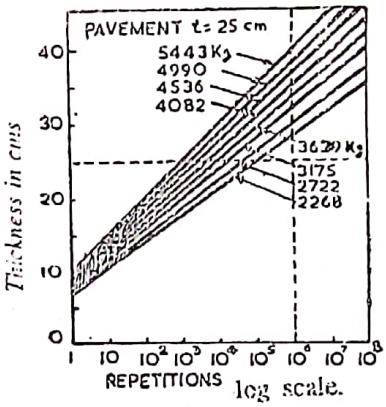


Fig.5 Relation between Repetitions and EWLF

2015

2. Moisture Factors: The reduction in moisture content may cause shrinkage and increase in moisture will cause swell in the soil of the subgrade. Both these changes in moisture will cause change in strength of the subgrade and deterioration of the road surface. Generally all soils decrease their strength with the increase in moisture content, more specially clayey soils. On the other hand decrease in moisture content, increase the strength of subgrade soils. These effects are likely to cause considerable damage to the pavements.

Causes of increase of moisture in soil:

(i) Percolation of surface water through cracks in road surface (ii) Entry of water through edges of the road (iii) Seepage of water in hilly areas.(iv) Capillary rise from high water table or due to rise of table in rainy season (v) Transfer of water vapour through soil due to difference in vapour pressure.

V.V.I

3. Climatic Factors: The performance of a pavement is adversely affected by the climatic conditions (frost action) of a place. Frost action affects the pavements in two ways. (i) Frost heave and (ii) Frost melting.

2015

Frost heave refers to rising up of the pavement portion. When the temperature falls slowly below freezing temperature, the free water in the larger pores of the soil freezes and forms ice crystals. The process of increasing ice crystals continues till the capillary go on supplying water and the soil above these crystals ultimately heave up. If the rise the supporting power of subgrade is affected adversely. If the rise is nonuniform, the supporting power of subgrade is affected adversely.

Frost melting refers to melt of ice crystals due to rise of temperature. Ice melting water accumulated in the voids of soil below the pavement, which decreases the load carrying capacity of the pavement. Thus the freezing and thawing or melting ice crystals which occur alternately due to variation in the weather cause much damage to the pavement. The over all effect due to frost heave, frost melting and alternate freezing & thawing cycle is called **Frost Action.** The frost action is influenced by the following factors:

(a) Frost susceptible soil (b) Soil grain size (c) Low temperature below freezing point (d) Supply of water.

2015

4. Soil Factors: Large variations may occur in the properties of soil under the pavement foundation. The soil strength varies with type of soil, bulk density, moisture content, permeability, internal structure of the soil. As the elastic properties of soil are very low, the supporting power of subgrade is very important factor in the design of flexible pavements. Following properties of soil are determined for supporting power of subgrade (i) Shear strength (ii) Bearing power (c) CBR value.

Class Test

Write the name of methods for design of flexible pavement practiced by different organizations.

Write the name of methods for design of rigid pavement practiced by different organization.

Write short note on:

* Prime Coat 2018, 2017, 2015, 2014, 2013, 2012, 2011, 2010, 2009
* Tack Coat 2008, 2007
* Seal coat 2007
* Surface dressing or Surface painting or surface treatment. 2016
* Built-up spray Grout
* Penetration Macadam*
* Coated Macadam*
* Bituminous carpat
* Bituminous concrete
* Rolled Asphalt
* Mastic Asphalt
* Recycling of Bituminous layer **

2018, 2017, 2016

Discuss the methods of road constructions in swamps and water-logged areas. (sheet + search on internet about (i) Bog blasting (ii) vertical sand drain)

Flexible Pavement Design Methods: So many methods practiced by different organizations are as follows: (1) Indian Road Congress (IRC) method (2) California Bearing Ratio (CBR) method (3) Road Note 31 method (4) Asphalt Institute method (5) AASHTO design method (6) Group Index method (7) Wyoming method.

Rigid Pavement Design Methods: So many methods practiced by different organizations are as follows: (1) Westergaard's Corner Load formula (2) Portland Cement Association (PCA) method (3) Road Note 29 (4) Indian Road Congress (IRC) method (5) Transport & Road Research Laboratory (TRRL) method.

Types of Bituminous Courses: Bituminous materials (bitumen, road tar, cut back or emulsion) are used as a binder in a variety of specifications. The specifications can be classified as follows—

(1) Prime coat is the first single coat of liquid bituminous material to an absorbent surface before placing bituminous wearing course. It (i) promotes bond between the base and wearing course (ii) binds together any loose aggregate in the base (iii) plugs the capillary voids (iv) consolidate the base for integrity with w. course.

(2) Tack coat is an application of a bituminous binder on surfaces previously treated before giving a new bituminous wearing course. It ensures a bond between the new construction & old surface, otherwise peel off.

(3) Seal coat is a very thin surface treatment or a single coat of surface dressing over certain pervious bituminous pavements. It (i) develop the skid resistance (ii) make water proof (iii) increase the life of surface.

(4) Surface dressing or Surface painting or Surface treatment is a process whereby a thin film of bituminous binder is sprayed on the road surface, covered with a coat of mineral aggregates and well rolled. Functions are (i) to dust proof a WBM layer (ii) to water proof a WBM layer (iii) to renew the worn out surfaces (iv) to increase skid resistance of smooth surfaces (v) to improve the light reflection characteristics. Surface dressing on new WBM roads is done in two coats. The first coat (heavier) is treated as part of the base and the second coat (lighter) is the wearing course. A light surface dressing coat is provided as a seal coat.

(5) Built-up-spray Grout is a method of road construction in which single size stones are laid in layers of thickness equal to the stone size, and a very small quantity of binder is grouted that imparts adhesion amongst the aggregates. The built-up-spray grout specification is inferior in strength and costly than WBM specification.

(6) Penetration Macadam is a compacted layer of coarse aggregates into which has been introduced a binder which is allowed to penetrate into the layer and bind the course aggregates. A layer of key aggregates is spread on the constructed surface and rolled. A seal coat is provided to make the surface impervious to water.

(7) Coated Macadam is a form of premixed work where aggregates and binder are mixed prior to placement. The stability of the mix is mainly due to the interlock between the aggregate particles and the frictional resistance developed at the contact points. The mix is an open-graded type, with voids content as high as 20 – 25%.

(8) Bituminous Carpet is premix prepared from 10 to 12 mm size chippings with sand and bitumen. Compacted thickness is 20 mm and serve as a surface course. It covered by a suitable seal coat before opening.

(9) Bituminous Concrete is a pavement specification composed of a thoroughly controlled hot-mixed material having as ingredients (i) dense graded aggregates (ii) filler and (iii) bitumen. It is a superior type of pavement.

(10) Rolled Asphalt consists of a mortar of fine aggregate and penetration grade bitumen to which is added a quantity of coarse aggregate. The mix with 30 % coarse aggregates is used as a wearing course and mix with 60 % is suitable for base course. Rolled asphalt exhibits considerable strength and stability and has long life.

(11) Sheet Asphalt consists of well-graded sand and a suitable penetration grade bitumen to form a dense and impervious layer. It is superior type of surface, generally for heavily trafficked city streets but relatively costly.

(12) Mastic Asphalt is a mixture of bitumen, fine aggregates and filler in suitable proportions which yields a void less and impermeable mass. The final product is very hard, stable & durable and suitable for heavy traffic.

(13) Recycling of Bituminous Layers: Bituminous layers lose their volatiles in course of time and the binder gets oxidised. Thus the binding property of the material is lost, making it brittle. If additional binder is introduced into the old coated material, it is possible to achieve the same properties as a new material. Also has other advantage such as (i) reduction in the excess height of the pavement & (ii) reduction in pollution hazards.

Roads in Swampy and Water-Logged Area: Swamps are locations where there is a perpetual stagnation of water and the soil is saturated. If possible, swamps should be bypassed. If unavoidable, the road must cross where its width is narrow and depth is shallow. Methods of road construction through swamps are (1) Bog blasting and (2) Vertical sand drain. Water-logged areas (like land of irrigation) are those where the level of the sub-soil water table is very high, thus, favouring capillary rise of water into the sub-grade. Injurious salts ($NaSO_4$ and $MgSO_4$) in courses are mixed with raised water and volume of salt is increases when they crystallise under suitable hygroscopic and temperature conditions. The repeated volume changes of salts due to alternate hydration and dehydration leads to breaking of the pavement. One of the most effective measures to depress the water table is a system of sub-surface drains leading to suitable natural drainage channels. Black cotton soils are expansive clays. The road surface in such soils has a tendency to become wavy. Stone sink into the weak soil. Sand or local soil stabilised with lime (10 cm) can provided between the soil and the stone layer.

Joints in Cement Concrete Pavement

2018, 2017, 2013, 2012, 2010
Briefly discuss the various joints provided in rigid pavement.

2010, 2009, 2007
Write a short note on: Dowel Bar (Sheet - Transverse expansion Joints)

2009
Discuss the object of the following types of joint with neat sketches:

(i) Expansion joint. 2011

(ii) Contraction joint

(iii) Longitudinal joint.

2011, 2005
Explain - 'Joint is nothing but it is designed crack.'

Joints is nothing but it is designed crack. Joints are installed in concrete pavements to control the stresses resulting from the combined effects of temperature and moisture changes and wheel loadings. Different types of joints are provided such as:

1. To control cracking of slab resulting from contracting and to relieve temperature warping stresses Transverse contraction joints are used.
2. To provide space in the concrete allow for the expansion of the slab, Transverse expansion joints are used.
3. To develop proper bond between the new and old concrete, Tranverse construction joints are provided.
4. To prevent movement of one slab with respect to the other, Longitudinal joints are provided.
5. To relieve stresses included due to warping, warping joints are provided.

Hence, we can say that, joints are nothing but designed cracks.

2015, 2014, 2011
What are the requirements of a good joint.

JOINTS IN CEMENT CONCRETE PAVEMENT

Joints are installed in concrete pavements to control the stresses induced by volume changes in the concrete. These stresses may be produced in a concrete slab because of (1) its contraction due to a uniform temperature drop or a decrease in moisture, (2) its expansion due to a uniform temperature increase, and (3) the effects of the "warping" of pavements due to a vertical temperature or moisture differential in the slab.

Joint is nothing but it is designed crack. To control the stresses resulting from the combined effects of temperature and moisture changes and wheel loadings, four types of joints are provided for concrete pavement:

(1) Transverse Contraction Joints: are used for (i) to control cracking of the slab resulting from contraction and (ii) to relieve temperature warping stresses. Design of most widely used contraction joint called weakened-plane joint is shown in Fig.1. As contraction occurs, the lower portion of the slab cracks at the weakened plane and the structural integrity of the joint is maintained by the dowel bars and aggregate interlock. This type of joint is also called a "dummy" contraction joint. The ⅛" width of the groove in the top the slab is later filled with poured rubber or rubber-asphalt compounds. One side of dowel bar is bonded to the concrete and other side is painted or lubricated for freedom to movement.

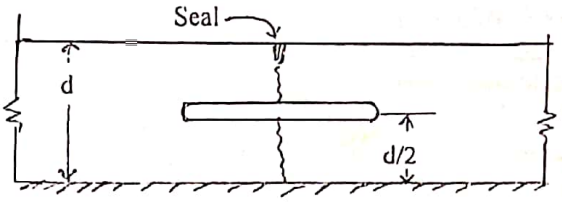


Fig.1 Weakened plane or dummy contraction joint.

(2) Transverse Construction Joints: may be placed at the end of the day's "run" or when work ceases due to some other interruption. Except for emergency stops, construction joints should be located at the regular sites of expansion or contraction joints. If this joint falls within the middle third of the regular joint interval, they are provided to develop proper bond between the new and old concrete provided with key and reinforcing bar.

(3) Transverse Expansion Joints: are usually designed to provide space in the concrete to allow for the expansion of the slabs thereby preventing the high compressive stresses. These joints also serve as contraction joints, warping joints and construction joints. The load transference across the transverse joint is carried out throughout a system of reinforcement provided at suitable interval projecting in the concrete in longitudinal direction. Such a device is named as *dowel bar* shown in Fig.2. Joint is 29 to 25 mm wide and extend the full depth of the slab. The joint space is filled with filler materials.

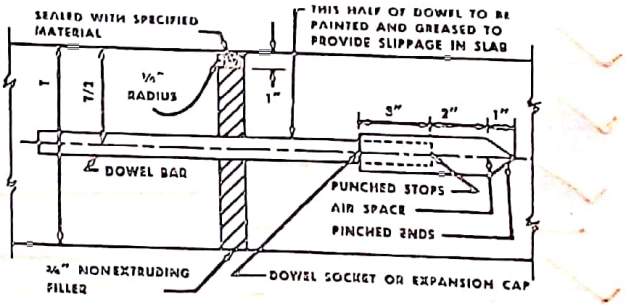


Fig.2 Typical doweled expansion joint

(4) Longitudinal Contraction and Construction Joints
Longitudinal joint is a joint running continuously the length of the pavement. It divides a two-lane road into two sections and tied together by means of steel tie bars to prevent movement of one slab with respect to the other. Warping joints (*hinged joints*) are provided to relieve stresses included due to warping. Longitudinal joints with tie bars fall in this class of joint as shown in Fig.3.

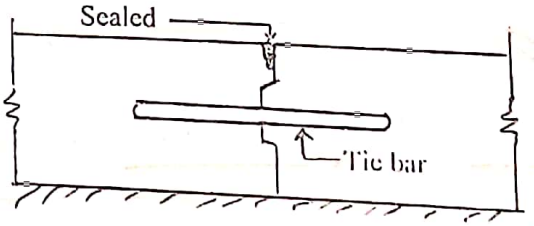


Fig.3 Typical longitudinal(hinged) joint

Requirements of good joints: Following requirements must be fulfilled by good joints.
(1) Joints must be free to move (2) Joints must be water tight (3) Joints should be at the same level of the slab.

Joint Filler and Sealer

2018, 2016, 2014, 2013, 2012, 2011, 2010, 2009
Write down the properties of joint filler and sealer

2018, 2016, 2014
Write down the functions of joint filler and sealer with neat sketches.

(i) Fig.(a) shows the normal position of filler and sealer at normal temparature.

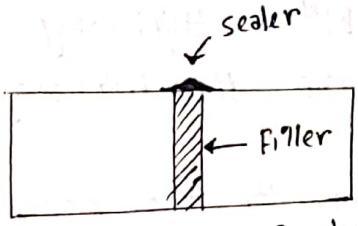


Fig.(a) During Construction

(ii) Fig.(b) shows that pavement expands due to rise in temperature and open gap gets reduced. In such condition, the filler gets compressed, and e sealer compound gets spilling out of joints.

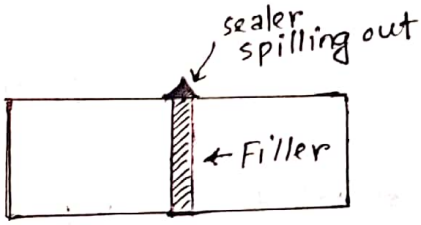


Fig.(b) During Summer

(iii) fig.(c) shows, during winter the edges of pavement move back to contraction and the open gap is increased. The sealer material will flow and spread round the joint.

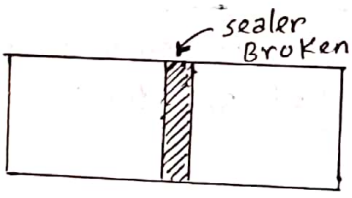


Fig.(c) During winter

construction of cement concrete pavement:

2018, 2017
Write down the construction steps of cement concrete pavement.

Pavement Evaluation

Define Pavement Evaluation.
Write down the purposes/objectives of pavement Evaluation. ***
write the name of methods for pavement Evaluation.
2017, 2016, 2015, 2014, 2008
Write a short note on: PSI

JOINT FILLER AND SEALER

Joints form the weakest plane in the concrete pavement and can allow infiltration of rain water and ingress of stone grits. The infiltration of water may damage the sub-grade and the ingress of stone grit reduces the effective width of the joint causing faults like spoiling of the joint.

Joint Filler: A material which is used for filling the joints is known as filler. Joint filler should possess the following properties: (1) Compressibility (2) Elasticity (3) Durability. Material most commonly used as fillers are: Bituminous material, Cork, Rubber, Cork-rubber compounds, Soft wood, Impregnated fiber board.

Joint Sealer: The material which is used for sealing the joints is known as sealer. Joint sealer should possess the following properties: (1) Adhesion (2) Extensibility (3) Durability (4) Resistance to ingress of grit. Material most commonly used as sealers are: (a) Bitumen either alone or with mineral filler (b) Rubber-bitumen compound (c) Air-blown bitumen

CONSTRUCTION OF CEMENT CONCRETE PAVEMANT

1. Mix design: The mix design requires that the following factors be known:
(i) Minimum compressive strength/flexural strength of the concrete in the field at 28 days.
(ii) Maximum size of the aggregate to be used and its gradation. (iii) Degree of workability needed.
(iv) Degree of quality control that will be exercised and the tolerance level that will be permitted.

2. Preparation of Base: Base should be checked for line, grade, irregularities and cross-section.

3. Form Work: Final levels and evenness of the pavement depend upon the forms. Steel forms are preferred.

4. Placing of Reinforcement: In very poor sub-grade and heavy traffic conditions, slab may be reinforced.

5. Mixing and Laying of Concrete: The aggregates and cement are first introduced into the concrete mixer and water is added within 15 minutes of dry mixing. About one and half minutes are needed for a satisfactory mixing. After placing and spreading the concrete in place, concrete is rodded with suitable tools.

6. Compacting: Compacting should be done preferably by vibratory screed. The temper is drawn ahead with a sawing motion in combination with a series of lifts and drops alternating with lateral shifts. Compaction and tamping is carried on till the mortar in the mix just works upto the surface. Excess water in mix should avoid.

7. Finishing: The finishing work consist of a number of operation such as:

(i) Floating: consists of smoothening and compacting manually by a longitudinal wooden float It is operated along road and parallel to carriageway in a sawing motion, passing from one side of the pavement to the other.

(ii) Straight-edging: Any depressions found are immediately made good with freshly mixed concrete, struck, compacted and refinished. Finally, the irregularities should not be more than 3mm.

(iii) Belting: is carried out with a two-ply canvas belt of 200mm wide and longer than slab width. Belts are operated with short strokes transverse to the carriageway and with a rapid advance parallel to the centre line.

(iv) Brooming: Brooms of steel or fiber is pulled gently over the surface of the pavement from edge to edge.

(v) Edging: After belting and brooming, but before the concrete has taken its initial set, the edges of the slab are carefully finished with an edging tool having a radius of 6mm.

8. Curing: Curing is necessary to prevent evaporation of water which is needed for chemical reaction and to minimize shrinkage.

9. Opening to Traffic: Traffic is allowed after 28 days where Ordinary Portland Cement is used. This period can be curtailed to 7 days when rapid hardening cement is used.

C.T→4

Pavement Evaluation

Pavement evaluation (pavement condition survey and rating of pavement) is a technique of assessing the condition of a pavement, both structurally and from the point of view of surface characteristics. It's purposes:

(1) To research on the performance of pavements of different specifications over a period of time.

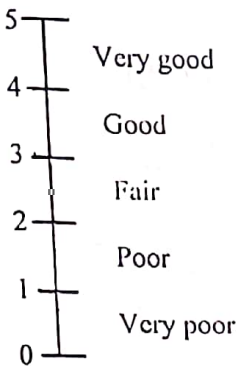
(2) To assess maintenance needs such as patch repairs, renewals and resealing.

(3) To assess the need for structural overlays on distressed pavements.

Methods of pavement evaluation: (i) Visual Rating Method (ii) Pavement Serviceability Index (PSI) Concept (iii) Roughness Measurements Method (iv) Benkelman Beam Deflection Method. (Ref. L.R. Kadiyali p - 625)

2015, 2014

Pavement Serviceability Index (PSI) represents the momentary ability of pavement to serve traffic and the performance of the pavement. The PSI is based upon the concept of correlating user opinions with measurements of road roughness, cracking, patching and rutting. The panel numbers drive over selected pavements and rate the pavements on the scale shown below:

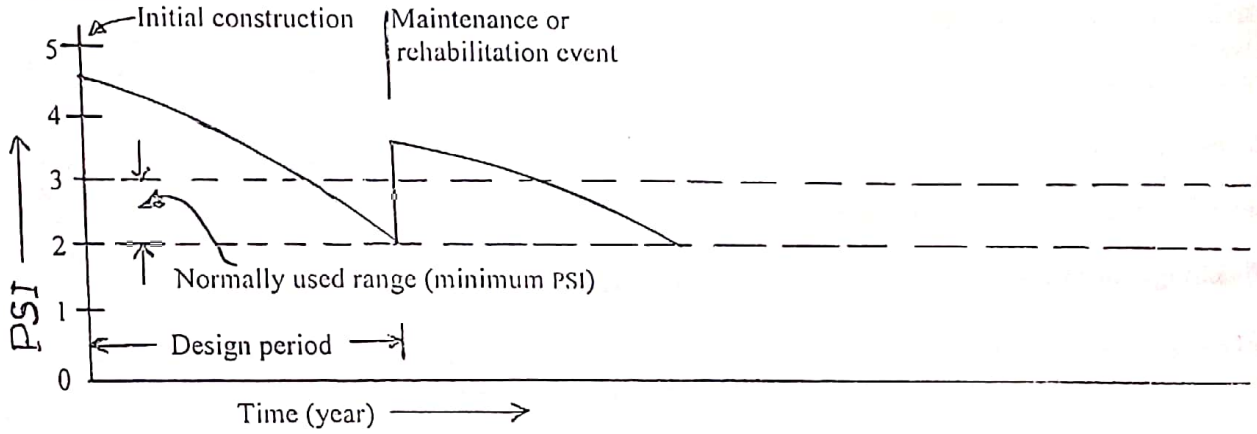


Rating Scale

For flexible pavement, $PSI = 5.03 - 1.91 \log (1+SV) - 1.38 (RD)^2 - 0.01\sqrt{C+P}$

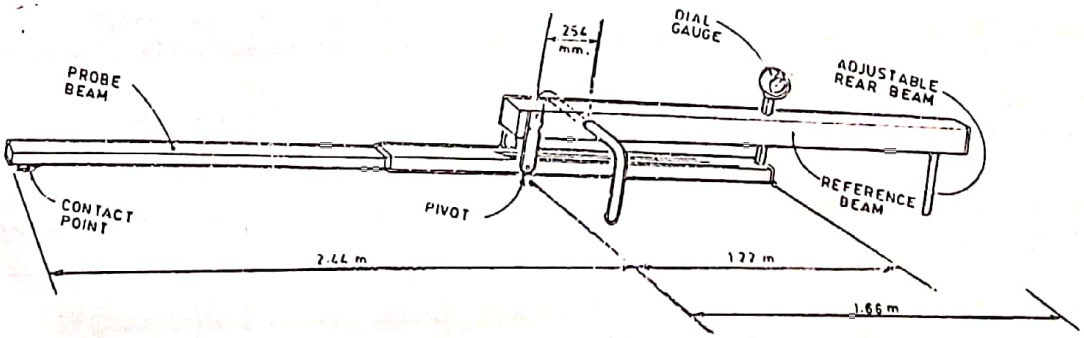
For rigid pavement, $PSI = 5.41 - 1.80 \log (1+SV) - 0.09\sqrt{C+P}$

Where, PSI = Pavement Serviceability Index
SV = Slope variance giving an index of the longitudinal profile
RD = Rut depth in inches (both wheel tracks) under a 4 ft. straight edge
C = in inches distress in terms of lineal feet of cracks/1000 sq.ft area
P = Bituminous patched area in ft^2 per 1000 sq.ft area



Concept of pavement performance using PSI

The Benkelman Beam & Lacroix Deflectograph measures the deflections (Rebound deflection i.e recoverable and Residual deflection i,e non-recoverable) of a flexible pavement under standard wheel load conditions.



Benkelman Beam

Highway Failure and Their maintenance

What do you mean by 'failure of the pavement'.

Write down the causes of the failure of the pavement.

Define Highway maintenance. what operations/works are involved with the highway maintenance.

Write the economic benefits of a well planned maintenance policy.***

Failure in Flexible Pavement

What are the causes of failure of subgrade.**

What are the causes of failure of sub-base and base course.**

What are the causes of failure of bituminous wearing course

2017, 2013, 2010, 2011

Briefly discuss the causes and remedial measures of following surface defects:

(*) Bleeding 2015

(*) shoving**

(*) Rutting 2015

(*) cracking 2015

(*) waves and corrugations 2015, 2014

(*) Pot Hole 2016, 2016, 2013, 2012, 2011, 2010

Write down the different types of maintenace operations*

Write short note on: MMS*

Highway Failure and their Maintenance

The failure of the pavement is defined as the localized depression and heaving up in its vicinity, which hamper the rapid, safe and convenient movement of traffic. Failures occur due to (1) defects in the quality of materials used (2) defects in construction method and quality control (3) inadequate surface or sub-surface drainage. Maintenance is required to improve the riding quality of highway.

Highway maintenance can be defined as preserving and keeping each component of the highway as far as possible in their original condition and provide such additional work which is necessary to keep the traffic moving safely. The maintenance operations involve the assessment of road condition, diagnosis of the problem and adopting the most appropriate maintenance step. Maintenance of highway comprises of the following maintenance works: (1) pavement surface (2) shoulders (3) roadway drainage (4) bridges and (5) road sides. The economic benefits of a well-planned maintenance policy are: (1) Reduction in road user costs, such as vehicle operating costs, travel time savings and accident costs. (2) Reduction in the level of future maintenance and rehabilitation costs (remember: a stitch in time saves nine) (3) Reduction or prevention of the economic loss due to road closures. From the above, it is clear that a good policy of maintenance should be aims of RHD.

FAILURES IN FLEXIBLE PAVEMENT

The localized settlement of any one component layer of the flexible pavement structure could be enough to cause pavement failure. Ultimately there is surface deformation when failure takes place either in sub-grade or sub-base or base or surface.

Failure of sub-grade: One of the prime causes of flexible pavement failure is excessive deformation in sub-grade soil. Excessive unevenness of pavement surface is considered as pavement failure. Sub-grade fails due to
(1) Inadequate stability: weakness of soil itself, excessive moisture in soil and inadequate compaction & thick
(2) Excessive stress application: application of more load than designed and increase of load repetitions.

Stability may be defined as the resistance to deformation under applied loads.

Failure of sub-base and base course: Failure of these course takes place due to the following reasons-
(1) Inadequate strength: improper mix proportion, inadequate thickness, soft aggregate, poor quality control.
(2) Loss of binding action: repeated application of load or stress, poor load distribution property of the layer.
(3) Loss of material: suction of pneumatic tyres of first moving vehicle causes removal of binding material.
(4) Inadequate thickness of wearing course: ill effect due to rains, frost action and traffic action.
(5) Use of inferior material: many structural failures are observed due to continuous cycles of weather changes.

2013, 10, 11

Failure of bituminous wearing course: Failure of wearing course may be attributed due to following factors-
(1) Improper mix design (2) Inadequate binder (3) Low quality of binder (4) Poor quality control (5) Oxidation.

Some of the typical failure of flexible pavements:

2015

(1) Bleeding of an asphalt mixture occurs when the asphalt flows to the top of the mix surface under the action of traffic loading due to (i) too much binder (ii) unsuitable binder. Development, if neglected (a) the road surface become slippery when wet (b) separation and break-away of surface layer under the action of traffic.
Remedies: (1) Sanding (coarse sand is scattered by shovel over the affected surfaces and then spread out with a broom for evenly covered) (2) Surface dressing (carpeting, sheet asphalt, mastic asphalt).

(2) Shoving: is displacement of the asphalt mixture that take place during the compaction or later under traffic (Location: usually on either side of the wheel tracks) due to (i) ingress of water reduce bearing capacity (ii) poor quality materials (iii) insufficient compaction (iv) passing of heavy vehicle. Development, if neglected (a) forcing up of weak materials as deformation occurs (b) progressive disintegration of the pavement.
Remedies: Filling in of irregularities, step-1 sweep the area for clean & dry, step-2 mark out the area to be repaired and remove any high spots with a pick axe, step-3 application of tack coat, step-4 fill the depression with cold bituminous mix, step-5 compaction, step-6 resealing to prevent penetration of water

2015

(3) Rutting: is displacement of the mixture in both vertical and transverse directions under traffic loads (rut is in the wheel tracks and depression is in the local area) due to (i) insufficient foundation or pavement strength (ii) inadequate stability of the bituminous surfacing materials. Development, if neglected (a) rapid increase of

rutting due to water leading to cracking and breakup of the pavement. Remedies: (1) for slight rutting – filling in of the ruts and depressions and (2) for deep rutting – local restoration of the pavement structure. Filling in of the ruts and depressions: step-1 sweep the area for clean & dry, step-2 mark out the area to be repaired and remove any high spots with a pick axe, step-3 application of tack coat, step-4 fill the depression with cold bituminous mix, step-5 compaction, step-6 resealing to prevent penetration of water.

2015

(4) Cracks: (1) Longitudinal (2) Transverse (3) Mesh (Alligator) cracking due to (i) poor quality materials (ii) poor workmanship (iii) shrinkage (iv) insufficient pavement thickness. Development, if neglected (a) general or local destruction of the pavement. Remedies: (1) Local sealing (2) Filling in of the cracks (3) Patching. Technique of local sealing – step-1: sweep the area for clean and dry, step-2: mark out the area to be sealed, step-3: distribution of binder over the surface, step-4: distribution of aggregate (coarse sand or chippings).

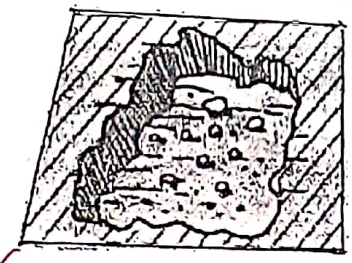
2015, 14

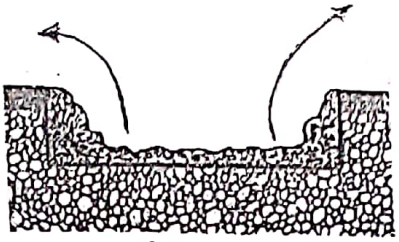
(5) Waves and Corrugations: is the undulated surface due to (i) defective rolling (ii) poor sub-grade (iii) inadequate surface course (iv) poor mix (v) compaction temperature (vi) weak or unstable underlying layers. Remedial measures: Corrugations may be rectified up to design sections by cutting of the high ridges. The inequalities and waviness may be removed by filling the depressions with premixed material after applying tack coat over the cleaned surface.

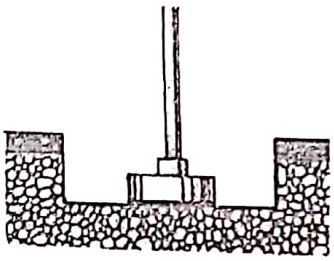
2013, 12, 10, 11

(6) Pot holes: are isolated depressions to a depth of 50 to 75 mm in a road surface due to (i) poor quality of materials (ii) lack of binding properties (iii) infiltration of water (iv) brake away of material under the action of traffic (v) local sub-grade failure or defects in consolidation (vi) lake of proper maintenance of the surface. Development, if neglected (a) progressive enlargement of the hole and (b) formation of additional potholes.

Remedy: Pot holes may be rectified by premix patching. Patching consists of the following operations: Step-1. Marking out the area to be repaired and trimming the sides vertically up to the defective depth in rectangular or square shape around the defects. Step-2.Remove the loose materials up to firm depth and then trim the bottom of the hole. Step-3.Painting the sides & bottom of the hole with a tack coat. Step-4 Backfilling the pot hole or the *patch repair work* with well graded premixed material. Step-5 Rolling or hand tamping and checking the profile with straight edge. Level kept 1cm above the surface for further compaction under traffic.







Maintenance of Shoulders: Shoulder is a portion between the edge of pavement and the edge of embankment formation, act as a (i) lateral support (ii) space for parking, overtaking, pedestrians, cyclists and bullock carts. Rain cuts should be made to remove accumulated water in a ditch at the junction of the pavement and shoulder

Maintenance of Slopes of Embankments: Rain cuts erode the embankment slopes up to the pavement edges and damage the pavement ultimately. Turfing is one of the easiest & most effective ways of maintaining slops. The slopes of embankments subjected to inundation and flooding are protected often with boulder pitching.

Drainage Maintenance: The quick and efficient removal of water prevents slips and landslides and road deterioration. Drainage arrangement such as catch water drains, cross-drainage structures, side drains and burried drains should be inspected before the monsoons and cleared of all obstructions.

Types of maintenance operations

(1) Routine repairs, including patching, earthwork, shoulder, drainage, road furniture, road signs, arboriculture.
(2) Periodical repairs, including renewal of surface at specified intervals.
(3) Special repairs, such as flood damage restoration, major painting of steel girders, etc.

Maintenance Management System (MMS) also known as Pavement Management System (PMS), is a computer package which facilitates maintenance planning and optimal allocation of resources. Its main elements are (i) a basic road data bank (ii) a pavement performance model (iii) selection of intervention levels and (iv) listing out priorities for maintenance (renewal and overlay) for a given budget.

Failure in Rigid Pavement

what are causes of failure of Rigid pavement.

What are the typical failure of rigid pavement? Discuss briefly.

2015, 2014, 2013, 2012, 2011, 2010

Write short note on: Mud Pumping.

2018, 2016

write down the causes of mud pumping and describe its maintenance operations with net sketches.

2018, 2017

Explain the term 'Stripping'

eds of Overlays: When the extent of deterioration is beyond the simple maintenance (patching and periodic renewals) solutions, the pavement needs an additional overlay. Strengthening with such an overlay will overcome the structural inadequacy caused by traffic that has used the pavement so far and will enable the strengthened pavement to withstand the expected traffic in the design period.

Importance of Skid-Resistance of Surface: One of the common causes of road accidents is skidding of fast-moving vehicles. If a vehicle skids, the driver loses control of the vehicle and the resulting accident is normally of a serious nature. With the driver towards better roads and speedier vehicles, skidding has to be reckoned as a major factor in the design of road surface, and particularly so, in areas of high rainfall and snow.

FAILURES IN RIGID (CEMENT CONCRETE) PAVEMENT

The failures are mainly due to two factors.

(I) Deficiency of pavement materials: due to (1) Soft aggregates (2) Poor joint construction (3) Poor joint filler and sealer material (4) Poor surface finish (5) Improper and insufficient curing.

(II) Structural inadequacy of the pavement system: due to (1) Inadequate pavement thickness (2) Inadequate sub-grade support and poor sub-grade soil (3) Incorrect spacing of joints.

Typical failure of rigid pavements:

Scaling of cement concrete: due to the deficiency in the mix or presence of some chemical impurities.

Shrinkage cracks: in longitudinal as well as in transverse direction due to shrinkage of concrete after curing.

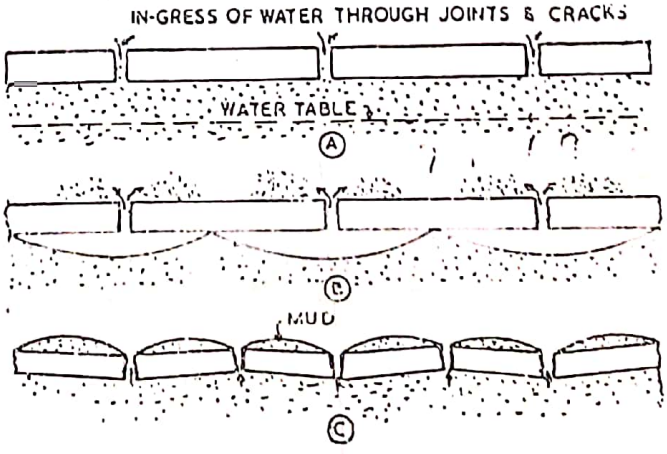
Warping cracks: due to improper joints, warping of slab developed excessive stress causes cracks.

2015, 14, 13, 12, 11, 10

Mud pumping: water may percolate into the soil sub-grade through defective joints & cracks and may soften it. Due to repeated load of traffic, soft soil settled and small initial spaces are developed under the slab. With further percolation of water, the softened sub-grade soil forms soil slurry, which starts ejecting out through joints. The process of ejecting out or forcing out the soil slurry, results in hollowing of underneath space and loss in sub-grade support. A stage is reached when slab gets cracked. The process of ejecting out the soil slurry through joints and cracks, under the action of wheel loads is known as mud pumping.
Once pavement starts pumping, the remedy for correcting it lies in providing the effective drainage. Mud jacking process consists of drilling number of holes 4 cm to 5 cm diameter 1.5 m to 3 m apart in the cement concrete slab. Grouting (1: 3.5) in such slabs is done under pressure through these holes using the compressor. The slabs are thus raised from below by the pressure grout, up to the desired level.

Structural weakness: cracks generally develop near edges & corners due to heaver wheel load than designed.
Slipperiness of surface: due to dropping of soil or grease or when it is thinly covered with moistened dust.

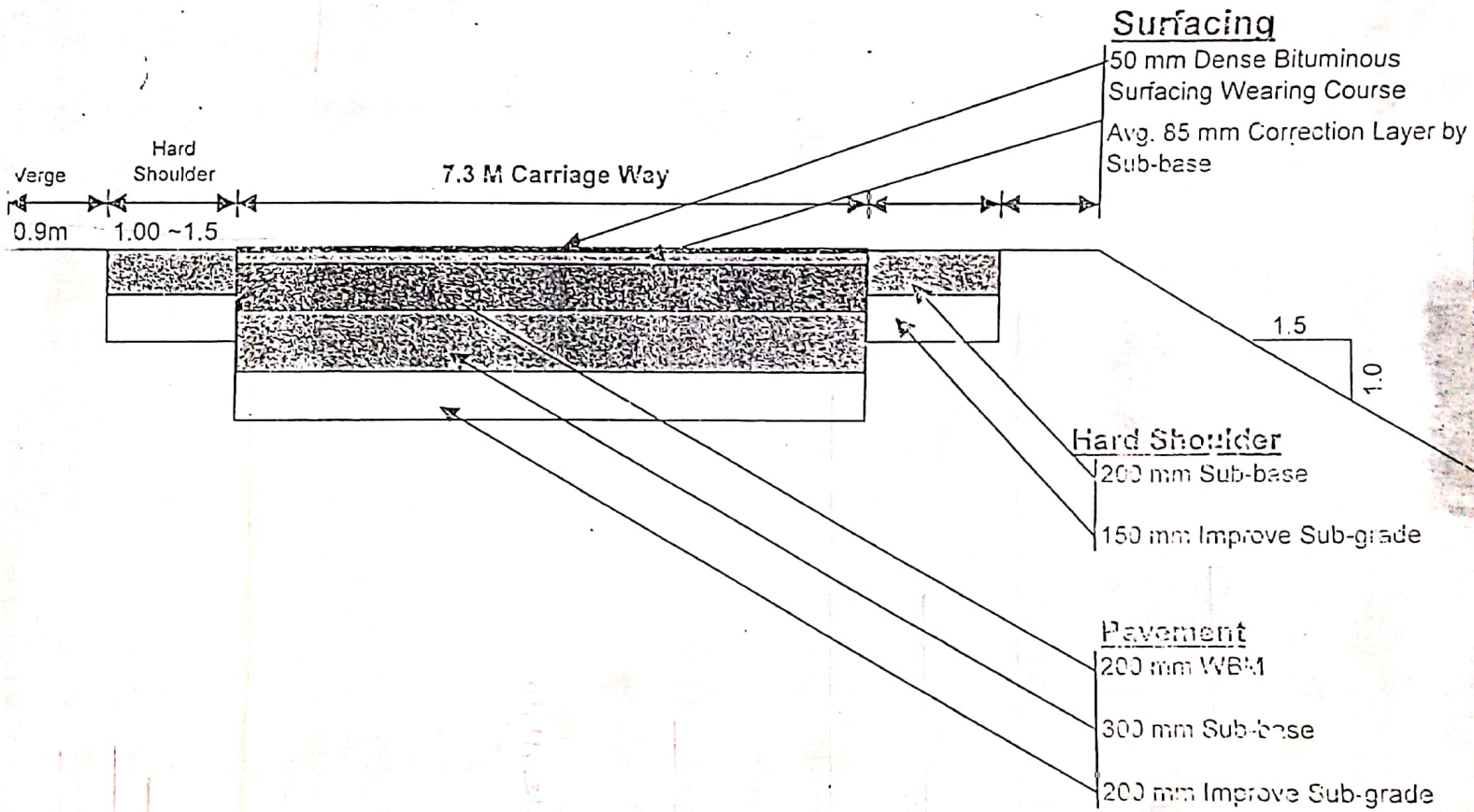
Maintenance of Joints: Fine cracks are not harmful but wide cracks allow surface water to infiltrate in side, then they should be attended immediately to avoid further damage to the pavement. Cracks should be cleaned of all dirt, sand or any other loose particles by sharp tool and air blowing by air blower. Filler & sealer should be intact



Mud-pumping.

C.T.

-SECTION OF RAJSHAHI CITY BY-PASS



(12)

CBR Test

2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011, 2010

Define CBR / (Short note)

It means California Bearing Ratio.

The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The CBR value is calculated from the following formula:

$$CBR = \frac{\text{unit load carried by sample at defined penetration level}}{\text{unit load carried by standard crushed stones at above penetration level}} \times 100$$

2018, 2017

write down the application of CBR value.

1. It is used in the design of flexible pavement.
2. It is used for classifying and evaluating the soil subgrade and base course materials.

2016, 2014

Why soaked CBR is considered for road design?.

In the rainy season, most of the time the soil gets soaked. As a result, the soil may expand or swelling can occur, which is the weakest condition of soil to prepare a subgrade for the pavement.

That's why the soaked CBR test is performed to know the load carrying capacity of soil at soaked condition.

2014

How soaked CBR is determined in the laboratory?

(i) 5 kg fine grained soil was mixed with water upto OMC.

(ii) The moist soil sample was compacted by adopting heay compaction.

(iii) The soil compacted in five equal layers with 56 blows of the 4.89 kg rammer for each layer to obtain a specimen of exactly 125 mm height.

(iv) The mould with compacted soil was inverted and placed in position over base plate.

(v) surcharge weights of 2.5 kg were placed over the perforated plate and then mould was placed in a water tank for soaking.

(vi) The dial gauge was placed on the top edge of the mould.

(vii) The initial dial gauge reading was recorded and the test was kept undisturbed in the water tank to allow soaking of the soil specimen for 96 hrs.

(viii) The final dial gauge reading was noted to measure expansion or swelling of the soil specimen due to soaking. The expansion ratio is calculated from the following formula:

$$\text{Expansion ratio}(\%) = \frac{d_f - d_i}{h} \times 100$$

Bituminous Mix Design

write should note on : Bituminous mix

Bituminous mix is a type of mix. in which the aggregates are bounded together by bituminous material. It consists of the following materials:

1. Coarse aggregate
2. Fine aggregate
3. Mineral Filler
4. Binder

What are the requirements of a good bituminous mix

A good bituminous mix should exhibit -

1. Stability.
2. Durability.
3. Workability.
4. Skid resistance.
5. Economy.

write down the characterestics of Bituminous mix.

(i) sufficient Bitumen content to coat aggregate particle thoroughly for proper bond.

(ii) sufficient stability to satisfy traffic requirement without distortion and displacement.

(iii) Sufficient voids to provide space for expansion of bitumen.

(iv) Sufficient workability so that may be placed in pavement with ease and efficiently.

2018, 2017, 2015, 2014

What is the role of "Bitumen" — in Bituminous Mix.

(i) It helps to lubricate all the aggregate particles.

(ii) It facilitates the compaction of the mixture to the required density.

(iii) It imparts cohesion to the mixture.

(iv) It increases the stability of the mix.

(v) It acts as binder and keeps the aggregate particles in the positions.

2018, 2017, 2015, 2014

What is the role of "coarse aggregate" in Bituminous Mix.

(i) It imparts stability to the mix by the internal friction with in the particles.

(ii) It imparts skid resistance.

(iii) The coarse aggregate resist the abrasive action of traffic and withstand wear.

what is the role of fine aggregates in Bituminous mix.

(i) They also add to the stability to the mix.

(ii) They fill the voids in the matrix of the coarse aggregate and help to secure dense gradation.

(iii) They facilitate greater load transfer from one aggregate to the other.

What is the role of mineral filler in Bituminous Mix.

(i) The filler tends to stiffen the asphaltic cement by getting finely dispersed it

(ii) The filler helps to lower the temperature susceptibility of the binder.

(iii) It acts as a final void-filling medium and complete the process of making the mixture as dense as possible.

2018, 2016, 2015, 2013, 2012, 2011, 2009

Write short note on: OBC

It means Optimum Bitumen Content.

It is defined as the maximum bitumen content at which, maximum unit weight, maximum marshall stability and 4% air voids is obtained.

It is calculated as:

$$OBC = \frac{\text{BC for max. unit weight} + \text{BC for max. stability} + \text{BC for 4\% air voids}}{3}$$

2018, 2015, 2013, 2012, 2011, 2009

Write short note on: VMA

It means voids in mineral aggregate.

It is defined as the percentage of void in the pavement plus percentage of volume occupied by the bitumen.

For well graded aggregate, VMA should be less than 20%.

It can be calculated as:

$$\%\,VMA = 100 - \frac{G_{mb} \times P_s}{G_{sb}}$$

2016, 2011

Write short note on : Marshall stability

It is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C

2009

Write short note on: Flow

The flow is the deformation of the marshall test specimen that undergoes during the loading, up to the maximum load, in 0.25 mm unit.

2012

Write short note on: Maximum specific gravity (Gmm)

It is the theoretical (maximum) specific gravity of paving moisture (no air voids). It is expressed by 'Gmm'.

It can be calculated as following:

$$G_{mm} = \frac{P_{mm}}{\frac{P_s}{G_{sb}} + \frac{P_b}{G_b}}$$

2014

Discuss the necessary steps for Bituminous mix design.

(i) selection of material and determination of specific gravity of materials.

(ii) selection of aggregate grading. (The Asphalt Institute, 1974)

(iii) Preparation of specimen.

(iv) Determination of bulk specific gravity.

(v) Make stability test for the specimen.

(vi) Determination of $\%V_a$, %VMA and %VFB.

(vii) selection of OBC from the obtained data.

(viii) check Marshall Design criteria.

The Asphait Institute engineers developed a structural thickness design method suitable for a variety of asphaltic pavements. The method is based on two assumed stress-strain conditions :

1. The wheel load, W, is transmitted to the pavement surface through the tire at a uniform vertical pressure P_w. The stresses are then spread through the pavement structure to produce a reduced maximum vertical stress P_z at the subgrade surface (Fig. 1).

2. The wheel load W causes the pavement structure to deflect, creating both compressive and tensile stresses in the pavement structure (Fig. 2). In developing the design procedure, A.I. engineers calculated induced horizontal tensile strains ϵ_t at the bottom of the asphalt layer and vertical compressive strains ϵ_c at the top of the subgrade (Fig. 3).

Internal friction = Frictional resistance + interlocking

Fig. 4 – A frame-work of rounded aggregate particles has considerably less stability due to less internal friction.

Fig. 5 – A frame-work of aggregate particles in a mix of crushed, graded aggregate has considerable stability due to high internal friction.

Fig.6 – A properly designed bituminous mix. The frame work of stones is held in position by binding action of the bitumen. Voids left in Fig. 5 between stone particles filled with bitumen leaving 3-8% air voids in Fig.6.

Fig. 7 – A bituminous mix having larger amount of bitumen than required. The interlocking effect of the stone particles is destroyed and individual stone particles will just be floating. This greatly reduces the traffic load carrying capacity of the road. This condition results in bleeding, shoving or rutting.

On the other hand, low bitumen content may develop brittle pavement which ravell [illegible] under the action of traffic.

19.13.4. Role of aggregates, filler and binder

The coarse aggregate fraction, which is the material retained of I.S. Sieve 2.36 mm performs the following functions :

1. It imparts stability to the mix, by the mechanical interlock between the particles and the frictional resistance developed at the interface between the particles (Fig. 19.17). The combination of interlocking and frictional resistance is termed as internal friction.
2. The rough texture of the protruding particles imparts skid resistance.

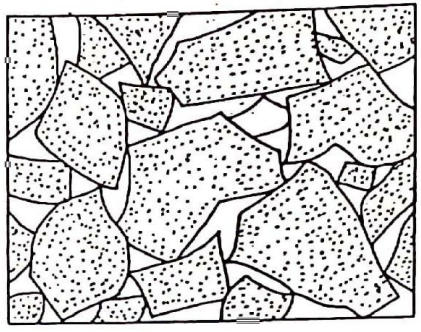


Fig. 19.17. Matrix of aggregates in asphaltic concrete.

3. The coarse aggregates resist the abrasive action of traffic and withstand wear.

The find aggregates, which are the particles passing through I.S. Sieve 2.36 mm and retained on 75 micron I.S. Sieve serve the following functions :

1. They also add to the stability of the mix by increasing the interlock. The frictional resistance is also increased because of the larger number of contact points.
2. They fill the voids in the matrix of the coarse aggregates and help to secure dense gradation.
3. They facilitate greater load transfer from one aggregate to the other in view of the increased number of contact points.

The mineral filler, which is an inert material passing through I.S. Sieve No. 600 micron, performs the following role :

1. The filler tends to stiffen the asphaltic cement by getting finely dispersed in it.
2. The filler helps to lower the temperature susceptibility of the binder and thus helps it to retain its hardness at higher temperatures.
3. It acts as a final void-filling medium and completes the process of making the mixture as dense as possible.

The asphaltic cement (binder) has the following functions :

1. It helps to lubricate all the aggregate particles and thus facilitates the compaction of the mixture to the required density.
2. It imparts cohesion to the mixture and thus increases its stability. Cohesion is the shearing resistance of the mixture and is an important factor determining the resistance to displacement of the paving mixture.
3. It acts as a binder and keeps the aggregate particles in the positions they occupied during the compaction.

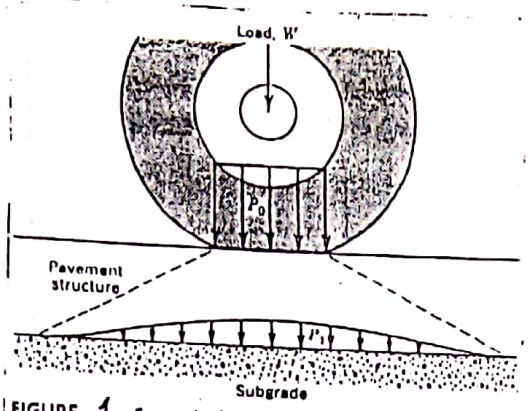


FIGURE 1. Spread of wheel load pressure through pavement structure. (Courtesy The Asphalt Institute.)

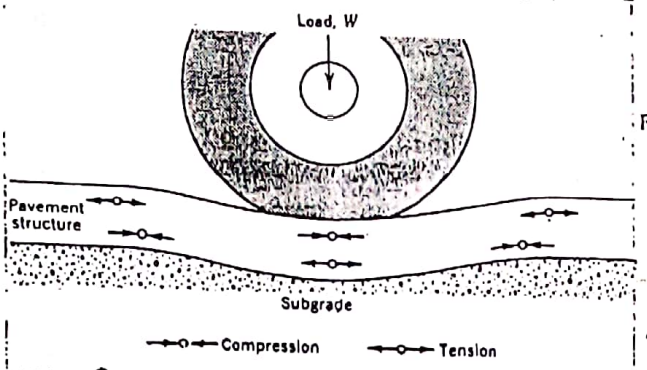


FIGURE 2. Pavement deflection results in tensile and compressive stresses in pavement structure. (Courtesy The Asphalt Institute.)

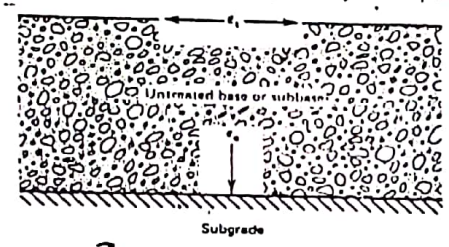


FIGURE 3. Strains in a flexible pavement.

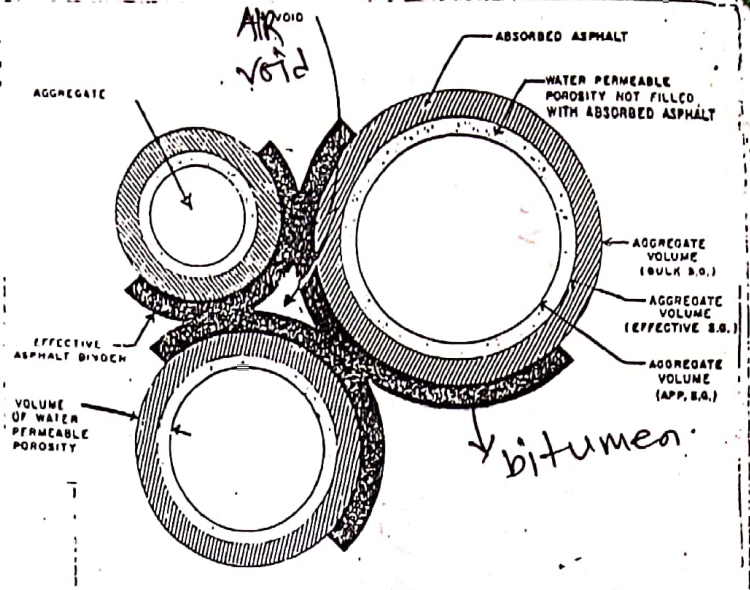
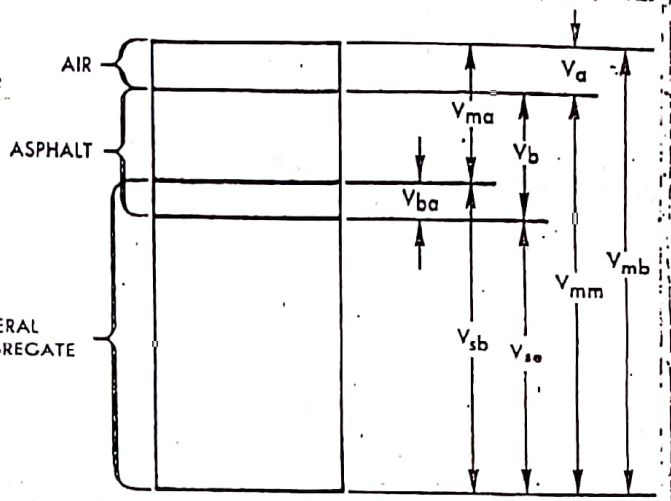


Figure 8 Illustrating VMA, air voids and effective asphalt content in compacted asphalt paving mixture



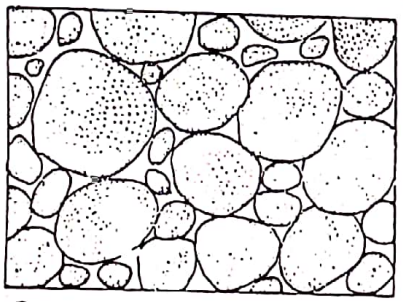


Fig-4 Rounded compacted aggregate

* Round- No inter-lock → No used

V_{ma} = Volume of voids in mineral aggregate
V_{mb} = Bulk volume of compacted mix
V_{mm} = Voidless volume of paving mix
V_a = Volume of air voids
V_b = Volume of asphalt
V_{ba} = Volume of absorbed asphalt
V_{sb} = Volume of mineral aggregate (by bulk specific gravity)
V_{se} = Volume of mineral aggregate (by effective specific gravity)

Figure 9 Representation of volumes in a compacted asphalt specimen

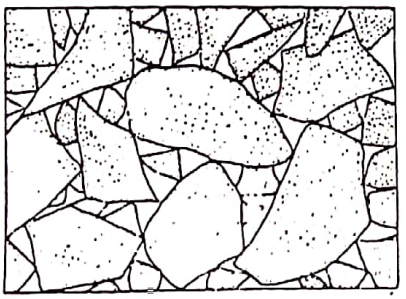


Fig. 5 Compacted aggregate angular. NO bitumen

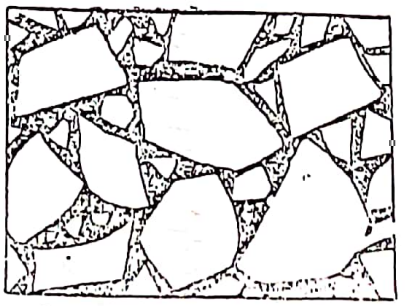


Fig. 6 Correct Proportion of bitumen in compacted road optimum.

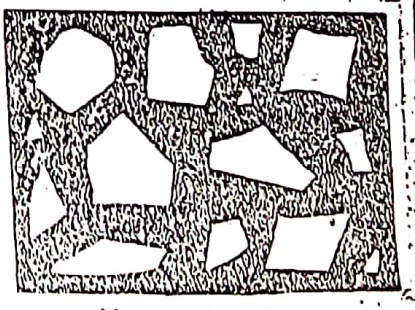


Fig. 7 Excess bitumen in pavement. ① No interelock. ② slipping.

Waterway Engineering

2012

Define waterway Transportation.

2018, 2015, 2012 2012

Write down the advantages of and disadvantages of waterway transportation.

2018, 2017

Explain the importance of inland water transportation in Bangladesh.

Define the following terms:

* Ocean
* sea
* coast ***
* Beach
* wind
* storm
* cyclone
* Hurricane

Write short note on:

* wave 2016
* Littoral Drift 2018, 2016, 2014, 2013, 2011
* Harbor. 2013, 2012
* port
* coastal structures. 2012
* Break waters 2018, 2015, 2014, 2012
* Jetties 2018, 2014, 2013, 2011, 2017
* Groin 2018
* DOCKS 2018, 2016, 2015, 2013, 2014, 2012
* Dry docks 2017
* Wet docks 2017

* Sea walls 2018, 2015, 2013, 2011

* Bulkheads 2011

* Revetments

2015, 2013, 2012
What are the requirments of a good harbor.

Write down different features of a harbor.

2018, 2013, 2012, 2011, 2017, 2016, 2015
Write the factors considered for the best location of a harbor.

2018, 2017, 2016, 2015
What are the requirements of a good port?

2016
With neat sketches, Discuss the functions of the coastal structures

Distinguish between -

* a breakwater and a jetty **

* Wave and Tide

* Harbor and Port ** 2011

2012

Water Transportation: Traffic transported or carried by means of water as river or ocean etc. Water transportation is most suitable for carriage of bulky and heavy commodities (goods) for long distances and for which time of transportation is not a critical factor. Two categories of water transportation are – 2015

(i) Inland water transportation: It is possible either in the form of river transportation or canal transportation. There are certain restrictions and special guidance is necessary.

(ii) Ocean water transportation: About 75% of international trade is carried out by this way i.e. by shipping. Ocean water transportation has no limitations and it possesses high flexibility. Transportation by this system is possible between ports on the sea routes.

2015,12

Advantages – (1) The cheapest (2) Possesses high load carrying capacity (3) Cheap driving power for working and needs minimum energy to haul a unit load through unit distance (4) Leads to overall development of commerce, industry & international trade (5) Assists and provides a power full means of defense of national security. — B.L Gupta.

2012

Disadvantages – (1) The speed is very low (2) Along particular routes only where water is available (3) Accidents occur due to ocean storms causing great loss of cargo (4) Loading and unloading operations are affected due to more tide range. (5) Waterfalls, mountainous rivers cause hindrance in water transportation.

OCEAN is big water mass and SEA is comparatively smaller water mass SHORE is line by the land skirting the sea. COAST is sea shore. BEACH is the sea shore with easy slope. The environment of the coast is harsh and corrosive. Water transportation facilities must be designed to withstand the various destructive biological, physico-chemical and mechanical action that are inherent to the coastal environment. The behavior of winds, waves and tides influence the design of dock, port and harbour structures to a great extent.

নাবিকদের-মাইল

WIND – is air in motion and specified by direction & speed. (1kont =1.852 km/hr. =1NM/hr.)

STORM- is atmospheric disturbance characterized by high wind velocity about 110 km/hr.

CYCLONE- when wind rotates round a center of minimum barometric pressure.

HURRICANE- is a tropical cyclone with wind spiraling inward and sustained surface wind velocities of 120 kmph or more.

WAVE – is uneven surface of water. The sea wave is the most power full force acting on harbor and barriers. It has a tremendous damaging power.
The impact of the waves on the sea shore structures creates the following effects:

(1) Direct horizontal force causing compression.
(2) Deflected upward vertical force tending shear.
(3) Deflected downward vertical force destructs the foundation.
(4) Suction due to return water after striking, disturbs the mounds of foundation.

TIDES – The periodic rise and fall of the sea water level is known as the phenomenon of tides.

2014,13,11

LITTORAL DRIFT- When the direction of the prevailing wind is not at right angles to the shore, the tangential component of the wind produces a current and waves parallel to the shore that strike the shore. These waves tend to stir up and move the lighter particles of sand in suspension. The process of movement and deposition of sand near the fore shore is known as littoral drift.

2013,12

Harbor is a sheltered area (partially enclosed area) of the sea where facilities for loading and unloading of cargo and passengers are provided. In harbor vessels are also built, repaired and launched. In time of storms vessels may also take refuge in harbor.

Harbors can be classified in three categories as follows:
1. Natural harbors (P-5.23) 2. Sami natural harbors (P-5.24) and 3. Artificial harbors (P-5.24) → B.L gupta

Requirements of a good harbor 2015,13,12

1. The ship channels should have sufficient depth for the draft of the visiting vessels.
2. The bottom of the harbor should provide secured anchorage to hold the ships.
3. To protect destructive wave action, the land masses or break water must be provided.
4. Entrance should be wide enough for shipping & narrow enough to restrict the wave energy.

Features of a harbor

1.Entrance channel 2. Approach channel 3. Berthing basin 4. Break water 5. Jetties 6. Docks 7. Slipways 8. Go downs 9. Sheds 10. Fire protection towers.

2013,12,11

Following factors play a great role in the selection of site for harbor. 1. Availability of cheap land and construction materials. 2. Natural protection form waves and winds. 3. Transport and communication facilities 4. Sufficient depth of water 5. Secure anchorage area 6. Availability of fresh water and electrical energy 7. Defence and strategic aspects 8. Favorable marine condition.

Port is a portion of a harbor having terminal facilities such as stores, landing of passengers and cargo etc.

Requirements of a good port 2015

1. It should be located centrally for the hinter land 2. It should get good tonnage 3. It should command extensive and valuable trade 4. It should afford to all ships in all season of the year 5. It should have good communication with rest of the country through rail and highway 6. The passage to open sea must have sufficient depth and width 7. The coast line land should be hard so that frequent repairs are not required.

2011

Harbor	Port
1. Harbor is a partially enclosed area of water that serves as a place of refuge for ships.	1. Port refers to a portion to a harbor that serves as a base for commercial activities.
2. It protects the waves & winds and control the erosion of beaches & coast lines.	2. It provides facilities for ships to obtain fuel, to repair and to transfer passengers and cargo.
3. Every port is a harbor.	3. Every harbor is not a port.

The coastal structures 12

1. Offshore structures (Break waters): constructed to lessen the wave height and velocity. ✗ Reduce
2. Structures at angle to shore (Jetties & Groins): constructed to control the littoral drift. ✗ সঞ্চালন প্রবাহ
3. Structures near shore line (Seawalls, Bulkheads & Revetments): constructed to protect the shore from the erosive forces of waves.

2015, 12, 14

Breakwaters are the structures constructed to enclose the harbors to protect them from the effect of wind generated waves by reflecting and dissipating their force or energy. The main function of a breakwater is to breaks the mornentum of water by means of wave breakers. Sometimes the inner side of break water is constructed as a quay for cargo handling. Break waters with different methods of protection are shown in Figure. 5.8 to 5.10.

2014, 2013

Jetties are structures in the form of piled protections or open type. They are built from the shore to the deep water. In the sea, jetties are provided at places where entrance is affected by littoral drift or the sea is shallow for a long distance. The jetties extended from the shore to the deep sea to receive the ship. In case of rivers, the jetties works like groins. They deflect the water current away from the river bank and prevent the scouring action near the bank. A typical RCC cylinder pier jetty is shown in Figure 6.3 (vazirani-196).

Groin is a structure that is constructed approximately perpendicular to the shore in order to retard erosion of an existing beach or to build up the beach by trapping littoral drift.

2015, 13, 14, 12

Docks are the enclosed areas required for berthing (space for loading and unloading) the ships to keep them afloat at a uniform level during tides to facilitate loading, unloading & repairs. Docks required for berthing of ships or vessels to facilitate the loading and unloading of passengers and cargoes are called **wet docks** and those used for repairs of ships are known as **dry docks**.

Slipway technique is used for repairs as well as for building of vessels. It consists of a inclined path of stone laid on a firm ground. On this inclined path a series of rails are fixed. The rails run up from a sufficient depth of water to the required height above the high water level.

2015, 13, 11

Seawalls are the structures constructed parallel to the shore line to develop a demarcating line or dividing line between land area. The aim of construction of these structures is to stop further erosion of the land ward line. Fig. 14.2

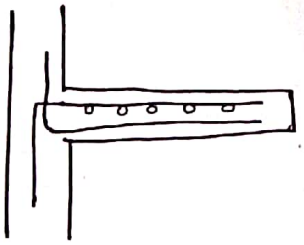
Coastal Structure 2011

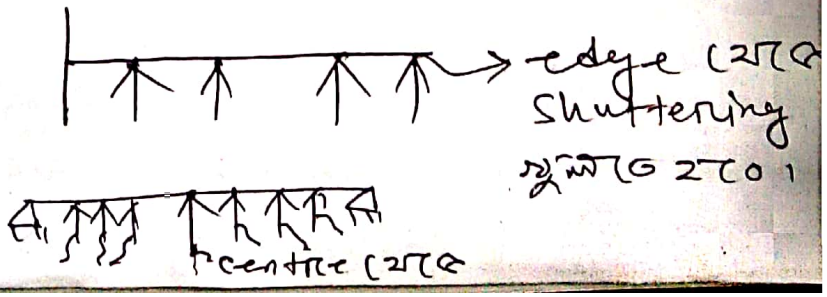
Bulkheads are constructed along the shore line to prevent encroachment of the sea by direct wave action. They prevent sliding of land and also provide protection from waves. Purpose is the same as that of sea wall but are adopted where wave action is less severe. Figure 14.3

Revetments are protective cover or pavement supported by an earth bank. It protects the land from wave erosion. It may be constructed of stone or bituminous or cement concrete. Figure 14.4 shows a concrete block revetment. Generally stone revetment is preferred.

Distinguish between a breakwater and a jetty

Breakwaters are massive structures built generally parallel to the shore line to protect a shore line to protect a shore area or to develop an artificial harbor. A jetty is a structure built roughly perpendicular to the shore extending some distance seaward for the purpose of maintaining an entrance channel and protecting it from waves and undesirable currents. Structurally, breakwaters and jetties are similar; however, the design standards for jetties may be slightly lower than are those for breakwaters. This results from the fact that juttles are not subject to direct wave attack to as great an extend as are breakwaters.





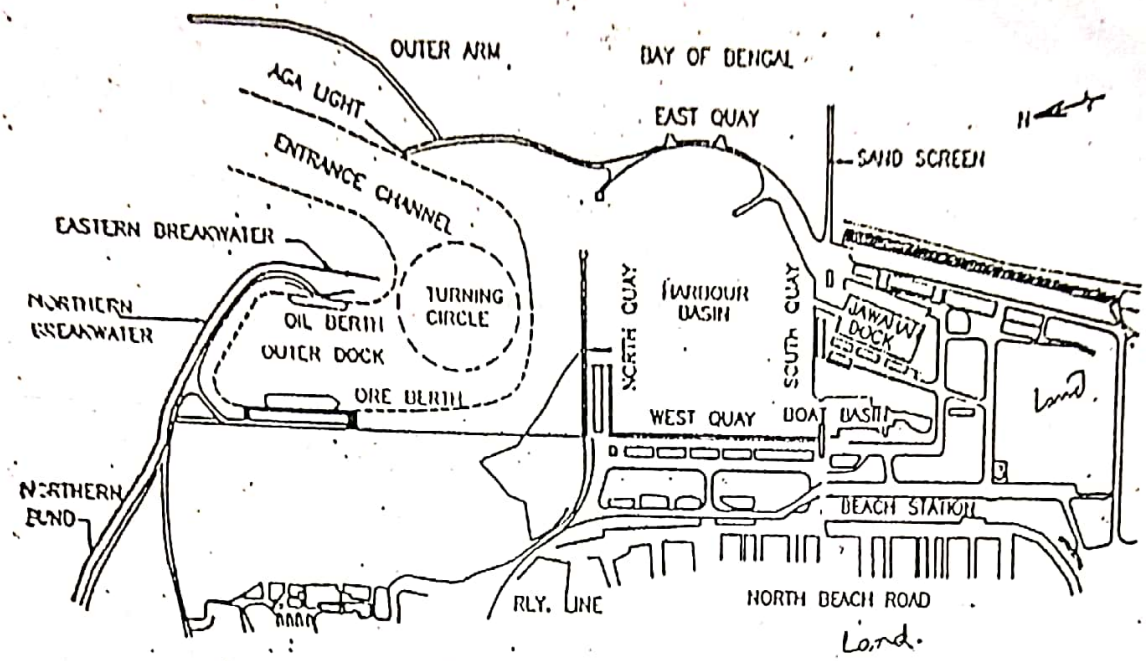


Fig. 4.11. Madras harbour with outer dock

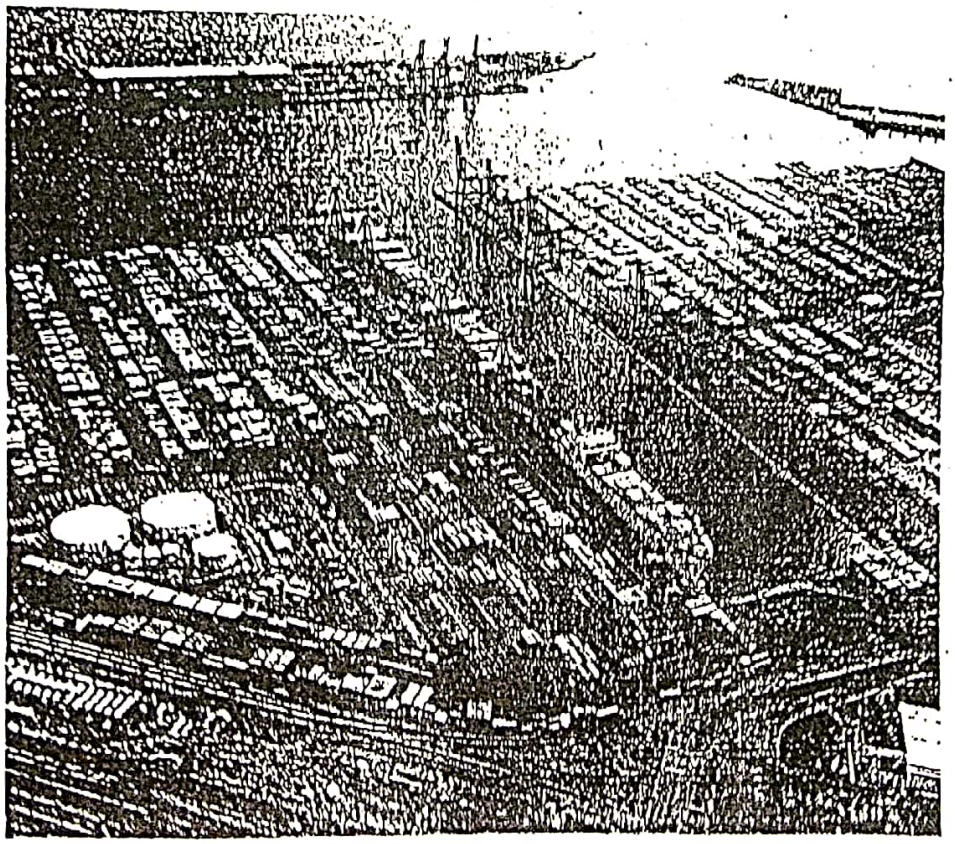


Fig. 22-12. A containership terminal. (Courtesy The Port of Long Beach.)

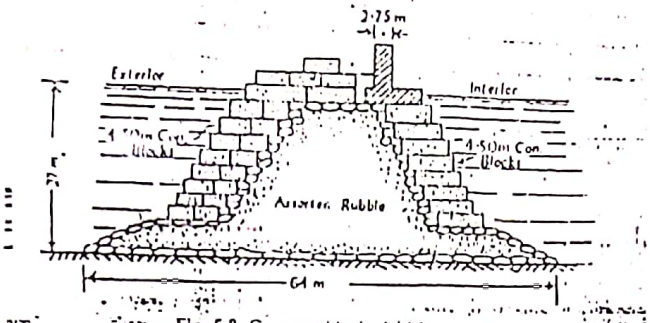


Fig. 5.8. Concrete blocks laid in regular courses

Fig. 5.9. Top protection by granite paving

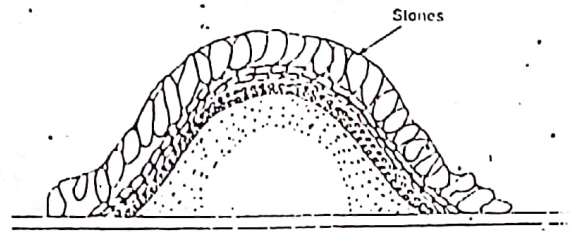


Fig. 5.10. Shows a typical rubble mounted break water

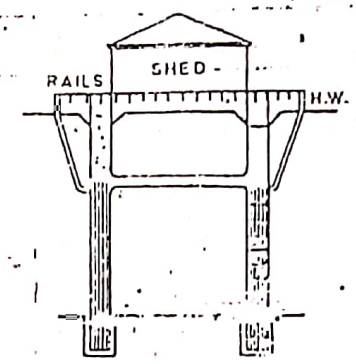


Fig. 6.3. Typical RCC Cylinder Pier Jetty.

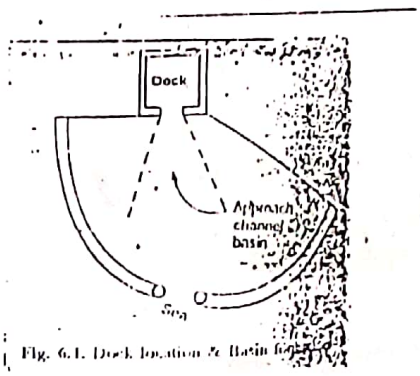


Fig. 6.1. Dock location & Basin

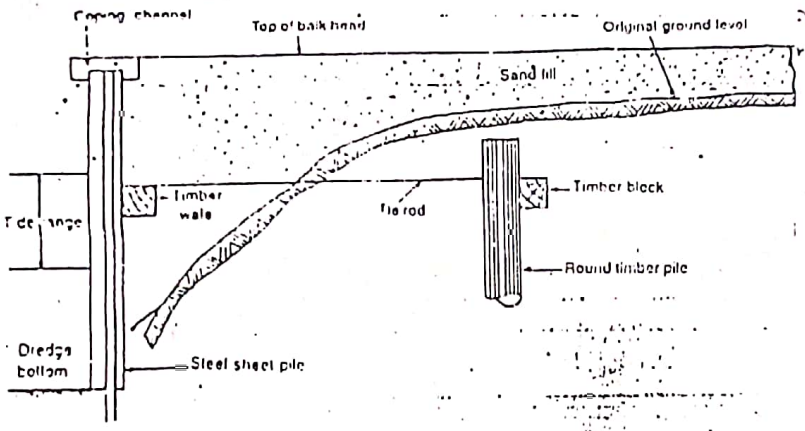


Fig. 14.3. Steel sheet pile bulk head

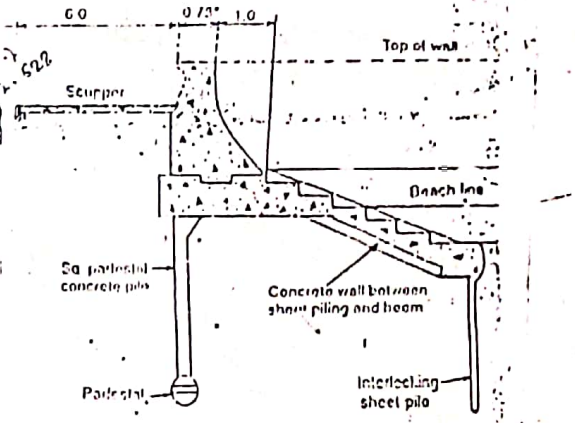


Fig. 14.2. Concrete stepped and curved face sea wall

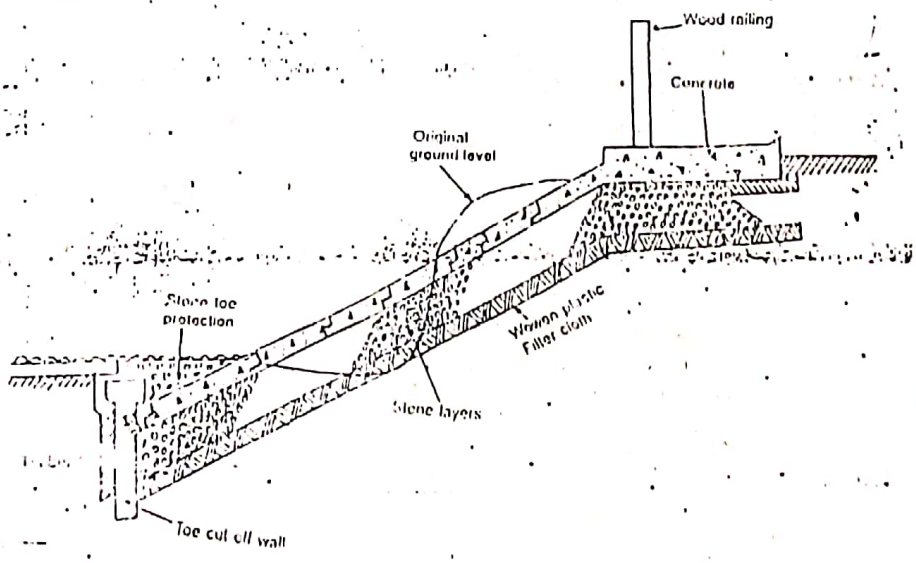


Fig. 14.4. Integrated concrete block revetment

ESWL & EWLF

Determine the value of ESWL for a dual wheel assemble carrying 2000 Kg for each wheel, for pavement thickness of 12, 18 and 24 cm. c/c distance between tyres is. 25 cm and clear distance between tyres is 10 cm.

Solution:

Here, $P = 2000$ Kg

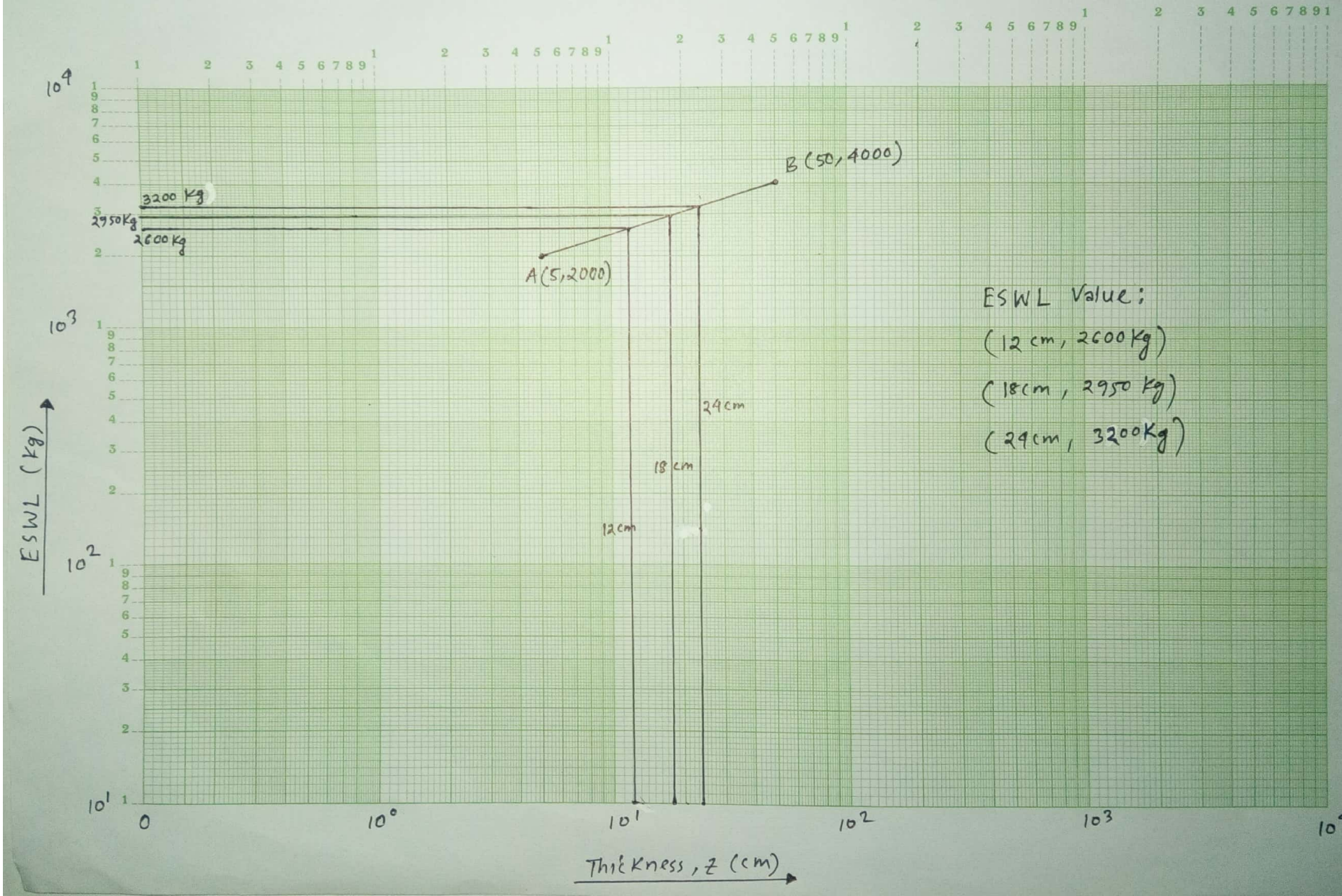
$s = 25$ cm

$d = 10$ cm

point A $= (d/2, P) = (5, 2000)$

point B $= (2s, 2P) = (50, 4000)$

Plot A and B in log-log graph paper:



2017

Using following daily traffic count data, determine design repetition for 25 years for various wheel load equivalent to 2268 kg wheel loads. Roads is two lane and traffic counted in a day was 10000.

Wheel load (kg)	2268	2722	3175	4082	4536	4993	other minor type
% of total traffic volume	25	15	11	15	9	5	rest percentage

Solution:

$* (5) = (1) \times \frac{(2)}{100} \times (3) \times (4) \times 365$

	(1)	(2)	(3)	(4)	
Wheel load (kg)	Average Daily Traffic	% of total traffic volume	No of years	EWLF	Design repetition equivalent to 2268 kg
2268	10000	25	25	1	22.8125×10^6
2722	10000	15	25	2	27.375×10^6
3175	10000	11	25	4	40.15×10^6
4082	10000	15	25	16	219×10^6
4536	10000	9	25	32	262.8×10^6
4993	10000	5	25	64	292×10^6
				Total	864.1375×10^6

∴ Total estimated repetitions (both direction) $= 864.1375 \times 10^6$

∴ Design repetition equivalent to 2268 kg wheel load per lane $= \frac{864.1375 \times 10^6}{2} = 43068750$

(Ans.)

Design of Flexible Pavement

田 IRC Standard Axles Method:

Design a flexible pavement with the following avaiable data:

(a) CBR (with respect to standard proctor)

Subgrade = 2 % at 95% compaction

(b) Field Data:

(i) No. of commercial vehicles per day (in both direction) = 100

(ii) Annual growth rate of commercial traffic = 8%

(iii) Design life of the pavement = 10 years.

(iv) The terrain is plain, pavement with thin bituminous surfacing.

F = 2.25 (সূত্রমতে পাওয়া গেল)/ chart থেকে পাওয়া

Solution:

Projected Traffic at the end of the design life of the pavement,

$$N_s = \frac{365 \times A[(1+r)^N - 1]}{r} \times F$$

Given, A = 100 cv/day

r = 8% = 0.08

N = 10 year

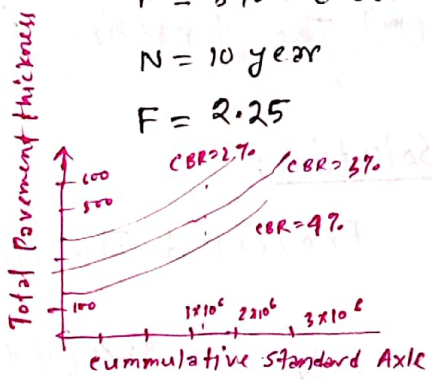
F = 2.25

$$= \frac{365 \times 100 \times [(1+0.08)^{10} - 1]}{0.08} \times 2.25$$

$$= 1189708.943 \text{ Nos.}$$

$$\simeq 1.19 \times 10^6 = 1.19 \text{ Millions}$$

(Cummulative No. of Axle in Design life)



Using Pavement thickness Design chart, we obtain,

The total pavement thickness = 680 mm

For Cummulative standard axle (0.5 – 2 Million), Table

Surfacing, X = 20 mm

Base, Y = 225 mm

Sub Base, Z = (680 − 20 − 225) = 435 mm

IRC Standard Axles Method

TABLE 4.3 STRUCTURAL SECTIONS

Cumulated Standard axles	Minimum thickness of component layers compacted thickness (mm)		
	Surfacing (X)	Base (Y)	Sub-base(Z)
0.5 M	20 mm PC/2-Coat SD	150	(T-150) Minimum thickness 100 mm on subgrades of CBR less than 20%
0.5-2 M	20 mm PC/MS	225	(T-225) Minimum thickness 150 mm on subgrades of CBR less than 20%
2-5 M	20 mm PC//MS/SDC + 50 mm/75 mm BM	250	(T-300/325) Minimum thickness 150 mm on subgrades of CBR less than 30%
5-10 M	25 mm SDC/AC + 60 to 80 mm DBM	250	(T-335 to 355) Minimum thickness 150 mm on subgrades of CBR less than 30%
10-15 M	40 mm AC + 65 to 80 mm DBM	250	(T-355 to 370) Minimum thickness 150 mm on subgrades of CBR less than 30%
15-20 M	40 mm AC + 80 to 100 mm DBM	250	(T-370 to 390) Minimum thickness 150 mm on subgrades of CBR less than 30%
20-30 M	40 mm AC + 80 to 115 mm DBM	250	(T-390 to 405) Minimum thickness 150 mm on subgrades of CBR less than 30%

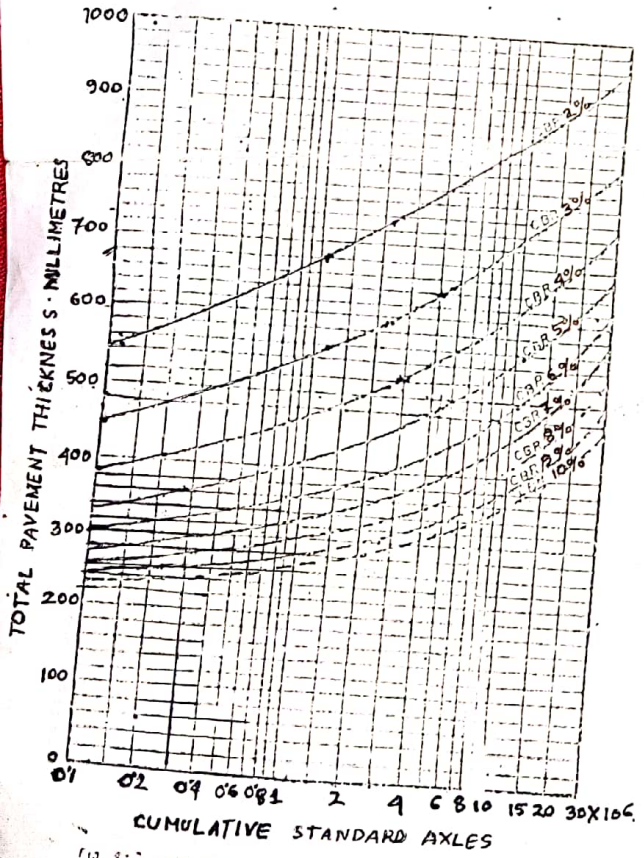


Fig. 4.1 : Structural thickness design chart
1. Read total & pavement thickness from continuous curves
2. Use dotted curves for crushed stone sub-base thickness

Fig. Pavement Thickness Design Chart

TABLE 4.2 INDICATIVE VDF VALUES

Vehicle Damage Factor

Initial traffic intensity in terms of number of commercial vehicles/day	Terrain	VDF values (standard axles of 8.16 tonnes per commercial vehicle)		
		Unsurfaced	Thin bituminous surfacing	Thick bituminous surfacing
(#) Less than 150	Hilly	0.5	0.75	
	Rolling	1.5	1.75	
	Plain	2.0	2.5	
150-1500	Hilly		1.0	1.25
	Rolling		2.0	2.25
	Plain		2.5	2.75
More than 1500	Hilly		1.25	1.5
	Rolling		2.25	2.5
	Plain		2.75	3.0

Where sufficient information is not available, the tentative indicative values of vehicle damage factor as given in Table 4.2 may be used. These may be judiciously modified to any special conditions with regard to traffic mix, type of transportation, etc. The validity of the value chosen may be checked after the pavement has been put to use, so that the warranted corrective steps can be undertaken.

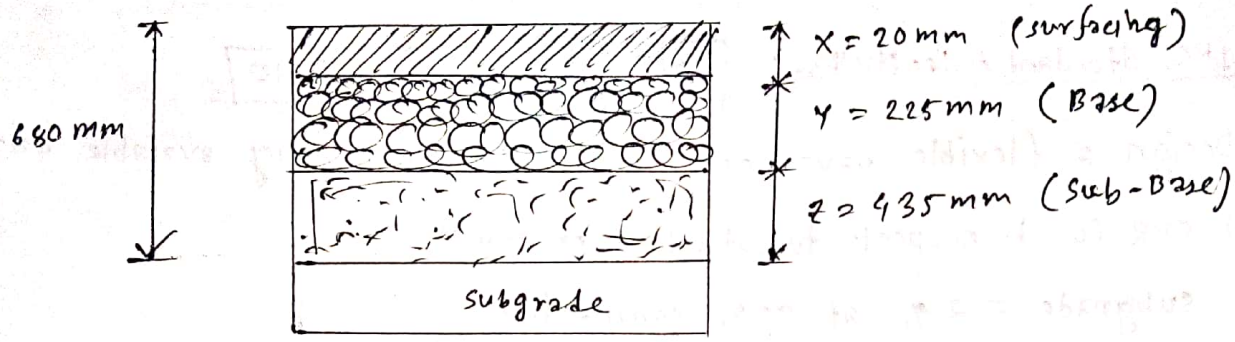


Fig. Proposed Thickness of pavement Layer

Design a flexible pavement with the following available data:

(a) CBR (with respect to standard proctor) = 1% at 95% compaction.

(b) Field Data:

(i) No. of commercial vehicle per day (in both direction) = 300

(ii) Annual growth rate of commercial traffic = 10%

(iii) Design life of the pavement = 12 years.

(iv) The terrain is hilly, pavement with thick Bituminous surfacing.

F = 1.25 (chart)

Solution:

Projected Traffic at the end of the design life of pavement,

$$N = \frac{365 \times A[(1+r)^N - 1]}{r} \times F$$

$$= \frac{365 \times 300 \times [(1+0.10)^{12} - 1]}{0.10} \times 1.25$$

$$= 29269738.41$$

$$\simeq 2.93 \times 10^6 = 2.93 \text{ Millions.}$$

(Cummulate No. of standard Axles in design life

using pavement thickness design chart,

the total thickness of the pavement = 525 mm

For cummulative standard axle (2-5 million),

Surfacing, X = 50 mm

Base, Y = 250 mm.

∴ sub-Base, Z = (525 − 250 − 50) = 225 mm

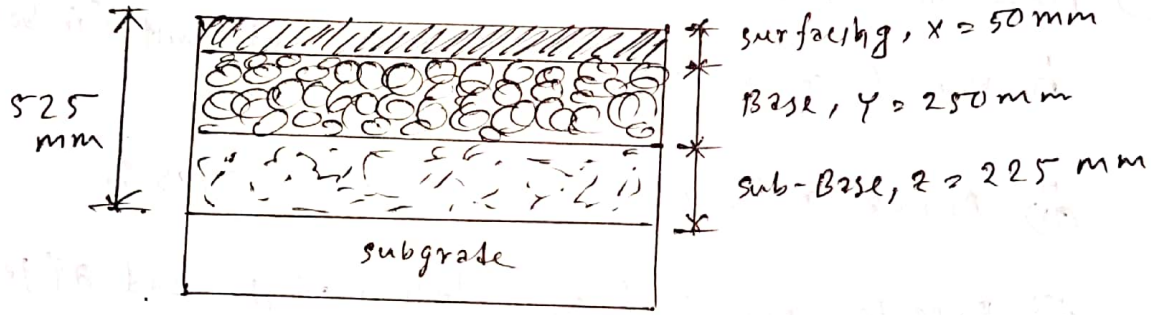


Fig. Proposed Thickness of pavement Layer.

IRC CBR Method:

Design a flexible pavement with the following available data:

(a) CBR (with respect to standard proctor):

(i) subgrade = 3% at 95% compaction

(ii) Improved sub grade = 8% at 98% compaction

(iii) sub-base = 30% at 100% compaction.

(iv) Base = 60% at 100% compaction.

(b) Field and other data:

(i) No. of commercial vehicles as per last count (in both direction) = 30

(ii) Annual rate of traffic increase = 7.5%

(iii) Expected period of completation of the road after last count = 2 years.

(iv) Design life of the pavement = 10 years.

Solution:

Projected traffic at the end of the design life of pavement,

$A = P(1+r)^{n+N}$

$= 30 \times (1+0.075)^{2+10}$

$= 71.45 \simeq 72$ Nos. CV/day in both direction.

Given, $P = 30$

$r = 7.5\% = 0.075$

$n = 2$ years

$N = 10$ years.

In case of Double lane road, this figure should be adopted.

(In case of single lane load, A = (2×72) = 144 Nos. CV/Day)

* Problem – এ Single lane নাকি Double lane উল্লেখ থাকবে।

Using Table, (45–150 CV/day) ⟶ Class – C

The traffic classification = C

Using CBR curve (Adopted by IRC)-

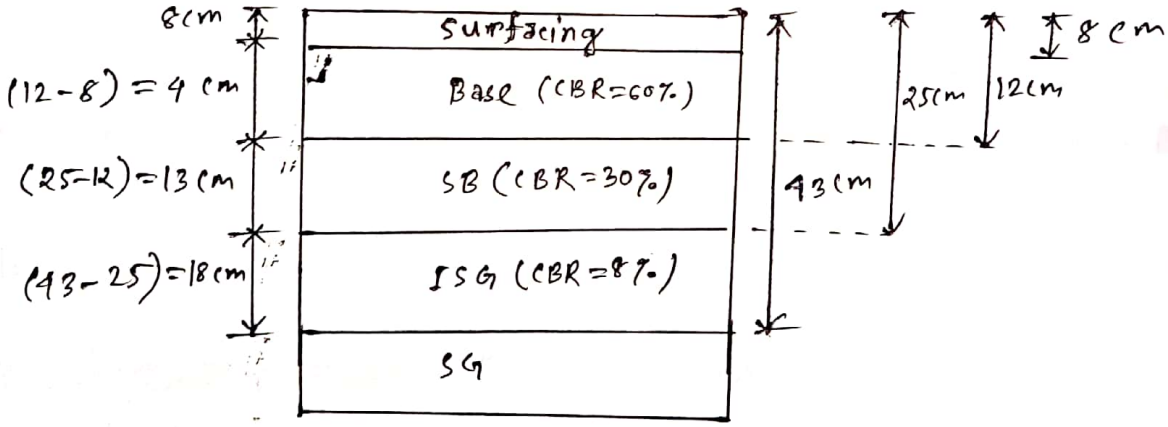
the following depth is obtained:

Depth above subgrade (CBR = 3%) = 43 cm

Depth above Improved subgrade (CBR = 8%) = 25 cm

Depth above sub base (CBR = 30%) = 12 cm

Depth above Base (CBR = 60%) = 8 cm.



(* Minimum surfacing = 2.5 cm. এটা structural portion হিসেবে কাজ করে না অর্থাৎ wheel load carry করে না)

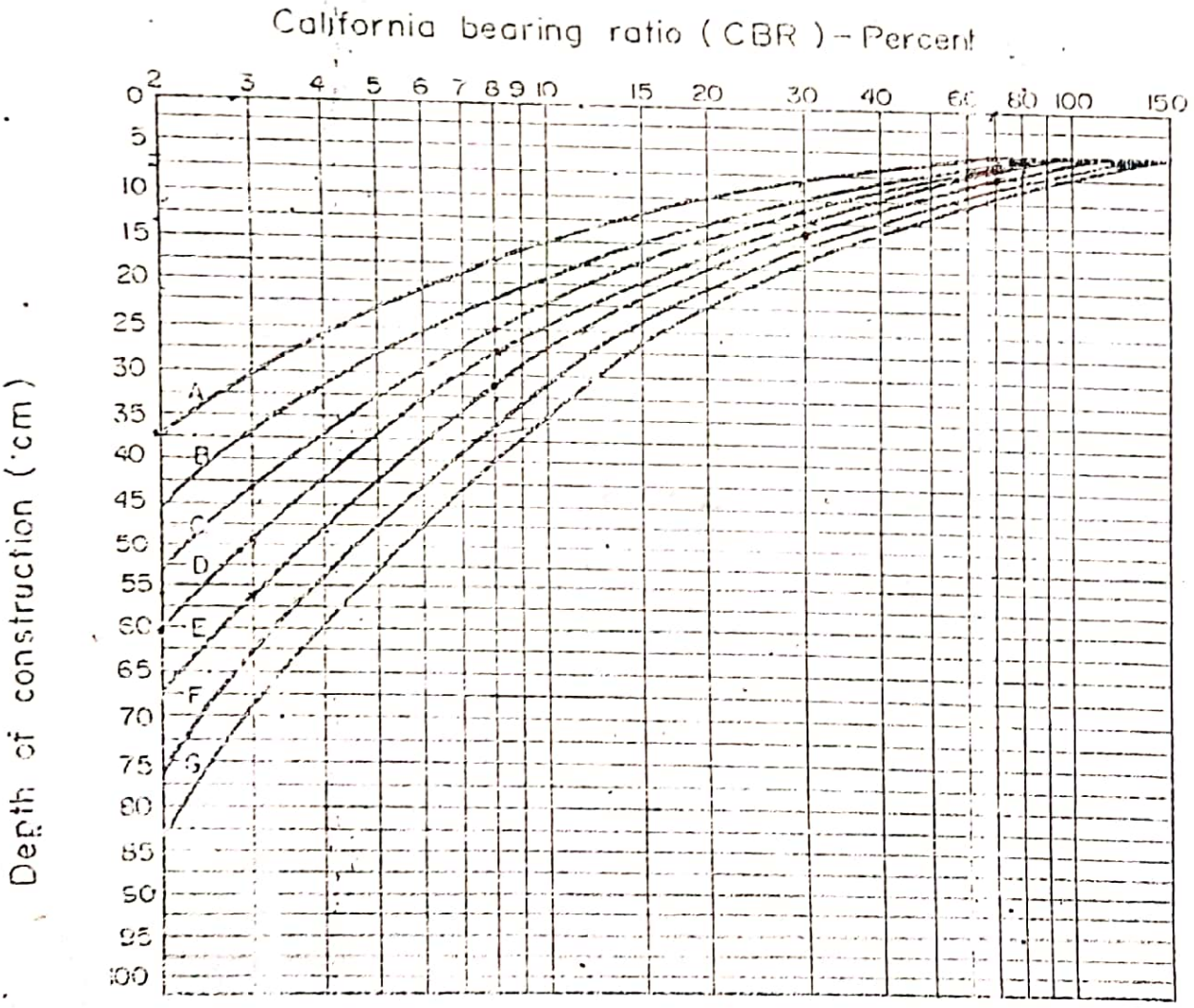
* Surfacing এর thickness > 5 cm হলে, structural portion হিসেবে কাজ করে।

* surfacing এর thickness < 5 cm হলে, structural portion হিসেবে কাজ করে না।

CBR IRC Method

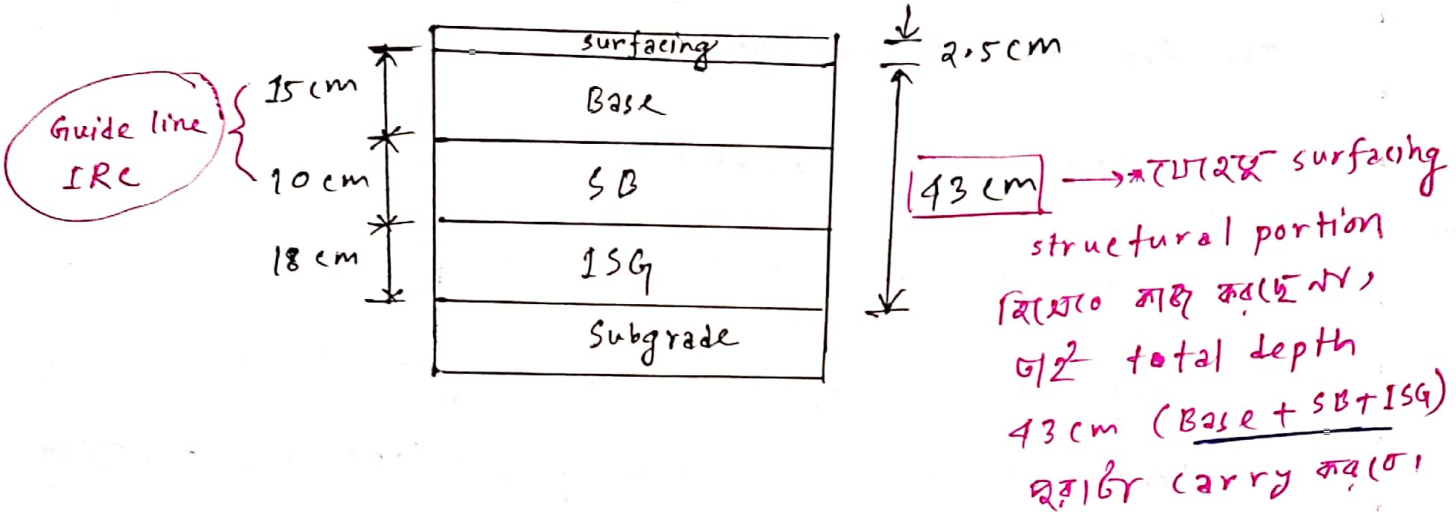
TABLE 4.3

Traffic Classification.	
Traffic	CBR Design Curve Applicable
0-15	A
15-45	B
45-150	C
150-450	D
450-1500	E
1500-4500	F
Exceeding 4500	G



CBR Curve for Flexible Pavement Design, as adopted by IRC.

if we want to provide surfacing as 2.5 cm then other layers may be adjusted as:



যদি Question-এ surfacing এর thickness যেভাবে থাকে তারপর যেটা যেমন থাকবে ওটাই use করতে হবে।

Guide: (IRC)	Minimum Base thickness	Minimum Sub-Base thickness
* upto 150 CV/Day	— 150 mm	— 100 mm
(150 – 450) CV/Day	— 225 mm	— 150 mm
(450 – 1500) CV/Day	— 250 mm	— 150 mm

Flexible Pavement Design

2017, 2013, 2011

Calculate the total thickness of flexible pavement by IRC Standard Axles method and IRC CBR method using the data:
(i) subgrade CBR = 3% (ii) CV/Day = 300 (both direction) (iii) Annual growth rate = 7% (iv) Design life = 10 years (including construction period) and (v) Terrain is plain; Pavement is thick bituminous surfacing.

Solution: (By IRC Standard Axles Method)

Projected Traffic at the end of the design life of the pavement,

$$N_s = \frac{365 \times A\left[(1+r)^N - 1\right]}{r} \times F$$

$$= \frac{365 \times 300 \times \left[(1+0.07)^{10} - 1\right]}{0.07} \times \underbrace{2.75}_{\text{(Chart)}}$$

Terrain – plain & CV/Day = 300
B. surfacing – Thick

$$= 4160477.9 \text{ Nos.}$$

$$\simeq 4.2 \times 10^6 \text{ Nos.} = 4.2 \text{ Millions standard Axles.}$$

Using Design chart, we obtain,
The total thickness of pavement = 640 mm

For cummulative standard axle (2.0 – 5.0 million),

Sarfacing, X = 50 mm
Base, Y = 250 mm
> Table

∴ Sub-base, Z = (640 – 50 – 250) = 340 mm

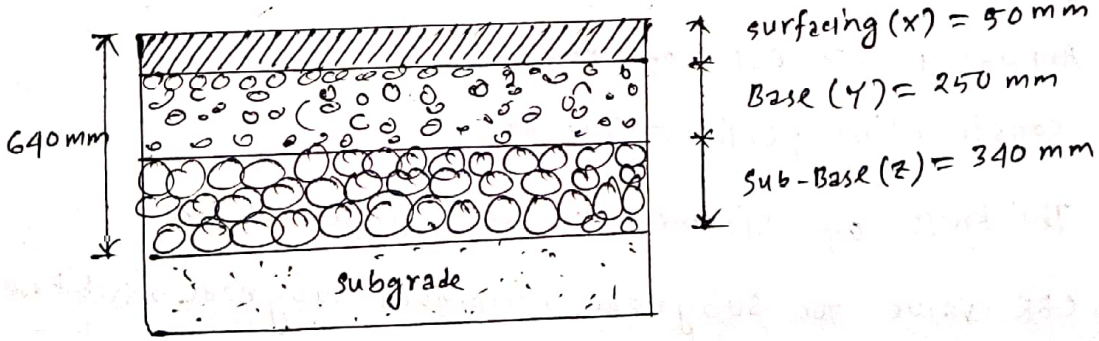


Fig. Proposed pavement thickness.

(By IRC CBR method)

Projected traffic at the end of design life,

$$A = P(1+r)^{n+N}$$

$$= 300 \times (1+0.07)^{10}$$

$$= 590.15 \text{ Nos}$$

$\simeq$ 591 cv/Day (both direction)

considering double lane road,

The traffic classification = E (using Table)

using CBR value,

Depth above subgrade (CBR = 3%) = 56 cm

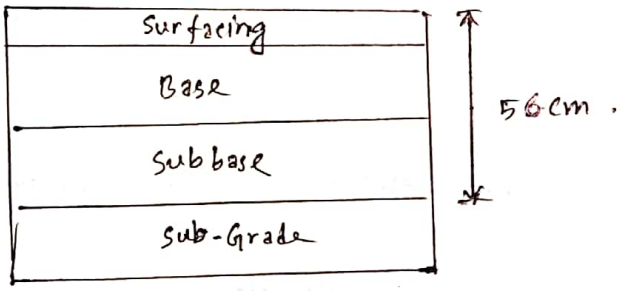


Fig. Proposed Pavement thickness.

2016

Design a flexible pavement for single lane two way from the following data:

(i) present ADT = 300 cv/day (both direction)

(ii) Annual growth rate of traffic = 7%

(iii) construction period = 3 years.

(iv) Thickness of Bitumen surface course = 4 cm

(v) CBR value for subgrade, improved subgrade, sub base and base course are 3%, 10%, 20% and 95% respectively.

(vi) Design period = 10 years.

Solution: projected traffic at the end of the design life,

$$A = P(1+r)^{n+N}$$

$$= 300 \times (1+0.07)^{3+10}$$

$$= 722.95 \text{ Nos.}$$

$$\simeq 723 \text{ cv/day (both direction)}$$

For single lane road, $A = (2 \times 723) = 1446$ cv/day

using table, the traffic classification = E

using IRC curve, the following depths are obtained,

Above subgrade = 56 cm

Above Improved subgrade = 27 cm

Above sub-base = 18 cm

Above Base = 7 cm

But, we have to provide the surface thickness of 4 cm.

Thus, the others layer have to be adjusted as follows;

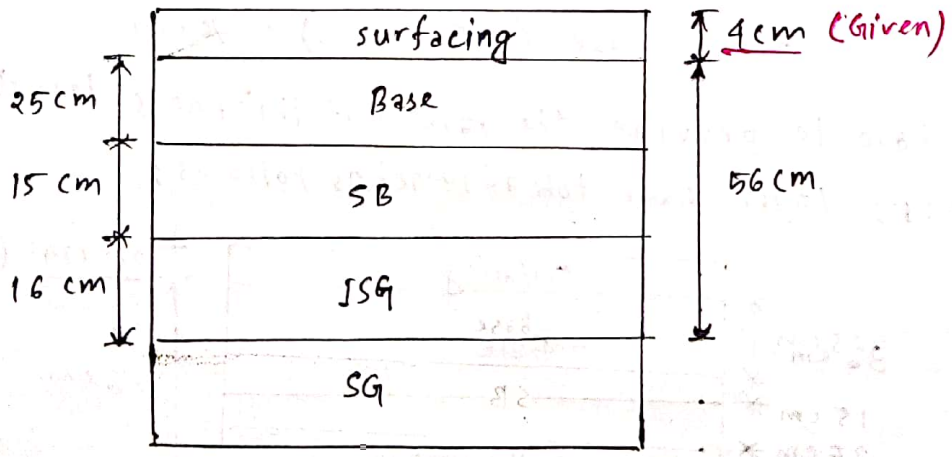


Fig. Proposed total thickness of pavement layer.

2015

Design a flexible pavement from the following data:

(i) present ADT = 500 cv/day (both direction) (ii) r = 6%.
(iii) Design life = 10 years (iv) Bituminous surfacing < 5 cm
(v) subgrade CBR = 3%, (vi) Sub-base CBR = 20%. (vii) Base CBR = 95%.
(viii) construction period = 2 years.

Solution:

Projected traffic at the end of the design life,

$$A = P(1+r)^{n+N}$$

$$= 500 \times (1+0.06)^{2+10}$$

$$= 1006.1 \text{ Nos.}$$

$$\simeq 1007 \text{ cv/day (both direction)}$$

considering the double-lane road, (using Table),

The traffic classification = E

using CBR value,

Depth above subgrade (CBR = 3%) = 56 cm

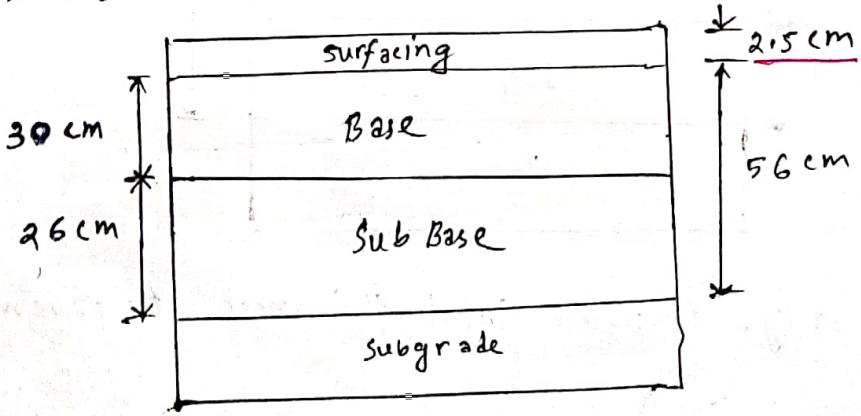
~~above improved subgrade (CBR = 10%) = 27 cm~~

above sub base (CBR = 20%) = 18 cm

above base (CBR = 95%) = 7 cm

But we have to provide the pavement thickness less than 5 cm.

Thus, others layers have tobe adjusted as follows:



(less than 5 cm এর কম 2.5 cm দিব)

2014, 2012

Design the flexible pavement components by IRC CBR method for 10 years from the following data:

(i) subgrade CBR = 3% (ii) sub-base CBR = 20% (iii) Base course CBR = 95%
(iv) Minimum thickness of the bituminous surfacing = 5cm, (v) n = 3yrs
(vi) Annual growth rate = 7% (vii) Present ADT = 400.

Solution:

Projected traffic at the end of the design life,

$$A = P(1+r)^{n+N}$$
$$= 400 \times (1+0.07)^{3+10}$$
$$= 963.94 \text{ Nos.}$$
$$= 964 \text{ cv/day. (both direction)}$$

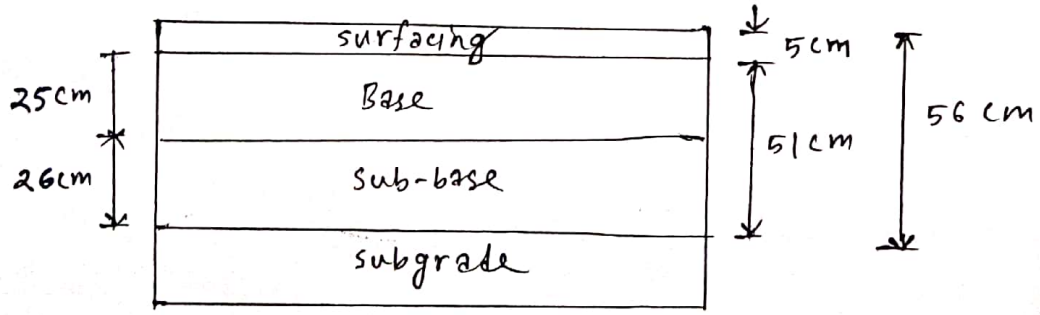
Considering the double lane road,

using table, the traffic classification = E

using CBR value,

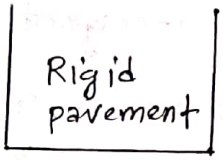
Depth above subgrade (CBR = 3%) = 56 cm
above sub base (CBR = 20%) = 18 cm
above base (CBR = 95%) = 7 cm.

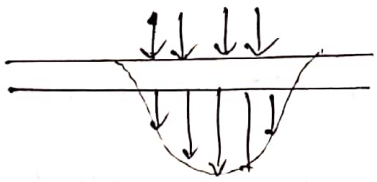
But we have to provide the pavement thickness of 5 cm.
Thus, other layers have tobe adjusted as follows:



Design of Rigid Pavement

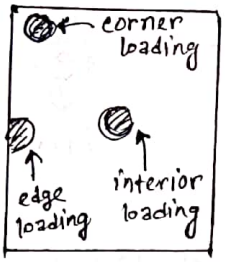
Westergard's Formula:

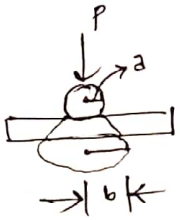




Rigid Pavement

Flexible Pavement





Interior wheel stress,

$$s_i = 0.31625 \frac{P}{h^2}\left[4 \log_{10}\left(\frac{l}{b}\right) + 1.0693\right]$$

Edge wheel stress,

$$s_e = 0.57185 \frac{P}{h^2}\left[4 \log_{10}\left(\frac{l}{b}\right) + 0.3593\right]$$

Corner wheel stress, (Weakest Condition)

$$s_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

Here, $l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}$ ↓ radius of relative stiffness

Where,

p = wheel load (Kg)

h = slab thickness (cm)

a = Radius of area of contact of wheel (cm) $= \sqrt{\frac{P}{\pi c}}$ ↓ tyre pressure

b = radius of equivalent distribution of pressure at the bottom of the slab. (cm)

* when $a \geq 1.724h$, then $a = b$

* when $a < 1.724h$, then $b = \sqrt{(1.6a^2 + h^2)} - 0.675h$

2010

Calculate the thickness of cement concrete pavement using westergard's corner load formula from the following data:

(i) Wheel load, P = 4100 Kg (* যদি P না দেওয়া থাকে, Max^m Equivalent wheel load = 4085 Kg ধরতে হবে)

(ii) Radius of contact area, a = 10 cm (* না দেওয়া থাকলে Formula দিয়ে বের করতে হবে)

(iii) Modulus of rupture of concrete, M_r = 50 Kg/cm^2

(iv) Factor of safety = 2

(v) $E_c = 2.1 \times 10^5$ Kg/cm^2

(vi) Poisson's ratio for concrete, $\mu = 0.15$ (* না দেওয়া থাকলে 0.15 ধরব)

(vii) Modulus of subgrade reaction, $K = 4$ Kg/cm^3

* $a = \sqrt{\frac{P}{\pi p}}$, p = Tyre pressure

Solution: Allowable flexural stress, $\delta_c = \frac{M_r}{F.S.} = \frac{50}{2} = 25$ Kg/cm^2

Now, From Gold-Beck's formula, $\sigma_c = \frac{3P}{h^2}$

$\therefore 25 = \frac{3}{h^2}$

$\Rightarrow h^2 = \frac{3 \times 4100}{25}$

$\therefore h = 22.18$ cm

Hence, Assume thickness of pavement, $h = 20$ cm (কম ধরব)

Now,

$$l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}} = \sqrt[4]{\frac{2.1 \times 10^5 \times 20^3}{12 \times 4 \times (1-0.15^2)}} = 77.355 \text{ cm}$$

Then, $S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right] = \frac{3 \times 4100}{20^2} \times \left[1 - \left(\frac{10 \times \sqrt{2}}{77.355}\right)^{0.6}\right]$

$\therefore S_c = 19.66$ Kg/cm^2 $< (\delta_c = 25$ Kg/cm$^2)$ (OK)

But For economical design, (S_c এর মান 25 এর কাছাকাছি হলে economical design)

Assume, thickness, $h = 18$ cm

$$l = 4\sqrt{\frac{2.1\times10^5\times18^3}{12\times4\,(1-0.15^2)}} = 71.48 \text{ cm}$$

$$S_c = \frac{3\times4100}{18^2}\times\left[1-\left(\frac{10\sqrt{2}}{71.48}\right)^{0.6}\right] = 23.6 \text{ kg/cm}^2 < 25 \text{ kg/cm}^2$$

(OK)

Again, assume, thickness, $h = 17.5$ cm

$$l = 4\sqrt{\frac{2.1\times10^5\times17.5^3}{12\times4\times(1-0.15^2)}} = 69.98 \text{ cm}$$

$$S_c = \frac{3\times4100}{17.5^2}\times\left[1-\left(\frac{10\sqrt{2}}{9.98}\right)^{0.6}\right] = 24.78 \text{ kg/cm}^2 < 25 \text{ kg/cm}^2$$

(OK)

Hence, Adopt a slab of thickness = 17.5 cm.

(Ans.)

2014

Calculate the thickness of Rigid Pavement using westergard's edge load formula. from the following data:

(i) Wheel load = Max ESWL

(ii) Tyre pressure = 7 Kg/cm²

(iii) Design flexural stress of concrete = 25 Kg/cm²

(iv) poisson's ratio = 0.15

(v) $E_c = 2.5 \times 10^5$ Kg/cm²

(vi) K = 5 Kg/cm³

Solution: Given, Design flexural stress of concrete, $S_c = 25 Kg/cm^2$

From Gold-beck,

$$\sigma_c = \frac{3P}{h^2}$$

$$\Rightarrow 25 = \frac{3 \times 4085}{h^2} \quad \Rightarrow h^2 = \frac{3 \times 4085}{25}$$

$$\therefore h = 22.14 \text{ cm} \quad (\text{Assume } h = 18 \text{ cm})$$

Now, $$l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}} = \sqrt[4]{\frac{2.5 \times 10^5 \times 18^3}{12 \times 5 \times (1-0.15^2)}} = 70.61 \text{ cm}$$

Now,

$$S_e = 0.57185 \times \frac{P}{h^2} \left[4 \log_{10} \left(\frac{l}{b} \right) + 0.3593 \right]$$

Here, $$a = \sqrt{\frac{P}{\pi q}} = \sqrt{\frac{4085}{3.1416 \times 7}} = 13.63 \text{ cm}$$

$$1.724 h = (1.724 \times 18) = 31.03 \text{ cm} > a$$

Hence,

$$b = \sqrt{(1.6a^2 + h^2)} - 0.675h$$

$$= \sqrt{(1.6 \times 13.63^2 + 18^2)} - 0.675 \times 18$$

$$= 12.77 \text{ cm}$$

$$\therefore, Se = 0.57185 \times \frac{4085}{18^2} \times \left[4 \times \log_{10}\left(\frac{70.61}{12.77}\right) + 0.3593\right]$$

$$= 24 \text{ Kg/cm}^2 < 25 \text{ Kg/cm}^2$$

(OK)

Hence, Adopt a slab thickness of 18 cm.

(Ans:)

2013, 2012 ('a' given)

Calculate the thickness of cement concrete pavement using westgard's corner load formula using following data:

(i) Wheel load = Maximum ESWL

(ii) Tyre pressure = 7 Kg/cm²

(iii) Impact load = 10% of wheel load (* Load factor = 1.1 এভাবেও দেয়া থাকতে পারে)

(iv) safety factor = 2

(v) Modulus of Rupture of concrete = 50 Kg/cm²

(vi) $E_c = 3 \times 10^5$ Kg/cm²

(vii) $\mu = 0.15$ and $k = 5$ Kg/cm²

Solution: Allowable flexural stress, $\sigma_c = \frac{M_r}{F.S} = \frac{50}{2} = 25\ kg/cm^2$

From Gold Beck formula,

$$\sigma_c = \frac{3P}{h^2}$$

Here,

$P = 4085 + 4085 \times \frac{10}{100}$

$= 4493.5\ Kg$

$$\Rightarrow 25 = \frac{3 \times 4493.5}{h^2}$$

$$\therefore h = 23.22\ cm$$

Assume, thickness, $h = 18\ cm$

$$\therefore l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}} = \sqrt[4]{\frac{3\times10^5 \times 18^3}{12\times5\times(1-0.15^2)}} = 73.90\ cm$$

Now,

$$a = \sqrt{\frac{P}{\pi q}} = \sqrt{\frac{4493.5}{3.1416 \times 7}} = 14.29\ cm$$

$$\therefore S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$= \frac{3\times4493.5}{18^2}\left[1 - \left(\frac{14.29\sqrt{2}}{73.9}\right)^{0.6}\right]$$

$$= 22.5\ kg/cm^2 < 25\ kg/cm^2 \quad (OK)$$

'economic design,

Assume thickness $h = 17\ cm$

$$l = \sqrt[4]{\frac{3\times10^5 \times 17^3}{12\times5(1-0.15^2)}} = 70.80\ cm$$

$$S_c = \frac{3\times4493.5}{17^2} \times \left[1 - \left(\frac{14.29\sqrt{2}}{70.80}\right)^{0.6}\right] = 24.66\ kg/cm^2 < 25\ kg/cm^2$$

$\therefore$ Adopt a slab thickness of 17 cm (Ans.)

2016

Calculate the radius of relative thickness of a rigid pavement from the following data:

(i) pavement thickness = 7 inch (ii) Modulus of subgrade reaction = 5 kg/cm³ (iii) Modulus of elasticity = 2.5×10^5 kg/cm²

Solution:

Radius of relative thickness,

$$l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}$$

Here, h = 7 inch

$E = 2.5 \times 10^5$ kg/cm²

K = 5 kg/cm³

$\mu = 0.15$ (Let)

$$\Rightarrow l = \sqrt[4]{\frac{2.5 \times 10^5 \times 7^3}{12 \times 5 \times (1-0.15^2)}}$$

$\therefore l = 69.14$ cm

(Ans.)

2011

Calculate the stress due to interior load on rigid pavement using westergaard's formula from the following data:

(i) wheel load = Max. ESWL, (ii) $E_c = 3.5 \times 10^5$ kg/cm², (iii) $\mu = 0.15$ (iv) K = 5 kg/cm³, (v) a = 12 cm (vi) h = 18 cm. Allow 10% for impact load.

Solution:

we know,

for interior loading,

$$S_i = 0.31625 \frac{P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 1.0693\right]$$

Now,

$1.724h = (1.724 \times 18) = 31.032 > a = 12$ cm

Hence, $b = \sqrt{(1.6a^2 + h^2)} - 0.675h$

$= \sqrt{(1.6 \times 12^2 + 12^2)} - 0.675 \times 18$

$= 7.2$ cm

Then, $P = \left(4085 + 4085 \times \frac{10}{100}\right) = 4493.5$ kg

$$\therefore s_1' = 0.31625 \times \frac{4493.5}{18^2} \times \left[4 \log_{10}\left(\frac{l}{b}\right) + 1.0693\right]$$

Here, $l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}} = \sqrt[4]{\frac{3.5\times10^5 \times 18^3}{12\times5(1-0.15^2)}} = 76.81 \text{ cm}$

$$\therefore s_1' = 0.31625 \times \frac{4493.5}{18^2} \times \left[4 \log_{10}\left(\frac{76.81}{7.2}\right) + 1.0693\right]$$

$$= 22.73 \text{ Kg/cm}^2$$

(Ans.)

Road Note 29 Method.

Calculate the thickness of subgrade, sub-base, slab for 20 years with 2 million standard axles (MSA). (Assume the subgrade is Normal)

Solution:

(i) **Thickness of subgrade:**

To take care of the poor quality subgrade, a cement treated subgrade layer of 200 mm thick shall be provided.

→ for all cases 200 mm

(ii) **Thickness of sub-base:**

Type of subgrade is Normal. → CBR value (2%–15%)

Hence using Table

- the thickness of sub base = 80 mm

(iii) **thickness of slab:** Given, cumulative No. of standard axles = 2 millions.

using Graph, (Fig-01)

the slab thickness = 180 mm

* 2 Million এর নিচে যেকোন থাকলে

1. Unreinforced concrete
2. Reinforced concrete

দুই টা slab thickness বের করতে হবে।

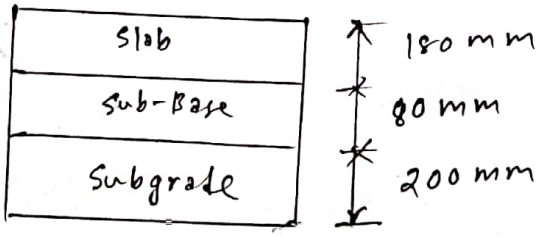


Fig. Proposed Rigid Pavement

TRRL (Transport and Road Research Laboratory) Method.

*** calculate the thickness of subgrade, sub base, slab for 20 Years with 2 million standard Axles (MSA). Assume the subgrade is weak.

Solution:

(i) **Thickness of subgrade:**

To take care of the poor quality of subgrade, a cement treated subgrade of 200 mm thick, shall be provided.

→ for all cases.

(ii) **Thickness of sub base:**

Type of subgrade is weak. Hence using table

the thickness of sub base = 150 mm.

(iii) **thickness of slab:** Given, Cummulative Traffic = 2 MSA

using Graph, (Fig-02)

(I) Reinforce concrete slab thickness = 123 mm

(ii) Unreinforced concrete slab thickness = 147 mm

(Ans.)

Classification of subgrades for concrete roads and minimum thickness of sub-base required

Table-1

Type of subgrade	Definition	Minimum thickness of sub-base required
Weak	All subgrades of CBR value 2 percent or less	150 mm
Normal	Subgrade other than those defined by the other categories · CBR value → 2% – 15%	80 mm
Very stable	All subgrades of CBR value 15 percent or more. This category includes undisturbed foundations of old roads	0

To take care of the poor quality sub-grade, a cement treated sub-grade layer of 200 mm thick, shall be provided. This has become a practice to the developed countries. The principal benefits of cement sub-

IRC-29

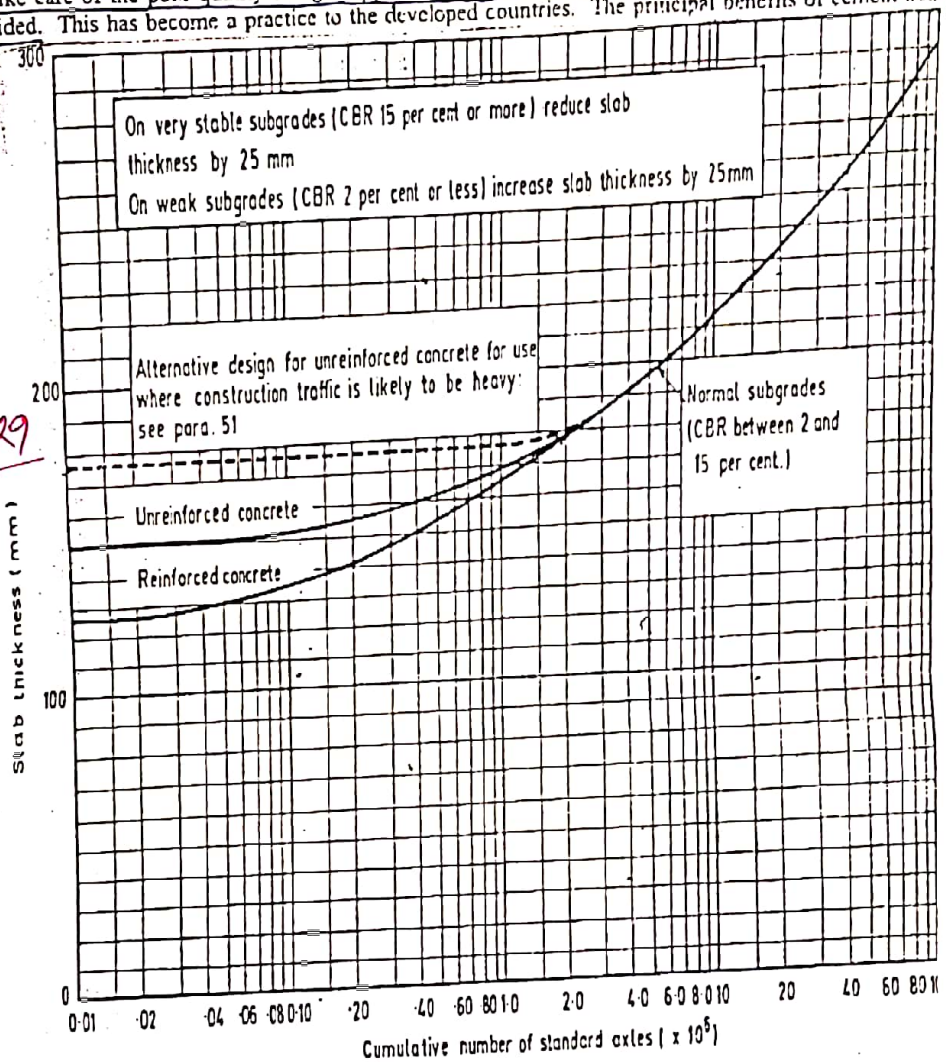


Figure 01 Concrete: minimum thickness of slab. (according to Road Note 29)

(TRRL)

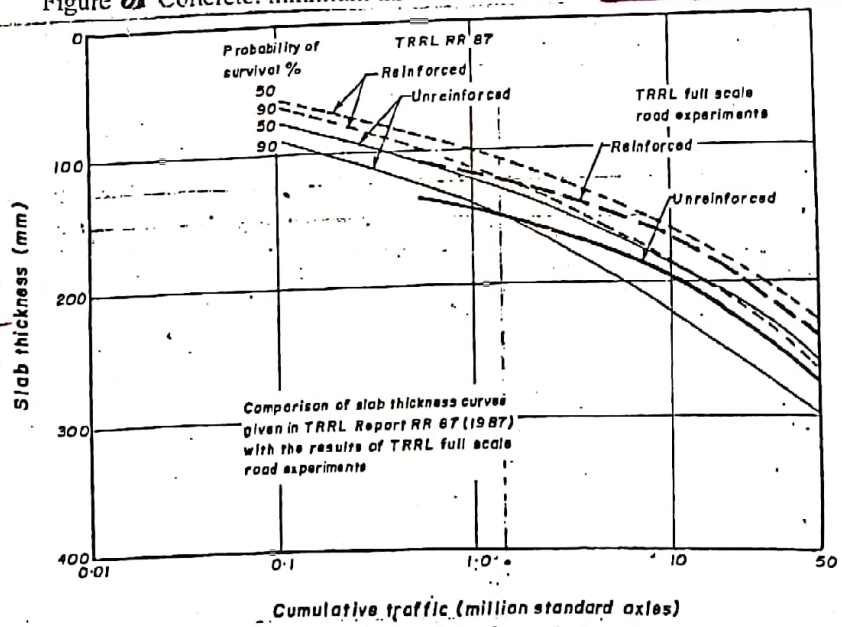


Fig. 02 Design thickness charts for concrete road slabs.

* Design based on Temperature variation

Design slab thickness from the following data:

(i) Design wheel load = 5100 kg.

(ii) present Traffic, P = 300 CVPD

(iii) Design period = 20 years

(iv) Traffic growth rate, r = 7.5%

(v) Temperature variation = 13°C

(vi) Modulus of subgrade reaction, K = 6 kg/m³

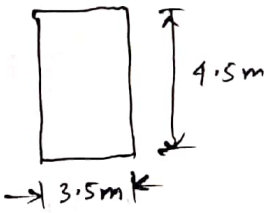
(vii) Flexural strength of concrete = 40 kg/cm²

(viii) Elastic modulus of concrete = 3×10^5 kg/cm²

(ix) Poisson's Ratio, $\mu = 0.15$

(x) Temperature co-efficient, $\alpha = 10 \times 10^{-6}$ /°C

(xi) Radius of contact area, a = 15 cm



Solution:

Assume, length of the pavement, L = 4.5 m (Lx)

width of the pavement, W = 3.5 m (Ly)

and, Slab thickness, h = 20 cm

Radius of relative stiffness, $l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}$

$= \sqrt[4]{\frac{3 \times 10^5 \times 20^3}{12 \times 6 \times (1-0.15^2)}}$

$= 76.4$ cm

Now, $\frac{L}{l} = \frac{4.5 \times 100}{76.4} = 5.89$ (critical)

$\frac{W}{l} = \frac{3.5 \times 10}{76.4} = 4.58$

* যেটা বড় সেটা critical

using Graph (Fig-03)

$c = 0.9$ (* point এর পর one digit নিব)

stress due to temperature effect, Using Graph (Fig-04)

$\Delta t = 13^\circ C$ (Given)

$S_{te} = 18\ Kg/cm^2$

Now,

Residual strength of concrete = flexural strength − S_{te}

$= (40 - 18)\ Kg/cm^2$

$= 22\ Kg/cm^2$

(i) Edge Load stress condition:

For slab thickness $h = 20cm$ and $K = 6$, $P = 5700\ kg$

we obtain from Graph. (Fig-07)

EDGE Load stress $S_e = 28\ Kg/cm^2$

Hence, $F.S = \frac{22}{28} = 0.79 < 1$ (not ok)

Again Assume. thickness of slab = 23 in.

$\therefore l = \sqrt[4]{\frac{3 \times 10^5 \times (23)^3}{12 \times 6 \times (1 - 0.15^2)}} = 84.86\ cm$

$\therefore \frac{L}{l} = \frac{450}{84.86} = 5.3$ (critical)

$\frac{w}{l} = \frac{350}{84.86} = 4.12$

using Graph (fig-03) we obtain, $C = 0.77$

using graph (Fig-04), we obtain, $S_{te} = 15$ kg/cm²

∴ Residual strength of concrete = (40 − 15) = 25 kg/cm²

Now, using Graph (fig-07), $S_e = 22$ kg/cm²

∴ $F.S = \frac{25}{22} = 1.14$ (OK)

(* FS এর মান 1 এর কাছাকাছি হলে economic design)

Adopt slab thickness = 23 in. (for Edge loading)

(ii) Corner load stress condition:

same procedure

use (Fig-08)

* যদি Design wheel load = 4100 kg এরচেয়ে বেশি,

use Fig-05 for Edge load stress

Fig-06 for corner load stress

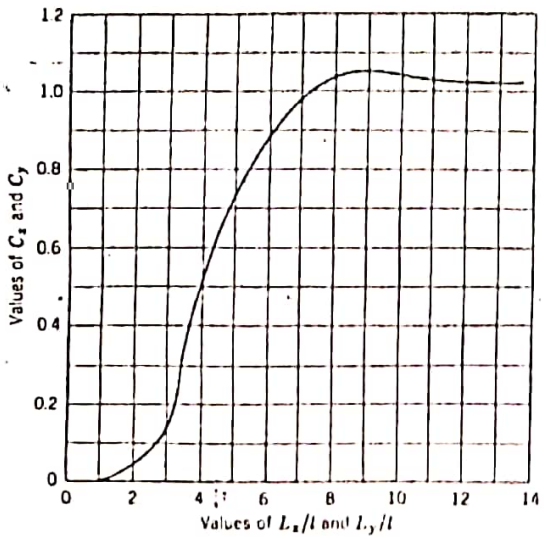


Figure 03 Warping stress coefficients (From Bradbury)

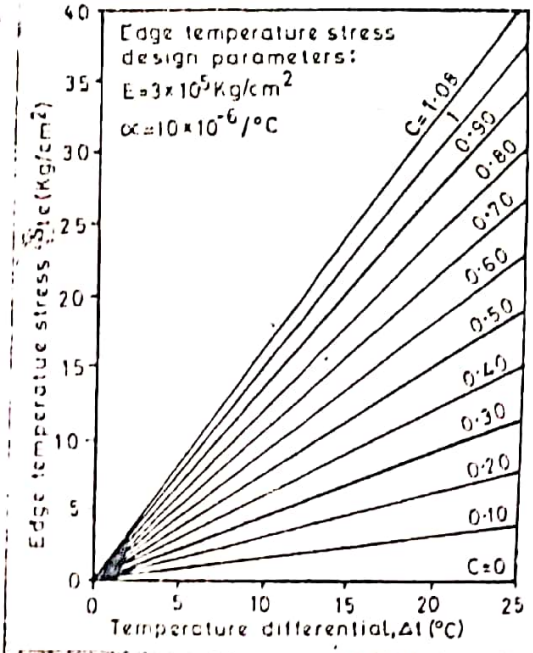


Fig 04 Temperature stress at edge

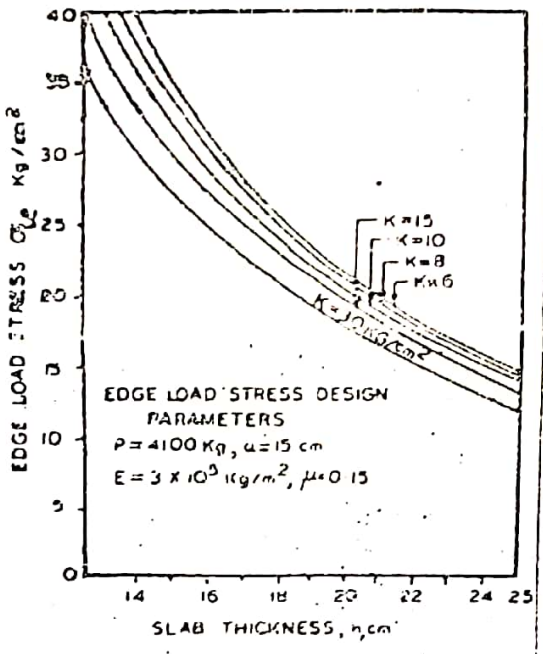


Fig. 05 Design chart for calculation of edge load stress.

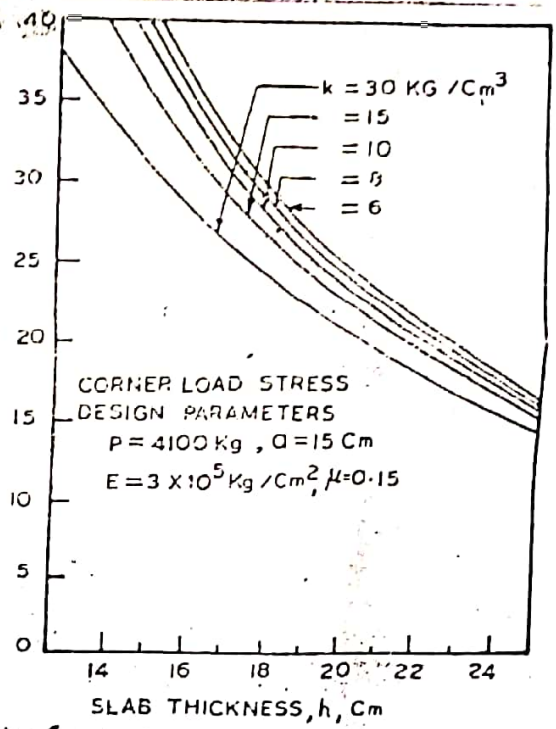


Fig. 06 Design chart for calculation of corner load stress.

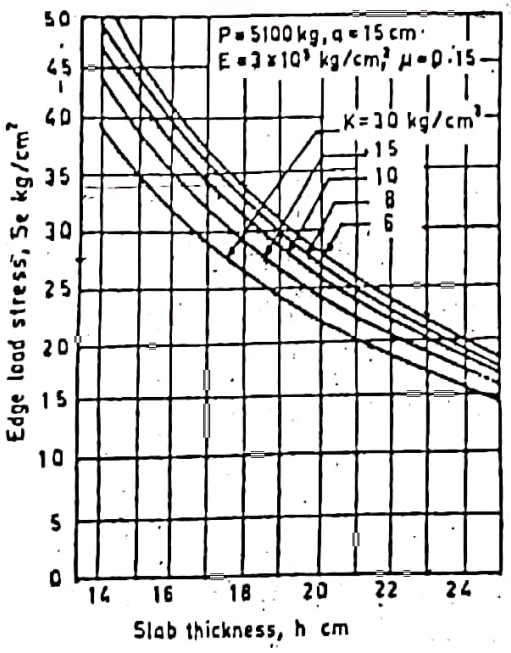


Fig. 07 Edge load stress chart (IRC)

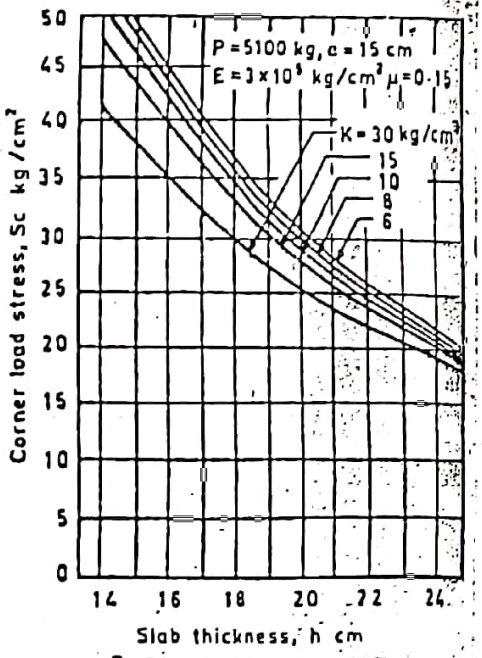


Fig. 08 Corner load stress chart (IRC)

#*** A road is two lane two way. Calculate the cummulative standard axle in design life from following data:

(i) Present traffic = 900 cvpd

(ii) Growth rate per year = 7%.

(iii) Design life = 15 year

(iv) Vehical damage factor, = 3

(v) Strengthnening period = 3 years

Solution:

Traffic after completion of strengthening,

$$A = P(1+r)^{n+x}$$

$$= 900 \times (1+0.07)^{3+0}$$

$$= 1102.54 \text{ Nos.} \simeq 1103 \text{ Nos.}$$

No. of cummulative standard axle for design life,

$$N = \frac{365 \times A[(1+r)^N - 1]}{r} \times F$$

$$= \frac{365 \times 1103 \times [(1+0.07)^{15} - 1]}{0.07} \times 3$$

$$= 30350455.85 \text{ Nos.}$$

$$\simeq 30350456 \text{ Nos.}$$

$$= 30.35 \times 10^6 \text{ MSA (million standard axle)}$$

(Ans.)

CBR Test

Calculate the design CBR value of subgrade soil from the following data:

Penetration (mm) :	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	7.5	10
Unit load (Kg/cm^2) :	0.05	0.1	0.3	0.6	1.0	1.5	2.1	2.6	3.1	3.5

Solution:

We know,

$$\text{CBR value} = \frac{\text{Unit load carried by sample at standard penetration level}}{\text{Unit load carried by standard crushed stone at above penetration level.}} \times 100$$

So,

CBR value for 2.5 mm penetration $= \frac{1.0}{70} \times 100 = 1.43\%$

for 5.0 mm penetration $= \frac{2.6}{105} \times 100 = 2.48\%$

for 7.5 mm penetration $= \frac{3.10}{134} \times 100 = 2.31\%$

for 10 mm penetration $= \frac{3.5}{162} \times 100 = 2.16\%$

∴ Design CBR value $= 2.48\%$

But, CBR for 2.5 mm penetration < CBR for 5.0 mm penetration

Hence, Test should be repeated. (Ans.)

Standard Load Values:

Penetration (mm)	2.5	5.0	7.5	10.0	12.5
Unit load (Kg/cm^2)	70	105	134	162	183
Load (Kg)	1370	2055	2630	3180	3600

2012

Assertain the accepted CBR value from the following Data:

Penetration (mm)	Total Load (Kg)	
	Test (Initial)	Test (Repeated)
2.5	50	52
5	76	80

Solution:

For initial Test,

$$\text{CBR value } (2.5\text{ mm}) = \frac{50}{1370} \times 100 = 3.65\%$$

$$\text{CBR value } (5.0\text{ mm}) = \frac{76}{2055} \times 100 = 3.7\%$$

↳ মূলমান গ্রহণ করা

For repeated Test,

$$\text{CBR value } (2.5\text{ mm}) = \frac{52}{1370} \times 100 = 3.8\%$$

$$\text{CBR value } (5.0\text{ mm}) = \frac{80}{2055} \times 100 = 3.9\%$$

since, for repeated test,

CBR value for 2.5 mm penetration < CBR value for 5.0 mm penetration

Hence, the Accepted CBR value = 3.9 %

(Ans.)

Bituminous Mix Design

2018, 2015, 2010

Calculate % Va and % VMA of a compacted bituminous mix specimen for 6% BC from the following data: $G_b = 1.02$, $G_1 = 2.27$, $G_2 = 2.46$, $G_3 = 2.44$, $G_{mm} = 2.29$, dry weight = 1160 gm, weight in water = 639 gm and absorbed water weight = 3 gm. percentage in Mix: CA = 58%, FA = 38% and MF = 4%.

Solution: Given, dry weight, A = 1160 gm

$\therefore$ SSD weight, B = weight in water + absorbed water by specimen
= (1160 + 3) = 1163 gm

weight in water, C = 639 gm

$\therefore$ Bulk specific gravity of the specimen $G_{mb} = \frac{A}{B-C}$

$= \frac{1160}{1163-639}$

$= 2.214$

Given, $G_{mm} = 2.29$

$\therefore \% V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 = \frac{2.29 - 2.214}{2.29} \times 100 = 3.32\%$

Now,

$$G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}} = \frac{58 + 38 + 4}{\frac{58}{2.27} + \frac{38}{2.46} + \frac{4}{2.44}} = 2.345$$

$$\% \text{ VMA} = \left(100 - \frac{G_{mb}}{G_{sb}} \times P_s\right) = \left(100 - \frac{2.214}{2.345} \times 94\right) = 11.25\%$$

(Ans.)

2017

Calculate the % V_a and % VMA of compacted bituminous Mix specimen for 5% BC from the following data: $P_1 = 58\%$, $P_2 = 38\%$, $P_3 = 4\%$, $G_1 = 2.77$, $G_2 = 2.46$, $G_3 = 2.56$, $G_b = 1.03$, $G_{mm} = 2.52$ and $G_{mb} = 2.42$ for compacted specimen with 6% BC.

Solution: Given, $G_{mb} = 2.42$ and $G_{mm} = 2.52$

$$\therefore \%V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 = \frac{2.52 - 2.42}{2.52} \times 100 = 3.97\%$$

Now,

$$G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}} = \frac{58 + 38 + 4}{\frac{58}{2.77} + \frac{38}{2.46} + \frac{4}{2.56}} = 2.635$$

$$\therefore \%\ VMA = \left(100 - \frac{G_{mb}}{G_{sb}} \times P_s\right) = \left(100 - \frac{2.42}{2.635} \times 94\right) = 13.67\%$$

2016, 2013 (similar), 2011 (Ans:)

Calculate the V_a and VMA of Marshall test specimen for 6% BC from the following data:

Constituent in Mix	CA	FA	MF	Bitumen
Percentage in Mix	55.1	36.1	3.8	5.0
specific gravity	2.79 (G_1)	2.46 (G_2)	2.63 (G_3)	1.02 (G_b)

For 5% BC, $G_{mm} = 2.555$, for 6% BC $G_{mb} = 2.423$.

Solution: Given, $G_{mm}(5\%) = 2.555$

$$\therefore G_{se} = \frac{P_{mm} - P_b}{\frac{P_{mm}}{G_{mm}} - \frac{P_b}{G_b}} = \frac{100 - 5}{\frac{100}{2.555} - \frac{5}{1.02}} = 2.775$$

Now, $$G_{mm}(6\%) = \frac{P_{mm}}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} = \frac{100}{\frac{100-6}{2.775} + \frac{6}{1.02}} = 2.515$$

Given, $G_{mb}(6\%) = 2.423$

$$\therefore \%\ V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 = \frac{2.515 - 2.423}{2.515} \times 100 = 3.66\ \%$$

Now,

$$G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}} = \frac{55.1 + 36.1 + 3.8}{\frac{55.1}{2.79} + \frac{36.1}{2.46} + \frac{3.8}{2.63}} = 2.649$$

$$\therefore \%\ VMA = \left(100 - \frac{G_{mb}}{G_{sb}} \times P_s\right) = \left(100 - \frac{2.423}{2.649} \times 94\right) = 14.02\%$$

(Ans.)

2012

Calculate $\%V_a$ and $\%VMA$ for 6% BC in mix from the data: $G_1 = 2.75$, $G_2 = 2.46$, $G_3 = 2.62$, $G_{mm} = 2.38$, dry weight of specimen = 1250 gm, weight in water = 700 gm and weight of water absorbed by specimen = 2 gm. Ratio of MF : FA : CA = 1 : 7 : 12 in Mix.

Solution: Given, $A = 1250$ gm

$B = (1250 + 2) = 1252$ gm

$C = 700$ gm

$$\therefore G_{mb} = \frac{A}{B - C} = \frac{1250}{1252 - 700} = 2.26$$

$$\therefore \%\ V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100 = \frac{2.38 - 2.26}{2.38} \times 100 = 5.04\ \%$$

Given, MF : FA : CA = 1 : 7 : 12

$\Rightarrow$ CA : FA : MF = 12 : 7 : 1

$$\therefore P_1 = \frac{12}{12 + 7 + 1} \times 100 = 60\%$$

$P_2 = \frac{7}{20} \times 100 = 35\%$

$P_3 = \frac{1}{20} \times 100 = 5\%$

Now, $G_{sb} = \frac{P_1 + P_2 + P_3}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}} = \frac{60 + 35 + 5}{\frac{60}{2.75} + \frac{35}{2.46} + \frac{5}{2.162}} = 2.163$

$\therefore \%\ VMA = \left(100 - \frac{G_{mb}}{G_{sb}} \times P_s\right) = \left(100 - \frac{2.126}{2.163} \times 94\right) = 19.22\%$

*Additional: $\%\ VFB = \frac{VMA - V_a}{VMA} \times 100 = \frac{19.22 - 5.04}{19.22} \times 100 = 73.78\%$

(Ans.)

Introduction

Comparison with Road way:

1. **Load Handling Capacity:** Railway can handle heavier loads at higher speeds.
2. **Construction, maintenance and operative cost:** Railway has higher construction and maintenance cost but lower operation cost.
3. **Speed:** High speed rails are much faster than roadway.
4. **Degree of Freedom:** Railway movements are restricted to be in one direction.
5. **Length of haul (Distance):** Railway is much more convenient for long haul (greater than 500 Km trips)
6. **Topography:** Railway is less suitable in hilly terrain with curves.
7. **Energy Consumption:**
   - Energy required in railway per ton is less than roadway.
   - very environment friendly if 'clean' electricity is used.

Advantages of Railway:

1. Higher Capacity.
2. Lower Operation Cost.
3. High Speed.
4. Fixed route and easier operation.
5. Time savings.

Classification of Railway System:

Three types of railway system are:

(i) Intercity railway system.

(ii) Urban railway system.

(iii) sub-urban railway system.

(i) Intercity railway system:

- Long Distance
- Generally not very frequent. (Every 20 or 30 minutes to once a day)

(ii) Urban railway system:

- short haul
- Frequent: Frequency as high as every 3 minutes.

(iii) Sub-Urban railway system:

- suburban to main city.
- Mostly caters to community traffic.

Responsibilities of Civil Engineers:

civil Engineers responsible for-

(i) planning the railway track.

(ii) designing the alignment.

(iii) right of way designing.

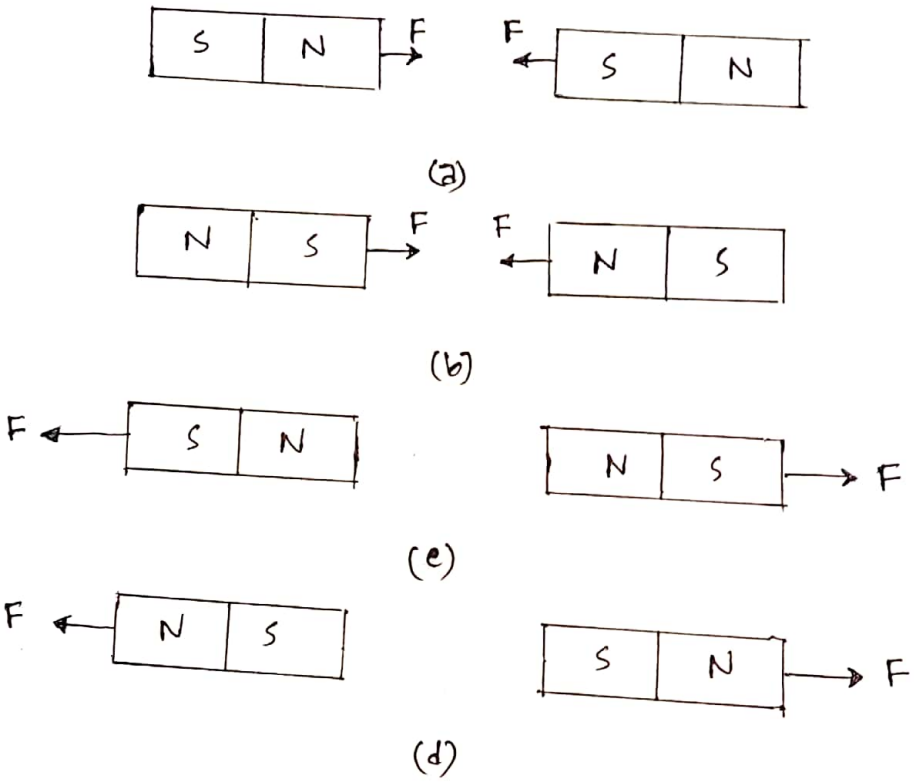
(iv) operations.

(v) maintenance.

2017, 16

Write short note on: Magnetic Levitation (Maglev) Principle

- Opposite poles on magnets keep train above track.



- Train is propelled by electro-magnetic system in the sides of the guideway instead of on board engine.

- Trains float over a guideway without any contact between train and rail resulting zero frictional loss.

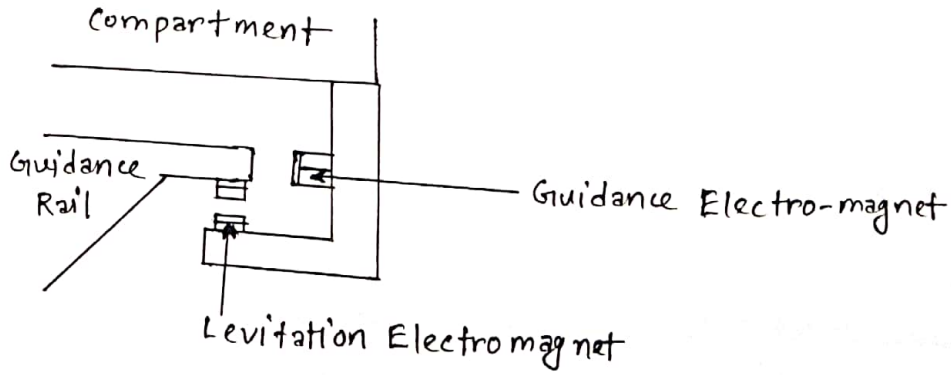


Fig. Maglev Principles.

Railway Track

2017, 19, 13, 12, 11, 10, 16

Define Railway Track:

- Railway track is also known as permanent way.
- The name of permanent way is given to the track to distinguish the final track constructed for the movements of trains from the temporary track laid for transporting the construction materials.

2010

Name the different components of a Railway track.

- The typical components are:

(i) Rails.
(ii) Sleepers.
(iii) Ballast.
(iv) Fittings and Fastenings.
(v) Formations.

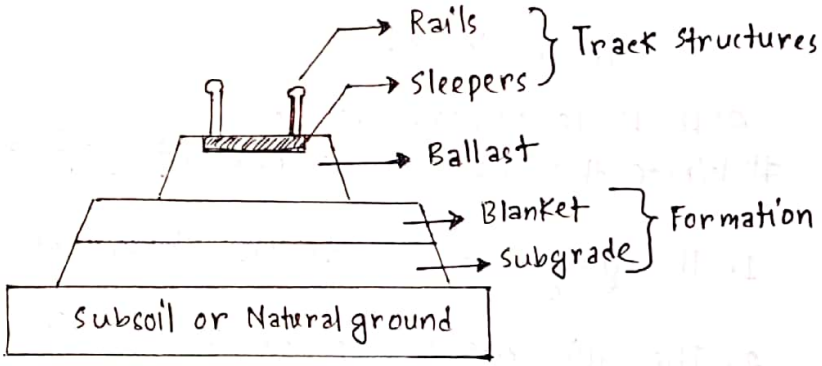


Fig. Components of a Railway track.

- The railway track costs about 40% of the total investment in the railway.

2010

Discuss Functions of each components of Railway Track.

(i) **Rails:** Transmit the wheel loads of trains to the sleepers below.

(ii) **Sleepers:**
- Hold the rail in proper position
- provide a correct gauge with the help of fittings and fastenings.
- Transfer the train load to the ballast below.

(iii) Ballast:

- Holds sleepers in position
- provide a uniform level surface and drainage to the track.
- transfer the train load to to a large area of formation below.

(iv) Fittings and Fastenings:

- provide a grip between rails and sleepers.
- fasten the rails with sleepers.

(v) Formation:

- gives a level surface where the ballast rest
- takes the total load of the track as well as the moving train loads.

2018, 17, 16, 14, 13, 12, 11, 10

Write the basic requirements of an ideal railway track.

1. The gauge of the track should be correct and uniform.
2. The alignment of the track should be correct.
3. On curves, should have proper super elevation.
4. The gradient should be uniform as gentle as possible.
5. The track should be resilient and elastic to absorb shocks and vibrations.
6. The drainage of the track should be perfect.
7. The friction between the wheels of the rolling stock and rails should be minimum.
8. The track should be designed in a such way that the load of the train should be distributed uniformly over it.
9. The track should possess high resistance to the damage at the time of derailment.

10. The track should possess anti-theft and sabotage qualities.

11. The rails should have perfect cross level.

2015, 14, 13, 11

Write short note on: Capacity of a railway track

- The capacity of railway track is defined as the maximum number of trains that can run safely on any given length of the track per hour.
- The maximum number of trains which can be handled in a yard per day is known as terminal capacity.
- In actual practice, it is some what less due to safety considerations as speed of train, control and signalling system.

2018

Suggest some measures to increase the capacity of a track:

(i) The speed of all trains should be kept same.

(ii) All sections should be made of equal lengths.

(iii) Multi aspect signalling may be adopted to alert the driver.

(iv) By removing speed restrictions and suitable modifications.

(v) Reduction in stoppage time.

(vi) Traffic control on Broad Gauge and Meter gauge should be constructed.

2018, 2010, 2008

Write short note on: Sleeper Density

- Sleeper density is defined as the number of sleepers per rail length.
- Generally one sleeper is used for everyone meter length of the rail.
- If the spacing is less, more number of sleepers are used, which is specified as, 'N+x' where,

  N = length of rail in meter

  x = mathematical number which varies on many factors.

- For Broad Gauge (BG):

  N = 13 m and x = 7

  For Meter Gauge (MG):

  N = 12m and x = 4

What are the factors that sleeper density depends on.

- Sleeper density depends on the following factors:

  (i) Axle load and Speed of train.

  (ii) Type and section of rail.

  (iii) Type and strength of sleeper.

  (iv) Depth of Ballast-cushion.

  (v) Nature of formation.

What are the forces that acts on the railway track?

(i) vertical loads consisting of dead loads and dynamic loads

(ii) Lateral forces due to movement of live loads, eccentric vertical loads and shunting of locomotives etc.

(iii) Longitudinal forces due to traffic effort and braking forces and thermal forces.

(iv) contact stresses due to wheel and rail contact.

(v) stress due to surface defects like flat spots on wheel etc.

Define Formation

The surface prepared to receive the ballast of the track, sleepers and rails for constructing the railway track is called formation or subgrade. It may be in embankment or cutting.

Write the functions of formation:

(i) It provides a smooth and uniform bed on which the track is laid.

(ii) It bears the entire load transmitted to it from the rolling stock through the ballast.

(iii) It provides drainage facilities.

(iv) It provides stability to the track.

Write the design aspects of formation:

(i) Width of formation: The width of formation depends upon the following factors:

- Number of tracks to be laid over it.
- Gauge of the track.
- width of ballast layer.
- width of drains provided.

(ii) Height of formation: depends on:

- topography of the alignment.
- Gradients adopted.

(iii) Side slopes: depends on:

- Characterestics of soil.
- Shear strength of soil.
- Angle of repose etc.

2007
Draw a single line railway track in cutting showing full Details

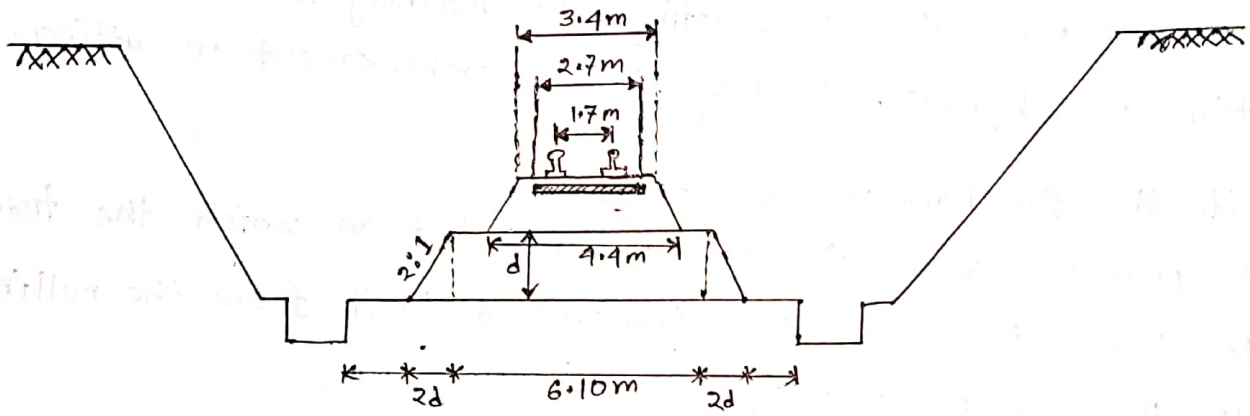


Fig. Single Lane BG Track in cutting.

2012
Draw a typical single line track on embankment showing full details.

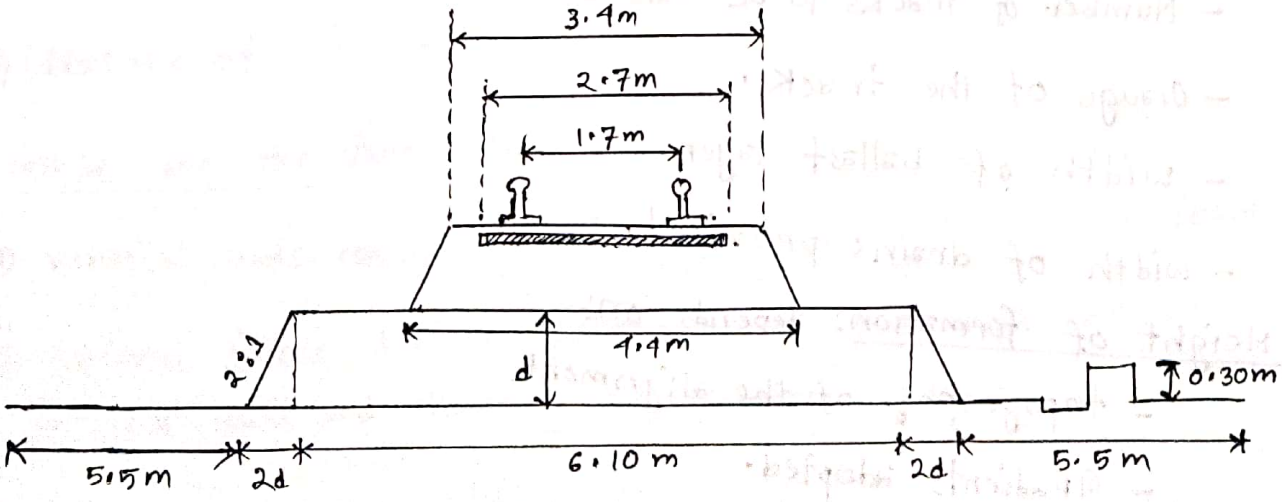


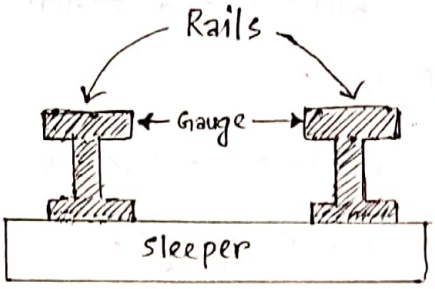
Fig. Single Lane BG Track on Embankment.

Rail Gauge

2017, 16, 15

Define gauge of a railway track.

- Rail gauge is defined as the clear minimum horizontal (perpendicular) distance between inner (running) faces of two rails forming a track.



- In European countries, the gauge is measured between the inner faces of two rails at a point 14 mm below the top of the rail.

2017, 16, 15, 14, 13, 12, 11

Discuss the factors which affect the choice of a railway gauge.

Following factors are affecting the choice of a railway gauge:

(i) Traffic Conditions:

If the intensity of traffic is more, BG is more acceptable than the standard gauge.

(ii) Development of poor areas:

To develop the poor areas smaller gauge rail facilities may be provided at less expenditure. They are known as Narrow gauge.

(iii) Cost of track:

If sufficient funds are avaiable, then Broad gauge adoption is the best. In case, sufficient funds are not avaiable for B.G. and S.G, then Meter gauge is adopted.

(iv) cost of Construction:

- only a marginal increase in the cost of track, if a wider gauge is adopted.

- Proportional increase in the cost of acquisition of lands, earthwork, rails, sleepers, ballast and other track items when constructing a wider gauge.

- cost of building bridges, culverts and tunnels increases only marginally due to a wider gauge.

- cost of constructing station buildings, platforms, staff quarters, level crossing, signals etc. associated with the railway network is more or less the same for all gauges.

(v) Speed of movement:

- speed is proportional to the gauge
- It is the function of wheel diameter
- As a thumb rule, diameter of the wheel is kept 75% of the gauge width.

(vi) Physical features of the country:

- It is possible to adopt steeper gradients and sharper curves for a narrow gauge as compared to a wider gauge.

(vii) Uniformity of the gauge:

- Existance of a uniform gauge in a country enables smooth, speedy and efficient operation of trains.

2009, 07

What are the disadvantages of adopting different gauge on the railways?

- Problems of Multi-gauge system:

(i) Inconvenience to passengers:

Due to the change of gauge, passenger have to change trains mid journey along with their luggage which causes inconvenience such as;

(a) climbing stairs and crossing bridges.

(b) Getting seats in the compartments of the later train.

(c) Missing connection with the later trains in case the earlier train is late.

(d) Harrassment caused by porters.

(e) Transporting luggage from one platform to another.

(ii) Difficulty in transshipment of goods:

Goods have to be trans-shipped at the point where the changes of gauge takes place causes the following problems:

(a) Damage to goods during trans-shipment.

(b) considerable delay in reciept the goods at the destination.

(c) Theft or misplacement of goods during trans-shipment and subsequent claims.

(d) Non-avaiability of adequate and specialized trans-shipment labour and staff, particularly during strikes.

(iii) Insufficient use of rolling stock:

As wagon have to move empty in the direction of the trans-shipment point, they are not fully utilized.

Idle wagons or engines of one gauge can not be moved on another gauge.

(iv) Hindrance to fast movement of goods and passengers:

- Due to change in the gauge, traffic can not move fast which becomes a major problem particularly during emergences such as war, floods and accedents.

(v) Additional facilities at stations and yards:

- Costly sheds and additional sheds and additional facilities need to be provided for handling the large volume of goods at trans-shipment points.

- Duplicate equipment and facilities such as yards and platforms need to be provided for both gauges at trans-shipment point.

(vi) Difficulties in balanced economic growth:

- Difference in gauge also leads to unbalanced economic gro ths, because industries set up near MG or NG stations can not send their goods economically and efficiently to areas being served by BG stations.

(vii) Difficulties in war time:

- Time is wasted in changing personnel and equipment if there is more gauges.

(viii) Difficulties ~~in future~~ in future gauge conversion:

- Gauge converson is quite difficult as it requires enormous effort to widen existing tracks.

- Widening the gauge involves heavy civil engineering work such as widening of embankment, bridges and tunnels as well as tracks.

- A wider rolling stock is also required.

- During the gauge conversion period, there are operational problems as well, since the traffic has to be slowed down and even suspended for a certain period in order to execute the work.

2008, 07

Write short on: Loading Gauge.

- Loading gauge consists of a vertical post with an arm.
- A steel arc is suspended from the top.
- Constructed at the exit of goods used.

Functions:

(i) It confirms that the top of the loaded wagon would clear all the structures (tunnels, bridges etc.) along the track.

(ii) It represents the maximum height and width up to the wagon could be loaded safety.

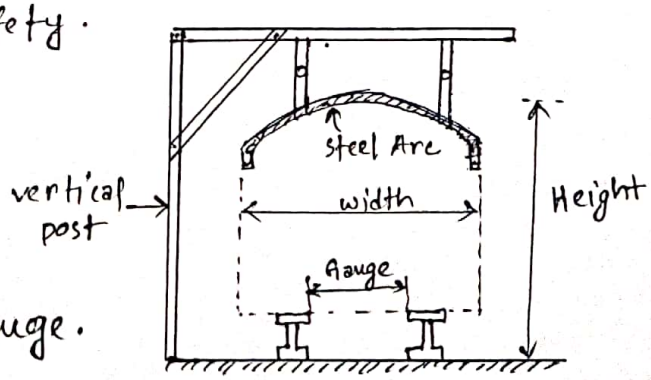


Fig. Loading Gauge.

2015, 14, 13, 11, 10, 09, 08, 07

Write short note on: Construction Gauge

Construction gauge is obtained by adding suitable clearence at the top and sides of the loading gauge.

Functions:

(i) It decides the dimensions (height and width) of the structures (bridge, tunnel etc.) along the track, so that all wagons may pass through them without any damages to the structures.

Rails

Define Rails:

Rail is similar to steel girder, made of high carbon steel. It is able to withstand stresses and is laid in two parallel lines to provide an unchanging track.

Write down the functions of Rails:

(i) Provide a continuous and level surface for the movements of trains.

(ii) provide a smooth path to trains which has a very less friction.

(iii) serve as a lateral guide for the wheels.

(iv) Bear the stresses developed due to vertical loads transmitted to them through axles and wheel of rolling stock as well as due to braking and thermal forces.

(v) Transmit the heavy load of rolling stock to the large area of formation through sleepers and ballast.

Write down the advantages of Flat footed rail or Vignole Rail.

(i) Easy to fix with sleepers.

(ii) stronger both vertically and laterally than Bull headed rail.

(iii) Cheaper than Bull Headed Rail.

(iv) Requires less fastenings than Bull Headed Rail.

(v) Distribute train load over a large number of sleepers.

(vi) Provides better stability to the track.

(vii) Provides longer life to the track.

(viii) Reduces maintenance cost.

What are the requirements of an ideal rail section.

1. The rail should possess adequate lateral and vertical stiffness.
2. The rail should have the most economical section consistent with strength, stiffness and durability.
3. Metal distribution in head, web and foot of the rail should be properly balanced.
4. The center of the gravity of the rail section should be located very near the center of the height of the rail, so that the maximum compressive and tensile stresses are equal.
5. The depth of rail head should be sufficient to allow the sufficient margin for the vertical wear.
6. The thickness of the web of the rail should be sufficient to withstand the load likely to come on the rail.
7. The width of the foot should be sufficient to spread on the large area of sleeper.
8. The contact area between the rail and wheel should be sufficient to minimize the contact stresses.
9. The rail should be shaped suitably.

2018 (short note)

What are the factors that affect the length of rail.

- Longer the rail, the lesser would be the number of joints and fittings required and hence the lesser the cost of the construction and maintenance.

- Longer rails are economical and provide smooth and comfortable rides.

- Length of a rail is however restricted due to the following factors:

(i) Lack of facilities for transport of longer rails particularly on curves.

(ii) Difficulties in handling long rails.

(iii) Difficulties in manufacturing very long rails.

(iv) Difficulties in acquiring bigger expansion joints for long rails.

(v) Heavy thermal stresses in long rails.

Taking above factors in to consideration,

A rail length of 13 m (42 ft) for Broad Gauge and 12 m (39 ft) for Meter Gauge are in use.

Minimum length of rail should not be less than 3.6 m (12 ft)

2017, 16, 15, 14, 13, 11, 10, 09, 07

Write short note on: coning of wheel.

The trade or rim of the wheel of a railway vehicle are not made flat, but sloped at about 1 in 20 to enable these vehicles to move smoothly on curves as well as on straight track.

The sloping surface along the circumference forms a part of a cone which is known as coning of wheel.

Coning is done due to:

(i) To avoid lateral movement of wheels and shocks to rails.

(ii) To maintain the wheel in the central position to the track.

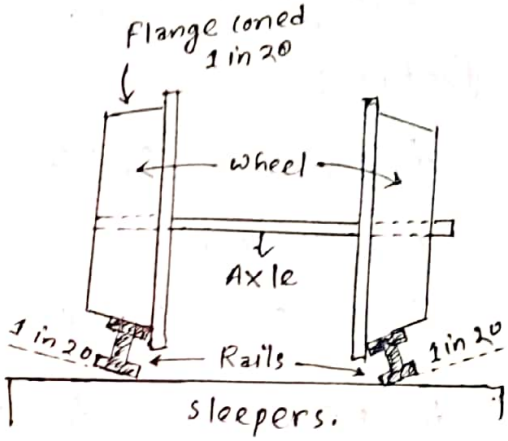


Fig. coning of wheel.

Write down the advantages and disadvantages of coning of wheel.

Advantages of coning:

(i) provides smooth riding

(ii) helps a vehicle to negotiate a curve smoothly

(iii) reduces the wear and tear of wheel.

Disadvantages of coning:

(i) Pressure of the horizontal component near the inner edge of the rails wears out the rail quickly.

(ii) pressure of the horizontal component tends to turn the rail outwardly and hence the gauge is widened sometimes.

(iii) Lateral bending stresses develop in the rail.

(iv) If no base plates are provided, sleepers under the outer edge of the rails are damaged due to non-uniformly distributed loads.

Defects in Rails:

1. Rail Wear: Rail head gets worn out in the course of service due to the passage of moving loads and friction between the rail and the wheel.

causes of wear: considerable wear and tear of vertical and lateral planes of the rail head causes due to -

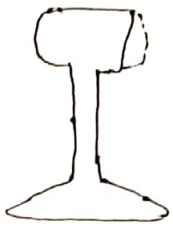


Fig. Worn curve rail cross-section.

(i) Impact of moving loads.
(ii) Effect of acceleration.
(iii) Abrasion due to rail wheel interaction
(iv) Effect of weather condition (temperature, snow, rains etc)
(v) Presence of materials such as sand.
(vi) lower standard of maintenance of the track.

measurement of wear:

(i) by weighing the rail
(ii) by profiling the rail section with the help of lead strips.
(iii) by profiling the rail with the help of needles.
(iv) by using special instruments designed to measure the profile of the rail and record it simultaneously on graph paper.

measures to reduce wear:

(i) Better maintenance of the track.
(ii) Reduction in the number of joints by welding.
(iii) use of heavier and higher ultimate tensile strength rails, which are more wear resistant.
(iv) use of bearing plates and proper adzoining in case of wooden sleepers.
(v) Lubricating the gauge face of outer rail in case of curves.
(vi) Providing check rails in case of sharp curves.
(vii) Interchanging the inner and outer rail.

2017, 15, 14, 13, 11, 10, 09

2. **Hogging of rails:** (short note)

Rails which are bent vertically at the ends is called Hogged rails and this phenomenon is known as Hogging of rail.

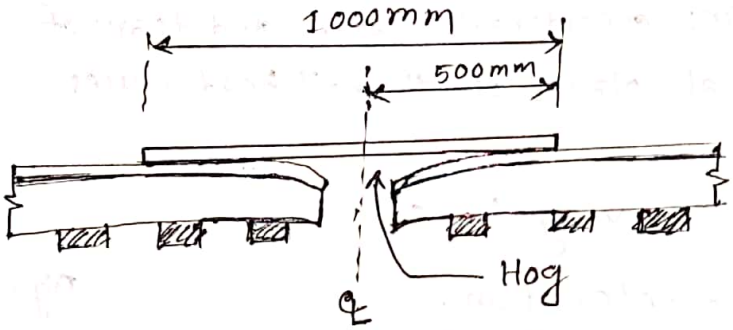


Fig. Hogging of rails.

causes:

(i) wear of rails at ends.
(ii) Poor maintenance of the rail joint.
(iii) Yielding formation.
(iv) Loose and faulty fastenings.
(v) other such reason which affect the quality of track.

Remedies:

(i) Replacing the hogged rails.
(ii) cutting one meter and fresh holes for fish plates.
(iii) welding the worn out rails.
(iv) Dehogging the rail.
(v) over packing the sleepers at joint.
(vi) Tightening the fittings.

3. Wheel Burns: (Short note) Class Test

- Caused by the sliping of the driving wheels of locomotive on the rail surface.
- As a consequence, extra heat is generated.
- surface of the rails gets affected, resulting a depression on the rail table.
- wheel burns are generally noticed on:
  (a) steep gradients
  (b) Places having heavy incidence of braking.
  (c) Near water columns.

2016, 15, 14, 13, 11, 10, 09

4. corrugation or Roaring of Rails: (short note)

In certain places, the minute depression are formed on the surface of rails karying in shape and size and occurs at irregular intervals. In other words upper surface of rail becomes wavy. When a train passes over such wavy surface, it produces a roaring sound, which is unpleasant to ears. This is known as corrugation or roaring of rails.

causes:

(1) Metallurgy and age of rails:
  (a) High Nitrogen content of rails.
  (b) Effect of oscillation at the time of moving.

(2) Physical and Environmental conditions of Track:
  (a) Yielding formation.
  (b) Steep gradient.
  (c) Long Tunnel.
  (d) Electrified section.

(3) Train Operations:

(a) High speeds and high axle loads.

(b) starting location of train.

(c) stopping of trains.

(4) Atmospheric Effect:

(a) Presence of sand particles,

(b) High moisture content in airs

5. Kinks or shoulder in Rails: (short note)

When the ends of adjoining rails move slightly out of positions and produces undesirable jerks, obstruct the smooth running of train, may cause defect in alignment at curves, this is known as kinks or shoulder of rails.

causes:

(i) Due to loose packing at joints.

(ii) Defective alignment and gauge.

(iii) Defects at joints in level crossing.

(iv) Due to formation of uneven wear at the rail head.

Remedies:

(i) Alignment must be correct at joints and curves.

(ii) Proper packing at joints.

(iii) Proper maintenance of the track.

Failure of Rails: (short note)

A rail is said to have failed when it is considered to replace immediately due to some faults in rails.

causes:

(i) Inherent defect in the rail.
(ii) Excessive corrosion of rail.
(iii) Fault of the rolling stock and abnormal traffic.
(iv) Poor maintenance of joints.
(v) Defects in welding of joints.
(vi) Improper maintenance of the track.
(vii) Derailment.

Write short note on: Tilting of rails

- To minimize the disadvantages caused by coning of wheels, the rails are tilted inward at an angle of 1 in 20.
- It is done due to –
  (i) reduce wear and tear on the rail as well as tread of wheel.
  (ii) maintain gauge properly.
  (iii) keep the wear of rail uniform.
  (iv) increase life of sleepers and rails.

2018

Write short note on: Bending of Rail

- For flat curves (degree of curvature less than 3°), rail can be laid without bending.
- For curves greater than 3° curvature, bend the rails with correct curvation.
- without bending elbows occur at the joints, which will disturb the alignment.

Sleepers

2013, 08, 06, 11

Define Sleepers.

Sleepers are transverse support for railway track to give stiffness to the track. It transmit the wheel load from the rails to the ballast.

2017, 2011, 2010

Explain the functions of sleepers in railway track.

1. To hold the rails to correct gauge and alignment.
2. To give a firm and even support to the rail.
3. To transfer and distribute the axle load through rails over a sufficiently large area of ballast.
4. To act as an elastic medium between the rails and ballast to absorb vibrations and blows of the moving wheels.
5. To maintain the alignment of the track.
6. To provide insulation for electrified track.
7. To provide proper grade, longitudinal and lateral stability to the track.
8. To provide means for easy replacement of rail fastenings without distributing the traffic during its service life.

2018, 08, 06, 05, 13

What are the requirements of ideal material of the sleeper?

(1) The initial and maintenance cost should be minimum.

(2) The weight of sleeper should be moderate, so that it can be handled easily.

(3) It should be easy to handle so that the gauge may be adjusted easily and maintained correctly.

(4) It should be shock and vibrations absorbent.

(5) The design and material of sleeper should be such that it may possible to have track circuiting.

(6) The material of sleeper should be such that it does not get damaged or break while packing below it.

(7) The sleeper should have sufficient bearing area.

(8) It should have anti-theft and anti-sabotage qualities.

(9) The design of sleeper and fastenings should be such that it is possible to fix and remove the rails easily.

2015, 11, 10, 07

Discuss the merits and demerits of concrete sleeper.

The evolution of concrete sleepers has taken place due to shortage of timber, economical considerations coupled with the changing of traffic pattern.

Advantages:

(i) gives more elastic modulus, strength and stability to the welded track.

(ii) maintains better gauge and alignment

(iii) more helpful for the track maintenance by mechanical devices.

(iv) can be used in track circuited sections.

(v) not susceptible to attack by vermin, corrosion and fire.

(vi) can be manufactured from local materials.

(vii) more useful life (40 to 50 years)

Disadvantages:

(i) Difficult and costly in handling and laying.

(ii) Heavy damage to sleepers at the time of derailment.

(iii) Have no scrap value.

Sleeper Spacing: (short Note)

- Sleeper spacing depends on sleeper density.
- It is not kept uniform throughout the rail length.
- It is closer near the joints because of the weakness of the joints and impact of moving loads on them.
- Limitation to the close spacing of the sleepers as enough space is required for working the beaters that are used to pack the joint sleepers.

Ballast

2015
Define Ballast.

Ballast may be defined as a layer of broken stone, gravel, moorum or any other material placed under and around the sleepers to distribute the load from sleepers to the formation and for providing drainage as well as providing lateral and longitudinal stability to the track.

2015, 08, 06, 05, 13
Write down the functions of ballast in railway track.

(i) It provides a suitable foundation to the sleepers.

(ii) It holds the sleepers in position during the passage of train.

(iii) It transfer and distribute loads from sleepers to a larger area of formation.

(iv) It increases the elasticity and resilience of the track for getting good riding comfort.

(v) It provides lateral and longitudinal stability to the track.

(vi) It provides an easy means of maintaining evenness and the alignment of the track.

(vii) It provide effective drainage to the track.

(viii) It helps in protecting the top surface of the formation.

2011, 10

What are the diserable properties of good ballast?
or, what are the requirement of good ballast.

1. It should be hard, tough and wear resistant
2. It should be hard, so that it does not get crushed under the moving loads.
3. It should be generally cubical with sharp edge.
4. It should be non porous and non absorbent of water.
5. It should be cheap and easily avaiable.
6. It should have sufficient elasticity and should resist attrition.
7. It should have sufficient grip over the sleeper to prevent their horizontal movements.
8. It should provide good drainage of water.
9. It should not be brittle.

Track Fittings and Fastening

2010
What is rail joint?

A rail joint is an inevitable feature of railway track. It is the weakest part of the track. In order to provide provision for expansion and contraction of rails due to variation in temperature, certain gap is provided at each joint.

It has been observed that joints need about 30% extra maintenance than the plain track.

Discuss the ill effects of rail joints:

(1) Maintenance Effort: Due to impact moving loads on joint -

(a) Packing under sleeper loosens.

(b) Geometry of track gets distorted very quickly.

(c) Joint requires frequent attention.

(2) Life span:

- Life of track components gets adversely affected due to extra stresses created by impact of moving loads on rail joint.

- Rail ends particularly battered and hogged.

- chances of rail fracture at joints are considerably high due to fatigue.

(3) Noise Effect:

- A lot of noise pollution is created due to rail joints making rail travel uncomfortable.

(4) Sabotage chances:

- Wherever there is a rail joints, there is a potential damages of the removal of fish plates and rails by the mischreants and greater susceptibility to sabotage.

(5) Impact on quality:

- Quality of track suffers because of excessive wear and ~~and~~ tear of track components and rolling stock caused by rail joints.

(6) Fuel consumption:

- Presence of rail joints results in increased fuel consumption because of extra effort.

2010

What are the requirements of an ideal rail joint?

1. It should hold both rail ends in their precise location in horizontal as well as vertical planes to provide as much continuity in track as possible.

2. It should have same strength and stiffness as parent rails if joins together.

3. It should have provide an expansion gap for free expansion and contraction of rails caused by changes in temperature.

4. It should provide flexibility for easy replacement of rails, whenever required.

5. It should be capable to adjust the surface contact between the rails and fish plates,

6. The initial cost of the joint and its maintenance cost should be minimum.

7. The maintenance should be easy.

8. It should be durable.

2010, 08

Welding of Rails: (Short Note)

The process of uniting two pieces of similar metal or adding extra metal to build up on existing pieces of metal in rails is called welding of rails.

purpose of welding:

(i) To join rail ends together by application of heat and thus eliminate evil effect of rail joints.

(ii) To achieve economy in maintenance of track

(iii) To repair wornout or damaged rails.

(iv) To build up wornout points and crossings.

(v) To build up burnt portion of rail head.

Advantages:

(i) It reduces the number of joints and increases life of rail.

(ii) It considerably reduces creep of rails.

(iii) It reduces amount of expansion due to temperature variation.

(iv) It provides comfort to passengers.

(v) It decreases the risk of sabotage.

(vi) It offers more stability to the track.

(vii) It reduces construction cost.

(viii) It gives facilities track circuiting on electrical tracks.

Methods that used in welding of rails:

(i) Gas pressure welding.
(ii) Electric or metal arc welding.
(iii) Flash butt welding.
(iv) chemical or thermit welding.

2012, 2007
11 What are the requirements of Ideal Fastenings:

1. It should be cheap and durable
2. It should be easy to fix and adjust.
3. It should be capable to absorb shocks and vibrations.
4. It should be capable to protect sleeper from action of vertical and horizontal forces.
5. It should give sufficient insulation to electrified track.
6. It should be capable to resist creep.
7. It should be able to resist corrosion.
8. It should contain less number of compartments.
9. It should have sufficient strength to resist damage due to derailment.
10. It should not affect rail or sleeper adversely in anyway.

Devices that used as Fastenings:

Following devices are used to connect rails and sleepers together to form track:

(i) Fish plate.
(ii) Fish bolt.
(iii) chairs.
(iv) Bearing plates.
(v) Keys.
(vi) Spikes.
(vii) Pandrol clip.
(viii) spring steel clip.

Write short note on: Fish Plates class Test

The plate which is used to attach a rail joint with the help of fish bolts.

The bearing capacity of fish plate should be high.

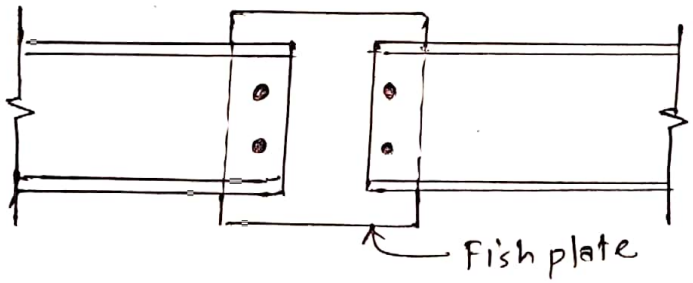


Fig. Fish plate

Track Alignment and Surveying

2016, 14, 13

Define Track Alignment.

- Marking the position of center line on ground and giving direction to railway track is known as alignment of the railway track.

- The alignment of the railway track comprises of two components:

(i) Horizontal components: It includes:

(a) straight path
(b) width
(c) curves and deviations etc.

(ii) vertical components: It includes:

(a) Changes in vertical curves.
(b) changes in gradient.

- Both components play a vital role in determining the alignment of a railway track.

- Improper alignment would result:

(i) increase in construction cost.
(ii) increase in maintenance cost.
(iii) increase in vehicle operation cost.
(iv) Increase in accident rate.

What are the basic requirements of a good alignment?

1. Purpose of opening new track:
   (i) Good Transportation facilities.
   (ii) strategic consideration.
   (iii) To connect industrial centers.
   (iv) To open up new track.
   (v) shortening the existing distance.
   (vi) To join ports with trade centers.
   (vii) To increase trade between developed areas.

2. Feasibility: The alignment should be easy to construct and maintain the track, operation of vehicle with easy gradients.

3. Economy: It should be economical for total cost i.e. initial cost, maintenance cost, vehicle operation cost in railway track.

4. safety: It should be safe for the traffic, construction and maintenance.

5. Aesthetic aspects: It should be aligned through beautiful natural sorroundings to provide pleasant and comfortable journey to the passengers.

2016, 13, 14, 11, 08

Discuss the factors which control the alignment of a rail way track.

1. Obligatory Points:

(a) The points through which alignment must pass: important intermediate towns, site of the bridge, site for tunnel, mountain pass etc.

(b) The points through which alignment should not pass: fertile lands, religious places, flooding area, heavy snowfall areas etc.

2. Traffic:

- The alignment should suit traffic growth.
- It should be suited carefully the impact of traffic growth.
- It should pass through thickly populated areas.

3. Geometric Design: The followings should be made carefully:

(i) Gradient should be below 3% as Normal or rulling gradient.

(ii) curves should be of minimum possible radii

(iii) curves near stations and on bridges should be avoided.

(iv) A long straight portion of minimum 30 m length should be provided between two reverse curve.

4. Topography:

- valley alingnment
- cross country alignment
- Mountain alignment. It includes - (i) by zig zag development. (ii) by switch back development. (iii) by spirals or complete loop development

5. Economy: Alignment construction cost, maintenance cost and vehicle operation cost should be minimum.

6. Other considerations:

(i) Marshly track should be avoided.
(ii) Excessive cutting should be avoided.
(iii) High embankment should be avoided.
(iv) water logged areas should be avoided. etc.

Discuss the surveys for railway track alignment.

1. Traffic survey: It includes:

(i) General characterestics of country
(ii) Population, industry, towns, villages
(iii) Location of existing structures, markets, industries. etc.
(iv) Estimation of traffic volume.
(v) Possibility of development of natural resources.
(vi) places of Tourism etc.

2. Reconnaissance Survey: It includes:

(i) Physical features of country, river, streams etc.
(ii) Type of soil.
(iii) Topography.
(iv) sources of water.
(v) Approximate elevation and depression on land.
(vi) climate conditions. etc.

3. Preliminary survey: Following works are carried out:

(i) Field work,
(ii) Office work.
(iii) Plane Table surveying.
(iv) levelling of the area.

4. Location survey: Following points are marked:

(i) Demarcation of land width.
(ii) Center line of tunnels.
(iii) center line ways of culverts.
(iv) Geological data along the alignment.
(v) Contour plan in details of the area surveyed.

Geometric Design of Railway Track

Discuss different types of Gradient.

There are four types of gradient used in railway track. They are discussed below:

1. Rulling Gradient: 2013

- Rulling gradient is the steepest gradient that exist in a section.
- It determines the maximum load that can be hauled by a locomotive on that section.
- severity of gradient, length and position to be taken in to considerations.
- power of locomotive to be put in to service also play's an important role:

  in plain terrain: 1 in 150 to 1 in 250

  in hilly terrain: 1 in 100 to 1 in 150

- once rulling gradient is specified for a section, all other gradients provided should be flatter making due to compensation of curvature.

2. Pusher or Helper Gradient:

- In hilly areas, to reduce overall cost a reduced length of railway line with gradients steeper than rulling gradient are provided.

- In such situations, one locomotive is not adequate to pull entire load load and an extra locomotive is required.

- when gradient is so steep as to necessiate use of an extra engine for pushing train, known as a pusher or helper gradient.

- Example: Darjeeling Himalayan Railway section.

3. Momentum Gradient:

- It is steeper than rulling gradient
- It overcomes by a train because of momentum, it gathers while running on section.
- In valleys, a falling gradient is sometimes followed by a rising gradient.
- In such a situation, a train coming down a falling gradient acquires good speed and momentum which gives additional kinetic energy to negotiate gradient steeper than ruling gradient.
- In sections with momentum gradient, no obstacles are provided in form of signals etc.

4. Gradients in station yards:

- Gradients in station yards are quite flat due to:

(a) prevent standing vehicles from rolling and moving away from yard by combined effect of gravity and strong winds.

(b) Reduce additional positive forces required to start a locomotive to extent possible.

- yards are not levelled completely and certain flat gradients are provided in order to ensure drainage.

- Maximum gradient prescribed in station yards is 1 in 400 and minimum gradient is 1 in 1000.

2011

Write short note on: Super elevation or Cant

The difference in height between inner and outer rail on curves is called the super elevation or cant in railway track.

It is provided by gradually rising outer rail above level of inner rail.

Inner rail is also known as gradient rail, is taken as reference rail and is normally maintained its original level.

Functions:

- provides better load distribution on two rails.
- provides smooth running of train on curves.
- reduces wear and tear of rails and rolling stock.
- It neutralises the effect of lateral forces.
- It prevents derailments and reduces creep.

2017, 16

Write short note on: Equilibrium Superelevation

To counteract the effect of centrifugal force, outer rail on curve is elevated with respect to inner rail by an amount equal to superelevation. A state of equilibrium is reached when both wheels exerts equal pressure on rail, which is known as equilibrium superelevation.

superelevation is enough to bring resultant of centrifugal force and force exerted by weight of vehicle at right angle to plane of top surface of rail.

Write short note on: Cant Deficiency

It is the difference between the equilibrium cant necessary for the maximum permissible speed on a curve and actual cant provided there.

Limitations: It is limited due to-

(i) Higher the cant deficiency, higher the discomfort caused to the passengers.

(ii) Higher the cant deficiency, higher the unbalanced centrifugal forces.

Gauge	Cant Deficiency
BG	75 mm to 100 mm
MG	50 mm
NG	40 mm

2017, 16

Write a short note on: Cant Excess

The difference between the actual cant provided and theoretical cant required for the low speed is called cant excess.

It occurs when a train travels around a curve at a speed lower than the equilibrium speed.

Gauge	Cant Excess
BG	75 mm
MG	65 mm

2014, 13, 11

Write short Note on: Negative Super elevation

considering the following figure we get-

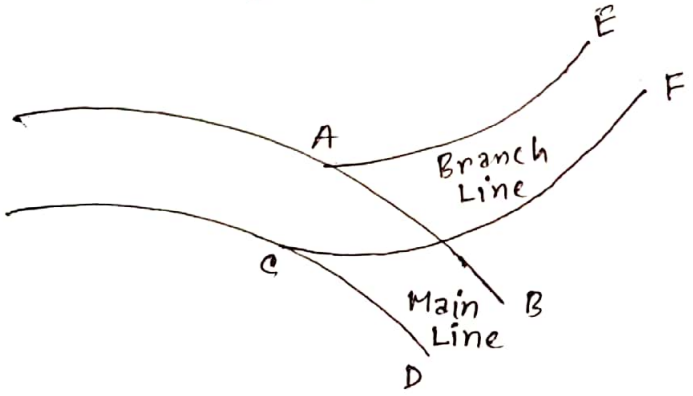


Fig. Negative Super elevation.

(i) AB & CD form the main line and AE & CF form Branch Line.

(ii) AB, outer rail of the main curve must be higher than CD.

(iii) Thus point A should be higher than C.

(iv) Similarly, for branch line CF is outer rail which is higher than AE and thus point C should be higher than A, which is contrary and impossible to satisfy both conditions simultaneously.

(v) In such conditions, a small amount of deficiency in super elevation is permitted on the branch line and speed on both tracks restricted, particularly on branch line. such super-elevation is known as Negative super elevation.

Traction and Tractive Resistance

Write short note on: Traction or, Define Traction

The source by which locomotive derives power to haul a train, is known as Traction.

It may be stream traction, diesel traction or electric traction.

What is Tractive Resistance:

When a train is in motion, there are various forces which offer resistance to the movement and speed of train such as:

(i) Train resistance
(ii) Resistance due to track profile
(iii) Resistance due to starting and acceleration
(iv) wind resistance.

Therefore, tractive force developed by the locomotive should be adequate to over come these resistances and haul the train at a specific speed.

Class Test

Write short note on: Hauling capacity of a locomotive

Hauling capacity of a locomotive is the product of co-efficient of friction and weight on driving wheel.

- co-efficient of friction depends on -
  (i) speed of locomotive
  (ii) condition of rail surface.

- Higher the speed of the locomotive, lower will be the co-efficient of fraction.

- If the rail surface is very smooth, co-efficient of friction will be very low.

∴ Hauling capacity = $n \times w \times \mu = W\mu$

where, n = number of pairs of driving wheels.

w = weight exerted on one driving wheel.

W = Total loads on driving wheels.

μ = co-efficient of friction.

- Hauling capacity varies from $\frac{1}{8}$ to $\frac{1}{4}$ of the total loads on driving wheels. (W)

Creep of Rail

2017, 16, 12

Write short note on: Creep of Rail

Creep may be defined as the longitudinal movement of the rails in a track in the direction of the locomotives.

It is common to all railway track, but varies considerably in magnitudes.

creep occurance may be noticed by-

(i) closing of successive expansion spaces at all rail joints in direction of creep and opening out of joints at the point from where creep starts.

(ii) Marks on rail flanges and webs made by spike heads due to scratching as the rails slide.

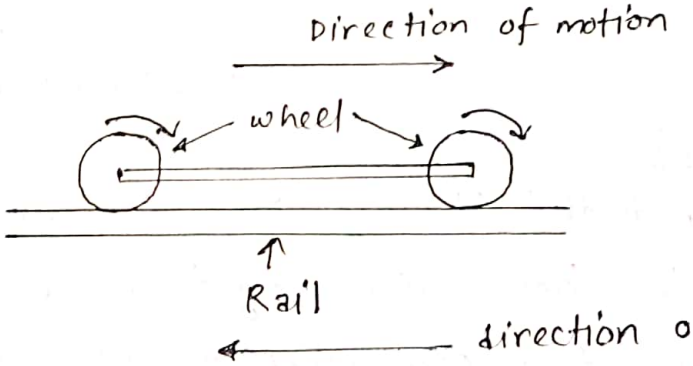


Fig. Creep During Starting.

Discuss the different theories of creep of rail

1. Wave Motion Theory:

- According to this theory, wave motion is set up in resilient track because of motion causing deflection in rail under load.
- The rails generally have wavy formation.

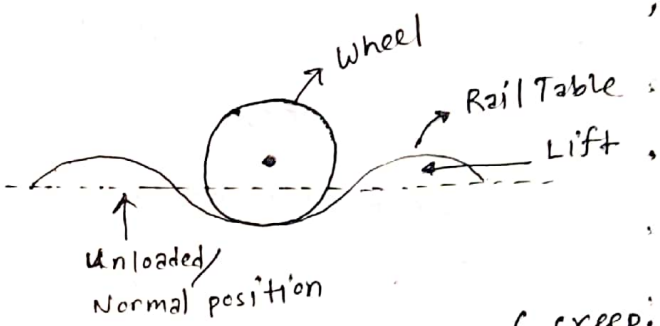


Fig. Wave theory of creep.

2. Percusion Theory:

- According to this theory creep is developed due to impact of wheel at rail end ahead a joint which push the rail longitudinally.
- Impact of a single wheel may be nominal.

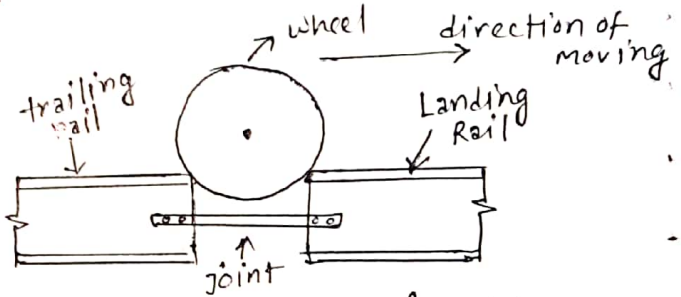


Fig. Percussion theory of creep

3. Drag theory:

- According to this theory, Backward thrust of driving wheels of locomotive has a tendency to push rail backward.
- while thrust of other wheel of locomotive and trailing wagon pushes rail in direction in which locomotive is moving.
- It results in longitudinal movement of rail in the direction of traffic, occur creep.

Write down the causes of creep.

(i) Ironing effect of the wheel.
(ii) starting and stopping operations.
(iii) Change in temperature.
(iv) Unbalanced Traffic.
(v) Poor maintenance of track.

Discuss the effect of creep.

(i) sleeper out of square.
(ii) Expansion gaps get disturbed.
(iii) Distortion of points and crossing.
(iv) Difficulty in changing rails.
(v) Effects of interlocking.
(vi) Possible buckling of track.
(vii) Other effects such as breaking of bolts and kinks etc.

How Adjustment of creep can be done.

(i) pulling back of rails.
(ii) use of anchores.
(iii) use of steel sleepers.
(iv) Increase in sleeper density.

Rolling Stock of Rail way

Write short note on: Arrangement of wheel

The arrangement of wheel is denoted by a special notation of three numbers as shown in figure below:

Meaning of 4-10-2:

1. The first number indicates the number of idle wheels in front of driving wheel.

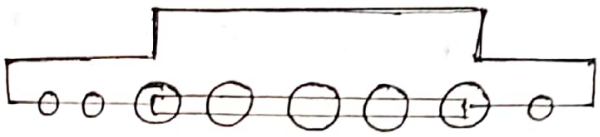


Fig. 4-10-2 locomotive

2. The middle number indicates the number of driving wheel.
3. The last number indicates the number of idle wheel after driving wheel.

Mention the salient features of Air conditioned coaches:

(i) Ash trays, magazine and hangers are provided in sufficient numbers.
(ii) Lights are arranged in a better way.
(iii) Coach is dust proof.
(iv) Size of window is kept quite large.
(v) To eliminate glare, outside glasses are tinted.
(vi) The size of bunks is quite large.
(vii) Toilet, bathroom and dressing room are attached to each other.
(viii) The design of each coach is made artistic.

Write short note on: Train Brakes

- To stop a moving train brakes are provided in a locomotive.
- Brakes are of following types: (i) Hand brakes (ii) steam brakes (iii) continuous automatic brakes.
- To stop locomotive it self only, hand brakes and steam breaks are used.
- To stop trains running at very high speed, continuous automatic brakes are used.

Stations and Yards

Define Rail-way station:

Station is a place on a railway line where trains are stopped for the passengers to enter or detrain and an authority to proceed is given to the train.

write down the functions of railway station

(i) To exchange of passengers.

(ii) To exchange of goods.

(iii) To control the movement of goods.

(iv) To take fuels and water for locomotive.

(v) To charge locomotive and running staff.

(vi) To attach and detach wagons and compartments.

(vii) To sort of bogies to form new train.

(viii) To facilate the trains on a single line track to cross from the opposite direction.

2018, 16, 15, 14

state the factors that influence/affect the selection of site for a railway station.

(i) The proposed site should be on a fairly level ground with good drainage facilities.

(ii) At the proposed site, portable water in sufficient quantities should be avaiable.

(iii) It should be near a town or big village.

(iv) sufficient area for future development must be avaiable.

(v) It should not situated on the curve of a railway line.

(vi) It should be able to serve needs of civil and military authorities.

(vii) The site should be such that permissible maximum gradient could be attained easily.

2015

write short note on: Marshalling yard

Marshalling yard is the place where goods wagons recieved from different centers are sorted out and placed in order to be detached at different stations. Empty wagons are also kept in marshalling yards.

2010, 06

write short note on: Level crossing:

When a railway line and a road surface meet at the same level, it is called crossing.

The road surface is kept at rail level and yards are kept along the road surface with the help of gaurd rail spiked to wooden sleepers.

Classifications:

1. special Class – where traffic is heavy.
2. A-Class – provided on metal roads.
3. C-Class – provided on unmetal roads.
4. D-Class – provided on cattles as ramps and pedestrian only.

Stations Equipment

2012

Write short notes on: Water Column

- It is provided to all main lines for supply water to locomotive.
- stations in which water columns are provided, known as watering stations.
- The distance between watering stations should not be more than 50 km.
- It is usually composed of two main parts:
  - (a) A vertical 4.92 m high column
  - (b) 2.25m long horizontal arm connected to the vertical column at top.

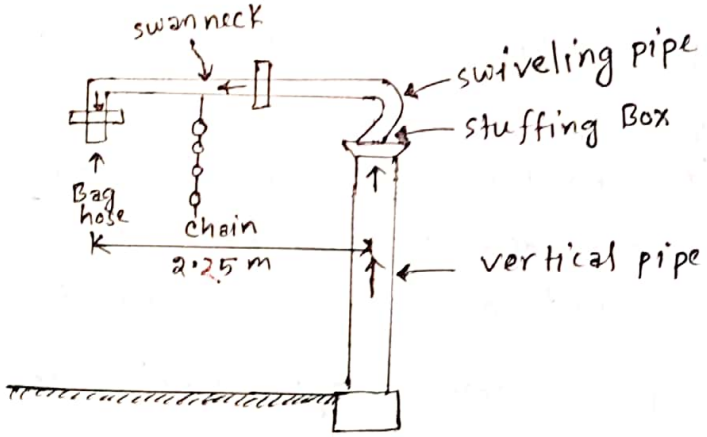


Fig. Water Column.

Write short note on: Triangle

- It is constructed to change the direction of locomotives.
- It needs large area but less cost than turn table.
- It is constructed at there, where sufficient land is avaiable.
- It is more useful on unimportant stations where installation of turn table is unjustified.
- In Triangle Three pairs of points and crossing are seen.

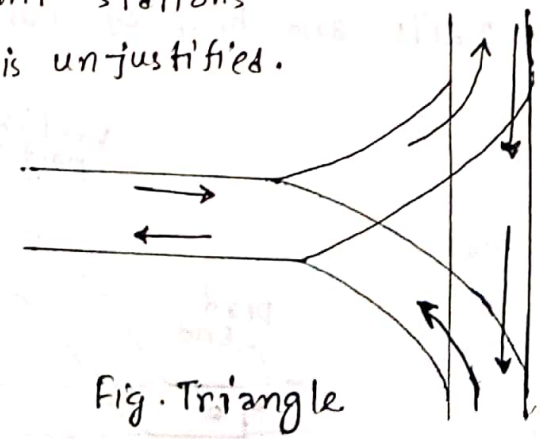


Fig. Triangle

Write short note on: Turn Table

- It is so costly
- It is a device used for changing direction of Locomotives.
- It is being costly installed in important stations.
- It is circular in shape and installed in a circular conical pit.
- The girder are supported at the central pivot
- Maximum size of locomotive is used.

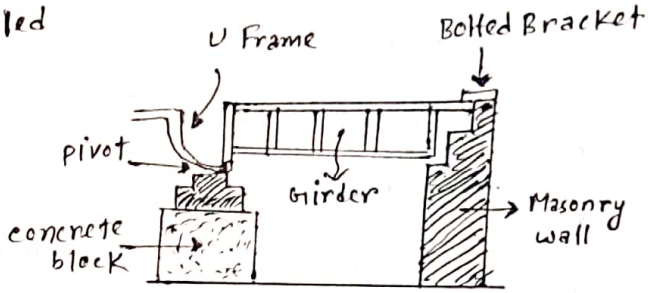


Fig. Turn Table.

- To drain off water, a suitable slope should be given on the bottom of the turn table.

2012, 13, 14, 15, 17, 18

Write short note on: Buffer Stops

- It is provided at dead ends of sidings or terminals to prevent movement of vehicles beyond dead ends.
- It is a simple type, consists of a timber beam of 30cm×10cm, section.
- Buffering beam held in horizontal position at buffer level of vehicle by a vertical post
- vertical posts are fixed to rails by suitable arrangements.
- For providing additional safety to beams and posts, bent rails and heave of earth is also provided.

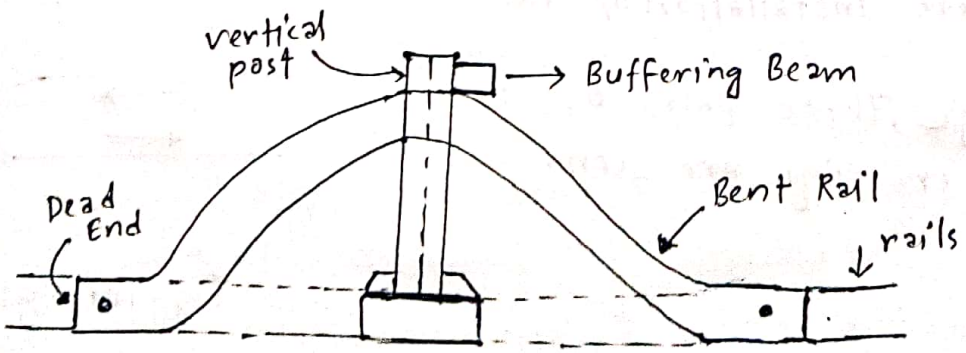


Fig. Buffer Stops.

2018, 17, 16, 15, 14, 13, 12, 11

Write short note on: Fouling Marks

- When two tracks coverage at a point, center to center distance between tracks constantly goes on decreasing.
- Ultimately, center to center distance becomes zero at point of crossing.
- A vehicle standing at a point where distance between tracks is less than the minimum strike, vehicle will pass on the next track. such points beyond which the center to center distance between tracks is less than the minimum strike are marked as Fouling Mark
- It is made of concrete or stone blocks.
- For proper visibility at night, it will be painted with black and white.

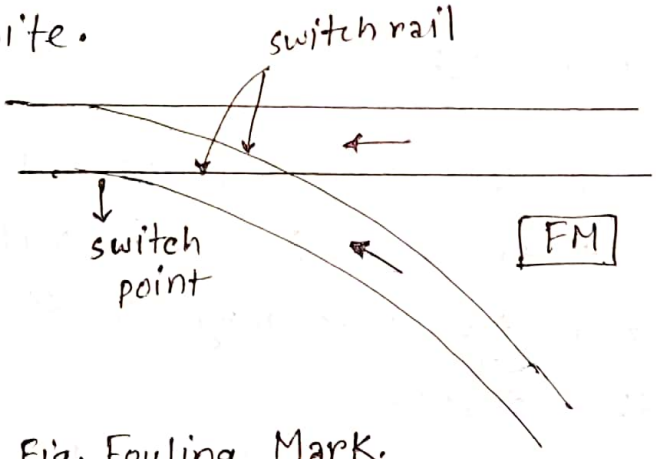


Fig. Fouling Mark.

Points, Crossings and Simple Lay out

Discuss the reasons for providing points & crossing on railway track.

(i) It is provided to facilitate change of railway vehicle from one track to another.

(ii) Tracks may be parallel, diverging or converging to each other

(iii) It is necessary due to inside flanges of wheel of railway vehicle.

(iv) crossing provide the gap in the rails to be crossed by flanged wheel.

(v) Points are suited aid to diverging the vehicle.

Write short note on:

- **Turn Out:** A complete set of points and crossing along with lead rails is known as turn out. With the help of this arrangement rolling stock may be diverted from one track to another track.

A turn out is designated as right hand turn out or left hand turn out depending upon whether the rolling stock is diverted to right or left by the turnout.

- **Switch:** 2010

. The switch is defined as the device used to divert the railway vehicles from one track to another track.

-A pair of tongue and stock rail with necessary connection and fittings form a switch.

- Tappered end of the tongue rail is called toe and thicker end is called heel of switch.

- **switch Angle:**

- The angle formed between the gauge face of the stock rail and that of tongue rail at the theoretical toe, of the switch in its closed position, is known as angle of switch.

- It is the function of the heel divergence and the length of the tongue rail.

- It is also called switch divergence.

- **Throw of switch:**

The distance or gap through which tongue rails moves laterally at toe, of the switch for movement of trains, is known as throw of switch.

2011

- **Check Rail or, Guard Rail:**

To guide the flange of wheels of vehicles so that they do not strike against nose of crossing while moving in a a facing direction length 365-610 cm.

- **Curve Lead:**

The distance between tangent point and the theoretical nose of crossing (TNC) measured along the length of the track is called curve lead.

- **Switch lead:**

The distance between the tangent point and the heel of the switch measured along the length of the track is called switch lead.

- **Lead of crossing:**

The distance between the theoretical nose of crossing (T.N.C) and the heel of the switch measured along the length of the main track is called lead of crossing.

- **Heel divergence:**

- The distance between the gauge faces of the stock rails and tongue rails at the heel, is called Heel divergence.
- It is the sum of tongue rail heel width at heel and flange way clearence.

- **Flange way clearence:**

- The distance between the adjoining face of running rails and check rails.
- It is provided so that the flange can move easily.

Signalling and Interlocking

2012, 09, 06

What do you mean by Signalling?

The device by which the movement of trains is controlled, is known as signalling.

2012, 09, 06

Write down the objectives of signalling.

(i) To provide safety to passenger, staff and rolling stock

(ii) To provide facilities for efficient movement of train.

(iii) To maintain a safe distance between trains running on the same line in the same direction.

(iv) To give directional indications at divergent junctions.

(v) To provide facilities for the maximum utility of the train.

(vi) During maintenance and repair operations, to run trains at restricted speeds.

2012, 09, 06

Write down the classification of signalling which are based on the rail way track.

- According to function: (i) stop signals
  (ii) warner signals.
  (iii) Disc signals.
  (iv) coloured light signals.

- According to the location: (i) outer signal.
  (ii) Home signal.
  (iii) starter signal.
  (iv) Advance starter signal.

- According to specific purposes: (i) Routing signal.
  (ii) Repeater signal.
  (iii) Shunting signal.
  (iv) Call on signal.
  (v) Miscellaneous signal.

- According to operational signal: (i) Hand signal.
  (ii) Fixed signal.
  (iii) Dectonating signal.

2018, 08, 06

Draw a neat sketch of a Semaphore signal and Explain it's working principle.

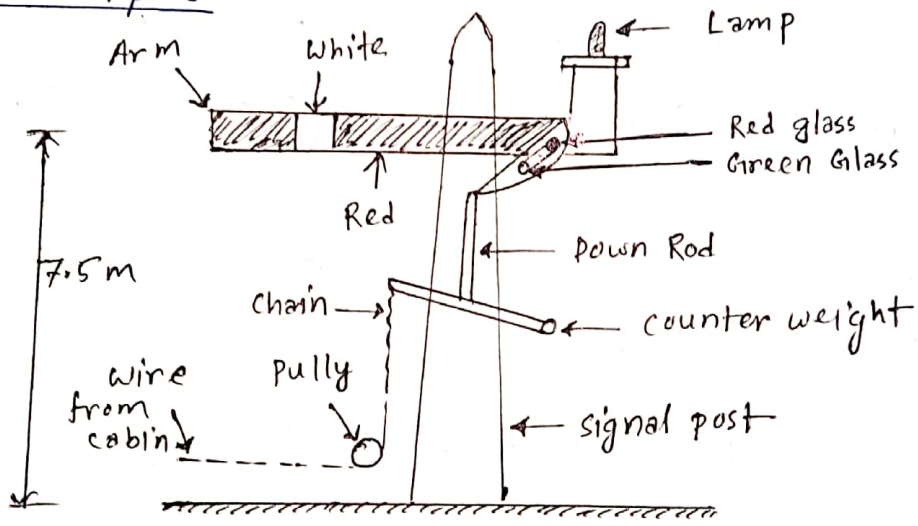


Fig. semaphor signal

working principle:

- The semaphore arm can take up two positions namely: (i) Horizontal and, (ii) Inclined position.
- The normal position of the signals is horizontal and it can be lowered by pulling wire from signal cabin.

- In horizontal position, signal indicates 'Danger stop' and it is said 'on position'

- when the arm is lowered at an angle of 40° to 60° with the horizontal, it indicates 'clear proceed' and it is said 'off position'.

- At night, light of lamp passing through spectacles gives signals.

- when arm is in horizontal position, red spectacle remains before lamp, and when arm is inclined, green spectacle remains before lamp.

- Red light indicates danger and green light indicates line clear.

Write short note on: Automatic signalling

- To avoid accidents due to human elements, automatic signalling has been found out.

- In this system, signals are operated by train themselves.

- when a train occupy a particular track, an electric current is passed through track. This current puts signals at danger position till train reaches a safe distance ahead.

- It requires no further protection in that section.

2018, 13, 12, 11

Write short note on: Interlocking

The mechanical connections established between various levers operating signals and points in such a way that the working of signal mechanism may not go contrary to the desired purposes, is known as Interlocking.

Interlocking device avoids the possibility of pulling wrong levers and prevents confusion in lowering the signals and avoids accidents.

2018, 16, 15, 14, 13, 12, 11, 10

Write short note on: Compensator

Objectives: To neutralise the effect of temperature change, compensators are used.

Construction: It consists of two cranks connected by pipe. one crank is acute angled and the other is obtuse angled.

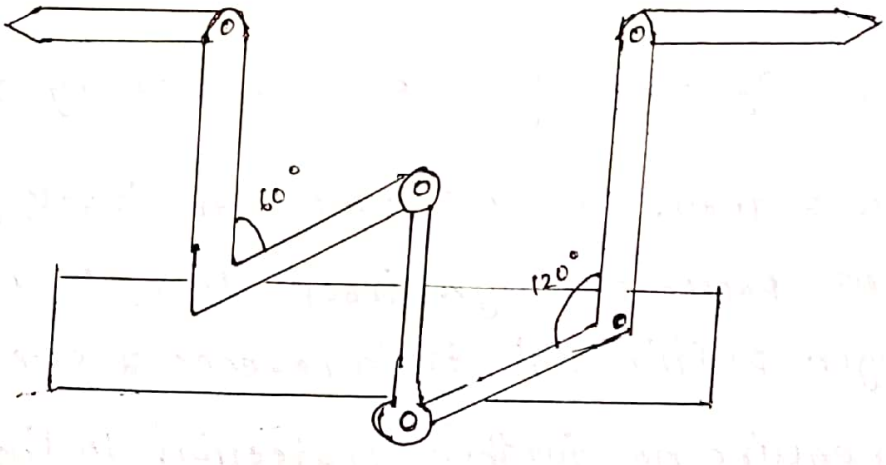


Fig. Compensator

working principle:

Compensator are installed to compensate the change in the length of wires used in the signal connections due to change in temperature.

Due to change in length, transmission rod may cause pull or push on locks, thus neutralise the effect of temperature change.

2015 Write short note on: Coupled Wheel

In coupled locomotives, a driving wheel is driven by locomotive's pistons and driving wheels are all coupled together with side rods.

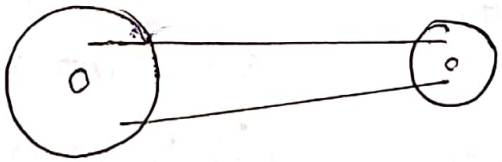


Fig. coupled wheel.

Maintenance and Accidents

2014, 13, 08, 06

Why is the maintenance of railway track is necessary?

- For new track:

(i) Newly laid railway track settles down slowly

(ii) To bring the embankment to proper formation, level maintenance is essential.

- For old track:

(i) Due to constant use of railway track, considerable wear and tear takes place. Thus proper maintenance is essensial.

(ii) To of track at a great extent.

2014, 13, 08, 06

List the various items of maintenance.

(i) surface of rail.

(ii) Track alignment.

(iii) Gauge.

(iv) Track components.

(v) Proper Drainage.

(vi) Bridge and its approaches.

(vii) Rolling stocks.

(viii) Points and fastenings.

(ix) Level crossing

(x) Tunnel, if any.

2015, 14, 13, 08, 06

What are the causes of accidents on railway?

Any occurance which affects or may affect the normal working of railway is called an accident. It may affect the safety of engine, rolling stock, permanent way, passengers or staff also.

causes:

(i) Human failure:

- Drivers running at excessive speeds.
- Drivers passing signals at danger position.
- Majority of accidents under this head occur due to error in judgement, fatigue, over work, negligence etc.

(ii) Natural causes:

- Breaches due to wash out of tracks
- Land slides.
- submergence under water due to heavy flood.
- Failure or washing away of bridges.

(iii) sabotage:

- Anti social elements sabotage trains for robbing passengers and looting goverment cash and valuable parcel, goods etc.
- Removal of fish plates and displacement of rails is most common mode of sabotage.

(iv) Level crossing accident:

- Gate man's failure to close the gates in time, when the train is coming.
- Drivers of road vehicle are not vigilant for the approaching trains.

(v) Miscellaneous causes:

- Defective maintenance of track
- Failure of brakes etc.

Railway Track

2017, 16, 14, 11, 12

For 1 Km length of BG Track ; Estimate the (i) Number of rails (ii) Number of sleepers (iii) Number of fish plate (iv) No. of fish bolt (v) No. of Bearing plate (vi) weight of rail

Solution:

For BG railway Track of 1 Km long,

(i) No. of rails per Km length $= \frac{1000}{\text{rail length}} \times 2$

$= \frac{1000}{13} \times 2$ → Even Number

$= 153.85 \simeq \boxed{154}$ Nos.

(ii) No. of sleepers per Km length $= \frac{\text{No. of rails per Km}}{2} \times \text{sleeper density}$

$= \frac{154}{2} \times (13+7)$

$= 1540$ Nos.

(iii) No. of fish plates per Km length = No. of rails × 2

$= (154 \times 2) = 308$ Nos.

(iv) No. of fish bolts per Km length = No. of rails × 4

$= (154 \times 4) = 616$ Nos.

(v) No. of bearing plate per Km length = No. of sleepers × 2

$= (1540 \times 2) = 3080$ Nos.

(vi) weight of rail per Km length = No. of rails × length of rail × weight of rail per unit length

$= (154 \times 13 \times 60)$ Kg

$= 120120$ Kg (Ans.)

2010

For a MG railway track, Estimate the quantity of materials required for 1 Km. track.

Solution: For MG railway Track of 1 Km long,

(i) No. of rails per Km length $= \frac{1000}{\text{Length of rail}} \times 2$

$= \frac{1000}{12} \times 2$

$= 166.67 \simeq 168$ Nos.

(ii) No. of sleepers per Km length $= \frac{\text{No. of rails}}{2} \times$ sleeper density

$= \frac{168}{2} \times (12+4)$

$= 1344$ Nos.

(iii) No. of fish plates per Km length = No. of rails $\times 2$

$= (168 \times 2) = 336$ Nos.

(iv) No. of fish bolts per Km length = No. of rails $\times 4$

$= (168 \times 4) = 672$ Nos.

(v) No. of bearing plates per Km length = No. of sleeper $\times 2$

$= (1344 \times 2) = 2688$ Nos.

(vi) Weight of rail per Km length = No. of rails $\times$ length of rail $\times$ weight of rail per unit length

$= (168 \times 12 \times 60)$ Kg

$= 120960$ Kg

(Ans.)

2017

Calculate the number of nails, sleepers, fish plates and fish bolts for 1300m. B.G. railway track.

Solution: For B.G. railway track of 1300 m long,

(i) No. of rails $= \frac{1300}{13} \times 2 = 200$ Nos.

(ii) No. of sleepers $= \frac{200}{2} \times (13+7) = 2000$ Nos.

(iii) No. of fish plates $= (200 \times 2) = 400$ Nos.

(iv) No. of fish bolts $= (200 \times 4) = 800$ Nos.

(Ans.)

Sleepers

2012

Find out the number of sleepers required for 700 Km. long broad gauge railway track.

Solution:

For 1Km B.G. track,

no. of rails per Km length $= \frac{1000}{13} \times 2$

$= 153.85 \simeq 154$ Nos.

$\therefore$ No. of sleeper per Km length $= \frac{154}{2} \times (13+7)$

$= 1540$ Nos.

Hence, For 700 Km B.G. Track,

No. of sleepers $= (1540 \times 700) = 1078000$ Nos.

(Ans.)

Geometric Design

Calculate super elevation and maximum permissible speed for 2° B.G. Transition curve on a high speed route having a maximum sanctioned speed of 110 kmph. The speed for calculating the equilibrium super elevation. The speed has given as 80 Kmph and the booked speed for goods traffic is 50 Kmph.

For B.G., $G_1 = 1750$ mm
For M.G., $G_1 = 1058$ mm
For N.G., $G_1 = 772$ mm

Solution:

(i) The radius for 2° curve,

$$R = \frac{1750}{\text{degree}} = 875 \text{ m}$$

(ii) super elevation for equilibrium speed, (80 Kmph)

$$e = \frac{GV^2}{127R} = \frac{1750 \times 80^2}{127 \times 875} = 100.79 \text{ mm}$$

(iii) Super elevation for maximum sanction speed, (110 Kmph)

$$e = \frac{GV^2}{127R} = \frac{1750 \times 110^2}{127 \times 875} = 190.55 \text{ mm}.$$

*MG 50 mm

$\therefore$ Cant deficiency $= (190.55 - 100.79) = 89.76$ mm < 100 mm.

Hence, $C_d = 89.76$ mm (safe and permissible)

and, $C_a = 100.79$ mm

(iv) super elevation for goods traffic, (50 Kmph)

$$e = \frac{GV^2}{127R} = \frac{1750 \times 50^2}{127 \times 875} = 39.37 \text{ mm}$$

*MG 65 mm

$\therefore$ cant excess $= (100.79 - 39.37) = 61.42$ mm < 75 mm.

Hence permissible

(v) Maximum permissible or safe speed on curve,

$$V = 0.27\sqrt{(C_a + C_d)R} = 0.27\sqrt{(100.79 + 89.76) \times 875}$$

$$\therefore V = 110.25 \text{ Kmph}$$

* For M.G. $V = 0.374\sqrt{(C_a + C_d)R}$

(vi) Maximum permissible speed over the curve will be the least of the following:

(a) Maximum sanctioned speed = 110 Kmph

(b) Maximum or safe speed over the curve = 100.25 Kmph

∴ Maximum permissible speed = 110 Kmph.

Answer: (i) super elevation to be provided = 100.79 mm ≃ 101 mm

(ii) Maximum permissible speed = 110 Kmph

Calculate the super elevation and maximum permissible speed and transition length for a 3° curve on a high speed BG track with following data:

(i) Maximum sanction speed = 110 Kmph

(ii) Equilibrium speed = 80 Kmph

(iii) Booked speed of goods train = 50 Kmph,

Solution:

(i) The radius for 3° curve, $R = \frac{1750}{3} = 583.33$ m

(ii) The super elevation for equilibrium speed (80 Kmph)

$$e = \frac{GV^2}{127R} = \frac{1750 \times 80^2}{127 \times 583.33} = 151.18 \text{ mm}$$

(iii) superelevation for maximum sanction speed (110 Kmph)

$$e = \frac{1750 \times 110^2}{127 \times 583.33} = 285.83 \text{ mm}$$

$\therefore$ cant deficiency $= (285.83 - 151.18) = 134.65$ mm > 100mm

Hence, $C_d = 100$ mm

$\therefore$ Actual cant, $C_a = (285.83 - 100) = 185.83$ mm > 165 mm

Hence, $C_a = 165$ mm

(iv) super elevation for goods train, (50 Kmph)

$$e = \frac{1750 \times 50^2}{127 \times 583.33} = 59.06 \text{ mm}$$

$\therefore$ cant excess $= (165 - 59.06) = 105.94$ mm > 75 mm

Hence, cant excess $= 75$ mm.

Actual cant now to be provided,

$$C_a = (75 + 59.06) = 134.06 \text{ mm} \simeq 135 \text{ mm}$$

$\therefore C_a = 135$ mm

$C_d = 100$ mm

$R = 583.33$ m

(v) safe speed, $V = 0.27\sqrt{(C_a + C_d)R} = 0.27\sqrt{(100+135)\times 583.33}$

$= 99.97$ kmph $\simeq 100$ kmph

(vi) Maximum permissible speed on curve is least of the following:

(a) Maximum sanctioned speed = 110 kmph

(b) Safe speed on curve = 100 kmph

∴ Maximum permissible speed = 100 kmph

(vii) Length of Maximum transition: (maximum of the following)

(a) Rate of change of cant consideration,

$$L = \frac{C_a \times V_m}{125} = \frac{135 \times 100}{125} = 108 \text{ m}$$

(b) Rate of change of cant dificiency consideration,

$$L = \frac{C_d \times V_m}{125} = \frac{100 \times 100}{125} = 80 \text{ m}$$

(c) consideration of cant gradient 1 in 720,

$$L = \left(0.72 \times \frac{135}{C_d}\right) = 97.2 \text{ m}$$

∴ Length of transition = 108 m

(Ans.)

2017, 2016

calculate the super elevation and maximum permissible speed for a 3° curve on high speed B.G. track with a maximum sanctioned speed of 130 Kmph. Assume the equilibrium speed to be 80 Kmph and the booked speed of goods train to be 50 Kmph. Also calculate transition length for the curve.

Solution:

Radius of curve, $R = \frac{1750}{\text{Degree of Curve}} = \frac{1750}{3} = 583.33\ m$

super elevation for equilibrium speed (85 Kmph)

$$= \frac{GV^2}{127R} = \frac{1750 \times 85^2}{127 \times 583.33} = 170.67\ mm$$

super elevation for maximum sanction speed (130 Kmph)

$$= \frac{GV^2}{127R} = \frac{1750 \times 130^2}{127 \times 583.33} = 399.21\ mm$$

$\therefore$ cant deficiency $= (399.21 - 170.67) = 228.54\ mm > 100\ mm$

$\therefore C_d = 100\ mm$

actual cant, $C_a = (399.21 - 100) = 299.21\ mm > 165\ mm$

Hence, $C_a = 165\ mm$.

Super elevation for goods train, (50 Kmph)

$$= \frac{GV^2}{127R} = \frac{1750 \times 50^2}{127 \times 583.33} = 59.06\ mm$$

$\therefore$ cant excess $= (165 - 59.06) = 105.94\ mm > 75\ mm$

Hence, cant excess $= 75\ mm$

$\therefore$ Actual cant to be provided, $C_a = (75 + 59.06) = 134.06\ mm$

$\simeq 135\ mm$

Now, safe speed, $V = 0.27\sqrt{(C_a + C_d)R}$

$= 0.27\sqrt{(135+100)\times 583.33}$

$= 99.96$ Kmph

$\simeq 100$ Kmph

Maximum permissible speed on the curve is least of the followings:

(i) Max. sanctioned speed = 130 Kmph.

(ii) safe speed = 100 Kmph.

∴ Max. permissible speed on the curve = 100 Kmph

Length of the transition:

It is maximum of the followings:

(a) Rate of change of cant consideration,

$$L = \frac{C_a \times V_m}{125} = \frac{135 \times 100}{125} = 108 \text{ m}$$

(b) Rate of change of cant deficiency consideration,

$$L = \frac{C_d \times V_m}{125} = \frac{10 \times 100}{125} = 80 \text{ m}$$

(c) consideration of cant gradient 1 in 720,

$$L = (0.72 \times 135) = 97.2 \text{ m}$$

∴ Length of the transition = 108 m

(Ans.)

2015, 14

A 5° curve diverges from 3° main curve in an opposite direction in the layout of a B.G. yard. If the speed on the branch is restricted to 30 Kmph, find out the speed on the main line. Assume permissible cant deficiency as 76 mm.

Solution:

Radius of the curve, $R = \frac{1750}{\text{Degree of Curve}} = \frac{1750}{5} = 350\ m$

∴ Equilibrium super elevation,

$$e = \frac{GV^2}{127R} = \frac{1676 \times 30^2}{127 \times 350} = 33.93\ mm \simeq 34\ mm$$

Negative Cant = Equilibrium Cant − cant deficiency

$= (34 - 76) = 42\ mm$

∴ Theoretical superelevation which can be provided on the main line $= (42 + 76) = 118\ mm$.

Speed on the mainline:

We know, $e = \frac{GV^2}{127R_m}$ Here, $R_m = \frac{1750}{3} = 583.33\ m$

$\Rightarrow 118 = \frac{1676 \times V^2}{127 \times 583.33}$

$\Rightarrow V^2 = 5215.86$

$\therefore V = 72.22\ Kmph$

(Ans.)

Point, Crossings and simple Layout

2017, 15, 13, 11

Calculate various elements for B.G. Track turn out for crossing No. 1 in $8\frac{1}{2}$ in. and heel divergence 12 cm.

Solution: For B.G. Track, $G = 1676\ mm = 1.676\ m$

Given, Crossing Number, $N = 8\frac{1}{2} = 8.5$

Heel divergence, $d = 12\ cm = 0.12\ m$

(i) curve Lead, $CL = GN + G\sqrt{1+N^2} = (1.676 \times 8.5) + 1.676\sqrt{1+8.5^2}$

$\therefore CL = 28.59\ m$

From approximate method, $CL = 2GN$

$= 2 \times 1.676 \times 8.5$

$= 28.49\ m$

The difference $= (28.59 - 28.49) = 0.1\ m = 10\ cm$

(ii) Radius, $R = R_o - \frac{G}{2}$

Here, $R_o = 1.5G + 2GN^2 = 1.5 \times 1.676 + 2 \times 1.676 \times 8.5^2$

$\therefore R_o = 244.7\ m$

$\therefore R = \left(244.7 - \frac{1.671}{2}\right) = 243.86\ m$

(iii) switch lead, $SL = \sqrt{2R_o d} = \sqrt{2 \times 244.7 \times 0.12} = 7.66\ m$

(iv) Lead, $L = (C.L - S.L) = (28.59 - 7.66) = 20.93\ m$

(Ans.)

Calculate the various elements for BG track turnout for a crossing number $1 \text{ in } 8\frac{1}{2}$ and crossing angle is $6°42'35''$ and heel divergence = 12cm

Solution: For B.G Track, $G = 1.676$ m

Given, $N = 8\frac{1}{2} = 8.5$

$\alpha = 6°42'35''$

(i) $C.L = G \cot\left(\frac{\alpha}{2}\right) = 1.676 \times \cot\left(\frac{6°42'35''}{2}\right)$ → $\tan(90 - \frac{\alpha}{2})$

$= (1.676 \times 17.06)$ m

$= 28.59$ m

(ii) $R = R_0 - \frac{G}{2}$ Here, $R_0 = \frac{CL}{\sin\alpha} = \frac{28.59}{\sin(6°42'35'')}$

$= \left(294.7 - \frac{1.676}{2}\right)$ $\therefore R_0 = 294.7$ m

$= 293.86$ m

(iii) $S.L = \sqrt{2 R_0 d} = \sqrt{2 \times 293.86 \times 0.12} = 7.66$ m.

(iv) Lead, $L = (CL - SL) = (28.59 - 7.66) = 20.93$ m

(Ans.)

2014, 12

Find out the angle of switch and theoretical length of the switch from the following data: (i) Thickness of tongue rail at toe = 0.63 (ii) Heel divergence = 13.3 cm and (iii) actual length of tongue rail = 6.4 m.

Solution:

(i) switch angle:

we know, switch angle = $\frac{\text{Heel divergence}}{\text{length of tongue rail}}$

or, $\sin\alpha = \frac{d-t}{D}$

$\Rightarrow \sin\alpha = \frac{13.3-0.63}{640\ cm} = 0.0198$

$\therefore \alpha = \sin^{-1}(0.0198) = 1.134^\circ$ or $1^\circ 8'$

(ii) Theoretical length of switch:

$$\frac{d-t}{D_2} = \frac{d}{D_1}$$

$$\Rightarrow \frac{13.30-0.63}{640} = \frac{13.3}{D_1}$$

$$\Rightarrow D_1 = \frac{13.3}{12.67} \times 640 = 671.82\ cm$$

$$\therefore D_1 = 6.72\ m$$

(Ans.)

2018

Calculate the lead and radius of a curve for a BG track turn out for the given data:

(i) crossing number = 1 in 8.50 (ii) Heel Divergence = 12 cm and (iii) angle of switch = 1.2°

Solution:

(i) crossing lead, $L = (G-d)\cot\left(\frac{\alpha+\theta}{2}\right)$

Here, $G = 1.676$ m ; $N = 8.5$ Hence, $\alpha = 6°42'35''$

$d = 12$ cm $= 0.12$ m ; $\theta = 1.2° = 1°12'$

$\therefore L = (1.676 - 0.12) \times \cot\left(\frac{6°42'35'' + 1°12'}{2}\right)$

$= 22.5$ m

(ii) We know, $R_o = \frac{G-d}{\cos\theta - \cos\alpha} = \frac{1.676 - 0.12}{\cos 1°12' - \cos 6°42'35} = 234.7$ m

Hence, $R = R_o - \frac{G}{2}$

$= \left(234.7 - \frac{1.676}{2}\right) = 233.862$ m

(Ans.)