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INTRODUCTION

Transportation : 1m

Transportation is a system by which persons and goods can be shifted from one place to another place by any sort of vehicles.

Role of Transportation:- (1m).V.V '08

["Development of BD is depend on the development of its transportation system" – justify it.]

1. Transportation contributes to the economic, industrial and cultural development of a country.
2. The importance of transportation of a country is comparable to the veins in the human body. Just as veins, transportation keep the health of a nation in a good condition by keeping the goods and people moving from one place to another.
3. Transportation is vital for the all-round development of a nation, or region since every commodities need transportation in all stages.
4. In the production stage, transportation is needed for carrying raw materials such as seeds, manure, cotton, Coal, sugercane etc.
5. In the distribution stage, transportation required to transport finished products from farm and factories to the distribution centers.
6. Thus for the economic, cultural and social development of a country an effective and adequate system of transportation is essential.

V. V. Imp
15, 14, 13, 11, 12

⊞ Role of Transportation in rural development:

1. With over 75% of the population of the country living in the villages, the development in the urban centers alone do not indicate the overall development of the country.
2. Only with the improvement of transportation facilities in rural areas, there could be faster development of the rural centers.
3. The fertilizers and their inputs of agriculture and cottage industries could reach the rural population easily.
4. The products produced can be sold at the nearest marketing centers for more remunerative price resulting in faster economic growth and decreased wastage.
5. With improved facilities for education, health care and other social needs in the villages, the urge for the migration to urban centers decreases.
6. Thus development of rural transportation system helps in balance development of the country as a whole.

⊞ Modes of Transportation:- (Imp) V 08

1. Land Transportation.
   - 1.a. Roadways.
   - 1.b. Railways

2. Water ways → 2.a. Inland. 2.b. Coastal. 2.c. Ocean.

3. Air ways → 3.a. Domestic. 3.b. International.

4. Other ways —
   a. Pipe lines → Oil, Gas.
   b. Elevators.
   c. Belt conveyors.
   d. Cable cars.
   e. Aerial ropeways.
   f. Monorails.

Advantages and disadvantages of differents modes of Transportation:

➡ Road Transport :-

Advantages	Disadvantages.
1. Less capital outlay.	1. Seasional nature.
2. Door to door service.	2. Accident and break down.
3. Service in rural areas.	3. Unsuitable for long distance and ~~bulk~~ bulky traffic.
4. Flexible services.	4. Speed not so high.
5. Rapid speed.	5. Slow speed.
6. Cost is less.	6. Lack of organisation.
7. Saving in packing cost.	
8. Suitable for short distances.	
9. Less risk in damage.	
10. Private owned vehicles.	

➡ Railway Transport:

Advantages	Disadvantages
1. Dependable. 2. Better organised. 3. High speed. 4. Suitable for bulky or heavy goods 5. cheaper transportation. 6. Safety. 7. Larger capacity. 8. Public welfare. 9. Employment-opportunities. 10. Administrative facilities of Government.	1. Huge capital outlay. 2. Lack of flexibility. 3. Lack of door to door service. 4. Monopoly. 5. Unsuitable for short distances and small loads. 6. Booking formalities. 7. No rural services. 8. Under utilised capacity. 9. centralised administrations.

➡ Airway Transport:-

Advantages	Disadvantages
1. Speed is very high. 2. comfortable and quick services. 3. No. investment in construction of tracks. 4. Easy acces. 5. Emergency services. 6. No physical bariars. 7. National defense. 8. Spaee exploration. 9. Most suitable for light loads. 10. Quick clearences.	1. Cost is high. 2. Carrying capacity small. 3. Uncertain or unreliable. 4. Break down and aceident. 5. Large investment. 6. specialised skill. 7. Unsuitable for cheap and bulky goods. 8. Legal restrictions.

Characteristics of Road Transport :- (V.V.Imp) 15.16.19.21

1. Roads are used by various types of vehicles such as cars, buss trucks, two or three wheeled ~~automobiles~~ automobiles, pedal cycle and animal drawn vehicles.
2. Road transport requires a relatively small investment for the Government.
3. Motor vehicles are more cheaper than other carriers like railways, wagon, water and air ways vehicles.
4. Construction and maintainance of road is also cheaper than railway tracks, docks, harbours and airports.
5. Road transport offers complete freedom to road users to transfer the vehicles from one lane to other and from one road to others.
6. In particular for short distances travel, road transport saves time.
7. Road transport is subjected to high degree of accident due to flexibility of movements.
8. Road transport is the only means of transport that offers itself to the whole community alike.

Elements of Transport :- (Imp)

1. It requires adequate infrastructure facilities for station to loading and unloading the passengers and goods.
2. Common elements —
   a. vehicles ~~or~~ or carrier to carry the passengers and goods.

b. Route or path for movement of carriars.
c. Terminal facilities for loading and unloading the goods and passengers from carriars.
d. Prime mover (fuel).
e. Transite time and cost.
f. Cargo

These elements influence the effectiveness of different mode of transport and their utility.

Major disciplines of transportation :-

Four major parts;

1. Transportation planning.
2. Geometric design.
3. Pavement design.
4. Traffic Engineering.

Question: What do you mean by good system of Transportation? Is the Transportation system of Bangladesh in good Condition? - Explain.

Answer: (sheet provided by Shobhan Sir page - 01. (নং ৫)

Highway Development & Planning

Highway planing: (2m)

Highway planning is the prerequisition before attempting on for any highway development projects.

Necessity of Highway planing:- V.V.(2m) 15,14,13,09

In present era, planing is considered as a pre-requisite for any development programme. Planing is the basic requirements for any New engineering project. Thus (highway planing is also a basic need for highway development.

When the available funds are limited and the total requirement is much higher then planing is of great importance.)

Objectives of highway planing:- (V.V. 4m) 15,14,13,09

1. To plan a road network for efficient and safe traffic operation but minimum cost.
2. To arrive at the road system and the length of the different categories of road which could provide the maximum ~~use~~ utility and could be constructed within the available resources during the plan period.
3. To fix up date wise priorities for development of each road link based on utility as the main criterion for

Phasing the road development programme.

4. To plan for future requirements and improvement of roads in view of anticipated development.

5. To work out financing system.

Macadam (British) Road Construction:-

John Macadam in 1815 introduced the first scientific Road Construction method. The Macadam Road construction methods are as follows;

1. Subgrade is compacted and prepared with a cross slope of 1 in 36 up to a desired width from 4.5m to 9m.

2. Broken stones of strong variety, all passing through 5cm sieve were compacted to a uniform thickness of 10cm.

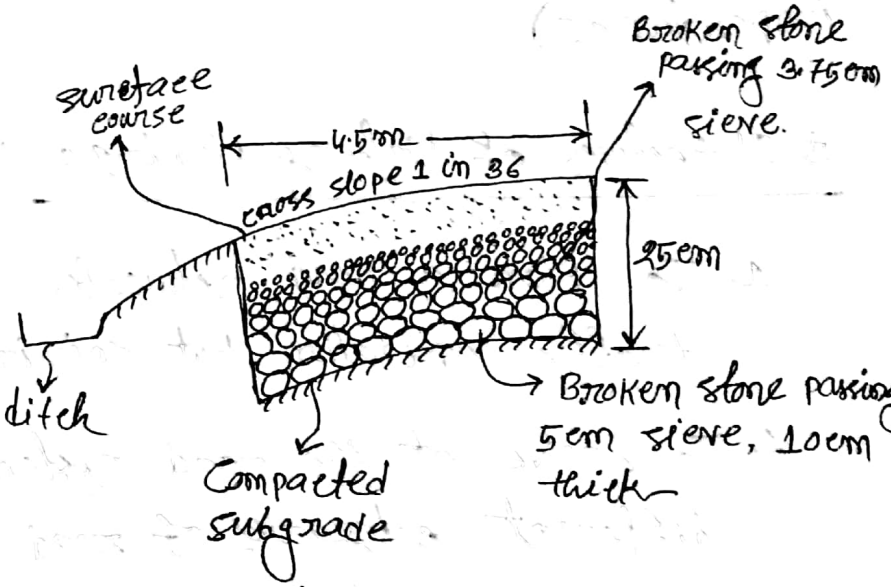


Fig: Cross section of Macadam construction.

3. The second layer of strong broken stone of size 3.75 cm was compacted to a thickness of 10 cm.

4. The top layer consists of stone of size less than 2 cm compacted to a thickness of about 5 cm and finished so that the cross slope of pavement surface was also 1 in 36.

Roman Roads:

During the period of Roman civilization many roads were constructed of stone blocks of considerable thickness. Many of those roads are still in existance after over 2000 years. The construction proceedure are as follows;

1. Along the proposed straight alignment, the loose and soft soil was removed.

2. A trench equal to the width of the carriage way was dug up to a depth untill a hard stratum was reached.

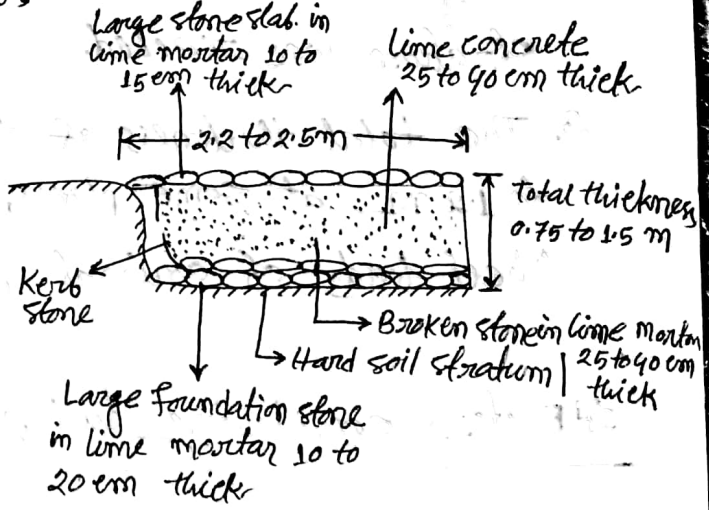


Fig: Cross section of Roman Roads.

3. One or two layers of large stone were laid in lime mortar at the bottom. The thickness of the layer varied from 10 to 20 cm. This layer is known as foundation layer.

4. Over the bottom layer, a second layer of lime concrete with large size broken stone was laid up to a thickness of 25 to 40 cm.

5. Another layer of lime concrete with small broken stone was

laid over the second layer. Generally the thickness of this layer was also kept of 25 to 40 cm but it could be increased if necessary.

6. At the top, the wear surface was provided of dressed large sized stone blocks embedded in lime mortar. The total thickness of this layer varied from 10 to 15 cm, making total thickness of the road as 75 to 125 cm.

Features of Roman Roads:-

1. They were built straight regardless of gradient.
2. They were built after the soft soil was removed and a hard stratum was reached.
3. The total thickness of the construction was as high as 0.75 to 1.2 m at some places, even though the magnitude of wheel loads of animal drawn vehicles was very low.

Factors considering during planing:- (V.V. Imp)

It is important to look ahead during planing stage and consider potential impact that a proposed facility or improvement may have while project is still in conceptual phase.

During planing, key decisions are made that will affect the future expansion or improvement.

The factors which are considered during planing are as follows;

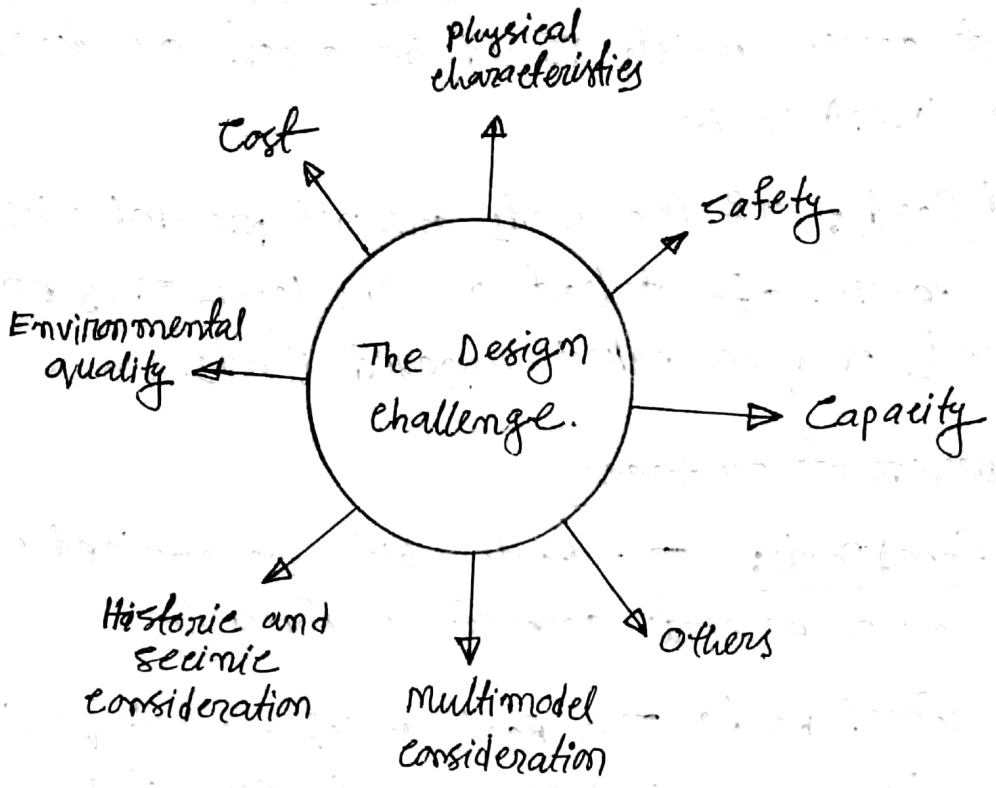


Fig. Factors considering during planing.

⊞ classification of Roads: (V.V. Imp)

① Based on usage:

1. All weather Roads:

All weather Roads are those which are negotiable during all weather, except at major river crossing where interruptions to traffic is permissible up to a certain extent, the road pavement should be negotiable during all weathers.

2. Fair weather Roads:

Roads which are called "Fair weather Roads", on those roads the traffic may be interupted during monsoon season at causeways where streams may over flow across the road.

② Based on carriage way:

a. Paved Roads: If the roads are provided with hard pavement coarse which should be atleast a water bound Macadam (WBM) layer.

b. Unpaved Roads: If the roads are not provided with a hard pavement coarse of at least a WBM layer. Thus earth and gravel roads may be called unpaved Roads.

③ Based on pavement surface:

a. Surfaced Roads: The Roads which are provided with a bituminous or cement concrete surfacing.

b. Unsurfaced Roads: The Roads which are not provided with a bituminous or cement concrete surfacing.

④ Based on Location and Function: V.V.Imp 15,07

a. Expressways:

- It is a separate class highway with superior facilities and designed standards.
- It is a Route having very high volume of traffic.
- Only fast moving vehicles are permitted to move.
- Parking, loading and unloading are restricted.
- Maximum speed 120 Km/hour.

b. National Highways (NH):

- Main Highway running through a country.
- It connects the major ports, foreign highways, capitals of large state and large industrial centers.

- It should have two lanes of at least 8m width and 2m wide shoulders on both sides.
- They run through the length and breadth of the country.

c. State Highways:

- Arterial roads of a state connected with national highways, distinct head quarters and important cities within state.
- It have two lane of 8m width and 2m wide shoulders on both sides of the road.

d. Major District Roads (MDR):

- It is important roads within the district.
- Lower speed and geometric design than NH ~~and MDR~~.
- It connects all important towns of the district with the head quarters.

e. Other District Roads (ODR):

- It serves rural areas.
- Lower design specifications than MDR.
- It connects a town with other towns or important villages in the district.

f. Village Road:

- It connects villages and groups of villages.
- These roads are generally unmetaled.
- These roads are very important for development of rural areas.

⑤ Based on Traffic Volume:

a. Light Traffic Roads:

- Equivalent Axle Load (EAL) is less than 10^4 or commercial vehicle per day less than 50.

b. Medium Traffic Roads:

- Equivalent axle load is equal to 10^4 or commercial vehicle per day is 50 to 100.

c. Heavy Traffic Roads:

- Equivalent axle load is more than 10^6 or commercial vehicle per day is more than 300.

⑥ Urban Roads:

a. Arterial Roads:

- It is the city road which are meant for through transportation in a continuous route.
- Spaced at less than 15 km in developed business centers whereas in less important areas may be 8 km apart.
- Pedestrians are permitted to cross them at intersections only.

b. Subarterial Roads:

- Lower level of traffic mobility.
- Spacing is 0.5 km
- loading and unloading is restricted.
- Pedestrians are permitted.

c. Collector Streets:

- It collects and distributes of traffic to and from local street.
- Located in residential, business and industrial areas.
- Accessible from building along them.
- Parking partly restricted.

d. Local Roads:

- Traffic carried either originates or terminates along local street.
- Depending upon importance.
- Pedestrians may move freely.

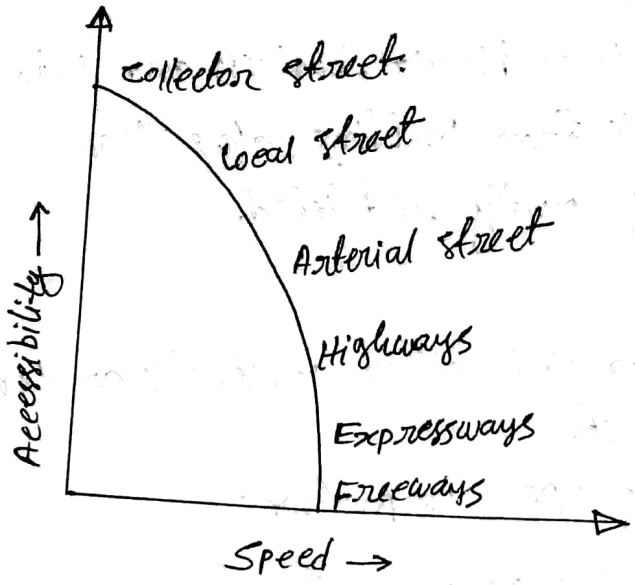
Highways:

- superior type of road in a country.
- Two types, Rural highways and urban highways.

Freeways:

- Access controlled divided highways.
- Four lanes – two lanes is in each directions.
- Access is controlled through use of interchanges.
- Rural Roads, another freeways.

The graphical presentation of different types of Roads are as follows;



Highway planing survey:- (3m) V.V 13, 11, 12

For assessing the road length requirement, field surveys are to be carried out to collect the data. This field survey for collecting factual data is called Highway planing survey.

It consist of the following studies;

① Economic studies:

- Population; its distribution and classification.
- Trend of population growth.
- listing of agricultural and industrial development.
- Income per capita.
- Banking.

② Financial studies:

- Sources of income.

- Revenue from taxation and road transport.
- living standard.
- court fees and local taxes.

③ Traffic or Road user studies:

- Traffic volume study.
- Traffic flow patterns.
- Accident study.
- Growth of vehicular traffic.
- Mass transportation facilities.
- Origine and Destination study.

④ Technical or Engineering study:-

- Road location and alignment study.
- Road life study.
- classification.
- Types of roads in use.
- Maintainance problem.

Types of Road Patterns: (V.V. Imp) 09

1. Rectangular or Block Pattern:

- This pattern is easy to set out using straight lines and rectangular coordinates.
- This method was originally adopted by Romans.
- This pattern is suitable for flat country without any predominant features.

- It has not been considered convenient from traffic operation view point.

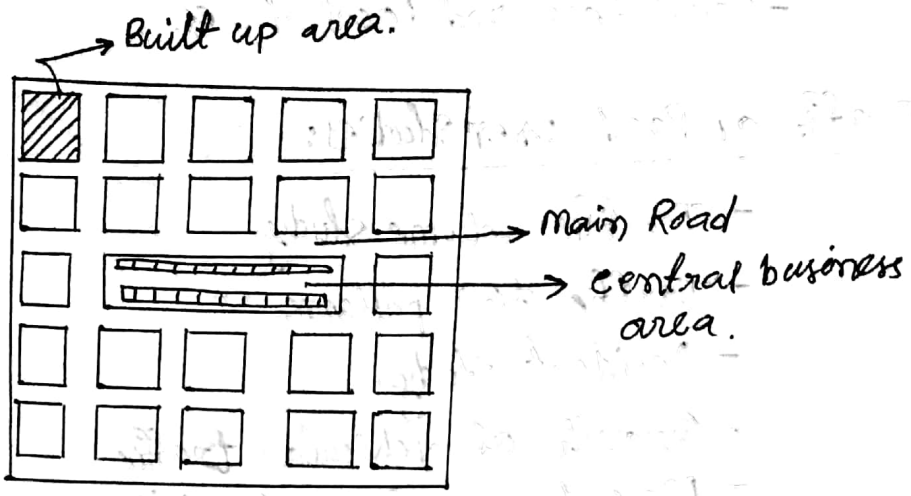


Fig: Rectangular or Block pattern.

2. Radial or star and block pattern:

- Entire area is divided into a network of roads radiating from business area outwardly.
- In between radiating main roads, built up area may be planned with rectangular blocks.

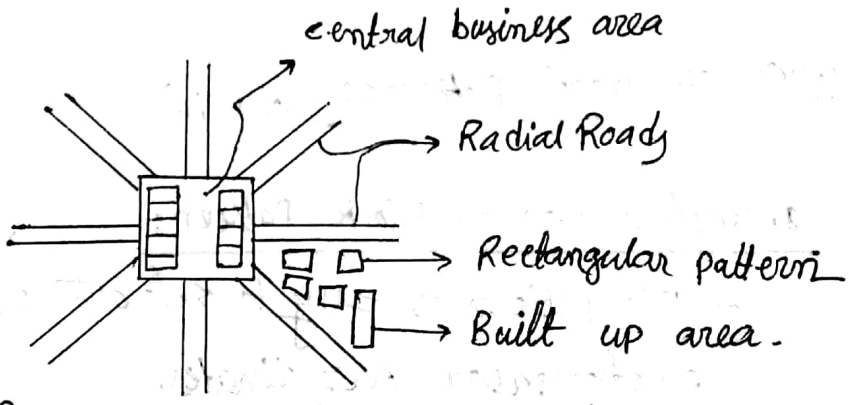


fig: Radial or star & block pattern.

3. Radial or star and circular pattern:-

- Main radial roads radiating from central business area connected together with concentric roads.

- In this pattern, the radial roads also connected with ring roads.

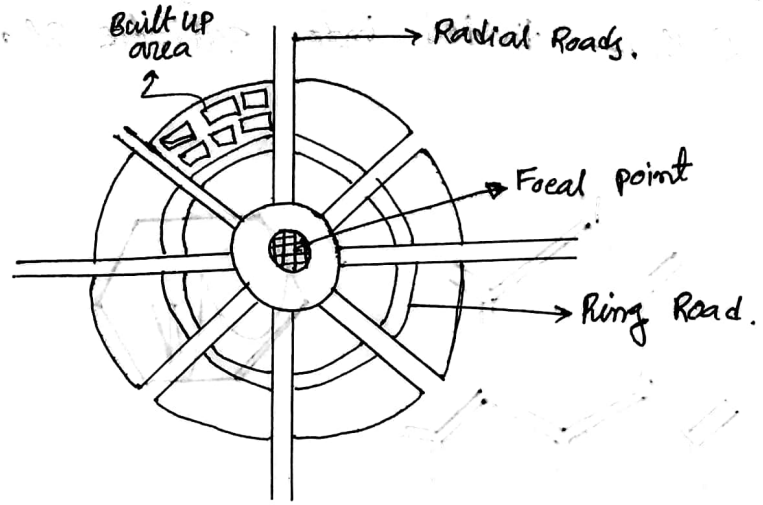


Fig: Radial or star and circular Roads.

4. Radial or star and ~~rigid~~ grid pattern:

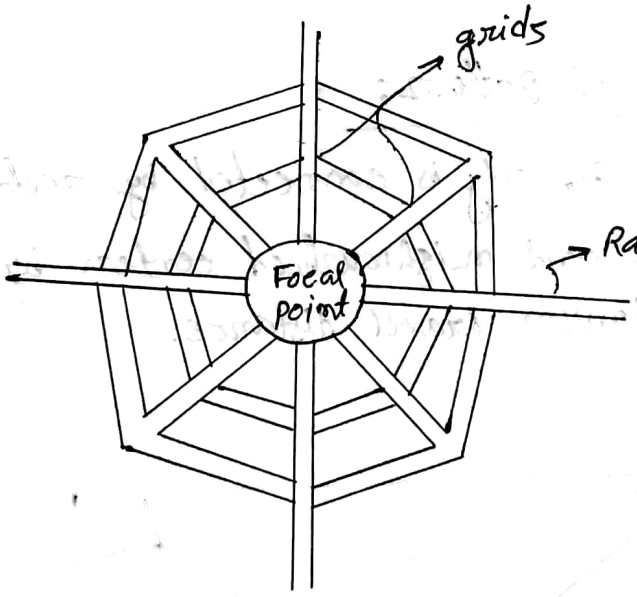


Fig: Radial or star and grid pattern

5. Hexagonal pattern:

- In this pattern, central area is provided with a network of roads forming hexagonal figure.
- At each ~~corr~~ corners of hexagon, three roads meet.

- Built up area bounded by the side of the hexagon further divided into suitable shape.

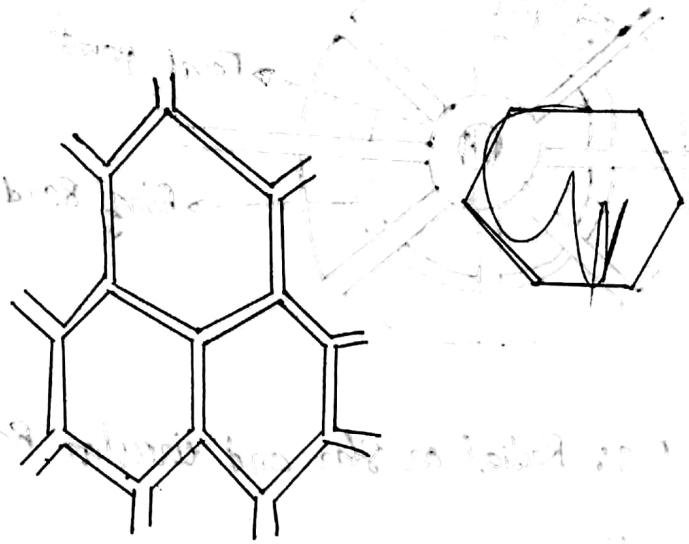


Fig: Hexagonal pattern.

6. Minimum Travel pattern:

- In this pattern, city is connected by sector centers, sub-urban center and neighbourhood centers by road which require minimum travel distance.

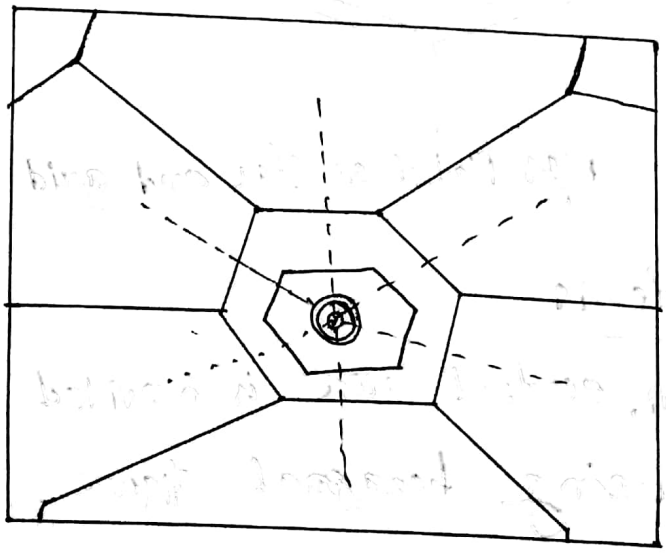


Fig: Minimum travel pattern.

Highway Alignment and surveys

Alignment:-

-(Marking position or layout of center line on the ground and giving direction to highway is called alignment.)

- Two components:-

1. Horizontal alignment – includes straight and curve path.
2. Vertical alignment – includes level and gradient.

- Alignment decision is ~~important~~ not important because a bad alignment will enhance construction, maintainence, vehicles and operating cost and increase in accident rate.

-Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structure by road side.

Requirements of an ideal alignment:- (V.V(9m) 15,11,09)

The basic requirements of an ideal alignment between two terminal stations are as follows;

1. Short:

- It is desirable to a shortest alignment between two stations.
- A straight alignment would be the shortest, though there may be several practical considerations which would cause deviations from the shortest path.

2. Easy:

- It is easy to construction and maintainance the road with minimum problems.
- It is easy for the operation of vehicles with easy gradients and curves.

3. Safe:

- It should be safe enough for construction and maintainance from the view point of stability of natural hill slopes, embankment and cut slopes and foundation of embankments.
- It should be safe for traffic operation with safe geometric features.

4. Economical:

- It could be considered economical if the total cost including initial cost, maintainance cost and vehicle operation cost is lowest.

The alignment should be such that it would offer maximum utility by serving maximum population and products. The utility of road should judge from its utility value per unit length of road.

Factors controlling Alignment:- (V.V. 2m) 14,12,09

The various factors which controll the highway alignment in generally may be listed below;

1. Obligatory points.
2. Traffic.
3. Geometric Design.
4. Economies.
5. Other considerations

V.V. 2m 14,13,11,08,07

① Obligatory points:

There are controll points governing the alignment of the highways. These controll points may be divided broadly into two categories.

a. Points through which the alignment is to pass.

① Bridge site:

- Bridge can be located only where the river has straight and permanent path and also where the abutment and the pier can be strongly founded.
- Road approach the bridge should not be curved and skew crossing.
- The roads always cross the river perpendicularly.

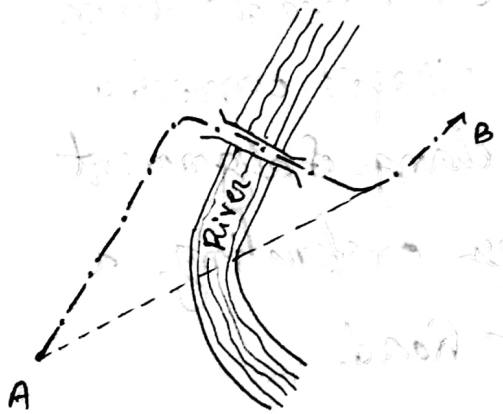


Fig: Proper bridge location.

(ii) Mountain:

- While alignment passes through a mountain various alternatives are to either construction a tunnel or to go around hills.
- The suitability of these alternatives depend on many other factors like topography, site condition and construction cost.

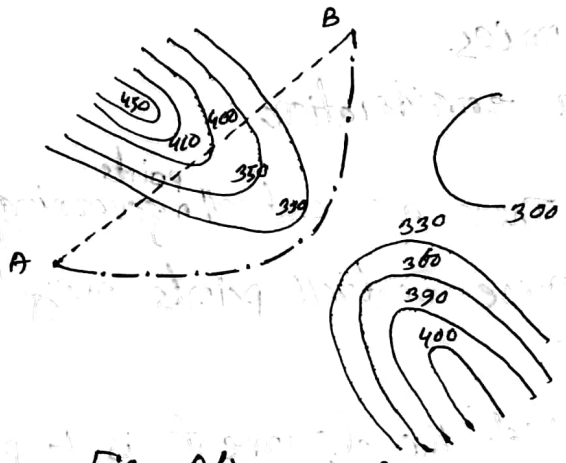


Fig: Alignment along a hill side pass.

(iii) Intermediate towns:

- Alignment may be slightly deviated to connect the intermediate town or village.
- The intermediate towns or villages connected by change of alignment or by constructing a link Road.

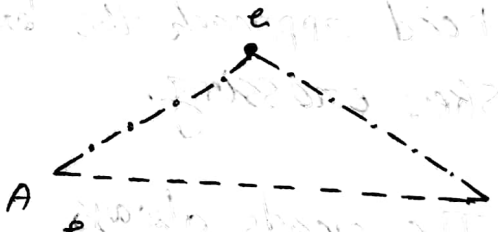
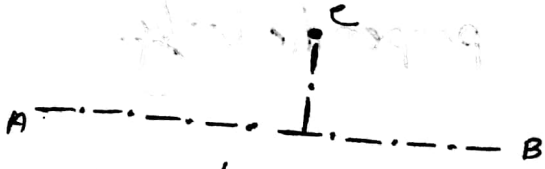


fig: connecting intermediate towns.



Connecting by link Road.

b. Points through which the alignment should not pass.

① Religious places:

- Religious places like Mosque, temple, church, grave have been protected by the law from being acquired for any purposes.

② costly structures:

- Acquiring costly structures would mean heavy compansation resulting in increased cost.

③ Lakes/Pond:

- Marshy, peaty and water logged areas are generally unsuitable for road construction and should be avoided as far as possible.

- A lake, a pond, a valley which falls on the path of straight alignment will also necessiate the alignment to deviate from the straight path and go around along the grade line.

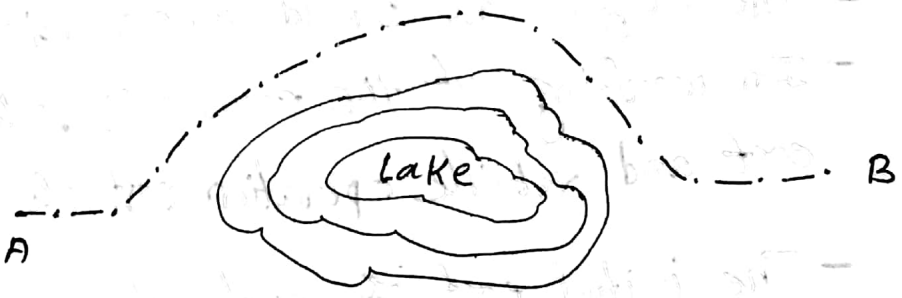


Fig: Alignment avoiding Lake.

② Traffic:

- The alignment should suit traffic requirements.
- Origin and destination study should be carried out in the area and the desired lines be drawn showing the trend of traffic flow.

- The new roads to be aligned should keep in view the desired lines, traffic flow pattern and future trend.

③ Geometric Design:

- Geometric design factors such as gradient, radius of curve and sight distance also would govern the final alignment of the highway.
- To keep radius of curve minimum, it may be required to change the alignment of highway.
- The alignment should be finalized in such a way that the obstruction to visibility do not cause restriction to the sight distance requirements.
- Design standard varies for different class of roads.

④ Economies:

- The alignment should be economical.
- In working out the economies, the initial cost, maintenance cost and vehicle operation cost should be taken into account.
- The initial cost of construction can be decreased if high embankments and deep cutting are avoided.
- The alignment is chosen in a manner to balance the cutting and filling.

⑤ Other considerations:

- Drainage considerations.
- Hydrological factors.
- Political considerations.
- subsurface water level.
- seepage.
- High flood level.
- Monotony. etc.

Special considerations of hilly Roads:

1. Suit stability:

- while aligning hill roads, special care should be taken to align the road along the side of the hill which is stable.
- A common problem in hill roads that is land slides.
- cutting and filling of earth to construct road on hill sides causes steeping of existing slopes that affects its stability.
- Gradient should not be very high.

2. Drainage:

- Numerous hill-side drains should be provided for adequate drainage facilities across the road.
- Cross drainage structures are costly.
- The number of cross drainage should be kept minimum
- Drainage should be in short time.

③ Geometric standards:

- Geometeric Design standards of hill roads such as gradient, curve, speed etc.
- Design speed should be lower.
- Minimising steep gradients.
- Hair pin bends and needless rise and fall.

4. Resisting Length:-

- The resisting length of the alignment should be kept as low as possible.
- Ineffective rise and executive fall should be kept minimum
- The resisting length of road may be calculated from the total work to be done to move the loads along the route taking the horizontal length, the actual difference in levels between the two stations and the sum of the ineffective rise and fall is excess of floating gradient.

$$\text{Resisting length} = \frac{\text{Gravitational work}}{\text{Horizontal work}}.$$

Engineering surveys for Highway Location:-

The surveys may be completed in four stages.

The stages of engineering surveys are;

1. Map study.

2. Reconnaissance.
3. Preliminary surveys.
4. Final location and detailed surveys.

(For Details, Pls see Book
Highway Engineering → Khanna & Justo.
Page → 55, Art: 3.2)

Question: Explain briefly the various stages of work in a new highway period. [07]

(Khanna — page: 64)

Steps of work in a new highway project is given:

1. Map study.
2. Reconnaissance survey.
3. Preliminary survey.
4. Location of final alignment.
5. Detailed survey.
6. Materials survey.
7. Design.
8. Earth work.
9. Pavement construction.
10. Construction controls.

Highway Geometric Design

Importances of Geometric Design: (V.V. 2m)

- Geometric Design of Highway deals with the dimension and layout of visible features of highway.
- Features normally considered as cross sectional element, sight distance, alignment and inter-sections.
- Design of these features is to a great extend influence by driver behavior and Psychology and vehicle characteristics, traffic characteristics such as speed and volume.
- Proper geometric Design will help in reduction of accident and their severity.
- Therefore objectives of geometric design is to provide optimum efficiency in traffic operations and maximum safety at reasonable cost.
- Planing can not be done stage-wise like that of pavement but has to be done well in advance.

Elements of Geometric Design: $\left(\frac{(2m).V.V}{13}\right)$

- 1. Cross sectional elements. includes;
  - a. Cross slope
  - b. width of pavements.
  - c. Formation and land.
  - d. surface characteristics
  - e. Features in Road margin.

2. Sight distance considerations. includes;

a. Cross slope.
b. Vertical slope.
c. Width and features in the road margin.

3. Horizontal Alignment. includes;

a. Super elevation.
b. Transition curve.
c. Extra widening.
d. Horizontal curve.

4. Vertical Alignment. includes;

a. Gradient.
b. Sight distance
c. Design of length of curve.

5. Intersection Elements. includes;

a. Layout
b. capacity

Factors affecting Geometric Design: V.V.(2m) 14, 11

① Design Speed.

- Defined as the highest continuous speed at which individuals vehicles can travel with safety on the highway when weather conditions are conducive.
- Different from legal speed limit which is speed limit imposed to curve a common tendency of

drivers to travel beyond accepted safe speed.
- Also different from desired speed which is a maximum speed in which driver can travel.

✓- Design speed is the single most important factors that affect geometric design of highway.

✓- It directly affect sight distance, horizontal curve and the length of vertical curve.

✓- Since the speed of the vehicle vary with driver, terrain etc a design speed is adopted for all Geometric design.

② Topography:

- It is easier to construct roads with required standards plain terrain.
- However, for a given design speed construction increases multiform with gradient and terrain.
- The topography or the terrain conditions influence the geometric design of highway significantly.
- The design standard specified for different classes of roads are differents depending on the topography.

③ Traffic factors:

- It is of crucial important in Highway design is traffic both current and future estimation.
- Traffic volume indicates the level of services for the highway is being planned.

- without traffic data, it is very difficult to design an economical highway.

④ Vehicles:

- Dimensions, weight of axle and operating characteristics of vehicle influences the design aspect such as width of pavement, radii of curves, clearence, parking etc.
- A design vehicle which has standard weight, dimension, operating characteristics are used to establish Highway to control to accomodate--vehicles of a designed type.

⑤ Human:

- Important human factors that influence geometric design are physical, mentals and Psychological characteristics of driver, pedestrians like reaction time.

⑥ Design Hourly Volume (DHV) & capacity:

- General unit for increasing traffic on Highway is Annual Average Daily Traffic volume abbreviated as AADT.
- Traffic flow or volume keeps fluctuating with time from low value during off peak hours to highest value during peak hours.
- It will be uneconomical to design road facilities for traffic flow, considering peak hours volume.

⑦ Environment:

- Environmental factors like aesthetics, Landscaping, air pollution, noise pollution and other conditions should be given due consideration in the geometric design of highway

⑧ Economy:

- Geometric Design adopted should be economical as far as possible.
- It should be match with funds alloted for capital cost and maintainance cost.

⑨ Others:

- Geometric Design shouldnt be such that aesthetics of region affected.

Highway Cross Section Elements:

- Features of cross section of pavement influence life of pavement as well as riding comfort and safety.
- Of these pavement surface characteristics affect both of these.
- Camber, Kerb and gradient of various cross section elements are important aspect of geometric design of High way.

Pavement surface characteristics:

- For a safe and comfortable driving four aspects are very important.

1. Friction between wheel and pavement surface.
2. Smoothness of pavement surface.
3. Light reflection characteristics of top of pavement surface.
4. Drainage of water.

① Friction:

- The friction between vehicle tyre and pavement surface is one of the factors determining operating speed and distance requirements in stoping and accelerating the vehicles.
- Frictional force is an important factors in the acceleration and retardation abilities of vehicles.
- skidding and sliping take place when the frictional force is small.
- Co-efficient of longitudinal friction is (0.35~0.40) depending on speed and co-efficient of lateral friction is 0.15
- Formar is useful in sight distance calculation and lateral and horizontal curve design.

② Skid: V.V.Imp 13,11

There are two types of skid.

① Longitudinal skid:

- occurs when the wheels slide without revolving or when the wheels partially revolves. ($L > 2\pi r$)
- Skidding happen when path traveld along road surface is more than the circumferential movement

of the wheels due to their rotation.
- when the brakes are applied, the wheels are locked fully or partially and if the vehicles moves forward, the longitudinal skidding takes place.
- It may vary from 0 to 100 percent.

② Lateral skid:

- It takes place while a vehicle negotiate a horizontal curves if the centrifugal force is greater than the counter-acting forces. (i.e Lateral friction and component of gravity due to the super elevation).
- Lateral skid is considered dangerous as the vehicles goes out of control leading to an accident.
- The Lateral skid co-efficient is generally equal to or slightly higher than the forward skid co-efficient in braking tests.

③ Slip: V.V. Jan 13, 11

- Occurs when a wheel revolves more than the corresponding longitudinal movement along the roads. ($L < 2\pi r$)
- Usually occurs in the driving wheel of a vehicle when the vehicles rapidly accelerates from stationary position or from slow speed on pavement surface, which is either slipary and wet or when the road surface is loose with sand.

Factors affecting friction and skid Resistance:

- Type of pavement surface namely cement concrete, bituminous, WBM, earth surface etc.
- Macro texture of the pavement surface or its relative roughness.
- Conditions of pavement namely wet or dry, smoothened or rough, oil spilled, mud or dry sand on pavement.
- Type and condition of tyre i.e new with good treads or smoothened and warn out tyre.
- Speed of vehicles.
- Extent of brake application or brake effieiency.
- Load and tyre pressure.
- Temperature of tyre and pavement.
- Type of skid if any.

Pavement unevenness:-

- Always desirable to have an even surface but it is seldom possible to have such one
- Even if a road is constructed with high quality pavers it is possible to develop unevenness.
- Unevenness affect vehicle operation cost, speed and safety.
- Unevenness index is the measure of unevenness which is cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road.

- Unevenness index may be measured in cm per Km.
- An unevenness index value less than 150 cm/Km is considered as good.
- A value of 250 cm/Km is satisfactory upto a speed of 100 Kmph
- If unevenness is greater than 350 cm/Km is considered very uncomfortable. even at a speed of 50 Kmph.

Light Reflection characteristics:

- Night visibility very much depends on the light reflection characteristics of pavement surface.
- The Glare caused by the reflection of head light is considerably high on wet pavement surface than on dry pavement.
- light colored or white pavement surface give good visibility at night particularly during rains and they produces glare and eye strain during bright sunlight.
- Black top pavement surface on other hands provides very poor visibility at night specially when the surface is wet.

Drainage of water:

- Pavement surface should be absolutely impermeable to prevent seepage.

Cross slope or camber:- V.V.Jan 14

- (Slopes provided to road surface in transverse direction to drain of water from road surface is called camber.)

- Drainage and quick disposal of rain water from the pavement surface by providing cross slope is considered important because ;

① To prevent the entry of surface water into the subgrade soil through pavement. The stability, life of pavement and surface condition get adversely affected if the water intery into the subgrade and the soils gets soaked.

② To prevent the entry of water into the bituminous pavement layers as continued contact with water causes stripping of bitumen from the aggregates and result in deterioration of pavement surface.

③ To remove the rain water from pavement surface as quickly as possible and to allow the pavement to get dry soon after rain ; the skid resistance of the road get considerably decreased under wet condition, rendering it slippery and unsafe for vehicle operation at high speed.

- Usually the camber is provided on the straight roads by raising the center of the carriageway with respect to the edges, forming a crown or highest point on the center line.

- The Rate of camber or cross slope is usually designed by 1 in n which means that the transverse slope is

in ratio 1 vertical to n horizontal.
- Camber is also expressed as percentage.
- If the camber is x%, the cross slope is x in 100.
- Required camber of a pavement depends on;
    ① The type of pavement surface.
    ② The amount of rainfall.
- A flat camber of 1.7 to 2.0% is sufficient on relatively impervious pavement surface like cement concrete or the bituminous concrete.
- In pervious surface like WBM or earth road which may allow surface water to get into the subgrade soil, steeper cross slope is required.
- Steeper camber is also provided in areas of heavy rainfall.

Effect of too steep cross slope:

Too steep cross slope is not desirable because of the following reason's;
- Transverse tilt of vehicle causes uncomfortable side thrust and a drag on the steering of automobiles, unequal wear of tyre as well as road surface.
- Discomfort causing throw of vehicles when crossing the crown during overtaking operations.
- Problems of toppling over of highly loaded bullock carts and ~~lod~~ trucks.
- Formation of cross ruts due to rapid flow of water.

- Tendency of most of the vehicles to travel along the center line.

Types of Camber or Cross slope:

① Parabolic: Parabolic or elliptic shape is given so that the profile is flat at the middle and steeper towards the edges, which is prefered by fast moving vehicles as they have to frequently cross the crown line during over-taking operation on a two lane high way.

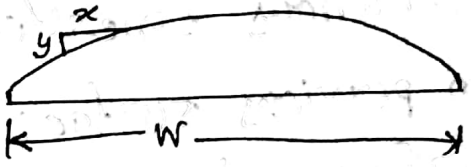


fig: Parabolic camber.

② Straight camber:

When the steel tyred wheels or animal drawn vehicles can cause considerable damage to the pavement surface due to high stress then straight camber is provided.

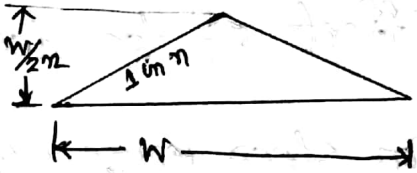


fig: Straight camber.

③ Combination of straight and parabolic camber:

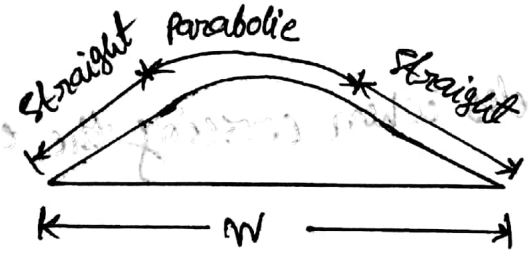


fig: combined camber.

A combined camber with parabolic central portion and straight line camber at the edges is prefered sometimes.

Camber of different types of Road surface:-

Serial	Types of road surface	Range of camber in areas of Rainfall Range	
		Heavy	light
1.	Cement concrete and high type bituminous surface.	2%	1.7%
2.	Thin bituminous surface	2.5%	2%
3.	WBM and gravel pavement	3.0%	2.5%
4.	Earthen road	4.0%	3.0%

Carriageway:-

- Metalled portion of the road over which the vehicles are intended to move.
- Different types of carriageway according to materials used for construction.

Traffic Lane:

- Carriageway intended for one line of traffic movement is called traffic lane.

Width of carriageway or pavement:- m

- Width of carriageway or pavement depends on the width of traffic lanes and number of lanes.
- Width of Traffic Lane depends on the width of vehicles and clearences.
- Side clearence improve operating speed and safety.

- Maximum permissible width of a vehicles is 2.44m and desirable side clearance for single lane traffic is 0.68m.
- This requirement of lane width of 3.75m for a single lane Road.
- However, side clearence is required about 0.53m on either side and 1.06m in center for two lane road.
- Therefore two lane Road width is about 7.0m.

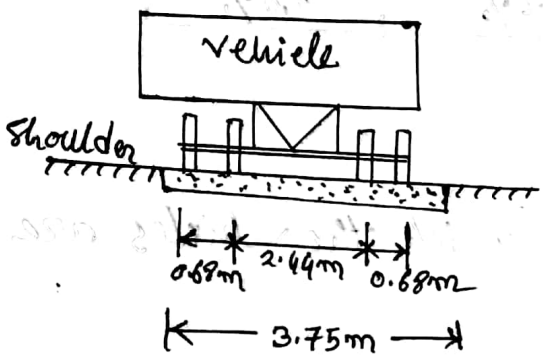


Fig: Single lane pavement.

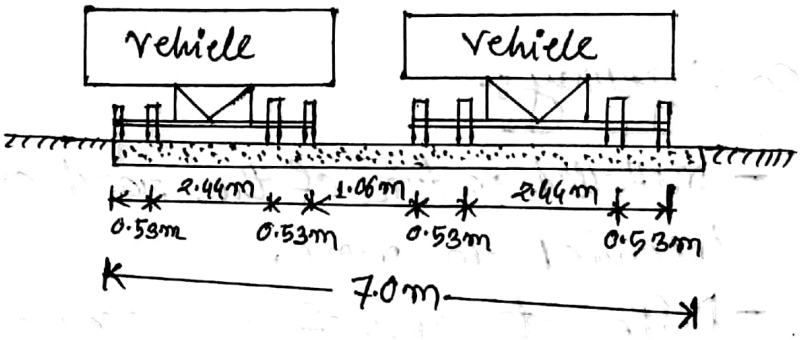


Fig: Two lane pavement.

Specifications for carriageway width:-

Sl.	Class of Road	Width of carriageway
1.	Single lane	3.75m
2.	Two lane without raised kerbs.	7.0m.
3.	Two lane with raised kerbs.	7.5m.
4.	Intermediate carriageway	5.5m.
5.	Multi lane pavements.	3.5m per lane

Traffic Separators or Medians:-

- Main function of traffic separators is to prevent head on collision between vehicles moving in opposite direction or adjacent lane.
- Traffic separators also helps to;
  - (i) channelize traffic into streams at intersections.
  - (ii) shadow the crossing and turning traffic.
  - (iii) segregate slow traffic and
  - (iv) protect pedestrians.)
- The traffic separators may be in form of pavement marking physical dividers or area separators.
- Pavement marking is the simplest of all traffic separators.
- Mechanical separators should be designed in such a way that even if wheels of vehicles enroach, no part of vehicle body should be damaged.
- Area separators may be medians, diving islands or park way strips, dividing the two directions of traffic flow.

Kerbs (Curb):

- Kerbs indicates the boundary between the pavement and shoulders or islands or foothpath or kerb & parking space.
- Kerbs may be mainly divided into three groups based on their functions.

They are discussed below;

1. Low or Mountable Kerbs:-

- It is provided such that they encourage traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty.
- The height of this kerb is about 10cm above the pavement edge with a slope which allows vehicles to climb easily.
- It is usually provided at medians and channelization schemes.
- It also helps in longitudinal drainage system.

2. Semi-barrier Kerb:

- When pedestrians traffic is high then this type of kerb is provided.
- The height is about 15cm above the pavement edge.
- It prevents encroachment of parking vehicles but an acute emergency it is possible to drive over this kerb with some difficulty.

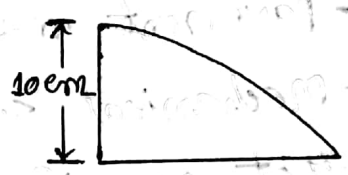


fig: low or mountable kerb.

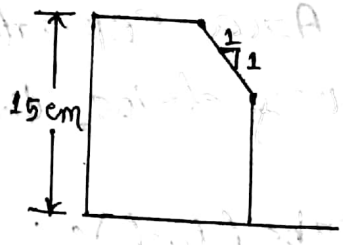


fig: semi-barrier kerb.

3. Barrier Kerb:

- It is designed to discourage the vehicle from leaving the pavement.
- It is provided when there is a considerable amount of traffic.

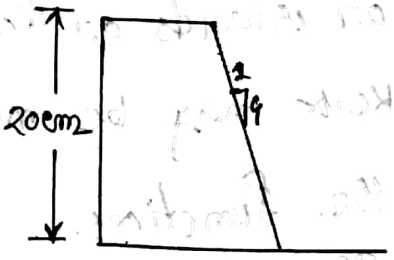


fig: Barrier kerb.

- The height is about 20 cm above pavement edge with steep batter of 1.0 vertical 0.25 horizontal.

4. Submerged Kerb:

- It is used in rural roads.
- It is provided at pavement edge between the edge and shoulders.
- It provides lateral confinement and stability to the granular base coarse and flexible pavement.

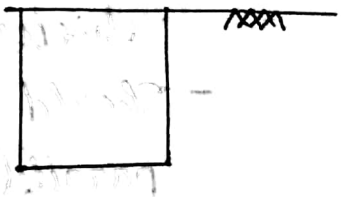


fig: submerged Kerb.

Road Margins:-

- Portion of Road beyond the carriage-way and on roadway.
- Various elements that form road margins are:-

① Shoulder:

- Provided along the road edge and are intended for the accomodation of stopped vehicles.
- Serve as a emergency lane for vehicles.
- Provided lateral support for base and surface coarse.
- Should be strong enough to bear the weight of fully loaded truck even in wet condition.
- width should be adequate.
- It is desirable to have a width of 4.6 m for shoulder.
- A minimum width of 2.5m is recommended.

2. Parking Lanes:- 3m

- Provided in urban roads for side parking.
- Parallel parking is prefered because it is safe for vehicles moving on road.
- Should have a minimum width of 3m in case of parallel parking.

3. Lay-byes:-

- Provided near public conveniences with guide maps to enable drivers to stop clear off the carriageway.
- Should be normally be of 3m width and atleast 30m length with 15m end tapers on both sides.

4. Bus-bays:-

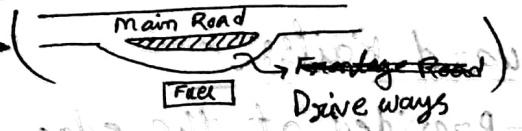
- Provided by recessing kerbs to avoid conflict with moving traffic.
- Provided so that they do not obstruct movement of vehicles in carriageway.
- Bus bays should be located at least 75m away from the intersections.

5. Frontage/Service Road:- v.v.3m / 14

- Provided to give access to properties along an important controlled highway like freeways and Express ways.
- Run parallel to the highway and will be isolated by separators and access to highway will be provided

only at selected points.
- Provided to avoid congestion in Express ways and as the speed of traffic in those lanes is not reduced.

6. Drive ways:-



- ~~Connect~~ Connect highway with commercial establishment like fuel station, service station etc.
- Should be properly designed and located, fairly away from an intersection.
- Radius of drive ways curve should be kept as large as possible.
- The width of the drive way should be minimised to reduce the length of cross walks.

7. Cycle Tracks:-

- Provided in urban areas when volume of cycle traffic on road is very high.
- A minimum width of 2m is provided and width may be increased 1 m for each addition cycle lane.
- The layout of cycle track should be carefully decided in large highway intersections and traffic rotaries.

8. Footpath or side walk:- v.v.Imp

- Exclusive right of way to pedestrians especially in urban areas.
- Provided for the safety of pedestrians.
- Minimum width is 1.5 m and may be increased based on traffic.

- Should be either as smooth as posible or more smoother than the adjacent traffic lane.

9. Guard Rails:

- Provided at the edge of shoulder when road is constructed on a fill so that vehicles are prevented from running off embankment, especially when the height of the fill exceede 3 m.
- Various designs of guard rails are in use.
- Guard stones are installed at suitable intervals along the outer edge of the formation at horizontal curves of road running on embankment along areas.
- Painted with black and white for better night visibility of the curves under head lights of vehicles.

10. Embankment slope:-

- This side slope should be as flat as possible for the purposes of safe traffic movement and also for aesthetic reason.
- The slope may be kept flat as permitted by economic considerations.
- Aesthetic features of road side, making road travel more pleasant.

Width of Roadway or Formation:-

- Width of formation or roadway is the sum of widths of pavements or carriageway including separators if any and the shoulders.
- It is top width of the highway embankment or the the bottom width of highway cutting excluding the side drains.
- The minimum roadway width on single lane bridges is 4.25 m.

Right of Way:-

- Right of way or land width is the width of land aquired for road along its alignment.
- It should be adequate to accomodate all CS (cross sectional) element of highway and any reasonably provided for future development.
- To prevent ribbar development (রাস্তার পাশে দোকান বা বসতি গড়ে ওঠা) along highway. "control-line" and "Building line" may be provided.)
- Control line is a line which represent the nearest limits of future uncontrolled building activities in relation to a road.
- Building line represent a line on either side of the road

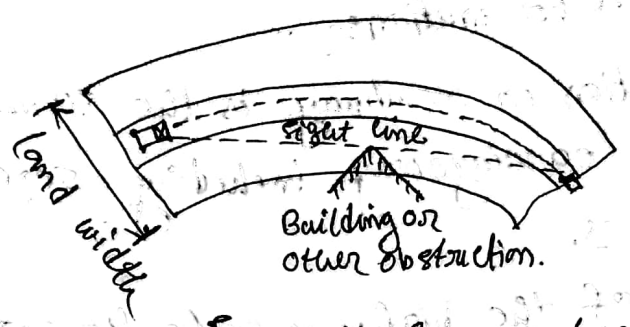


Fig: Right of way or Land width.

Right of way width:-

—It is Governed by the following factors:

1. Width of formation depending on the category of highway and width of roadway and road margin.
2. Height of embankment or depth of cutting which is governed by the topography and the vertical alignment.
3. Side slopes of embankment or cutting which depends on the height of the slope, soil type and several other considerations including aesthetics.
4. Drainage system and their size which depends on the rainfall, topography and run off.
5. Sigth & distance considerations on horizontal curves as there is a restriction to the visibility on the inner side of the curve due to obstruction.
6. Reserve land for future widening is to be planned in advance based on anticipated future development and increase in the traffic.

Sight distance:-

- The safe and efficient operation of vehicles on road depends among other factors on road length at which an obstruction if any becomes visible to driver in the direction of travell.
- In other words, the feasibility to see ahead or visibility is very important for safe vehicle operation on a Highway.
- Sight distance available from a point is the actual distance along road surface, which a driver from a specified height above carriageway has visibility of stationary or moving objects.
- In other words, (Sigth distance is the length of road visible ahead to driver at any instance.)
- Restriction to sigth distance may be caused at horizontal curves by object obstructing vision at the inner side of road or at vertical summit curves or at intersections.
- Sigth distance required by driver applies to both geometric design of highway and for traffic control.

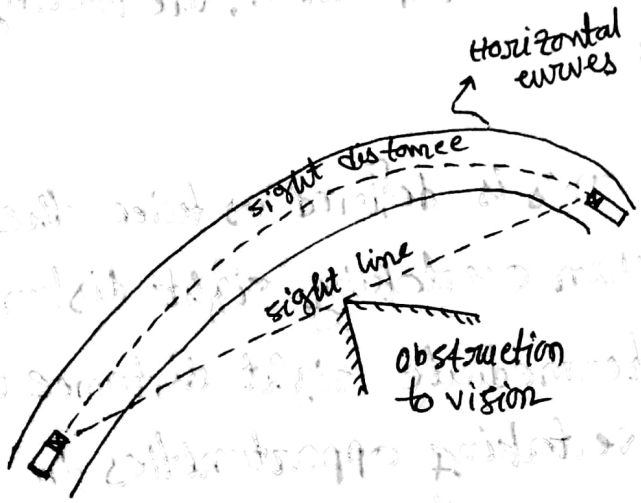


fig: Sight distance at horizontal curves.

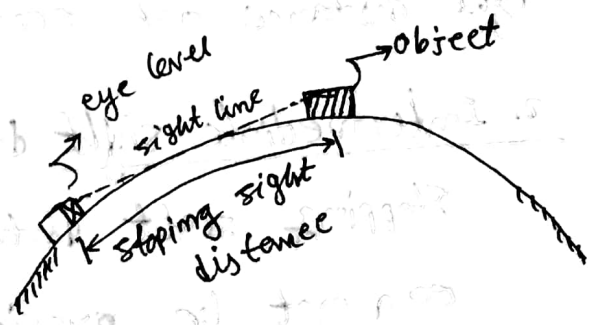


fig: Sigth distance at vertical summit curve.

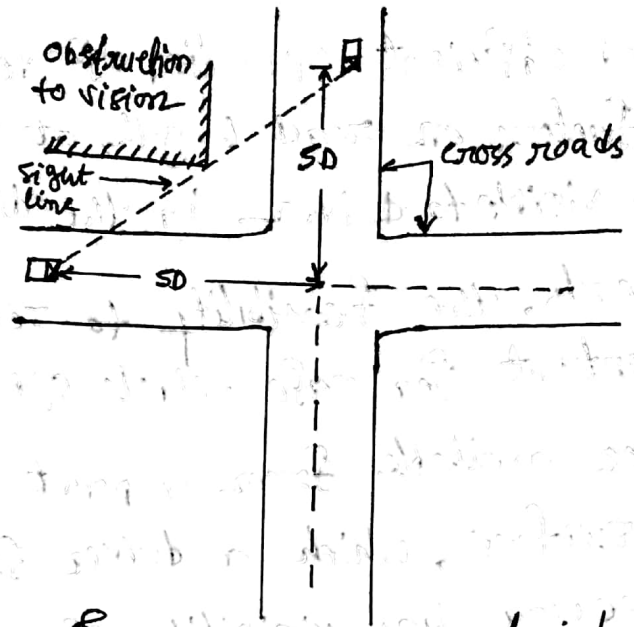


Fig: sigth distance at intersections.

Types of sight distance:-

- Three sight distance situations are considered in the design;
  1. Stopping or absolute minimum sigth distance.
  2. Safe overtaking or passing sight distance.
  3. Safe sight distance for entering into uncontrolled intersections.
- Apart from the three situation mentioned above, the following sight distance are considered;

a. Intermediate sight distance: This is defined as twice the stopping sight distance. When overtaking sight distance can not be provided, intermediate sight distance is provided to give limited overtaking opportunities to fast vehicles.

b. Head light sight distance: This is the distance visible to a driver during night driving under illumination of

the vehicle head light. This sight distance is critical at up gradients and at the ascending stretch of the valley curves.

Standard for sight distance:-

- The standards for sight distance should satisfy the following three conditions;

1. Driver travelling at the design speed has sufficient sight distance or length of road visible ahead to stop the vehicle, in case of any obstruction on the road ahead without collision.
2. Driver travelling at the design speed should be able to ~~satisfy~~ safely overtake, at reasonable intervals, the slower vehicles without causing obstruction or hazard to traffic of opposite directions.
3. Driver entering an uncontrolled intersection has sufficient visibility to enable him to take control of his vehicle and to avoid collision with other vehicles.

Stopping Sight Distance (SSD):-

- (Stopping sight distance (SSD) is defined as the distance needed for driver to see an object on road way ahead and bring their vehicle to safe stop before colliding with object.)
- This distances are derived for various design speed based on assumptions for drivers reaction time, braking efficiency of most vehicle, speed of vehicles, Frictional resistance between the road and tyres, Gradient of road if any.
- A Road way designed to criteria employs a horizontal and vertical alignment.

- Sight distance depends on -

a. Features of road ahead.
b. Height of drivers eye above road surface.
c. Height of object above road surface.

(Height of drivers eye above road surface is 1.2m
Height of object above road surface is 0.15m)

- Distance within a motor vehicle can be stopped depends on the following factors;

1. Total reaction time of driver.
2. Speed of vehicle.
3. Efficiency of brake.
4. Frictional resistance between the road surface and tyres.
5. Gradient of road if any.

Total Reaction Time of Driver :- V.V.Imp 13,12

(- It is the time from the instant the object is visible to the the driver to the instant the brakes are effectively applied.)

- The amount of time gap depends on several factors;
- During this time, the vehicle travel a certain distance at the original speed or design speed.
- Thus (the stopping distances increases with increase in the reaction time of the driver.) — Explain.
- Many of the studies show that reaction time of driver normally 1.5 second to 2 second.
- Higher values 2.5 second is normally used to design.

→ The total Reaction time may be split up into two parts.

1. Perception time.
2. Brake reaction time.

1. Perception time:

- It is the time required for a driver to realise that brakes must be applied.
- It is the time from the instant the object comes on the line of sigth of the driver to the instant he realises that the vehicle need to be stopped.
- It varies from driver to driver and also depends on several factors such as speed of vehicle, distance of object and other environmental condition.

2. Brake reaction Time:-

- It is the time from the instant the brake is applied by the driver to the instant the vehicle is deadly stopped.
- It depends on several factors such as skill of driver, speed of vehicle, type of problem etc.

PIEV Theory:- V.V. Im 13,12,05

According to this theory the total reaction time of the driver is split into four parts;

1. Perception.
2. Intellection.
3. Emotion.
4. Volition.

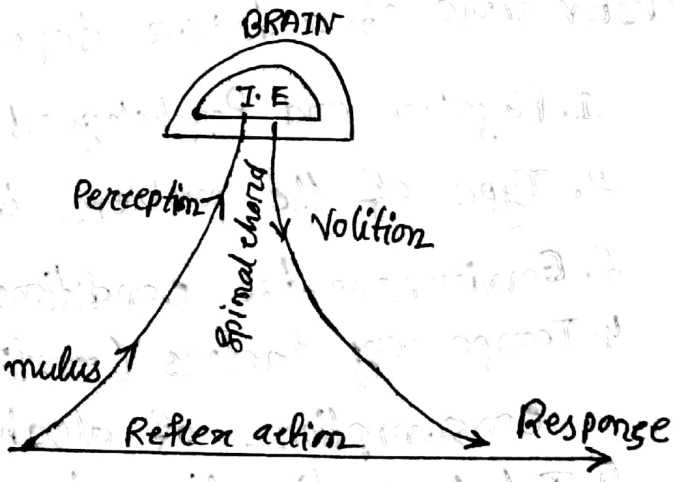


fig: Reaction time & PIEV process.

1. Perception:

It is the time required for the sentations received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord. In other words, it is the time required to perceive an object or situation.

2. Intellection:

It is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

3. Emotion:

It is the time elapsed during emotional sensation and disturbance such as fear, anger or any other emotional feelings such as superstition etc. with reference to the situation. Therefore the emotion time of a driver is likely to vary considerably depending upon the problem involved.

4. Volition:

It is the time taken for the final action. It is also possible that the driver may apply brakes or take any avoiding action by the reflex action, even without thinking.

V.V. Jha 19

PIEV time of a driver depends on general factors:-

1. Physical and Psychological characteristics of the driver.
2. Type of the problem involved.
3. Environmental conditions.
4. Temporary factors (motive of trip, travell speed, fatigue, consumption of alcahol etc.)
5. Total reaction time. (vary 0.5 sec to 4 sec)

Factors affecting sigth distance:-

1. Speed of vehicle:

- Speed of vehicle very much affect the sigth distance.
- During the total reaction time of the driver the distance moved by the vehicle will depend on the speed.
- The braking distance or the distance moved by the vehicle after applying the brakes, before coming to a stop depends also on the initial speed of the vehicle.
- The higher speed, higher will be the stopping distance.

2. Efficiency of brakes:-

- It depends on the age and characteristics of the veleicle.
- Brake efficiency is 50% considered in designing of geometric element of the road.
- Friction resistance between the tyre and road affect the brake efficiency.
- No separate probition is needed....
- This is taken only for longitudinal friction.
- So value of longitudinal friction is 0.35 to 0.4 and for lateral friction 0.15
- Gradient of the road.

Analysis of stopping distance: VV. Imp 13, 1205

- The stopping distance of a vehicle is the sum of;

1. Lag distance: The distance travelled by the vehicle during the total reaction time.
2. Braking distance: The distance travelled by the vehicle after the application of brakes, to a dead stop position.

Lag Distance:

- During total reaction time or PIEV time the vehicle may be assumed to proceed forward with a uniform speed at which the vehicle has been moving and this speed may be taken as design speed.
- If v is the design speed in m/sec and t is the total reaction time of the driver in seconds then

$$\text{Lag distance, } LD = Vt \text{ meter.}$$

- If V kmph is the design speed and Total reaction time t in seconds then

$$\text{Lag distance, } LD = V \times \frac{1000}{60 \times 60} \times t = 0.278\, Vt \text{ meters.}$$

- The total reaction time of a driver is considered 2.5 sec.

Braking Distance:-

1. For level Road:

For level road, braking distance may be obtained by equating the work done in stopping the vehicle and the kinetic energy.

If F is the maximum frictional force developed and braking distance l then work done against friction force to stop the vehicle $= Fl$
$= fWl$

f = Friction coefficient
W = Total weight of vehicle

The kinetic energy at the design speed v m/sec is

$$KE = \frac{1}{2} m v^2$$

Now equating these;

$$\frac{1}{2} m v^2 = f W l$$

$$\Rightarrow f W l = \frac{1}{2} \cdot \frac{W}{g} v^2 \qquad \left[\because m = \frac{W}{g}\right]$$

$$\therefore l = \frac{v^2}{2gf} \text{ meter}$$

Stopping distance = lag distance + Braking distance

$$SD = \left(vt + \frac{v^2}{2gf}\right) m.$$

If V in kmph then stopping distance;

$$SD = \left(0.278 Vt + \frac{V^2}{254f}\right) m$$

2. Stopping distance at slopes:-

- When there is an ascending gradient of say, +n% the component of gravity adds to the braking action and hence the braking distance is decreased.
- The component of gravity acting parallel to the surface which adds to the braking force is equal to,

$$W \sin\alpha = W \tan\alpha \qquad \left[\text{if } \alpha \lll \text{ then } \sin\alpha = \tan\alpha\right]$$

$$= W \cdot \frac{n}{100}$$

Now, equating kinetic energy and the work done, to stop the vehicle;

$$\left(fW + \frac{Wn}{100}\right) l = \frac{1}{2} \frac{W v^2}{g}$$

$$\therefore l = \frac{v^2}{2g\left(f + \frac{n}{100}\right)}$$

Similarly in descending gradient of -n%, the braking distance increases as the component of gravity now oppose the braking force. Hence

$$\left(fW - \frac{Wn}{100}\right) l = \frac{1}{2}\frac{Wv^2}{g}$$

$$\therefore l = \frac{v^2}{2g\left(f - \frac{n}{100}\right)}$$

Now General equation of stopping distance of gradient n%

$$SD = \left[vt + \frac{v^2}{2g(f \pm 0.01n)}\right] m.$$

If V in kmph then stopping distance;

$$SD = \left[0.278Vt + \frac{V^2}{254(f \pm 0.01n)}\right] m.$$

(Ans)

- Minimum stopping sight distance should be equal to stopping distance in one way traffic lane and also in two way traffic roads where the lanes are ~~spe~~ separated where there are two or more traffic lanes.
- On single lane roads where two way movement of traffic is permitted then minimum stopping sight distance should be equal to twice of stoping distance.
- When stopping sight distance for design speed is not available of any section of a road, speed should be restricted by a warning sign and a suitable speed limit regulation time.

- Head light sight distance is equal to stopping sight distance.
- Intermediate sight distance is equal to twice of stopping sight distance.

Example: 4.2, 4.3, 4.4, 4.5 should be practiced
Book: Khanna & Justo
Page—192~99
→ V.V. Imp.

Overtaking Sight distance:-

- (Overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of the opposite direction.)
- Measured along the center line of the road.
- The height of the driver eye level height is 1.2 m. Object height is 1.2 m of top.
- If the radius of the curve is more then the overtaking sight distance will be more and vice-versa.

Factors affecting overtaking sight distance:-

- Speed of overtaking vehicle (fast moving), overtaken vehicle (slow moving) and vehicle coming from opposite direction.
- Spacing between vehicles which in turn depends on speed.
- Skill and reaction time of driver.
- Rate of acceleration of overtaking vehicle.
- Gradient of road, if any.

Analysis of overtaking sight distance :-

V.V. Imp 24, 23, 22.

Let us consider the following figure for two way traffic in two lane road;

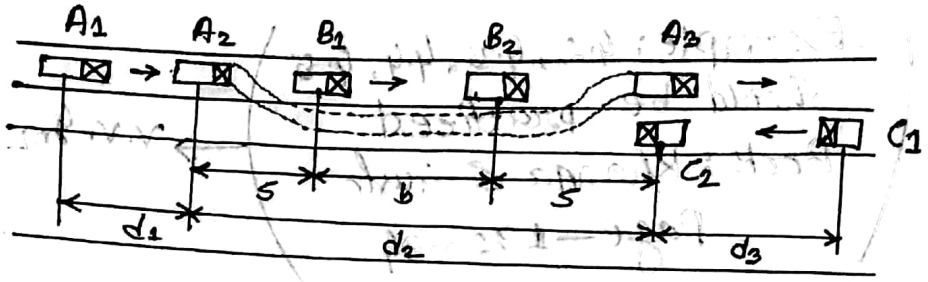


Fig: Overtaking Manoever.

- Vehicle A travelling at a design speed and another slow vehicle B on a two lane road with two way traffic.
- Third vehicle C comes from the opposite direction.
- The overtaking manoever may be split up into three operations, thus dividing the overtaking sight distance into three parts d_1, d_2 and d_3.

1. d_1 is the distance travelled by overtaking vehicle A during the reaction time t sec: of the driver from position A_1 to A_2.
2. d_2 is the distance travelled by the vehicle A from A_2 to A_3 during the actual overtaking operations in T sec:.
3. d_3 is the distance travelled by an coming vehicle C from C_1 to C_2 during the overtaking operation of A in T sec.

- Certain assumptions are made in order to calculate the values of d_1, d_2 and d_3.
  - A is the overtaking vehicle originally travelling at a design speed v m/s or V kmph.

- B is the overtaken or slow moving vehicle with uniform speed v_b ms^{-1} or V_b kmph.
- C is a vehicle coming from opposite directions at a design speed v ms^{-1} or V kmph.
- In a two lane road, the opportunity to overtake depends on the frequency of vehicles from the direction and the overtaking sight distance available at any instant.

- It may be assumed that the vehicle A is forced to reduce its speed v_b of the slow vehicle B and moves behind it allowing a space s, till there is an opportunity for safe overtaking operation.
- The distance travelled by A during its reaction time is d_1 and between positions A_1 and A_2.

$$\therefore d_1 = v_b \cdot t \quad m$$

- From position A_2, the vehicle A starts accelerating, shift to the adjoining lane, overtake the vehicle B and shift back to the original lane ahead B in position A_3 in time T sec.
- The straight distance between A_2 and A_3 is d_2.
- Minimum distance between position A_2 and B_1 may be taken as the minimum spacing s of the two vehicles while moving with a speed v_b ms^{-1}. (Empirical formula)

$$\therefore s = (0.7 v_b + 6) \ m.$$

The minimum distance between B_2 and A_3 is $s = (0.7 v_b + 6)$ m.

- If the time taken by vehicle A for the overtaking operation from position A_2 to A_3 is T sec. The distance covered by the

vehicle B travelling at a speed of v_b ms^{-1}.

$$\therefore b = v_b T \quad m.$$

- Time T depends on speed of overtaken vehicle B and the acceleration of overtaking vehicle A.
- Thus time T may be calculated by equating the distance d_2 with initial speed v_b ms^{-1} and acceleration a in ms^{-2}.

$$\therefore d_2 = b + 2s$$

$$d_2 = v_b T + \frac{1}{2} a T^2$$

where, $b = v_b T$

Therefore; $2s = \frac{1}{2} a T^2$

$$\therefore T = \sqrt{\frac{4s}{a}}$$

where, $s = (0.7 v_b + 6)$ m (v_b in ms^{-1})

$$\therefore d_2 = v_b T + 2s$$

- The distance travelled by vehicle c moving at design speed v ms^{-1} during the overtaking operation of vehicle A i.e during time T sec is the distance d_2 between position c_1 and c_2.

$$\therefore d_3 = vT$$

Thus the overtaking sight distance;

$$OSD = d_1 + d_2 + d_3$$

$$\therefore OSD = (v_b t + v_b T + 2s + vT) \quad m.$$

If V_b or V in kmph;

$$OSD = (0.28 V_b t + 0.28 V_b T + 2s + 0.28 VT) \quad m$$

where, $s = (0.2 V_b + 6)$ m

$$T = \sqrt{\frac{14.4s}{a}} \quad (a \text{ in kmph/sec})$$

- In case of the speed of overtaken vehicle V_b is not given then assume, $V_b = (V - 16)$ kmph where V is the design speed in kmph.

or, Assume, $v_b = (v - 4.5)\ ms^{-1}$ where v is the design speed in ms^{-1}.

Overtaking zones:-

- It is desirable to construct highway in such a way that the length of road visible ahead at every point is sufficient for overtaking.
- This is seldom practicable and there may be stretches where the safe overtaking distance can not be provided.
- In such zones where overtaking or passing is not safe or is not possible, sign post should be installed indicating "no passing" or "Overtaking prohibited" before such restricted zones starts.
- But the overtaking opportunity for vehicles moving at design speed should be given at frequent intervals. These zones which meant for overtaking are called overtaking zones.)
- The overtaking sight distance and the pavement width should be sufficient for safe overtaking operations.
- Sign post should be installed at sufficient distance in advance to indicate the start of the overtaking zone;
- This distance may be equal to $(d_1 + d_2)$ for one way roads and $(d_1 + d_2 + d_3)$ for two way roads.
- Similarly end of the overtaking zones should also be indicated by appropriate sign post installed ahead at distance mentin above.

- The minimum length of the overtaking zone should be three times for safe overtaking distance i.e $3(d_1+d_2)$ for one way roads and $3(d_1+d_2+d_3)$ for two way roads.
- It is desirable that the length of overtaking zones is kept five times the overtaking sight distance.

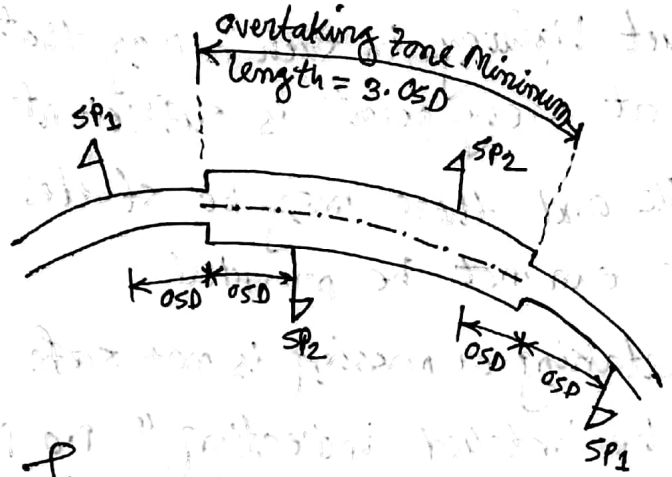


fig: Overtaking zones.

where,
OSD = overtaking sight distance
$= (d_1+d_2)$ for one way traffic
$= (d_1+d_2+d_3)$ for two way traffic

SP_1 = sign post "overtaking zone ahead"

SP_2 = sign post "End of overtaking zone"

(Problems → 4.6 and 4.7 have to be done From Khanna and Justo Book)

Sight distance at intersections:-

- It is important that on all approaches of intersection of road, there is a clear view across the corners from a sufficient distance so as to avoid collision of vehicles.
- This is all the more important at uncontrolled intersections.
- The sight line is obstructed by structures or other objects at the corners of the intersections.
- The area of unobstructed sight from by line of vision is called sight triangle.

➡ The design of sight distance at intersections may be based on three possible conditions;

1. Enabling the approaching vehicles to change speed.
2. Enabling approaching vehicles to stop.
3. Enabling stopped vehicles to cross the main road.

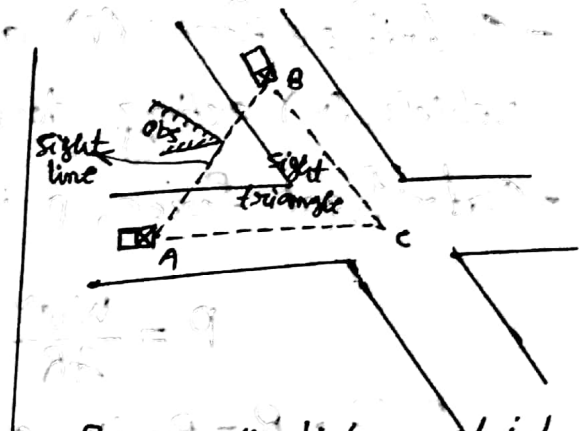


Fig: Sigth distance at intersecti

(For details, see book, Khanna and justo → P-102)

Horizontal curves:-

- Presence of horizontal curves impart centrifugal force which is a reative force acting outward on a vehicle negotiating it.
- Centrifugal force developed depends on the speed and radius of horizontal curve and is counteracted to a certain extent by transverse friction between tyre and pavement surface.
- On a curved road, this force tends to cause vehicle to overrun or to slide outward from the centers of the road curvature.
- For proper design of curve, the overturning force should be minimized.
- Various forces acting on the vehicle are illustrated in the following figure.

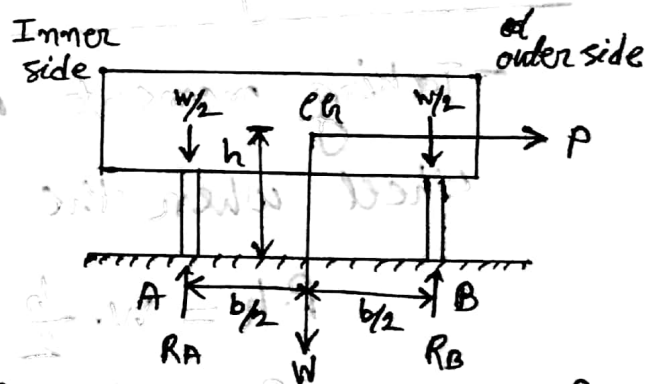


Fig: Overturning due to centrifugal force.

- Centrifugal force (P) acting outward and weight of the vehicle (W) acting downward.
- Centrifugal force, P is given by the equation;

$$P = \frac{W v^2}{gR}$$

where, R = Radius of circular curve, (m)
v = Speed of vehicle (ms^{-1}).
g = Acceleration due to gravity = 9.81 ms^{-2}.

V.V.Imp

Centrifugal Ratio:

The ratio of the centrifugal force to the weight of the vehicle is known as centrifugal ratio or impact factor.
Centrifugal ratio/Impact factor, $\frac{P}{W} = \frac{v^2}{gR}$.

V. Imp

Effect of centrifugal Force:-

- The centrifugal force acting on a vehicle negotiating on a horizontal curve has two effects;

1. A tendency to overturn vehicle about outer wheel:-

- Taking moment of force with respect to outer wheel when the vehicle is just about to overside;

$$P.h = W.\frac{b}{2}$$

$$\therefore \frac{P}{W} = \frac{b}{2h}$$

- The equilibrium condition, overturning is possible;

$$\frac{P}{W} = \frac{b}{2h}$$

$$\left[\because \frac{P}{W} = \frac{v^2}{gR}\right]$$

$$\therefore \frac{v^2}{gR} = \frac{b}{2h}.$$

- For the safety the following condition must satisfy;

$$\frac{b}{2h} > \frac{v^2}{gR}. \quad \text{——} (1)$$

2. A tendency of vehicle is for transverse skidding:-

- When centrifugal force is greater than maximum possible transverse skid resistance due to friction between the tyre and pavement surface then the transverse skidding occure.

- Transverse skid resistance, F is given by;

$$F = F_A + F_B$$

where,

F_A = Frictional force developed at wheel A.

F_B = Frictional force developed at wheel B.

$$F = f(R_A + R_B)$$

$$\therefore F = f.W$$

- This transverse skid resistance must balance the centrifugal force. From this; we get,

$$P = f.W$$

$$\therefore \frac{P}{W} = f$$

at the equilibrium skidding takes place when;

$$\frac{P}{W} = f = \frac{v^2}{gR}.$$

- For safety following condition must satisfy;

$$f > \frac{v^2}{gR} \quad \text{— ②}$$

- Equation ① and ② is stable condition for design.
- If equation ① will be violated, the vehicle will overturn at horizontal curve, if equation ② is violated, ~~vehicle~~ then lateral skid occurs.

Superelevation: (cant) or (Banking)

V.V. Imp 14, 12

(- Definition: Superelevation is defined as the difference in level or height between the outer edge and the inner edge of the road on a horizontal curved path.)

- Superelevation or Cant or Banking is transverse slope provided at horizontal curve to counteract the centrifugal force by rising the outer edge of the pavement with respect to inner edge throughout the length of the horizontal curve.
- When the outer edge is raised, a component of vehicle weight will be complimented in counteracting the effect of centrifugal force.

Analysis of Superelevation:-

-Let us consider the following figure;

Forces acting on the vehicle on horizontal curve of radius R(m) at a speed of $v\ ms^{-1}$ are;

(i) centrifugal force, P acting outward through the center of the gravity.

(ii) The weight of vehicle (W) acting vertically downward through the center of gravity.

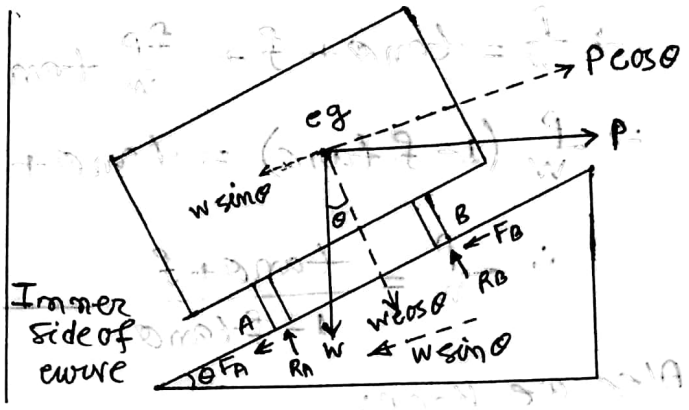


fig: Analysis of superelevation.

(iii) The frictional force (f) developed between the wheel and the pavement surface towards the center of the curve.

-At equilibrium, by resolving forces parallel to the surface of the pavement, we get;

$$P\cos\theta = W\sin\theta + F_A + F_B$$
$$= W\sin\alpha + f(R_A + R_B)$$
$$= W\sin\theta + f(W\cos\theta + P\sin\theta)$$
$$\therefore P\cos\theta = W\sin\theta + fW\cos\theta + fP\sin\theta \quad \text{---} (1)$$

where, W = weight of vehicle.
P = centrifugal force.
f = Frictional force.
θ = Transverse slope.

Dividing both side of equation ① by $W\cos\theta$, we get;

$$\frac{P\cos\theta}{W\cos\theta} = \frac{W\sin\theta}{W\cos\theta} + \frac{fW\cos\theta}{W\cos\theta} + \frac{fP\sin\theta}{W\cos\theta}$$

$$\Rightarrow \frac{P}{W} = \tan\theta + f + \frac{fP}{W}\tan\theta$$

$$\Rightarrow \frac{P}{W}(1 - f.\tan\theta) = \tan\theta + f$$

$$\therefore \frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta} \quad \text{---} \quad (2)$$

Also we know;

centrifugal ratio, $\frac{P}{W} = \frac{V^2}{gR}$

From equation ②, we get;

$$\frac{V^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta} \quad \text{---} \quad (3)$$

Normally, $f = 0.15$

$1 - f\tan\theta \approx 1$

$\theta < 4°$

As θ is very small so $\tan\theta \approx \sin\theta = e$ = superelevation.

∴ equation ③ becomes;

$$\boxed{e + f = \frac{V^2}{gR}} \quad \text{---} \quad (4)$$

This is the general form of superelevation equation. which is the relations between superelevation, e. f, V and R.

➡ Three specific cases can arise;

① If there is no friction ($f=0$) due to some practical reason;

$$e = \frac{v^2}{gR} = \frac{V^2}{127R} \quad [\because f=0]$$

This results in situation where the pressure on both wheel are same, requiring high superelevation.

② If there is no superelevation ($e=0$) provided due to some practical reason;

$$f = \frac{v^2}{gR} = \frac{V^2}{127R} \quad [\because e=0]$$

This results in the frictional force has to fully counteract the centrifugal ratio.

③ If $e=0$ and $f=0.15$ then the safe travelling speed from equation ④ is given by;

$$v_b = \sqrt{fgR} = \sqrt{1.472R}$$

where, v_b = Restricted speed.

If v_b is less than the design speed (v) then the design speed (v) should be restricted. If v_b is greater than the design speed (v_b) then v_b is considered as design speed.

(Example-4.8 Have to be done
Khanna & Justo → P-109)

V.V. 9m 14,12

⊞ Design of Superelevation in the field:-

– steps for designing superelevation in the field is as follows;

Step-1: Find e for 75% of design speed. neglecting f.

$$\therefore e_1 = \frac{(0.75V)^2}{gR}$$

Step-2: If $e_1 \leq 0.07$ then $e = e_1 = \frac{(0.75v)^2}{gR}$ else if $e_1 > 0.07$ go to next step.

Step-3: Find f_1 for design speed and maximum e.

$$\therefore f_1 = \frac{v^2}{gR} - e_{max}$$

$$f_1 = \frac{v^2}{gR} - 0.07$$

if $f_1 < 0.15$ then maximum $e = 0.07$ is safe for the design speed, else if goto next step.

Step-4: Find allowable speed V_a for maximum $e = 0.07$ and $f = 0.15$ then,

$$V_a = \sqrt{0.22gR}$$

if $V_a \geq V$ (design speed) then the design is adequate otherwise used speed adopt controll measures or look for speed controll measures.

(Example → 4.9, 4.10, 4.11 Have to be done.
Khanna & Justo → P-112 to 114)

⊞ Maximum and Minimum Superelevation :-

- Depending on ⓐ Slow moving vehicles and ⓑ Heavy loaded trucks with high cg (center of gravity) a maximum superelevation of 7% for plain and rolling terrain is recommended.
- On hilly terrain, 10% and on urban road 4% super-elevation is provided.
- Minimum superelevation if 2% to 4% for drainage purposes is provided especially for large radius of the horizontal curve.

$$\left(\text{Superelevation} \propto \frac{1}{\text{Radius of curve}}\right)$$

⊞ Attainment of Superelevation :- V.V. Imp 15,13,11,09

- The attainment of superelevation may be split up into two parts;

1. Elimination of crown of the cambered section.
2. Rotation of pavement cross section to attain full superelevation.

① Elimination of cambered :-

- The elimination of camber may be done by two methods. These are described below;

1.a. Rotating outer edge about crown :-

The outer half of the cross slope is rotated about the crown at a desired rate such that this surface falls on same plane as inner half.

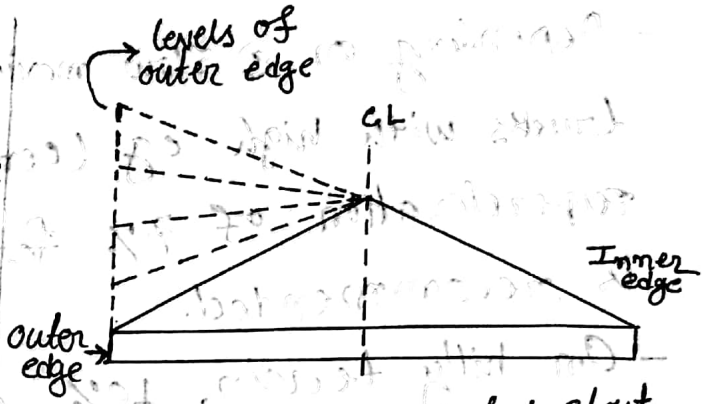


Fig: Outer edge rotated about the crown.

1.b. Shifting the position of the crown:

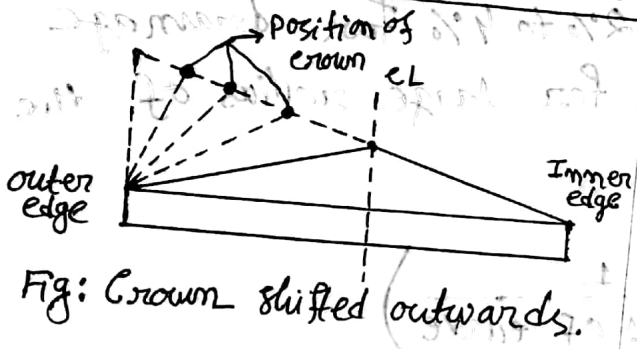


Fig: Crown shifted outwards.

It is also known as diagonal crown method.

Position of the crown is progressively shifted outwards, thus increasing the width of inner half or cross section progressively.

2. Rotation of pavement to attain full superelevation:-

-The rotation of pavement can be done by two methods;

2.a. Rotation about center line:

Pavement is rotated ~~& raising outer edge as well as center that outer edge is rai~~ such that inner edge is depressed and the outer edge

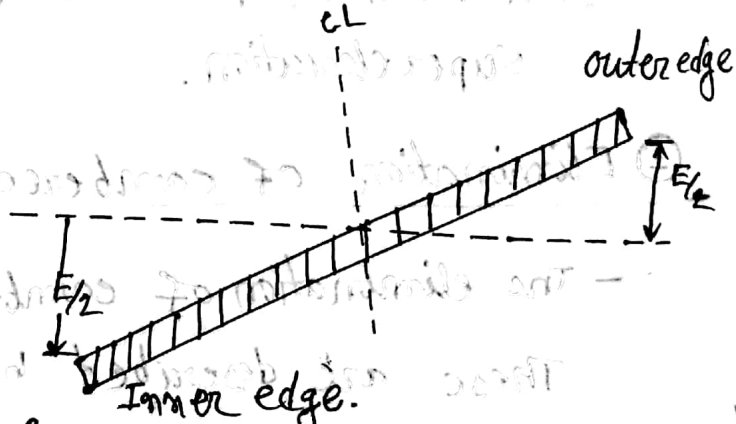


Fig: Rotation about center line.

is raised both by half of the total amount of super elevation i.e by $(\frac{E}{2})$ with respect to center.

2.b. Rotation about inner edge:-

Pavement is rotated by raising outer edge as well as the center that outer edge is raised by full amount of superelevation with respect to inner edge.

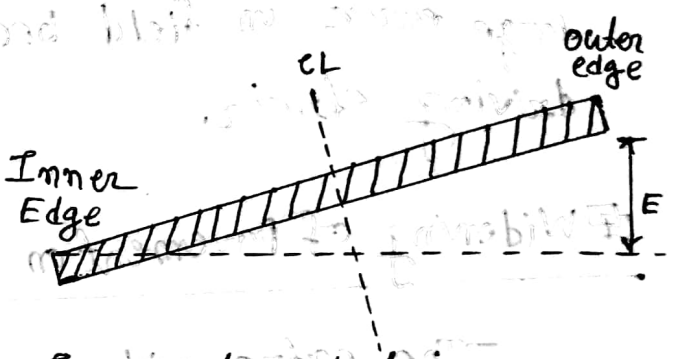


Fig: Rotation about inner edge.

4 Radius of Horizontal curve (R):-

- Radius of horizontal curve is an important design aspect of geometric design.
- Maximum comfortable speed on a horizontal curve depends on its radius (R).
- Although it is possible to design curve with maximum super elevation (e) and co-efficient of lateral friction (f), it is not desirable because re-alignment would be required if the design speed will be increased in future.
- Therefore, a ruling minimum radius (R_{ruling}) can be derived by assuming maximum super elevation (e) and co-efficient of lateral friction (f).

$$\therefore R_{ruling} = \frac{v^2}{g(e+f)}.$$

+ Ideally, radius of curve should be higher than R_{ruling}.

- Very large curve are not desirable because setting out large curve in field becomes difficult, it also enhances driving strain.

Widening of Pavement on Horizontal Curve:-

- The extra widening refers to additional width of carriage way that is required on a curve section of a road over and above that required on a straight alignment.

V.V.Imp (2 marks) 15,09

→ objectives of Extra widening:

- Objects of providing extra widening of pavement on horizontal curve are due to following reasons;

1. Off Tracking:

An automobile has a rigid wheel base and only the front wheel can be turned; when this vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of front wheel. This phenomenon is called off tracking.

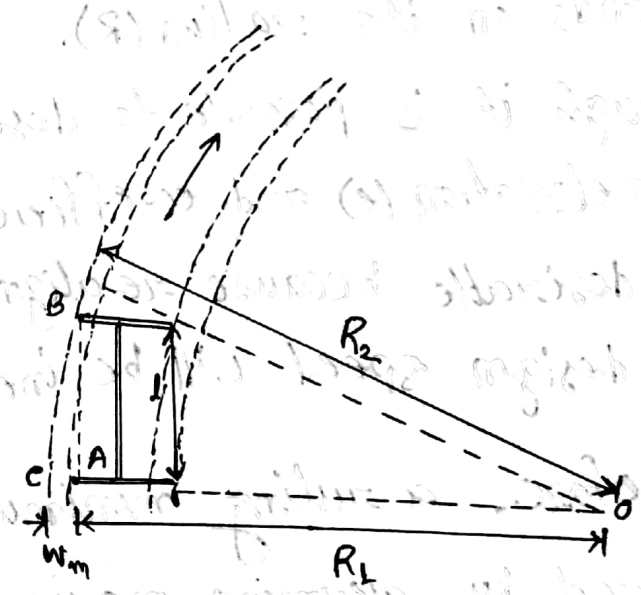


Fig: Mechanical widening on Horizontal curve.

Normally, the ~~rare~~ rear wheel follow the inner path on the curve as compared with those of the corresponding front wheels. This means that if inner front wheel takes a path on the inner edge of a pavement at a horizontal curve, inner rear wheel will be off the pavement on the inner shoulders.
The off-tracking depends on the length of the wheel base of the vehicle and the turning angle or the radius of the horizontal curve negotiated.

2. Transverse skidding due to excessive speed:

At speed higher than the design speed when the superelevation and lateral friction developed are not fully able to counteract the outward thrust due to the centrifugal force, some transverse skidding may occur and the ~~rare~~ rear wheel may take paths on the outside of those traced by the front wheels on the horizontal curves.

3. Towing vehicle:

The path traced by the wheels of a tailer in case of trailer unit, is also likely to be on either side of the central path of the towing vehicle.

4. Tendency of driver to follow the outer side of curve:

In order to take curve path with larger radius

and to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane, but to use the outer side at the begining of the curve.

5. Greater clearence between crossing or overtaking vehicles:

while two vehicles cross or overtaking at horizontal curves there is a psychological tendency to maintain a greater clearence between the vehicles, than on straight for increase safety.

V.I.Q.M 14.12

→ Required Extra Widening at horizontals curve(We) depends on;

1. The length of wheel based of the vehicle, l.
2. Radius of the curve negotiated, R.
3. Psychological factors which is a function of speed of the vehicles and the radius of the curve.

- It has been a practice therefore to provide extra width of pavement on horizontal curves when the radius is less than about 300 m.)

Analysis of Extra Widening on curves:-

- The extra widening of pavement on horizontal curves is divided into two parts;

1. Mechanical Widening.
2. Psychological Widening.

1. Mechanical Widening:-

The widening is required to account for the off-tracking due to rigidity of wheel based is called mechanical widening (W_m).

Let us consider the following figure;

R_1 = Radius of the path traversed by the outer rear wheel, m.

R_2 = Radius of the path traversed by the outer front wheel, m.

l = length of wheel base. m.

W_m = Mechanical widening or off-traking.

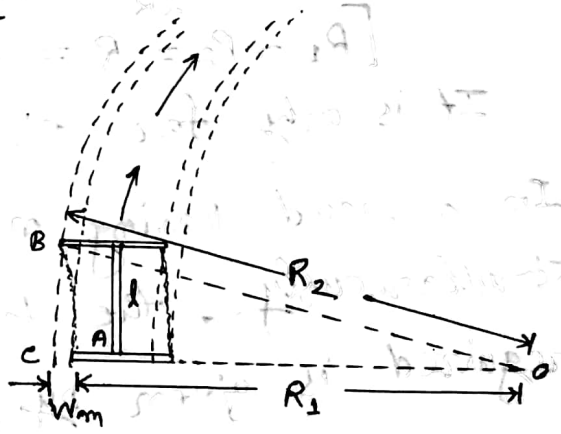


Fig: Mechanical widening.

From figure; we get,

$$W_m = OC - OA$$
$$= OB - OA \quad [\because OC = OB]$$
$$\therefore W_m = R_2 - R_1$$
$$R_1 = R_2 - W_m \quad \ldots\ldots\ldots\ldots (1)$$

From $\triangle OAB$;

$$OA^2 = OB^2 - AB^2 \quad \text{[Pithagoras theorem]}$$

$$R_1^2 = R_2^2 - l^2$$

$$(R_2 - W_m)^2 = R_2^2 - l^2 \quad \text{[using equation (1)]}$$

$$R_2^2 - 2R_2 W_m + W_m^2 = R_2^2 - l^2$$

$$W_m (2R_2 - W_m) = l^2$$

$$\Rightarrow W_m = \frac{l^2}{2R_2 - W_m}$$

Since, $R_2 >> W_m$ so neglecting W_m.

$$W_m = \frac{l^2}{2R_2}$$

$$W_m = \frac{l^2}{2R} \text{ (approximately)}$$

[$R_1 = R_2 = R$ = Radius of the curve]

It is only for single traffic lane Road.

- In a road having n lanes as n vehicles can travel simultaneously, the total mechanical widening required is given by;

$$W_m = \frac{nl^2}{2R}.$$

2. Psychological Widening:-

- Widening of pavement has to be done for same Psychological reasons;

a. To provide for greater widening of steering at higher speed.
b. To provide greater clearence for crossing and overtaking vehicles.
c. To allow for the extra space requirements for the overhangs of vehicles.

– An empirical formula has been recommended by IRC for calculating Psychological widening, W_{ps} is as follows;

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$

where,
V = Design speed in Kmph.
R = Radius of curve in m.

➡ So, the Total widening, We required on a horizontal curve is given by;

$$W_e = W_m + W_{ps}$$

$$\therefore W_e = \frac{n l^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

where, n = No. of traffic lanes.
l = length of wheel base. (m)
R = Radius of curve. (m)
V = Design speed. (Kmph)

Examples — 4.14 and 4.15
Khanna and Justo

Horizontal Transition curve:-

- It is provided to change horizontal alignment from straight to circular curve gradually.
- A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve.

V.V.Imp Qs → There are five objectives for providing horizontal transition curve;

1. To introduce gradually the centrifugal force between the tangent point and the begining of the circular curve, avoiding a sudden jerk on the vehicles.
2. To enable the driver to turn the steering gradually for his own comfort and security.
3. To enable gradual introduction of the designed super-elevation and extra widening of pavement at the start of the circular curve.
4. To improve the aesthetics appearence of the road.
5. To provide for a smooth change of direction of a vehicle from a straight to a curved path or vice-versa.

⊞ Types of Transition curve :-

- The types of transition curves commonly adopted in horizontal alignment are ;

1. Spiral or clothoid.
2. Lemniscate.
3. Cubic parabola.

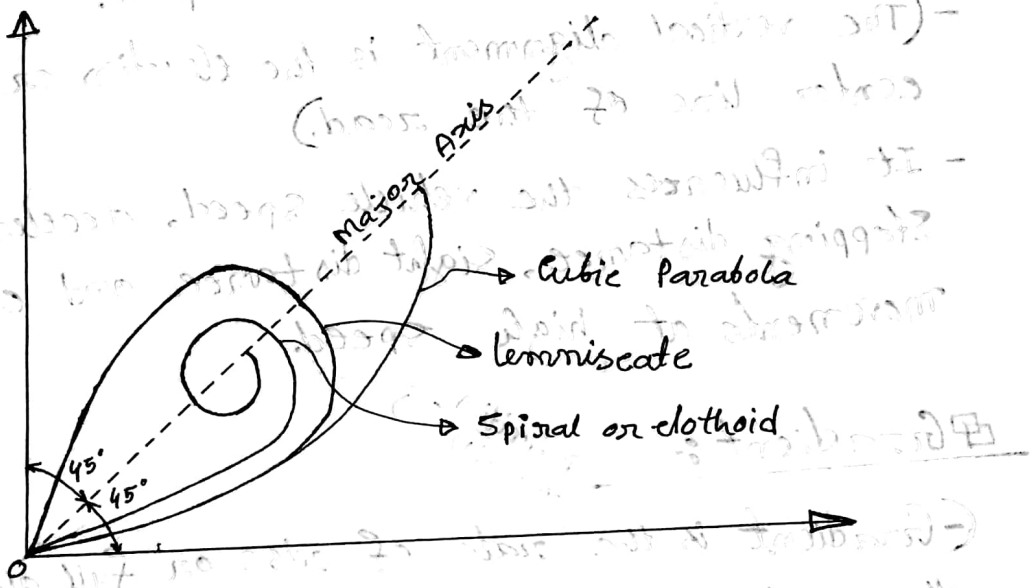


Fig: Different types of Transition curves.

⊞ Length of Transition curve :-

The length of transition curve may be determined by the following methods ;

1. By the rate of change of radial acceleration.
2. By an arbitary rate of change of super elevation.
3. By the time rate.
4. By empirical formula. (self study from Book)

Vertical Alignment :-

- The vertical alignment consist of gradient and vertical curves.
- It is usually drawn as a profile which is a graph with elevation as vertical axis and length as horizontal axis.
- Just as a circular curve, it is used to connect straight stretches of road to the curve path.
- (The vertical alignment is the elevation or profile of the center line of the road.)
- It influences the vehicle speed, acceleration, deceleration, stopping distance, sight distance and comfort in vehicle movements at high speed.

Gradient :-

Definition V.V. Sm (12)

(- Gradient is the rate of rise or fall along the length of the road with respect to the horizontal.
- It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal unit))
- while aligning a highway, the gradient is decided for designing the vertical curve.
- Usually very steep gradients are avoided as it is ~~not~~ most difficult to climb the grade but also the vehicle operation cost is increased.
- Before finalising the gradient, construction cost, the

practical problems in construction at the site and the vehicle operation cost have to be considered.

Effect of Gradient:

- The effect of long steep gradient on vertical curve is considerable.
- This is pertieularly important in roads where proportion of heavy vehicle is significant.
- Due to restrictive sight distance at uphill gradient, the speed of traffic can be limited.
- As a result, not only operating cost increased but ~~only~~ also the discomfort of driver and passengers and lake of safety.
- Further, due to high differential speed between heavy and light vehicle and between uphill and downhill the gradient should be optimised.

Representative of Gradient:-

- Gradients which are generally represented as n percent (n%) would mean that this is the value of the tangent of the angle made by the gradient with horizontal i.e $n\% = \tan\alpha$.
- She ascending gradients are given positive sign and are denoted as $+n_1$, $+n_2$ etc.

- The descending gradients are given negative sign and are denoted as $-n_3, -n_4$ etc.

→ **Deviation Angle (N):** The angle which measures the change of direction at the intersection of two gradients is called the deviation angle (N) which is equal to the algebric difference between the two grades.

Types of Gradient :-

- Many studies have shown that minimum 7% gradient should be provided.
- On the contrary, speed of heavy vehicle are considerably reduced when large gradient as flat as 2% is adopted.
- Although flatter gradient is desirable, it is evident that the vehicle operation cost is high in steeper gradient.
- The steeper gradients are permitted to a short duration of road.
- Gradients are divided into the following categories;

1. Ruling gradient.
2. limiting gradient.
3. Exceptional gradient.
4. Minimum gradient.

1. Ruling Gradient:

✓ Ruling gradient or Design gradient is the maximum gradient within which the designer attempts to design the vertical profile of road.

✓ This depends on terrain, length of grades, pulling power of the vehicle etc.

- In flatter terrain, it may be possible to provide flat grades but in hill roads it may not be economical or some times not even possible to adopt the same gradient because of large difference in levels to be covered in short length of road.

- Ruling gradient is adopted by the designer by considering a particular speed or design speed for a design vehicle with standard dimensions.

- But in out country has a heterogeneous or mixed traffic it is not possible to adopt ruling gradient.

✓ Hence, Some values of Ruling gradient for different types of terrain has been recommended by IRC is given below;

Plain Terrain —— 1 in 30

Rolling Terrain —— 1 in 30

Mountainous Terrain — 1 in 20

Steep terrain —— 1 in 16.70

2. Limiting Gradient:

- This gradient is adopted when the ruling gradient results in enormous increase in cost of construction.
- On Road Terrain and hilly terrain, it may be frequently necessary to adopt limiting gradient.
- But length of limiting gradient stretches should be limited and must be sandwiches

3. Exceptional Gradient :-

- Exceptional gradients are very steeper gradient which given at unavoidable situation.
- They should be limited for short stretches of road not greater than 100 m.
- In mountain and steep terrain the exceptional

gradients are provided in exceptional situations such as in approaches to canse ways or near hairpin bends etc.
- In hairpin bends, the gradient is restricted to 2.5%.

4. Minimum Gradients:

- It is provided only for drainage of rain water when the rainfall is very high.
- Camber with take care of limiting dimension.
- But longitudinal slope is essential to drain water along the side drains depending on the surface of the drains.
- Therefore a minimum gradient is provided to drain rain water.
- A minimum gradient of about 1 in 500 may be sufficient to drain water in concrete drains or gutter. But on inferior surfaces of drains a slope of 1 in 200 may be needed and in case of steeper slopes up to 1 in 100 may be needed.

⊞ Vertical curves:-

Due to changes in grades in vertical alignment of highway, it is neeessary to introduce vertical curves at the intersections of different grades to smoothen out the vertical profile and thuse ease off the change

in gradients for the fast moving vehicles.
The vertical curves used in highway may be classified into two categories;

1. Summit curves or crest curves with convexity upward.
2. Valley curve or sag curve with concavity upward.

1. Summit (crest) curves:-

- Summit curves are vertical curves of upward apex.
- It is ~~marked~~ made by four ways;

(a) When ascending gradient meet with ascending gradients
(b) When ascending gradient meet with flat gradient.
(c) When ascending gradient meet with descending gradient.
(d) When descending gradient meet with descending gradient

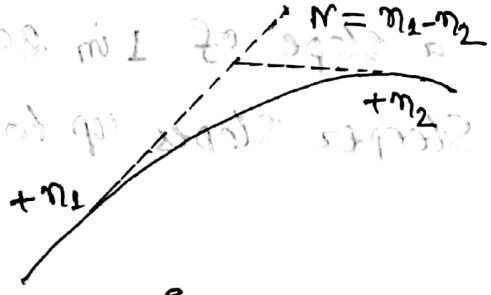
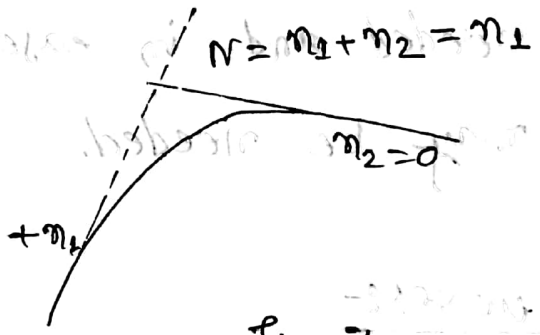


fig: a



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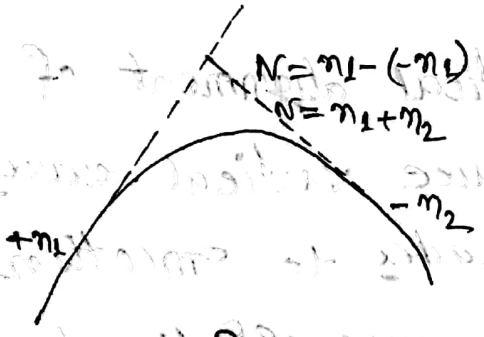


fig: c

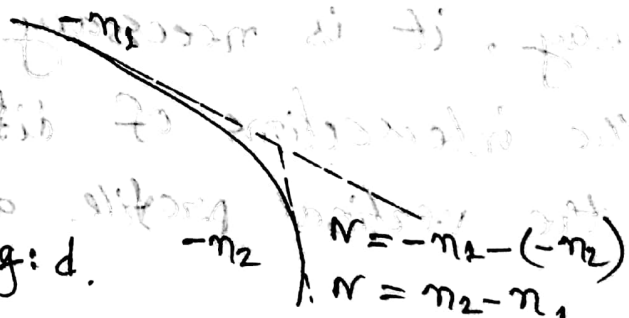


fig: d.

NB: Maximum deviation occur when the ascending gradient meets with descending gradient. Deviation angle; $N = n_1 - (-n_2) = n_1 + n_2$.

Length of summit (crest) curves:-

- Important design aspect of summit curve is determination of length of the curve which is parabolic.
- As noted earlier, the length of curve is parabolic so the sight distance should be adequate.
- That is why, a driver should be able to stop his vehicle safely.
- Equation of parabola is given by;

$$y = ax^2$$

where, $a = \frac{N}{2L}$

Here, N = Deviation angle.
L = length of summit curve.

- In deriving the length of summit curve, two situation can arise depending on uphill and downhill gradient. when the length of curve is greater than sight distance and the length of curve is less than sight distance.
- Let, L be the length of summit curve and S be the

SSD/ISD/OSD, N be the deviation angle, H be the driver eye level height (1.2m) and h be the hight of objects (0.15m).

Case-I: length of summit curve is greater than stopping sight distance (L > SSD).

we have,
equation of parabola;

$$y = ax^2$$

$$a = \frac{N}{2L}$$

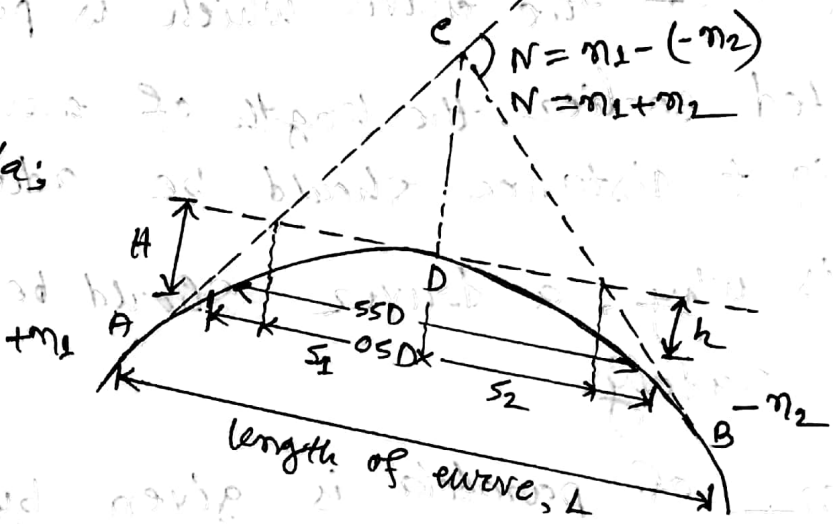


fig: length of summit curve.

From figure;

$$H = a S_1^2$$

$$\therefore S_1 = \sqrt{H/a}$$

and $$h = a S_2^2$$

$$\therefore S_2 = \sqrt{h/a}$$

Now, SSD, $S = S_1 + S_2$

$$\Rightarrow S = \sqrt{H/a} + \sqrt{h/a}$$

$$\Rightarrow (S)^2 = \left(\sqrt{H/a} + \sqrt{h/a}\right)^2 \quad \text{[By squaring]}$$

$$\Rightarrow S^2 = \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{H} + \sqrt{h}\right)^2$$

$$\Rightarrow S^2 = \frac{2L}{N}\left(\sqrt{H}+\sqrt{h}\right)^2 \qquad \left[\because a = \frac{N}{2L}\right]$$

$$\therefore L = \frac{NS^2}{2\left(\sqrt{H}+\sqrt{h}\right)^2} \qquad \text{——— (1)}$$

$H = 1.2\,m$ = Drivers eye level height.
$h = 0.15\,m$ = object height.

Putting this values in equation (1), we get;

Length of summit curve, $L = \frac{NS^2}{4.4}$

Case-II: When the length of summit curve is less than stopping sight distance ($L < SSD$).

The general equation for the length of parabolic summit curve, when it is less than the summit curve is given by;

$$L = 2S - \frac{\left(\sqrt{2H}+\sqrt{2h}\right)^2}{N}$$

Putting the values of $H = 1.2\,m$, $h = 0.15\,m$ we get;

$$L = 2S - \frac{4.4}{N}$$

→ Length of summit curve for safe overtaking sight distance (OSD) or Intermediate sight distance (ISD):-

Case-I: $L > OSD$ or $ISD\ (S)$

Length of summit curve;

$$L = \frac{NS^2}{8H}$$

Putting $H = 1.2\ m$ = driver eye level height, we get;

$$L = \frac{NS^2}{9.6}.$$

Case-II: $L < S$ (OSD or ISD).

Length of summit curve;

$$L = 2S - \frac{8H}{N}$$

Putting $H = 1.2m$ = driver eye level height, we get;

$$L = 2S - \frac{9.6}{N}.$$

(Example – 4.22, 4.23, 4.24 with excercise Khanna & Justo.)

⊞ Valley curve or Sag curve:

- Valley curve or Sag curve are vertical curves with concavity upwards.
- They are formed by four ways;

ⓐ When descending gradient meet with descending gradient.
ⓑ When descending gradient meet with flat gradient.
ⓒ When descending gradient meet with ascending gradient.
ⓓ When ascending gradient meet with ascending gradient.

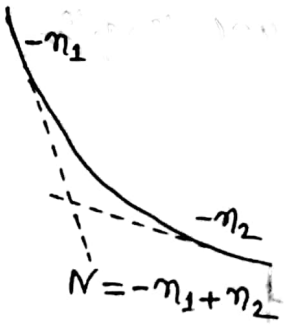


Fig: a

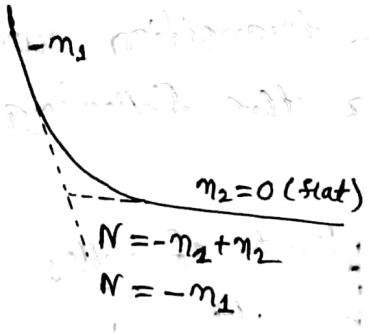


Fig: b.

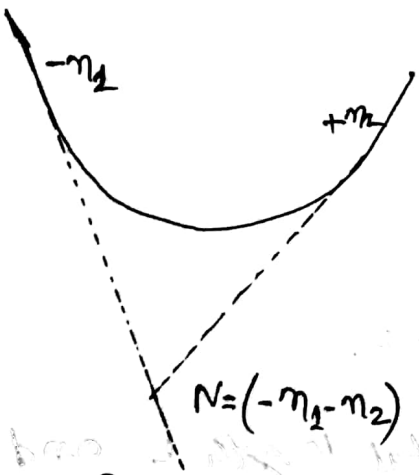


Fig: c

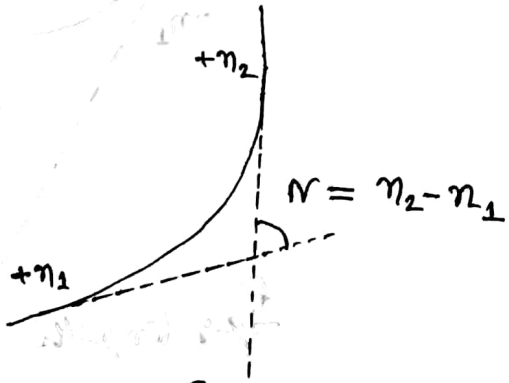


Fig: d.

Figure: Valley (Sag) curves.

Length of valley or Sag curves:

- The length of valley transition curve is designed based on two criteria;
  1. The allowable rate of change of centrifugal acceleration of 0.06 m/sec²/sec.
  2. The head light sight distance, and the higher of the two values is adopted.

- Usually the second criterion of head light sight distance is higher and therefore governs the design.

- The valley curve is made fully transitional by providing two similar transition curves of equal length.

Let us consider the following figure;

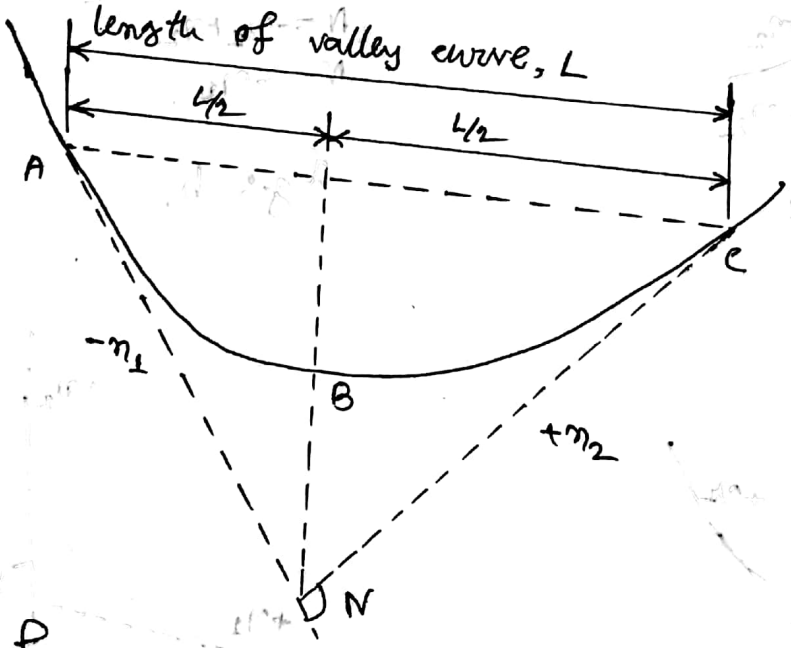


fig: length of valley curve.

Here, ABC is the valley curve of total length L and AB and BC are two equal transition curve each of

length $L_s = L/2$ having the minimum radius R at the common point B.

① Length of valley (sag) curve for comfort condition:-

With allowable rate of change of centrifugal acceleration $e = 0.06$ m/sec^2/sec. the length of valley curve for comfort condition is given by;

$$L = 2.\left[\frac{NV^3}{e}\right]^{1/2}$$

$$\therefore L = 0.38\,(NV^3)^{1/2}$$

Here,
V = Design speed in Kmph.
N = Deviation angle.

The minimum radius of valley curve for cubic parabola is given by;

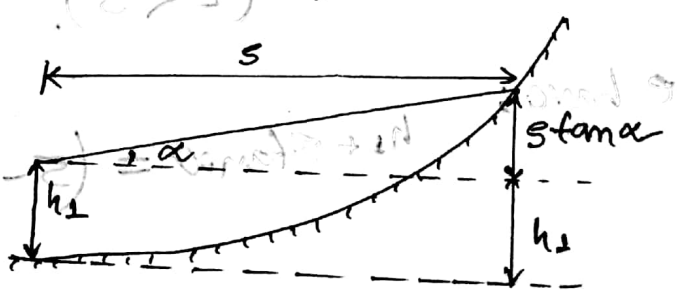
$$R = \frac{L}{2N}.$$

② Length of valley curve for Head light sight distance:-

Case-I: When the total length of valley curve is greater that Head light sight distance ($L > HSD$).

If the valley curve is assumed to be parabolic shape with equation

$$y = ax^2 \quad \text{——} (a)$$



where, $x = S$

$a = \frac{N}{2L}$

$y = h_1 + S\tan\alpha$

α = Head light beam inclination in degree.

h_1 = Height of head light beam.

S = Stopping sight distance.

N = Deviation angle.

L = length of valley curve.

From equation @; we get;

$$h_1 + S\tan\alpha = \frac{NS^2}{2L}$$

$$\therefore L = \frac{NS^2}{2(h_1 + S\tan\alpha)}$$

$h_1 = 0.75\,m$ = Average height of head light beam.

$\alpha = 1°$ = Head light beam inclination.

$$\therefore L = \frac{NS^2}{1.5 + 0.035S}$$

Case-II: Length of valley curve is less than Head light sight distance $(L < S)$.

We have;

$$h_1 + S\tan\alpha = \left(S - \frac{L}{2}\right) N$$

$$\therefore L = 25 - \frac{2h_1 + 25\tan\alpha}{N}$$

Substituting $h_1 = 0.75\,m$ and $\alpha = 1^\circ$, we get;

$$L = 25 - \frac{1.5 + 0.0355}{N}$$

(Example – 4.25 with excercise
Khanna and Justo.)

→ Flexibility = Low resistance to bending.

→ Ductility = Elongation before crack. Load remove করলে এটুকুও আগের অবস্থায় ফিরে আসে না।

→ Malleability = পিটিয়ে পাতলা পাতে পরিনত করা যায়।

→ Plasticity = Load remove করলে কিছু পরিমান পূর্বের অবস্থায় ফিরে আসা।

→ Elasticity = Load remove করলে সম্পূর্ণ আগের অবস্থায় ফিরে আসা।

→ Consolidation = চাপ পরি হবে হলে যে deformation হয় তাই consolidation.

➡ Compact (দৃঢ়ভাবে): Void ratio সবচেয়ে কম, closely packed. আকারের বিকৃতি হবে না।

➡ Compress (সংকুচিত): Force Apply করে Condense করা। যে ক্ষেত্রে আকারের বিকৃতি হতে পারে। To make something occupy a smaller space or volume

TRAFFIC ENGINEERING

1. Introduction

1.

Another note khata and sheet Provided by MAS sir.