# TRANSPORTATION ENGINEERING -I

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## Role of transportation in society

- Transportation is a non separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption.
- Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations.
- This chapter conveys an understanding of the importance of transportation in the modern society by presenting selected characteristics of existing transportation systems, their use and relationships to other human activities.
- Transportation is responsible for the development of civilizations from very old times by meeting travel requirement of people and transport requirement of goods. Such movement has changed the way people live and travel.
- In developed and developing nations, a large fraction of people travel daily for work, shopping and social reasons. But transport also consumes a lot of resources like time ,fuel, materials and land.

## Economic role of transportation

- Economics involves production, distribution and consumption of goods and services. People depend upon the natural resources to satisfy the needs of life but due to non uniform surface of earth and due to difference in local resources, there is a lot of difference in standard of living in different societies.
- So there is an immense requirement of transport of resources from one particular society to other. These resources can range from material things to knowledge and skills like movement of doctors and technicians to the places where there is need of them.

## The place, time, quality and utility of goods

- An example is given to evaluate the relationship between place, time and cost of a particular commodity. If a commodity is produced at point A and wanted by people of another community at any point B distant x from A, then the price of the commodity is dependent on the distance between two centers and the system of transportation between two points. With improved system the commodity will be made less costly at B.

## Changes in location of activities

- The reduction of cost of transport does not have same effect on all locations. Let at any point B the commodity is to be consumed. This product is supplied by two stations A and K which are at two different distances. from B. Let at present the commodity is supplied by A since it is at a lesser distance but after wards due to improvement in road network between B and K , the point K becomes the supply point of product.

## Conclusions

- Transport extends the range of sources of supply of goods to be consumed in an area, making it possible for user to get resources at cheap price and high quality.
- The use of more efficient systems of supply results in an increase in the total amount of goods available for consumption.
- Since the supply of goods is no longer dependent on the type of mode, items can be supplied by some alternative resources if usual source cannot supply what is needed.

## Social role of transportation

- Transportation has always played an important role in influencing the formation of urban societies.
- Although other facilities like availability of food and water, played a major role, the contribution of transportation can be seen clearly from the formation, size and pattern, and the development of societies, especially urban centers.

## Formation of settlements

- From the beginning of civilization, the man is living in settlements which existed near banks of major river junctions, a port, or an intersection of trade routes. Cities like New York, Mumbai and Moscow are good examples

## Size and pattern of settlements

- The initial settlements were relatively small developments but with due course of time, they grew in population and developed into big cities and major trade centers. The size of settlements is not only limited by the size of the area by which the settlement can obtain food and other necessities, but also by considerations of personal travels especially the journey to and from work. The increased speed of transport and reduction in the cost of transport have resulted in variety of spatial patterns

# Growth of urban centers

- When the cities grow beyond normal walking distance, then transportation technology plays a role in the formation of the city. For example, many cities in the plains developed as a circular city with radial routes, where as the cities beside a river developed linearly. The development of automobiles, and other factors like increase in personal income, and construction of paved road network, the settlements were transformed into urban centers of intense travel activity.

# Political role of transportation

The world is divided into numerous political units which are formed for mutual protection, economic advantages and development of common culture. Transportation plays an important role in the functioning of such political units.

- Administration of an area
- Political choices in transport

## Administration of an area

- The government of an area must be able to send/get information to/about its people. It may include laws to be followed, security and other needful information needed to generate awareness.
- An efficient administration of a country largely depends on how effectively government could communicate these information to all the country. However, with the advent of communications, its importance is slightly reduced.

# Political choices in transport

- These choices may be classified as communication, military movement, travel of persons and movement of freight. The primary function of transportation is the transfer of messages and information.
- It is also needed for rapid movement of troops in case of emergency and finally movement of persons and goods. The political decision of construction and maintenance of roads has resulted in the development of transportation system.

# Environmental role of transportation

The negative effects of transportation is more dominating than its useful aspects as far as transportation is concerned. There are numerous categories into which the environmental effects have been categorized. They are explained in the following sections.

- Safety
- Air Pollution
- Noise pollution
- Energy consumption
- Other impacts

# Summary

- The roles of transportation in society can be classified according to economic, social, political and environmental roles. The social role of transport has caused people to live in permanent settlements and has given chances of sustainable developments. Regarding political role, large areas can now be very easily governed with the help of good transportation system. The environmental effects are usually viewed negatively.

# Assignment

Make a ppt on

Factors affecting transportation

→ Define
→ function
→ Chractcristic
→ Types.
[ advantages
[ disadvantges
→ Size
→ Quantity

# CHAPTER 6

# Ballast

## 6.1 BALLAST

Ballast is the granular material usually broken stone or any other suitable material which is spread on the top of railway formation and around the sleepers.

## 6.2 FUNCTIONS OF BALLAST

Ballast in railway track performs the following functions :

(i) To hold the sleepers in position and preventing the lateral and longitudinal movement.

(ii) To distribute the axle load uniformly from sleepers to a large area of formation.

(iii) To provide elasticity to the track. It acts as an elastic mat between subgrade and sleepers.

(iv) To provide easy means of maintaining the correct levels of the two rails in a track.

(v) To drain rain water from the track.

(vi) To prevent the growth of weeds inside the track.

## 6.3 CHARACTERISTICS OF GOOD BALLAST

(i) It should have sufficient strength to resist crushing under heavy loads of moving trains.

(ii) It should be durable enough to resist abrasion and weathering action.

(iii) It should have rough and angular surface so as to provide good lateral and longitudinal stability to the sleepers.

(iv) It should have good workability so that it can be easily spread on formation.

(v) It should be cheaply available in sufficient quantity near and along the track.

(vi) It should not make the track dusty or muddy due to its crushing to power under wheel loads.

(vii) It should allow for easy and quick drainage of the track.

(viii) It should not have any chemical action on metal sleepers and rails.

## 6.4 TYPES OF BALLAST

In India, the following materials are used as ballast :

(i) Broken strong
(ii) Gravel
(iii) Sand
(iv) Ashes or cinders
(v) Kankar
(vi) Moorum
(vii) Blast furnace slag
(viii) Brick ballast
(ix) Selected earth

(i) **Broken Stone :** This is the best type of ballast as it possesses all the characteristics of a good ballast. It holds the track to correct alignment and gradient due to its high interlocking action. The stones which are non porous, hard and do not flake on breaking should be used. Igneous rocks such as granite, quartzite and trap make execllent ballast. This type of ballast is used for high speed tracks.

***Advantages***

(a) It is hard and resist crushing under heavy loads.
(b) It has angular and rough surface and hence gives more stability to the sleepers.
(c) Its drainage property is excellent.

***Disadvantages***

(a) It is expensive.
(b) It is not so easily available.

(ii) **Gravel :** Gravel is the second best material for ballast. This is obtained either from river beds or from gravel pits and has smooth rounded fragments. Gravel obtained from pits usually contains earth which should be removed by washing. Gravel obtained from river beds is screened and required size gravel is used. Larger size gravels are broken into required size. Round edges gravels are broken to increase their interlocking action.

***Advantages***

(a) Gravel is cheaper than stone ballast.
(b) The drainage property of gravel is excellent.
(c) It holds the track to correct alignment and gradient.
(d) It is easy to use gravel ballast than stone ballast at certain places where formation is unstable.

***Disadvantages***

(a) It requires screening before use due to large variation in size.
(b) Gravel obtained from pits requires washing.
(c) Due to round faces the packing under sleepers is loose.
(d) Gravel easily roll down due to vibrations.

(iii) **Sand :** Sand is reasonably a good material for the ballast. Coarse sand is generally preferred to fine sand for ballast. This type of ballast is suitable for packing pot sleepers. It is used only on unimportant tracks.

***Advantages***

(a) It is a cheap material.
(b) It is available in large quantities.
(c) It has good drainage properties.
(d) Sand ballast produces a silent track.

***Disadvantages***

(a) It has no stability and gets disturbed by the vibrations caused by moving train.
(b) It causes wear of rail, seats and keys.

(iv) **Ashes or Cinders :** These are waste products obtained from steam locomotives.

***Advantages***

(a) It is cheaper ballast material.
(b) It has very good drainage quality.
(c) It is available in large quantities and hence can be used in emergency.
(d) The handling and transportation are easy.

***Disadvantages***

(a) It is very sott and gets crumbled to powder under heavy loads.
(b) It has got corrosive quality and corrode steel sleepers and foot of the rails.

(v) **Kankar :** It is a natural material in the form of nodules from which lime is prepared.

***Advantages***

(a) It is cheaper.
(b) It has good drainage property.

***Disadvantages***

(a) It is soft and crumbles to powder under traffic load.
(b) The track laid on kankar ballast are difficult to maintain.

(vi) **Moorum :** It is a soft aggregate and is obtained by the decompositon of laterite. It has red or yellow colour. It is used in unimportant lines and sidings.

***Advantages***

(a) It is easily available in most parts of India.
(b) It has good drainage properties.
(c) It is used as blanket for new embankment.

***Disadvantages***

(a) It is soft and easily crumbles to powder under heavy loads.
(b) Maintenance of track laid on moorum ballast is very difficult.

(vii) **Blast Furnance Slag :** It is a waste product obtained from the blast furnance of steel industry. High grade slag fulfils all the characteristics of good ballast.

***Advantages***

(a) It is a cheap material.

(b) It has good drainage properties.

(c) It is a strong material.

(d) In holds the tracks in correct alignment and gradient.

***Disadvantages***

(a) It is not available in large quantity.

(b) Spreading of this material on the formation is difficult.

(c) Maintenance of track laid on slag ballast is difficult.

**(viii) Brick Ballast :** At places where good ballast material is not available over-burnt bricks are broken into suitable size to be used as ballast.

***Advantages***

(a) It is a cheap material.

(b) It prevents growth of vegetation

(c) It has good drainage properties.

***Disadvatages***

(a) It is soft and easily crumbles to powder under heavy loads.

(b) The rails laid over such ballast get corrugated.

**(ix) Selected Earth :** Hardened clay and decomposed rock are suitable for use as ballast. When tracks are laid on new formation, then sleepers are packed with earth for a few months. When the formation is consolidated and surface becomes hard, good type of ballast is laid. The use of earth ballast in the beginning is to prevent the loss of good ballast by sinking into soft formation.

## 6.5 SIZE AND SECTION OF BALLAST

The size of ballast used in railway track varies from 19 mm to 51 mm. Stones of size larger than 51 mm are not preferred because these do not provide good interlocking. The best size of ballast is that which contains equal proportions of different sizes of stones and varies between 19 mm to 51 mm.

The size of ballast mainly depends upon the type of sleeper used and location of the track. The following sizes of ballast are used in Indian Railways.

(i) For Wooden Sleepers - 51 mm

(ii) For steel sleepers - 38 mm

(iii) For point and crossing - 25.4 mm

The depth of ballast section under the sleepers is an important factor as the load carrying capacity and uniformity of distribution of traffic load on formation depends much on it. The more the depth of ballast below the sleeper more will be the load carrying capacity of the track. The depth of ballast remains uniform throughout on straight tracks as shown in Fig. 6.1, but on curves additional ballast is required to make up the super-elevation. The depth of ballast under the outer rail on the curves is increased so as to give the required superelevation. Extra shoulder of 150 mm is provided on the outside of curves to counteract the increased lateral thrust.

The lateral stability of the track depends partly on the quantity of ballast at the end of sleepers. The lateral stability increases with the increase in width of ballast section upto a certain limit. This limit is 380 to 430 mm from the end of sleeper.

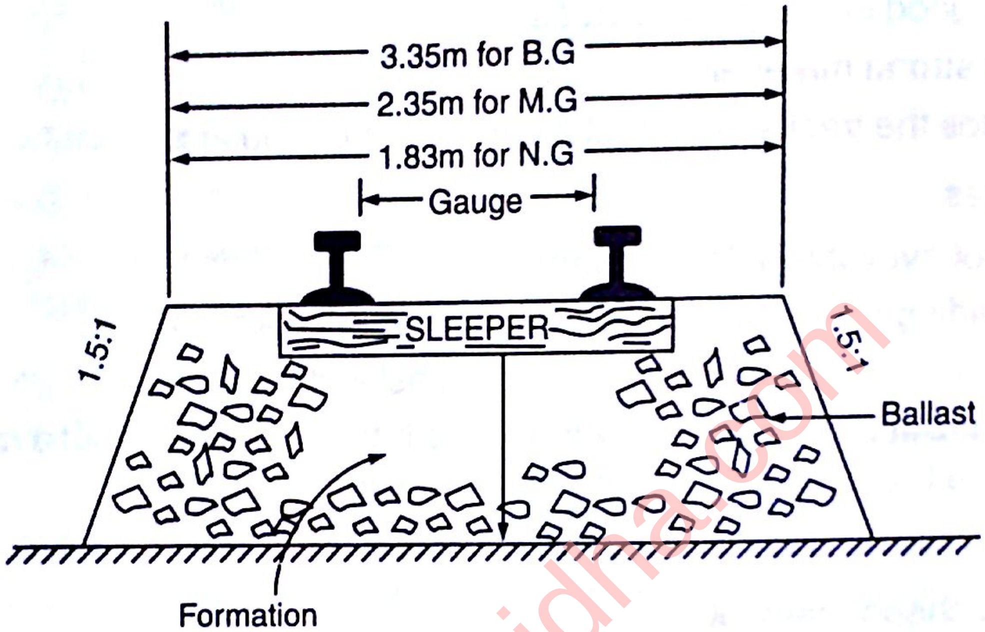


**Fig. 6.1** Ballast section on curved track

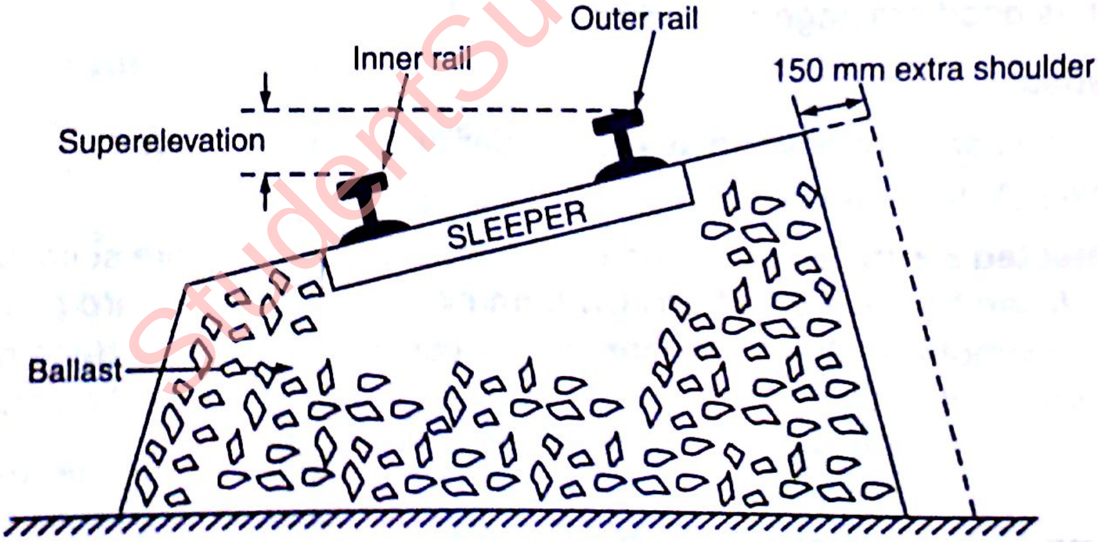


**Fig. 6.2** Ballast section on curved track

## 6.6 QUANTITY OF BALLAST

The quantity of ballast per metre tangent length is 1.036 cu m for B.G. 0.071 cum for M.G. and 0.053 cum for N.G.

## 3.1 HIGHWAY SURVEY

Before any highway alignment is finalized, various engineering surveys are required to be carried out. The survey work may be carried out in four stages. All the possible alternative routes are considered, in the first three stages, keeping in view the various requirements of highway alignment. In the fourth stage the detailed survey of the selected route is carried out.

*Following are various types of surveys :*

(a) Map study
(b) Reconnaissance survey
(c) Preliminary survey
(d) Location survey.

4 Stages

## 3.2 MAP STUDY

In this topographical maps of the concerned area are studied. These maps are available from the survey of India department. The main features like rivers, hills, valleys etc. along with contour lines at 15 to 30 m interval are shown on these maps. By careful study of such maps in the office one or more possible alignment can be marked keeping in view the topographical features and obligatory points. It is possible to drop certain alignments because of unavoidable obstructions and undesirable ground conditions. In map study it should be ensured that proposed alignment do not exceed ruling gradient anywhere. Thus map study gives a rough general idea about various possible alignments.

## 3.3 RECONNAISSANCE SURVEY

After map study and marking various possible alternative routes, the second set of surveys for highway location is the reconnaissance survey. In this type of survey fairly wide stretch of land along the proposed routes is studied. Very simple instruments like Tangent

> **DO YOU KNOW?**
>
> Topographical maps are drawn to a scale of 1 : 50,000.

Clinometer, Abney level, Barometer compass etc. are used in this survey to collect details not available in the map.

### 3.3.1 Object of Reconnaissance Survey

(i) To locate positions of hills, valleys, lakes, ponds, marshy land, permanent structures and other obstructions along the routes which are not available in the map.

(ii) To collect information regarding maximum flood level, underground water level, number and type of cross drainage structures along the probable route.

(iii) To determine the value of gradient, length of gradient and radius of curves of alternate alignment.

(iv) To obtain information regarding type of soil along the routes.

(v) To obtain information regarding climatic conditions in the area of the route.

(vi) To locate the sources of construction materials and water.

(vii) To collect data regarding the geological formation, type of rocks, seepage flow etc., when the road passes through hilly terrain.

### 3.2.2 Method of Conducting Reconnaissance Survey

*The reconnaissance survey is conducted in two steps :*

**(i) Area Reconnaissance :** The is carried out from the existing maps and aerial photographs obtained from the survey of India. In the absence of maps or aerial photographs, a basic map for reconnaissance is prepared. The latest technique to prepare the basic map is to take aerial photographs of the site and then through study of the photographs taken.

> **DO YOU KNOW?**
>
> A list of points on which data may be collected during ground reconnaissance survey is given in IRC-SP19.

**(ii) Route Reconnaissance :** This is carried out to check the practicability of each alternative route selected during area reconnaissance. This is done either by walking or by a helicopter. After working out the alternative routes the areas are restricted to small stretches of land and the required informations are then collected.

### 3.3.3 Preparation of Reconnaissance Report

*After collecting the various informations, a reconnaissance report is prepared in the following format :*

**(a) Introduction :** *This includes the following :*

(i) Purposes of reconnaissance survey

(ii) Study methods

(iii) Design criteria

**(b) General Alignment details :** In this following informations must be provided :

(i) Choice of routes, including advantages and disadvantages of various routes.

(ii) Interchange locations.

(iii) Service to communities.

(iv) Safety considerations.

(v) Drainage.

**(c) Project Cost Estimate :** This includes the estimate of the following :

(i) Roadway

(ii) Right-of-way
(iii) Structures
(iv) Utility re-location

**(d) Summary :** This includes conclusions and recommendations.

Finally a plan drawn to a scale 1 : 50,000 showing the alternative alignment is attached.

## 3.4 PRELIMINARY SURVEY

Preliminary survey is a large scale investigation of the alternative routes marked during reconnaissance survey.

> **DO YOU KNOW?**
> In preliminary survey, an accurate traverse line along the route already recommended during reconnaissance survey, is drawn. This line is called P-line.

### 3.4.1 Object of Preliminary Survey

(i) To survey the alternate alignments proposed during reconnaissance survey and to collect details of topography, soil and drainage.

(ii) To compare the various proposals in view of the requirements of a good alignment.

(iii) To estimate quantity of earthwork, materials etc. required for road construction along each alternative alignment of the road.

(iv) To finalize the best suited alignment from all considerations.

### 3.4.2 Method of Conducting Preliminary Survey

*The preliminary survey is carried out by one of the following methods :*

(i) Conventional Method
(ii) Aerial photogrammetry method

**(i) Conventional Method :** This method of preliminary survey is carried out in following steps :

**(a) Primary Traverse :** This is the first step in the preliminary survey. In this primary traverse is established along the route recommended in the reconnaissance survey. The angles and length of centre line should be measured very accurately as these traverses are open traverses and no adjustment of errors is possible later on.

**(b) Topographical Features :** After establishing the centre lines of preliminary survey, the topographical features are recorded. Physical features such as buildings, trees, monuments, ports, railway lines, drainage channels etc. are surveyed and plotted. The width to be covered for such detailing should be about the land width proposed to be acquired.

**(c) Levelling Work :** The levelling along with plane tabling is also carried out side-by-side to give centre line profile and typical cross-section. In the preliminary survey the levelling work is kept to a minimum, just sufficient to get the approximate earth work in the alternate alignments.

**(d) Hydrological Data :** The hydrological data are collected to get information on highest flood level, rainfall intensity, catchment areas of streams and to estimate the type, number and size of cross drainage structures. The grade line of the alignment is also decided based on the hydrological and drainage data.

**(e) Soil Survey :** After collecting the hydrological data, soil survey is conducted to work out details of earth work, slopes, sub-soil and surface drainage requirements. This also helps in deciding the pavement type and approximate thickness required.

**(ii) Aerial Photogrammetry Method :** This is the most modern and quick method of preliminary survey. This survey is very much suited when the distance and area to be covered are vast. Aerial photographs of the strips of land are taken and are examined by using photo-interpretation method to decide the geological feature, soil conditions, drainage requirements etc.

After collecting the various data from the preliminary survey of various alternate route, a comparative study is done to decide the best possible and economical route for location survey.

## 3.5 LOCATION SURVEY

The purpose of the final location survey is to fix the centre-line of the selected alignment in the field and to collect additional data for the preparation of the drawings.

### 3.5.1 Method of Conducting Location Survey

*The location survey is carried out in two steps :*

**(a) Location of Centre Line :** The centre line of the proposed road is transferred from the basic map to the ground. The centre line should touch all the major and minor control points. Pegs are driven at 30 m intervals with the help of theodolite and steel tape while locating the centre line. Depending upon the sharpness of the curve, stakes may be put at closer intervals in the horizontal curves. All curve points, namely beginning of transition, beginning of circular curve, end of circular curve and end of transition should be marked and referenced.

**(b) Detailed Survey :** First bench marks should be established at intervals of 250 m and then precise levelling is done. A single datum should be used for the entire level works. Longitudinal section and cross-sections are taken at close intervals to assess quantities correctly. Where there is major change in level, additional cross-sections are taken. All river crossings, valleys etc. should be surveyed in detail upto considerable greater distances on either side of the route.

All topographical details like town, valley, hill, river, railway lines etc. are noted and plotted using conventional signs. Sufficient hydrological data are also collected and recorded.

A detailed soil investigation is carried out to draw the soil profile and also to get the bearing capacity of soil.

## 3.6 HIGHWAY PLANS

*Highway plans are the drawings prepared from the collected data during highway survey. The following highway plans/drawings are generally prepared in a highway project :*

(a) Locality map-cum-site plan
(b) Land acquisition plans
(c) Detailed plan and longitudinal section
(d) Detailed cross-section
(e) Drawings for cross-drainage
(f) Drawings of masonry works

### (a) Locality map-cum-site Plan

This is a combination of the key map drawn to a scale of 1 : 2,50,000 and the index map to a scale of 1 : 50,000. This map should show the location of the project in state and indicate the names of towns and cities.

### (b) Land Acquisition Plans

This is prepared from the survey drawings for land acquisition details. Scales of 1 : 2000 to 1 : 8000 are suitable. These plans should show wells, land boundaries, trees, nature of land and the nature of crops.

### (c) Detailed Plan and Longitudinal Sections

Detailed plan should show the final centreline, right-of-way boundaries, cross-roads, railway lines, positions of points of transit, location of cross-sections, contours etc. The longitudinal section should show the final road profile, existing road profile, superelevation, cross-fall etc. The normal practice is to show both the plan and profile together in one sheet. These are drawn by using scale of 1 : 2500 for horizontal and 1 : 250 for vertical.

### (d) Detailed Cross-section

Cross-sections should be drawn at every 50-100 m in plain terrain, 50-75 m in rolling terrain and 20 m in hilly terrain. It is drawn to a scale of 1 : 100. The cross-sections should show the existing ground profile, are of cut and fill, proposed road levels etc.

### (e) Drawings for Cross-drainage

This is drawn to scale of 1 : 50.

### (f) Drawing of Masonry Work

This is usually drawn to scale of 1 : 100. For details of any complicated portion of structure scale of 1 : 10 may be used.

# GEOMETRIC DESIGN UNIT-II

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# Sight distance

## Overview

- The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead . This distance is said to be the sight distance.
- Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects.

# Types of sight distance

- Stopping sight distance (SSD) or the absolute minimum sight distance
- Intermediate sight distance (ISD) is defined as twice SSD
- Overtaking sight distance (OSD) for safe overtaking operation
- Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
- Safe sight distance to enter into an intersection
- The most important consideration in all these is that at all times the driver traveling at the design speed of the highway must have sufficient carriageway distance within his line of vision to allow him to stop his vehicle

# sight distance depends on:

- Reaction time of the driver
- Speed of the vehicle
- Efficiency of brakes
- Frictional resistance between the tyre and the road
- Gradient of the road.

# sight distance depends on:

**Reaction time of the driver**

- Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied.
- The total reaction time may be split up into four components based on PIEV theory.
- In practice, all these times are usually combined into a total perception-reaction time suitable for design purposes as well as for easy measurement.
- Many of the studies shows that drivers require about 1.5 to 2 secs under normal conditions. However, taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 secs.

# Speed of the vehicle

- The speed of the vehicle very much a effects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

# Efficiency of brakes

- The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied.
- But practically, it is not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes are less.
- Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency

# Frictional resistance between the tyre and the road

- The frictional resistance between the tyre and road plays an important role to bring the vehicle to stop.
- When the frictional resistance is more, the vehicles stop immediately. Thus sight required will be less.
- No separate provision for brake efficiency is provided while computing the sight distance.
- This is taken into account along with the factor of longitudinal friction. IRC has specified the value of longitudinal friction in between 0.35 to 0.4.

# Gradient of the road.

- Gradient of the road also a effects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less.
- While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

# Stopping sight distance

- **Stopping sight distance** (SSD) is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction.
- **Safe stopping distance-**It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete.
- Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance at least equal to the safe stopping distance should be provided.
- The stopping sight distance is the sum of lag distance and the braking distance.

- **Lag distance** is the distance the vehicle travelled during the reaction time t and is given by vt, where v is the velocity in m/sec.
- **Braking distance** is the distance travelled by the vehicle during braking operation.
- For a level road **breaking distance** is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is Fl = fWl where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\frac{1}{2}mv^2 = \frac{1}{2}\frac{Wv^2}{g}$$

$$fWl = \frac{Wv^2}{2g}$$

$$l = \frac{v^2}{2gf}$$

- SSD = lag distance + braking distance and given by

$$SSD = vt + \frac{v^2}{2gf}$$

- where v is the design speed in m/sec, t is the reaction time in sec, g is the acceleration due to gravity and f is the coefficient of friction.

# Coefficient of longitudinal friction

| Speed, kmph | <30 | 40 | 50 | 60 | >80 |
|---|---|---|---|---|---|
| $f$ | 0.40 | 0.38 | 0.37 | 0.36 | 0.35 |

- Ascending gradient of say +n%, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the the braking force is equal to Wsinα ≈W tanα = Wn/100. Equating kinetic energy and work done:

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

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

Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)}$$

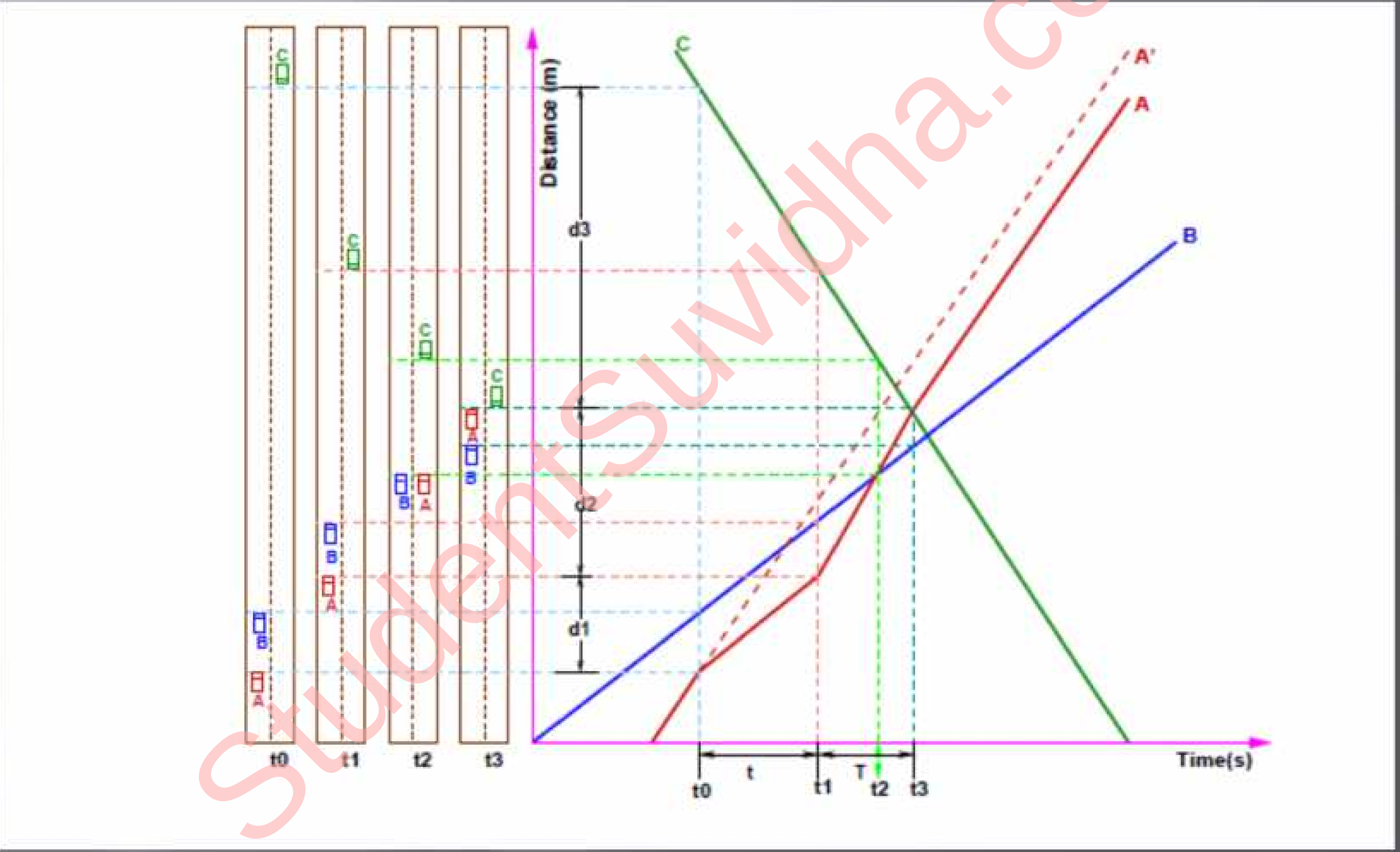
# Overtaking sight distance(OSD)

- The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction.
- The overtaking sight distance or passing sight distance is measured along the centre line of the road over which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2 m above the road surface.

# The factors that affect the OSD

- Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.
- Spacing between vehicles, which in-turn depends on the speed
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

# Time-space diagram: Illustration of overtaking sight distance



- The x-axis denotes the time and y-axis shows the distance travelled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B. The trajectory of the vehicle is shown initially with a steeper slope.
- The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the figure with same slope from $t_0$ to $t_1$. Then it overtakes the vehicle B and occupies the left lane at time $t_3$. The time duration $T = t_3 - t_1$ is the actual duration of the overtaking operation. The snapshots of the road at time $t_0$; $t_1$, and $t_3$ are shown on the left side of the figure. From the Figure , the overtaking sight distance consists of three parts.

- d1 the distance travelled by overtaking vehicle A during the reaction time $t = t_1 - t_0$
- d2 the distance travelled by the vehicle during the actual overtaking operation $T = t_3 \quad t_1$
- d3 is the distance travelled by on-coming vehicle C during the overtaking operation (T).

Therefore:

$$OSD = d_1 + d_2 + d_3$$

- It is assumed that the vehicle A is forced to reduce its speed to $v_b$, the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d1 is given by:

$$d_1 = v_b t$$

- Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle A maintains the spacing s before and after overtaking. The spacing s in m is given by:

$$s = 0.7v_b + 6$$

- Let T be the duration of actual overtaking. The distance travelled by B during the overtaking operation is $2s+v_bT$. Also, during this time, vehicle A accelerated from initial velocity $v_b$ and overtaking is completed while reaching final velocity v. Hence the distance travelled is given by:

$$
\begin{aligned}
d_2 &= v_b T + \frac{1}{2} a T^2 \\
2s + v_b T &= v_b T + \frac{1}{2} a T^2 \\
2s &= \frac{1}{2} a T^2 \\
T &= \sqrt{\frac{4s}{a}} \\
d_2 &= 2s + v_b \sqrt{\frac{4s}{a}}
\end{aligned}
$$

- The distance travelled by the vehicle C moving at design speed v m/sec during overtaking operation is given by:

$$d_3 = vT$$

- The the overtaking sight distance is

$$OSD = v_b t + 2s + v_b\sqrt{\frac{4s}{a}} + vT$$

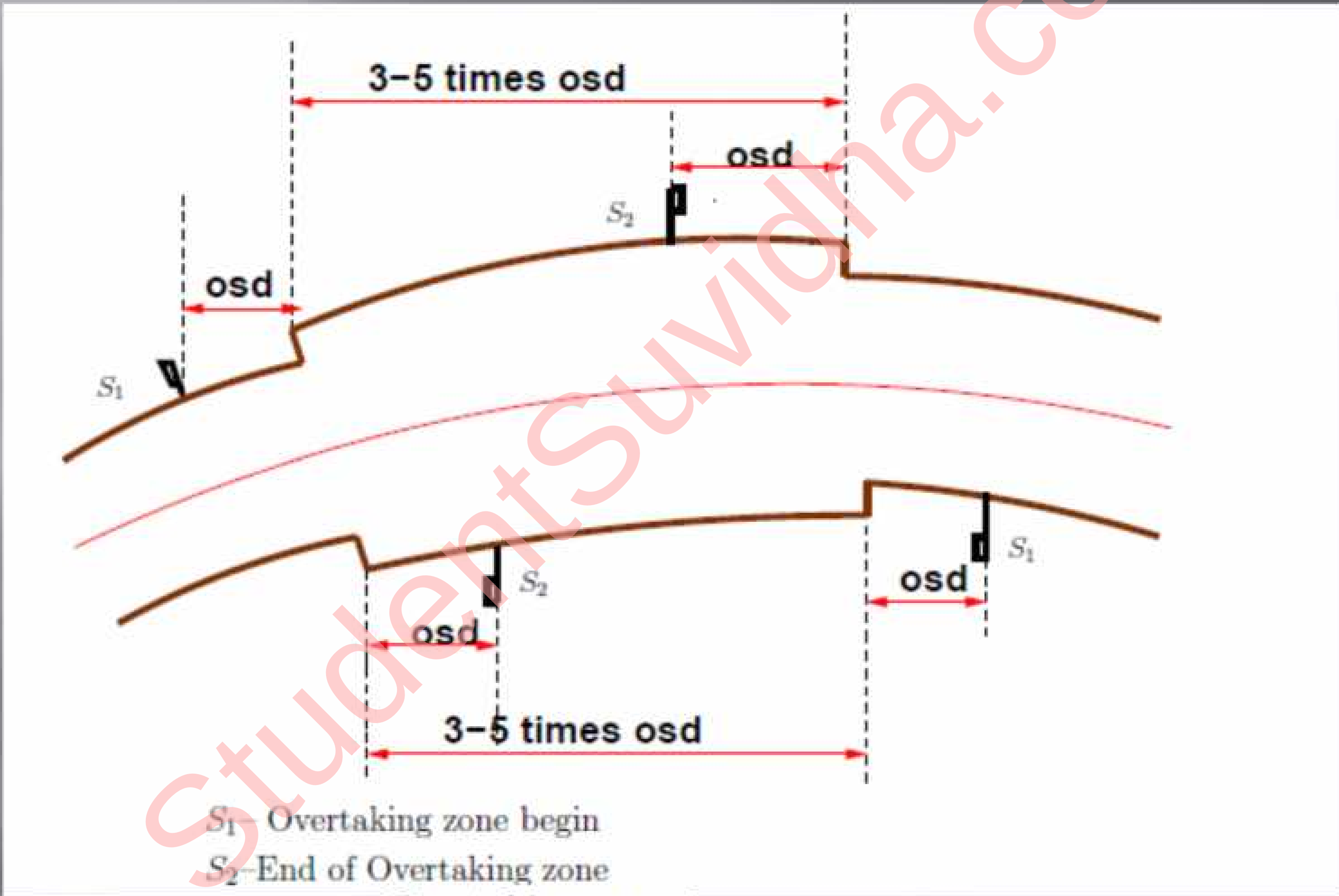
# Maximum overtaking acceleration at different speeds

| Speed (kmph) | Maximum overtaking acceleration ($m/sec^2$) |
|---|---|
| 25 | 1.41 |
| 30 | 1.30 |
| 40 | 1.24 |
| 50 | 1.11 |
| 65 | 0.92 |
| 80 | 0.72 |
| 100 | 0.53 |

- On divided highways, d3 need not be considered
- On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD, but only SSD is sufficient.

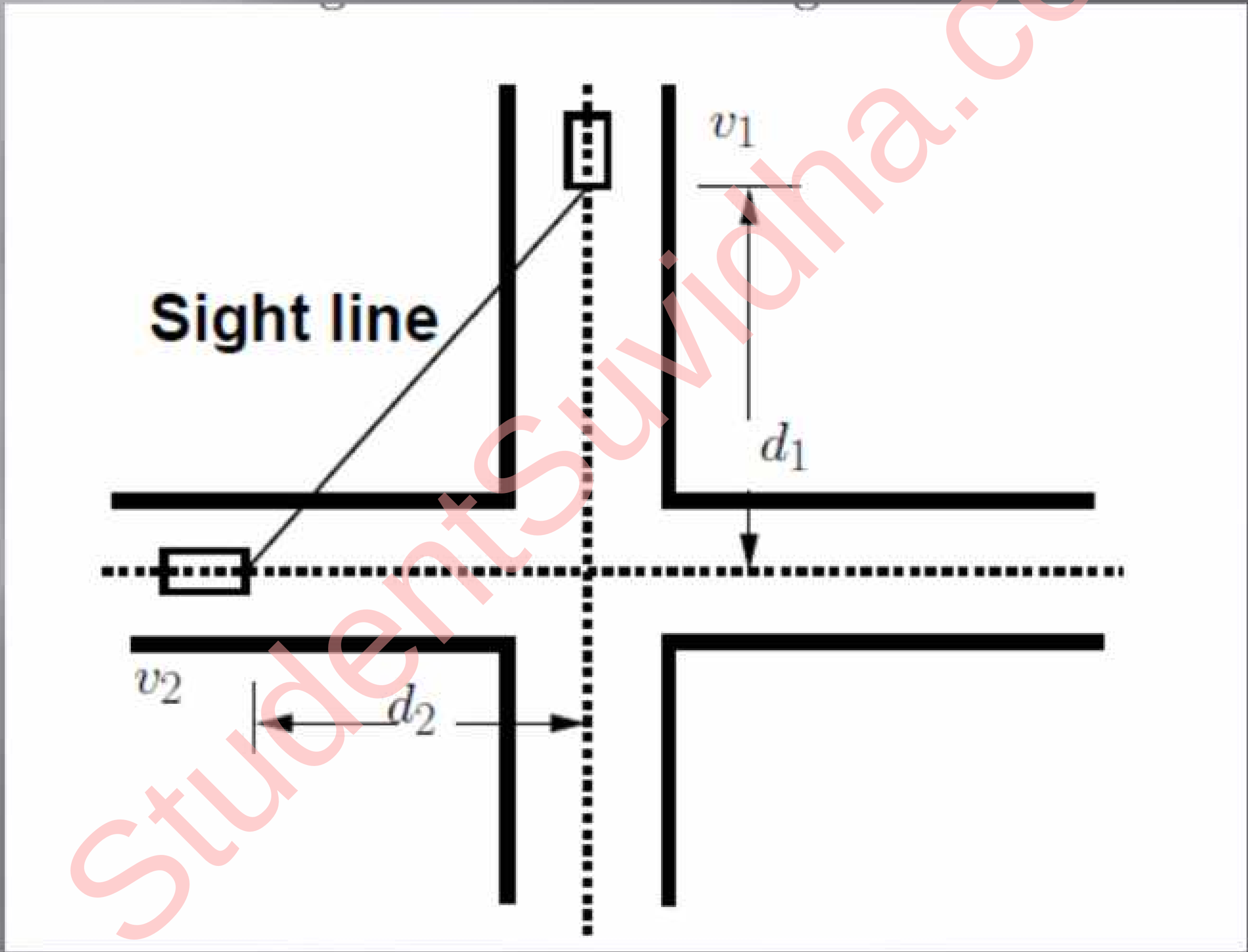
*Overtaking zones*

Overtaking zones are provided when OSD cannot be provided throughout the length of the highway. These are zones dedicated for overtaking operation, marked with wide roads. The desirable length of overtaking zones is 5 time OSD and the minimum is three times OSD (Figure 2).




Overtaking zones

Sight distance at intersections



# Sight distance at intersections

- At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either sides. They should be able to perceive a hazard and stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other. Design of sight distance at intersections may be used on three possible conditions
- Enabling approaching vehicle to change the speed
- Enabling approaching vehicle to stop
- Enabling stopped vehicle to cross a main road

# Problems

1. Calculate SSD for V =50kmph for (a) two-way traffic in a two lane road (b) two-way traffic in single lane road. (Hint: f=0.37, t=2.5) [Ans: (a)61.4 m (b) 122.8 m.

2.Find minimum sight distance to avoid head-on collision of two cars approaching at 90 kmph and 60 kmph. Given t=2.5sec, f=0.7 and brake efficiency of 50 percent in either case. (Hint: brake efficiency reduces the coefficient of friction by 50 percent). [Ans: SD=153.6+82.2=235.8m]

3.Find SSD for a descending gradient of 2% for V=80kmph. [Ans: 132m]

4.Find head light sight distance and intermediate sight distance for V=65 kmph. (Hint: f=0.36, t=2.5 s, HSD=SSD, ISD=2*SSD) [Ans: 91.4 and 182.8 m]

5.Overtaking and overtaken vehicles are at 70 and 40 kmph respectively. find (i) OSD (ii) min. and desirable length of overtaking zone (iii) show the sketch of overtaking zone with location of sign post (hint: a=0.99m/sec2) [Ans: (i) 278 m (ii) 834 m/1390]

Thank you

## 3.7 HIGHWAY ALIGNMENT

Highway alignment is the position of the centre line of the highway on the ground.

The alignment of a new road should be done very carefully and accurately. Because once the road is aligned and constructed it is very difficult to change the alignment due to increase in cost of adjoining land and cost of shifting the costly structures along the road sides.

### 3.7.1 Basic Requirements of an Ideal Alignment

*The basic requirements of an ideal alignment of a road between two terminal stations are that it should be :*

(a) **Short :** The alignment should be as short as possible between two terminal stations. For this the alignment should be as straight as possible.

(b) **Easy :** The alignment should be such that it is easy to construct and maintain. For this alignment should be with easy gradient and curves.

(c) **Safe :** The alignment should be safe for the traffic operations. For this alignment should have safe geometric features, stable natural hill slopes, embankment and cut slopes.

(d) **Economical :** The alignment is said to be economical if the total cost including initial cost, maintenance cost and operation cost is lowest.

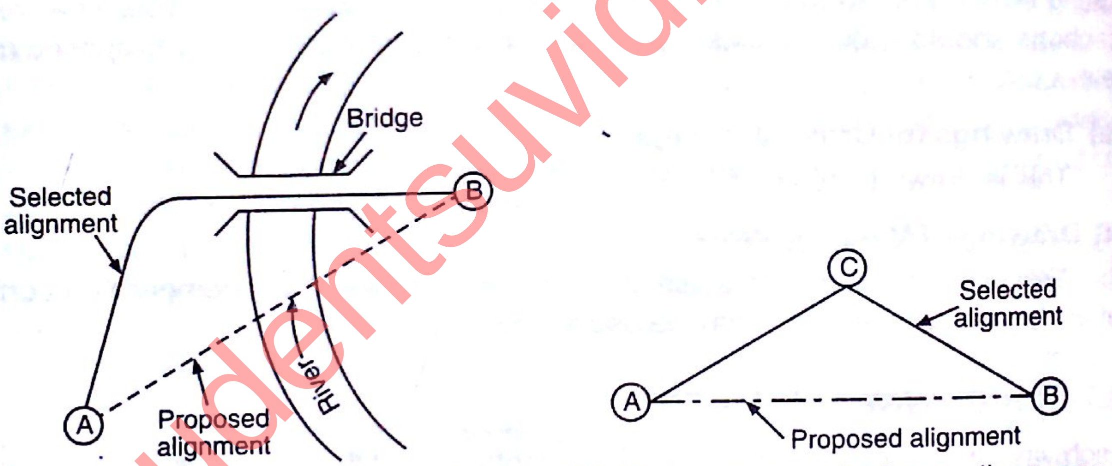
(f) **Useful :** The alignment should be such that it would be useful for maximum population and products.

### 3.7.2 Factors Controlling Alignment

*The various factors which control the highway alignment are :*

(i) Obligatory points
(ii) Economy
(iii) Geometric design
(iv) Traffic
(v) Other Considerations

**(i) Obligatory Points :** There are obligatory points through which road-alignment has to pass and for this alignment has to deviate from the shortest or easiest path. These points are intermediate town, bridge, a mountain pass, a quarry etc. There are also obligatory points through which road alignment should not pass and should be avoided while aligning a road. These points are like temples, church, mosques, marshy and water logged areas etc.




(a) Alignment to suit proper bridge site (b) Alignment connecting intermediate town c

**Fig. 3.1.** Obligatory points controlling alignment of roads

**(ii) Economy :** While finalizing the alignment this factor is also considered. In working out the economics, the initial cost, cost of maintenance and vehicle operation should be taken into account. The initial cost of construction can be decreased by choosing alignment in such a manner that cutting and filling are balanced.

**(iii) Geometric Design :** Geometric design factors like sight distance, gradient, radius of curve etc. also govern the final alignment of the highway. The alignment should be such that it provides enough visible distance for safe overtaking operation and for safe stopping of the vehicle. Alignment to be finalized should fulfil the sight distance requirements. While aligning a new road as far as possible the gradient should be flat and less than the ruling gradient. For this requirement the alignment is to be changed. Sometimes it may be necessary to make adjustment in the alignment of roads to obtain the minimum radius of curve.

**(iv) Traffic :** The alignment should suit the need of traffic. Before fixing any alignment traffic studies should be carried out which give an idea about goods and passengers traffic expected on the proposed road. If the traffic is mainly of slow moving type, the alignment may be of winding nature joining all the villages. Sharp curves may be allowed in such roads. But if the traffic is fast moving, proposed alignment should as far as possible be straight with easy curves.

**(v) Other Considerations :** Other factors which may govern the alignment of roads are hydrological factors, political considerations, monotony and drainage considerations. The alignment should not cross a foreign territory. It may tend to change the alignment so as to keep the road away from the foreign land. To avoid monotony caused due to lengthy straight routes, a slight bend should be provided to break the monotony. The vertical alignment is often guided by drainage considerations.

# Geometrical design

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# Guidelines on superelevation

- While designing the various elements of the road like superelevation, we design it for a particular vehicle called design vehicle which has some standard weight and dimensions. But in the actual case, the road has to cater for mixed traffic.
- Different vehicles with different dimensions and varying speeds ply on the road.
- For example,in the case of a heavily loaded truck with high centre of gravity and low speed, superelevation should be less, otherwise chances of toppling are more.
- Taking into practical considerations of all such situations, IRC has given some guidelines about the maximum and minimum superelevation etc. These are all discussed in detail in the following sections.

# Design of super-elevation

- For fast moving vehicles, providing higher super-elevation without considering coefficient of friction is safe, i.e. centrifugal force is fully counteracted by the weight of the vehicle or super-elevation.
- For slow moving vehicles, providing lower super-elevation considering coefficient of friction is safe, i.e. Centrifugal force is counteracted by super-elevation and coefficient of friction . IRC suggests following design procedure:

Step 1 Find $e$ for 75 percent of design speed, neglecting $f$, i.e $e_1 = \frac{(0.75v)^2}{gR}$.

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 step 3.

Step 3 Find $f_1$ for the design speed and max $e$, i.e $f_1 = \frac{v^2}{gR} - e = \frac{v^2}{gR} - 0.07$. If $f_1 < 0.15$, then the maximum $e = 0.07$ is safe for the design speed, else go to step 4.

Step 4 Find the *allowable speed* $v_a$ for the maximum $e = 0.07$ and $f = 0.15$, $v_a = \sqrt{0.22gR}$ If $v_a \geq v$ then the design is adequate, otherwise use speed adopt control measures or look for speed control measures.

# Maximum and minimum super-elevation

- Depends on (a) slow moving vehicle and (b) heavy loaded trucks with high CG. IRC specifies a maximum super-elevation of 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent.
- The minimum super elevation is 2-4 percent for drainage purpose, especially for largeradius of the horizontal curve.

# Attainment of super-elevation

1. Elimination of the crown of the cambered section by:

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

b) shifting the position of the crown: This method is also known as diagonal crown method. Here the position of the crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.

2. Rotation of the pavement cross section to attain full super elevation by: There are two methods of attaining super-elevation by rotating the pavement

- (a) rotation about the centre line : The pavement is rotated such that the inner edge is depressed and the outer edge is raised both by half the total amount of super-elevation, i.e., by E/2 with respect to the centre.
- (b) rotation about the inner edge: Here the pavement is rotated raising the outer edge as well as the centre such that the outer edge is raised by the full amount of super-elevation with respect to the inner edge.

# Radius of Horizontal Curve

- The radius of the horizontal curve is an important design aspect of the geometric design. The maximum comfortable speed on a horizontal curve depends on the radius of the curve. Although it is possible to design the curve with maximum super-elevation and coefficient of friction, it is not desirable because re-alignment would be required if the design speed is increased in future. Therefore, a ruling minimum radius $R_{ruling}$ can be derived by assuming maximum super-el ion.

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

# Extra widening

- Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.
- The first is referred as the mechanical widening and the second is called the psychological widening. These are discussed in detail below.

# Mechanical widening

- The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure . This phenomenon is called of-tracking, and has the effect of increasing the effective width of a road space required by the vehicle.
- Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles are using the road. Trailer trucks also need extra carriageway, depending on the type of joint.
- In addition speeds higher than the design speed causes transverse skidding which requires additional width for safety purpose. The expression for extra width can be derived from the simple geometry of a vehicle at a horizontal curve as shown in figure .

$$
\begin{aligned}
R_2^2 &= R_1^2 + l^2 \\
&= (R_2 - W_m)^2 + l^2 \\
&= R_2^2 - 2R_2 W_m + W_m^2 + l^2 \\
2R_2 W_m - W_m^2 &= l^2
\end{aligned}
$$

Therefore the widening needed for a single lane road is:

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

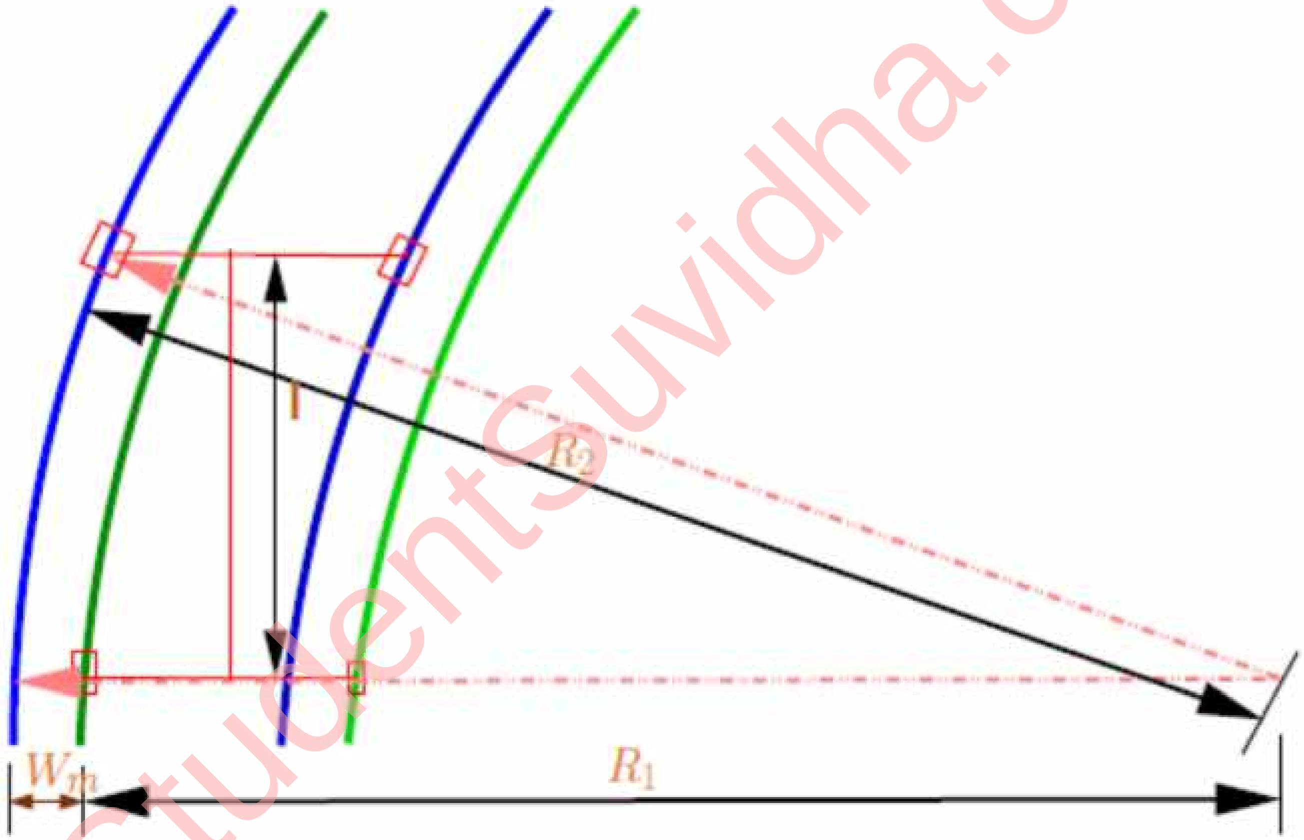
If the road has n lanes, the extra widening should be provided on each lane. Therefore, the extra widening of a road with n lanes is given by,

$$W_m = \frac{nl^2}{2R_2 - W_m}$$

Please note that for large radius, R2 = R, which is the mean radius of the curve,then Wm is give

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

Let R1 is the radius of the outer track line of the rear wheel, R2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, then the mechanical widening Wm (refer figure 15:1) is derived below



# Psychological widening

- Widening of pavements has to be done for some psychological reasons also. There is a tendency for the drivers
- to drive close to the edges of the pavement on curves. Some extra space is to be provided for more clearance
- for the crossing and overtaking operations on curves. IRC proposed an empirical relation for the psychological widening at horizontal curves Wps:

$$W_{ps} = \frac{v}{2.64\sqrt{R}}$$

$$\begin{aligned} W_e &= W_m + W_{ps} \\ &= \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} \end{aligned}$$

# Problems

1.A national highway passing through a rolling terrain has two horizontal curves of radius 450 m and 150m. Design the required super-elevation3.Two lane road, V=80 kmph, R=480 m, Width of the pavement at the horizontal curve=7.5 m.

2.Design super elevation for mixed traffic. (ii) By how much the outer edge of the pavement is to be raised with respect to the centre line, if the pavement is rotated with respect to centre line. [Ans:(i) 0.059 (ii)0.2

3.Design rate of super elevation for a horizontal highway curve of radius 500 m and speed 100 kmph. [Ans: e=0.07, f=0.087 and with in limits]

4. Given V=80 kmph, R=200m Design for super elevation. (Hint: f=0.15) [Ans: Allowable speed is 74.75 kmph and e=0.07]

5.Calculate the ruling minimum and absolute minimum radius of horizontal curve of a NH in plain terrain. (Hint: Vruling=100kmph, Vmin=80kmph., e=0.07, f=0.15) [Ans: 360 and 230 m]

6.Find the extra widening for W=7m, R=250m, longest wheel base, l=7m, V=70kmph. (Hint: n=2) [Ans:0.662m]

7.Find the width of a pavement on a horizontal curve for a new NH on rolling terrain. Assume all data. (Hint: V=80kmph for rolling terrain, normal W=7.0m, n=2, l=6.0m, e=0.07, f=0.15). [Ans: Rruling=230m, We=0.71, W at HC=7.71m] for the curves as per IRC guidelines.

# Horizontal Transition Curves

- Transition curve is provided to change the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point)
- There are five objectives for providing transition curve and are given below:

1. to introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
2. to enable the driver turn the steering gradually for his own comfort and security,
3. to provide gradual introduction of super elevation, and
4. to provide gradual introduction of extra widening.
5. to enhance the aesthetic appearance of the road.

# Type of transition curve

- Different types of transition curves are spiral or clothoid, cubic parabola, and Lemniscate.
- IRC recommends spiral as the transition curve because:

It fulfils the requirement of an ideal transition curve, that is;

(a) rate of change or centrifugal acceleration is consistent (smooth) and

(b) radius of the transition curve is ∞ at the straight edge and changes to R at the curve point ($Ls \propto 1/R$) and calculation and field implementation is very easy.

# Length of transition curve

- The length of the transition curve should be determined as the maximum of the following three criteria:

1. Rate of change of centrifugal acceleration,
2. rate of change of super-elevation,
3. Empirical formula given by IRC.

# 1. Rate of change of centrifugal acceleration

- At the tangent point, radius is infinity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. The rate of change of centrifugal acceleration should be adopted such that the design should not cause discomfort to the drivers. If c is the rate of change of centrifugal acceleration, it can be written as:

$$c = \frac{\frac{v^2}{R} - 0}{t}, = \frac{\frac{v^2}{R}}{\frac{L_s}{v}}, = \frac{v^3}{L_s R}.$$

Therefore, the length of the transition curve Ls1 in m is

$$L_{s_1} = \frac{v^3}{cR},$$

- where c is the rate of change of centrifugal acceleration given by an empirical formula suggested by by IRC as below

$$c = \frac{80}{75 + 3.6v},$$

subject to :

$$c_{\min} = 0.5,$$

$$c_{\max} = 0.8.$$

*2. Rate of introduction of super-elevation*

- Raise (E) of the outer edge with respect to inner edge is given by E = eB = e(W +We). The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve (typical range of N is 60-150). Therefore, the length of the transition curve $L_{s2}$ is

$$L_{s2} = Ne(W + W_e)$$

# 3. By empirical formula

- IRC suggest the length of the transition curve is minimum for a plain and rolling terrain:

$$L_{s3} = \frac{35v^2}{R}$$

and for steep and hilly terrain is:

$$L_{s3} = \frac{12.96v^2}{R}$$

and the shift s as:

$$s = \frac{L_s^2}{24R}$$

- The length of the transition curve Ls is the maximum of equations

$$L_s = \text{Max}: \ (L_{s_1}, L_{s_2}, L_{s_3})$$

# Setback Distance

- Setback distance m or the clearance distance is the distance required from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at a horizontal curve. The setback distance depends on:
- 1. sight distance (OSD, ISD and OSD),
- 2. radius of the curve, and
- 3. length of the curve.

- Case (a) Ls < Lc

For single lane roads:

$$\alpha = \frac{s}{R} \text{ radians}$$
$$= \frac{180s}{\pi R} \text{ degrees}$$
$$\alpha/2 = \frac{180s}{2\pi R} \text{ degrees}$$

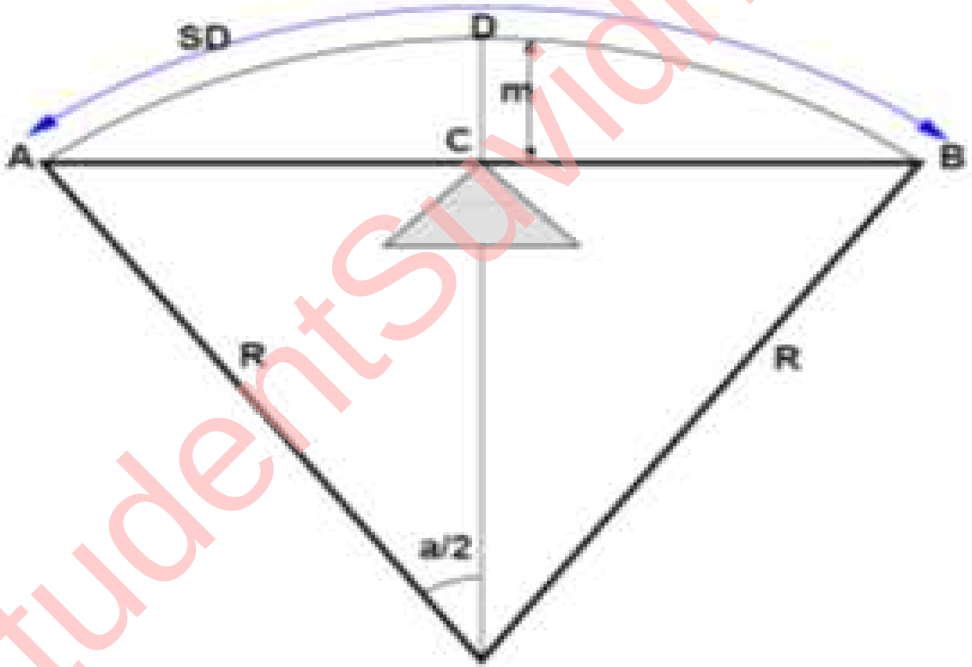
$$m = R - R\cos\left(\frac{\alpha}{2}\right)$$

For multi lane roads, if d is the distance between centre line of the road and the centre line of the inner lane, then

$$m = R - (R-d)\cos\left(\frac{180s}{2\pi(R-d)}\right)$$

$$m = R - R\cos\left(\frac{\alpha}{2}\right)$$

# Set-back for single lane roads (Ls < Lc)



Case (b) $L_s > L_c$

For single lane:

$$m_1 = R - R\cos(\alpha/2)$$
$$m_2 = \frac{(S - L_c)}{2}\sin(\alpha/2)$$

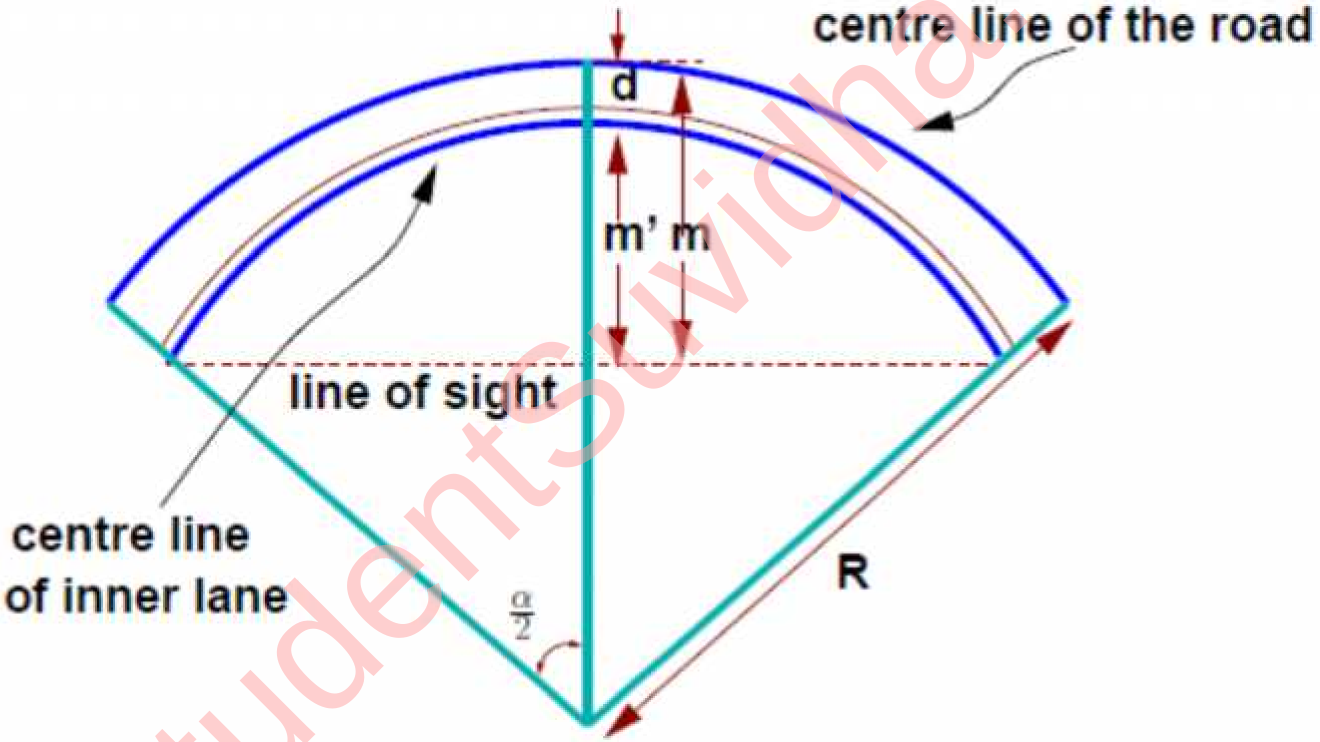
The set back is the sum of $m_1$ and $m_2$ given by:

$$m = R - R\cos(\alpha/2) + \frac{(S - L_c)}{2}\sin(\alpha/2)$$

where $\frac{\alpha}{2} = \frac{180 L_c}{2\pi R}$. For multi-lane road $\frac{\alpha}{2} = \frac{180 L_c}{2\pi(R-d)}$, and $m$ is given by

$$m = R - (R - d)\cos(\alpha/2) + \frac{(S - L_c)}{2}\sin(\alpha/2)$$

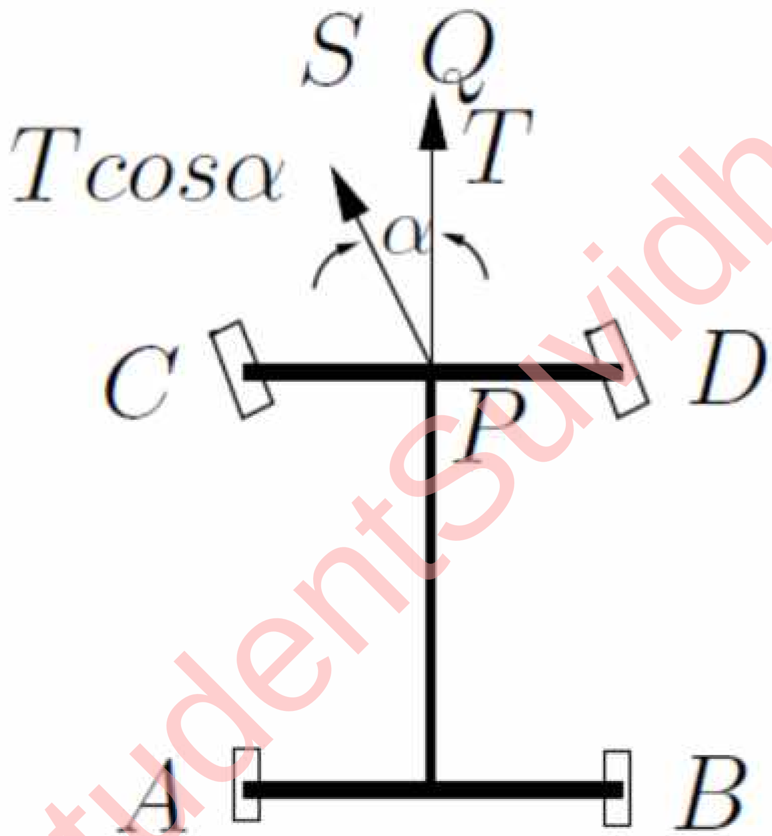
# Set-back for multi-lane roads (Ls < Lc)



# Curve Resistance

- When the vehicle negotiates a horizontal curve, the direction of rotation of the front and the r ear wheels are different. The front wheels are turned to move the vehicle along the curve, whereas the rear wheels seldom turn.
- This is illustrated in figure. The rear wheels exert a tractive force T in the PQ direction . The tractive force available on the front wheels is Tcosα in the PS direction as shown in the figure .
- This is less than the actual tractive force, T applied. Hence, the loss of tractive force for a vehicle to negotiate a horizontal curve is

$$CR = T - T\cos\alpha$$


S
Q
T
Tcosα
α
C
D
P
A
B

# Problems

1.Calculate the length of transition curve and shift for V=65kmph, R=220m, rate of introduction of super-elevation is 1 in 150, W+We=7.5 m. (Hint: c=0.57) [Ans: Ls1=47.1m, Ls2=39m (e=0.07, pav. Rotated w.r.t centerline), Ls3=51.9m, s=0.51m, Ls=52m]

2. NH passing through rolling terrain of heavy rainfall area, R=500m. Design length of Transition curve.(Hint: Heavy rainfall. Pavement surface rotated w.r.t to inner edge. V=80kmph, W=7.0m, N=1 in 150) [Ans: c=0.52, Ls1=42.3, Ls2=63.7m (e=0.057, W+We=7.45), Ls3=34.6m, Ls=64m]

3. Horizontal curve of R=400m, L=200 m. Compute setback distance required to provide (a) SSD of 90m,(b) OSD of 300 m. Distance between center line of road and inner land (d) is 1.9m. [Ans: (a) $\alpha/2$ 6:5o, m=4.4 m (b)OSD>L, for multi lane, with d=1.9, m=26.8 m]

*Thank you*