

**VISVESVARAYA TECHNOLOGICAL UNIVERSITY
BELGAUM**



TRANSPORTATION ENGINEERING

(Subject Code: BCV403)

LECTURE NOTES

IV-SEMESTER

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DEPARTMENT OF CIVIL ENGINEERING

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MODULE 1**TRANSPORTATION ENGINEERING:****Topics to be covered**

TRANSPORTATION ENGINEERING: Introduction, Different Modes of Transportation, M R Jayakar Committee recommendations, Road Classifications and Road Patterns.

Highway Alignment: Factors affecting highway alignment, Engineering surveys for alignment conventional and modern methods.

Highway Geometric Design: Factors affecting geometric design of roads, Cross Sectional Elements, Sight distances, Horizontal alignment- Transition curve, super elevation, Extra widening, Vertical alignment- gradients, summit and valley curves. **(No derivations)**

Problems on Sight distance, Super elevation, extra widening of curves, Length of transition curve, Length of summit and valley curve.

Importance of Transportation

Transportation is a toll to measure the Economic, Industrial, Social and Cultural development of any country. It is vital for the economic development of any region people and the communities are essentially to be transported material from one place to other. In the production stage transportation is required for carrying raw materials like seeds, manure, coal, steel etc. In the distribution stage transportation is required from the production centers via; farms and factories to the marketing centers and later to the retailers and the consumers for distribution. The importance of transportation may include:

- **Availability of raw materials:** Transportation helps in carrying the raw materials from one place to another place. Initially raw materials are made at one place and are being transported to another place for processing and for manufacturing goods.
- **Availability of goods to the customer:** The goods are being transported from one place to another place. These goods which are produced at one place are transported to other distant places for their usage. It flexibly moves the goods from one place to another place.
- **Enhances the standard of living:** It improves the standard of living. As the transportation of each and every good is being done then the productivity increases which results in the reduced or the effective costs. Because of reduction in the cost they can use different commodities for different purposes and can lead a secure life.
- **Helps a lot during the emergencies and even during natural disasters:** Transportation helps during the natural disturbances. It helps in quick moving from one place to another place and

supplies the required operations.

- **Helps for the employment:** Transportation provides employment for many people as drivers, captains, conductors, cabin crew and even the people are used for the construction of different types of transportation vehicles. And even by the use of transportation the remote people are being employed with the access to the urban facilities and the opportunities.
- **Helps in mobility of the laborers:** Many people are traveling to other countries on their employment basis. Transportation plays an important role in such cases.
- **Helps for bringing nations together:** Transportation on the whole is used for globalization i.e. it brings nations together and it creates awareness about the cultural activities and even about the industries and helps a lot for importing and exporting of different goods. These above are some of the necessities which make us to use transportation.

The importance and adequacy of transportation system of a country indicates its economic and social development.

Economic Activity: Two important factors well known in economic activity are:

1. Production or supply
2. Consumption for human wants or demand.

Economic activity is the process by means of which the products are utilized to satisfy human demand. The role of transportation in the economic activity starts its function from production stage to the final distribution. Increased productivity of various items such as agricultural and industrial products and their distribution through efficient transportation system can lower the cost of the products. The cost of transportation substantially influences the consumer price of the commodities.

Social Effects: The various social effects of transportation may be further classified into:

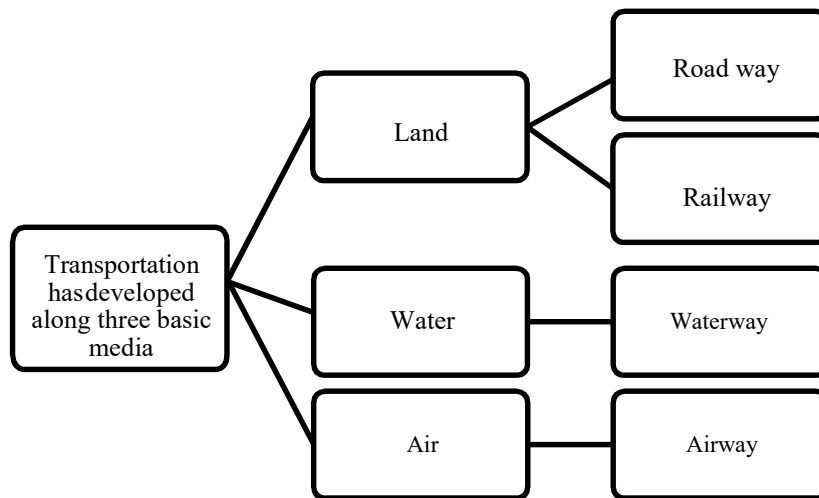
- **Sectionalism and transportation:** improved transportation has important implication in reducing sectionalism with in the country and also outside the country. More frequently travels in other part of the country and outside the country tends to increases knowledge of the people from other section of society.

Concentration of population into urban area: improves transportation facilities bring prosperity to the urban population. The employment opportunities, prosperity and superior facilities for education, medical care etc available in urban area attracts the population from other areas, resulting in enhanced economic activities. Inadequate transportation facilities lead to concentration of population in cities which often results in growth of slums in urban area, leading to various

associated problems. If efficient transportation facilities are available, the people would prefer to reside at localities away from urban centers and commute to the city for their work. In general, the transportation facilities are essential for the well-being of the community.

Aspect of safety, law and order: transport facilities are essential for restoring order to areas affected by an emergency to maintain law and order at home it is required to have an efficient system of transport network. To define the territory of the country against external aggression and to guard the borders with the foreign territories transport facilities are needed.

Different Modes of Transportation



Three basic modes of transport are by land, water and air. Land has given development of road and rail transport. Water and air have developed waterways and airways respectively. Apart from these major modes of transportation, other modes include pipelines, elevators, belt conveyors, cable cars, aerial ropeways and monorails. Pipe lines are used for the transportation of water, other fluids and even solid particles.

The four major modes of transportation are:

1. Roadways or highways
2. Railways
3. Airways
4. Waterways

Roadway

Advantages	Disadvantages
Lesser Risk of Damage in Transit	Seasonal Nature
Less Capital Outlay	Accidents and Breakdowns

Door to Door Service	Unsuitable for Long Distance and Bulky Traffic
Service in Rural Areas	Slow Speed
Flexible Service	Lack of Organization
Suitable for Short Distance	Large consumer of petroleum energy
Max service to one and all	
Private Owned Vehicles	
Feeder to other Modes of Transport	

Railway

Advantages	Disadvantages
Employment Opportunities	Huge Capital Outlay
Better Organized	Lack of Flexibility

High Speed over Long Distances	Lack of Door to Door Service
Suitable for Bulky and Heavy Goods	Unsuitable for Short Distance and Small Loads
Cheaper Transport	Booking Formalities
Larger Capacity	No Rural Service
Administrative Facilities of Government	Centralized Administration
Energy required is one fourth to one sixth of that required by the road	

Airway

Advantages	Disadvantages
Fastest mode of transport	The haul unit per unit length is costly.
Comfortable and Quick Services	Small Carrying Capacity
Emergency Services	Breakdowns and Accidents
Most Suitable for Carrying Light Goods of High Value	Large Investment
National Defense	Specialized Skill employees
Space Exploration	Unsuitable for Cheap and Bulky Goods
	Legal Restrictions

Waterway

Advantages	Disadvantages
Minimum energy to haul unit load through unit distance	Slowest mode of transport
Most energy efficient transport system	Operated only on sea routes between harbours and ports
Suitable for bulk cargo	Depends on weather condition
Leads to the development of the industries.	Ocean tides affects the loading and unloading operation
Cheapest: Cost per tonne is lowest	The route is circuitous.

Characteristics of Road Transport

- Roads are used by various types of road vehicles like cars, buses, truck, two and three wheeled automobiles, pedal cycles and animal drawn vehicles. But railway tracks are used only by rail locomotives and wagons, waterways are used only by ships and boats.
- Road transport requires a relatively small investment for the government. Motor vehicles are much cheaper than other carriers like rail locomotives and wagons, water and air carriers.
- Construction and maintenance of road is also cheaper than that of railway tracks, docks, harbors and airports.
- Road transport offers a complete freedom to road users to transfer the vehicle from one lane to another and from one road to another according to need and convenience. This flexibility of changes in location, direction, speed, and timing of travel is not available in other modes of transport.
- In particular, for short distances travel, road transport saves time.
- Speed of movement is directly related with the severity of accident. The road safety decreases with increasing dispersion in speed. Road transport is subjected to a high degree of accidents due to flexibility of movements offered to the road users.
- Road transport is the only means of transport that offers itself to the whole community alike.

Highway Development in India

In the beginning of fifth century A.D., emperor Ashoka had improved the roads and provided facilities for travelers. During the Pathan and Mughal periods, the roads of India were greatly improved during the time of Mughal period. Roads linking North-West and the Eastern areas through gangatic plains were built during this time. In 1865 Lord Dalhousie, governor general formed the public work department.

Jayakar Committee Recommendations and Implementation of Recommendations

Over a period after the First World War, motor vehicles using the roads increased and this demanded a better road network which can carry mixed traffic conditions. The existing roads were not capable of withstand the mixed traffic conditions. For the improvement of roads in India government of India appointed Mr. Jayakar Committee to study the situations and to recommend suitable measures for road improvement in 1927 and a report was submitted in 1928 with following recommendations:

- Road development in the country should be considered as a national interest. As the provincial and local government do not have the financial and technical capacity for road development.
- Extra tax to be levied from the road users as fund to develop road.

- A Semi-official technical body has to be formed to collect and pool technical knowhow from various parts of the country and to act as an advisory body on various aspects of the roads.
- A research organization should be instituted at National level to carry out research and development work and should be available for consultation.

Implementations

Majority of the recommendations were accepted by the government implemented by Jayakar Committee. Some of the technical bodies were formed such as,

- Central Road Fund (CRF) in 1929
- Indian Road Congress (IRC) in 1934
- Central Road Research Institute (CRRI) in 1950.

Central Research Fund (CRF)

- Central Research Fund (CRF) was formed on 1st March 1929.
- The consumers of petrol were charged an extra levy of 2.64 paisa/litre of petrol to build up this road development fund.

From the fund collected 20 percent of the annual revenue is to be retained as meeting expenses on the administration of the road fund, road experiments and research on road and bridge projects of special importance.

- The balance 80 percent of the fund to be allotted by the Central Government to the various states based on actual petrol consumption or revenue collected.
- The accounts of the CRF are maintained by the Accountant General of Central Revenues.
- The control of the expenditure is exercised by the Roads Wings of Ministry of Transport.
- At present the revised cess collected on petrol and high speed diesel towards CRF is @ Rs 2/ litre.

Indian Road Congress (IRC)

- It is a semi -official technical body formed in 1934.
- It was formed to recommend standard specifications.
- It was constituted to provide a forum of regular technical pooling of experience and ideas on all matters affecting the planning, construction and maintenance of roads in India.
- IRC has played an important role in the formulation of the 20-year road development plans in India.
- Now, it has become an active body of national importance controlling specifications, guidelines and other special publications on various aspects of Highway Engineering.

- The IRC publishes journals, research publications, standards, specifications, guidelines and other special publications on various aspects of highway engineering.

Central Road Research Institute (CRRI)

- CRRI was formed in the year 1950 at New Delhi
- It was formed for research in various aspect of highway engineering
- It is one of the National laboratories of the Council of Scientific and Industrial Research.
- This institute is mainly engaged in applied research and offers technical advice to state governments and the industry on various problems concerning roads.

Highway Research Board (HRB)

The HRB of the IRC was set up in 1973 with a view to give proper direction and guidance to road research activities in India. The objectives are to

- Ascertain the nature and extent of research required
- Correlate research information from various organizations in India and abroad with a view to exchange publications and information on roads.
- Co-ordinate and conduct correlation services
- Collect and disseminate results of research
- Channelize consultative services

Road Classification

Based on weather

- ❖ **All-weather roads:** These roads are negotiable during all weather, except at major river crossings where interruption of traffic is permissible up to a certain limit extent, the road pavement should be negotiable during all weathers.
- ❖ **Fair-weather roads:** On these roads the traffic may be interrupted during monsoon season at causeways where streams may overflow across the roads.

Based on the carriage way

- ❖ **Paved Roads:** These roads are provided with a hard pavement course which should be at least a water bound macadam (WBM) layer.
- ❖ **Unpaved Roads:** These roads are not provided with a hard pavement course of at least a WBM layer. Thus earth roads and gravel roads may be called as unpavedroads.

Based on Surface pavement provided

- ❖ **Surface Roads:** These roads are provided with a bituminous or cement concrete surfacing. Roads which are provided with bituminous surfacing are called as black topped roads and that of

concrete are referred to as concrete roads respectively.

- ❖ **Unsurfaced Roads:** These are not provided with bituminous or cement concrete surfacing.

Based on Traffic Volume

- ❖ Heavy traffic roads
- ❖ Medium traffic roads
- ❖ Light traffic roads

Based on Load transported or tonnage

- ❖ Class-I or Class-A
- ❖ Class-II or Class-B etc

Based on location and Function

The Nagpur road plan classified the roads in India based on location and function into following five categories

- ❖ **National Highways (NH):** The NH connects the capital cities of the states and the capital cities to the port. The roads connecting the neighbouring countries are also called as NH. The NH are at least 2 lanes of traffic about 7.5m d wide. The NH usually has concrete or bituminous surfacing. NH-1 is one of the national highways connecting Delhi to Amritsar.
- ❖ **State Highways (SH):** SH are the main roads within the state and connect important towns and cities of state. The width of state highways is generally 7.5m. The NH and SH have the same design speed and geometric design specifications. SH -88 is one of the state highway connecting Mysore – Hunsur- Periyapatna –Bylakuppe –Kushalanagar – Madkeri – Sulya - Puttur – Bhantwal.
- ❖ **Major District Roads (MDR):** These are the important roads within a district serving areas of production and markets and connecting with other major roads or main highways of a district. The MDR has lower speed and geometric design specification than NH/SH. The MDR should have at least metalled single lane carriage way (i.e., 3.8m) wide. The roads carry mixed traffic.
- ❖ **Other District Roads (ODR):** These roads serving rural areas of production and providing them outlet to market centres, taluk headquarters, block development headquarters or other main roads. These are of lower design specification than MDR. These roads have a single lane and carry mixed traffic.
- ❖ **Village Roads (VR):** These are roads connecting villages or groups of villages with each other to the nearest road of a higher category.

Modified Classification of Road system by Third Road Development Plan

- ❖ Primary System (Expressways and National Highways)
- ❖ Secondary System (State Highways and Major District Roads)
- ❖ Tertiary System (Other District Roads and Village Roads).

Expressways are a separate class of highways with superior facilities and design standards and are meant as through routes having very high volume of traffic. The expressways are to be provided with divided carriageways, controlled access, gradeseparations at cross roads and fencing. These highways should permit only fast moving vehicles. Expressway may be owned by the central government or state government, depending on whether the route is a NH or SH.

Road Patterns

1.Rectangular or block pattern

In this pattern, the whole area is divided into rectangular blocks of plots, with streets intersecting at right angles. The main road which passes through the center of the area should be sufficiently wide and other branch roads may be comparatively narrow. The main road is provided a direct approach to outside the city.

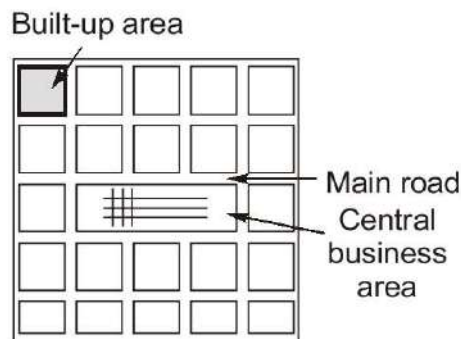
Advantages:

- ❖ The rectangular plots may be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front.
- ❖ In this pattern has been adopted for the city roads.
- ❖ The construction and maintenance of roads of this pattern is comparatively easier.

Limitations:

This pattern is not very much convenient because at the intersections, the vehicles face each other.

Example: Chandigarh has rectangular pattern



(a) Rectangular or Block pattern

2.Radial or star and block pattern

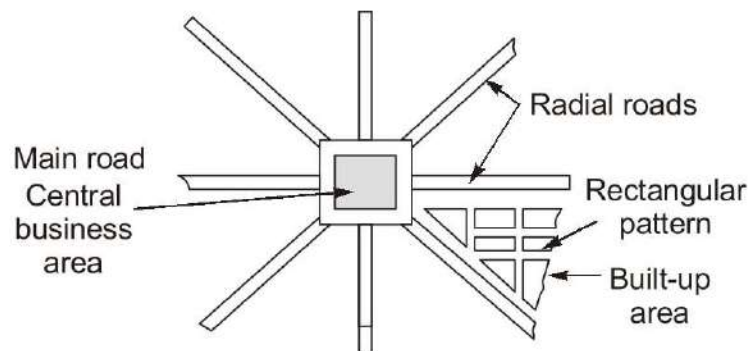
In this pattern, the entire area is divided into a network of roads radiating from the business outwardly. In between radiating main roads, the built-up area may be planned with rectangular block.

Advantage:

- ❖ Reduces level of congestion at the primary bottleneck location.
- ❖ Prevents traffic from accessing local flow routes in the direction of the event venue that operate in favor of degress traffic flow.
- ❖ If one is block then other side traffic can move.
- ❖ Vehicles face each other less than block pattern.

Limitations:

- ❖ Proves particularly effective if two-lane ramp traffic does not have to merge at downstream end of ramp.
- ❖ Safety appurtenances such as guide rail transitions, crash attenuators, and post support bases have not been designed to provide adequate protection at hazardous locations from the opposite direction of travel



(b) Radial or Star and Block pattern

3.Radial or star and circular pattern

In this system, the main radial roads radiating from central business area are connected together with concentric roads. In these areas, boundary by adjacent radial roads and corresponding circular roads, the built-up area is planned with a curved block system.

Advantages:

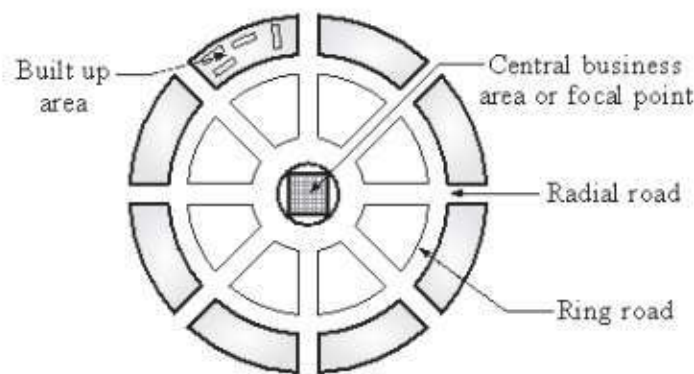
- ❖ At traditional intersections with stop signs or traffic signals, some of the most common types of crashes are right-angle, left-turn, and head-on collisions. These types of collisions can be severe because vehicles may be traveling through the intersection at high speeds. With circular pattern, these types of potentially serious crashes essentially are eliminated because vehicles travel in the same direction.

- ❖ Installing circular pattern in place of traffic signals can also reduce the likelihood of rear-end crashes.
- ❖ Removing the reason for drivers to speed up as they approach green lights and by reducing abrupt stops at red lights.
- ❖ Because roundabouts improve the efficiency of traffic flow, they also reduce vehicle emissions and fuel consumption.

Limitations:

- ❖ Center lines of roads leading to circular pattern should be properly aligned with the central island.
- ❖ Approach roads should be sufficiently curved, far enough in advance of circular pattern, to reduce vehicle speeds of entering drivers.
- ❖ Islands separating the approach and exit lanes, known as splitter islands, should extend far enough to provide pedestrian refuge and to delineate the roundabout.
- ❖ Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they are approaching a roundabout and that they should reduce their travel speed.
- ❖ For older drivers declines in vision, hearing, and cognitive functions, as well as physical impairments, may affect some older adults' driving ability. Intersections can be especially challenging for older drivers.

Example: Intersection with traffic signals converted to a circular pattern in Asheville, North Carolina



Radial or star and circular pattern

4.Radial or star and grid pattern

Change in direction, and because street patterns are the most enduring physical element of any layout, it could potentially contribute to systematic site planning and, consequently, deserves a closer look. Though the network is entirely interconnected, north-south movement becomes

circuitous, indirect, and inconvenient, making driving an unlikely choice and vividly illustrating that interconnectedness by itself is insufficient to facilitate movement.

Advantages:

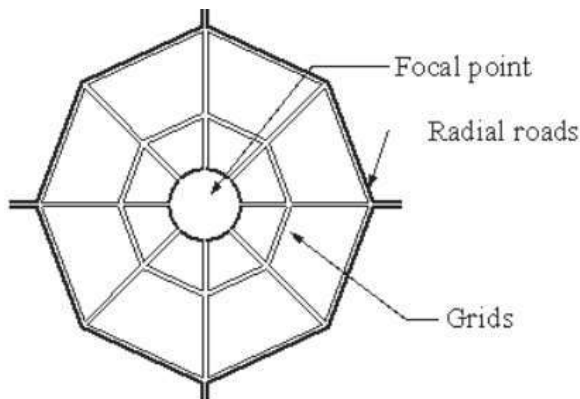
- ❖ Keep vehicular traffic safe with a high proportion of 3-way intersections.
- ❖ Reduce cut-through traffic by similar or other means.
- ❖ Improve traffic flow in both directions using Savannah’s cellular structure.
- ❖ Improve land use efficiency and unit density.

Limitations:

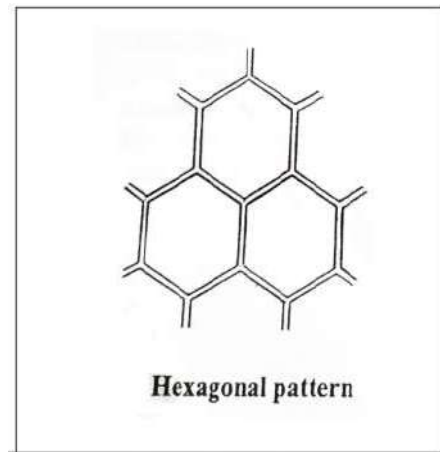
- ❖ Islands separating the approach and exit lanes, known as splitter islands, should extend far enough.
- ❖ Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.

Examples:

The Nagpur road plan formulae were prepared on the assumption of Grid pattern.



Radial or star and grid pattern



4.Hexagonal pattern

In this pattern, the entire area is provided with a network of roads formatting hexagonal figures. At each corner of the hexagon, three roads meet the built-up area boundary by the sides of the hexagons is further divided in suitable sizes.

Advantages:

Three roads meet the built-up area boundary by the sides of the hexagons.

Limitations:

Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed

HIGHWAYS ALIGNMENT

Introduction

The position or the layout of the center line of the highway on the ground is called the alignment. It includes horizontal alignment i.e., straight path, horizontal deviation and curves and vertical alignment i.e., changes in gradient and vertical curves.

If any improper alignment present, leads to increase in

- Construction cost
- Maintenance cost
- Vehicle operation cost
- Accident rate

Requirements of an Ideal Alignment

An ideal alignment between two stations should offer maximum utility by serving maximum population and products and also should possess following requirements

- **Short:** it is desirable to have a short alignment between two stations. A straight path between the two terminals would provide this.
- **Easy:** it is should be easy to construct and maintain the road with minimum problems and also the alignment should be easy for vehicle to operate with easy gradient and curves.
- **Safe:** it should be safe enough for construction and maintenance from the view point of stability of natural hill slopes, embankment and cut slopes. It should be safe for the traffic operation with safe geometric features.
- **Economical:** The road alignment could be considered economical only if the total cost including initial cost, maintenance cost and vehicle operation cost is lowest.

Factors Controlling Alignment

The various factors which control the highway alignment are

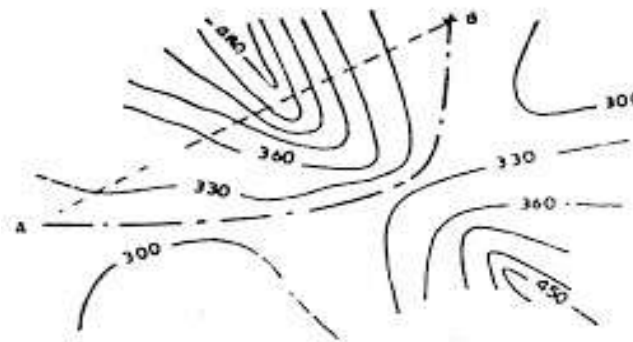
1. **Obligatory points**
2. **Traffic**
3. **Geometric design**
4. **Economics**
5. **Other considerations**

1.Obligatory Points: there are control points governing the alignment of the highways. These control points may be divided broadly into two categories.

- **Points through which the alignment is to pass**

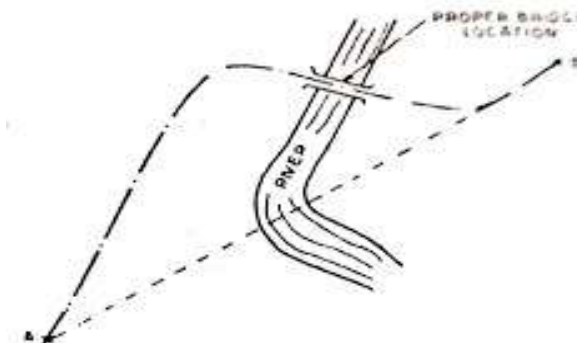
This may cause the alignment to often deviate from the shortest or easiest path. The various examples of this category may be bridge site, intermediate town, a mountain pass or quarry.

Case 1: When it is necessary to cross hill range, mountains the various alternatives are to cut a tunnel or to go around the hill. This suitability depends on many factors like site condition, topography, cost consideration etc. Figure (a) shows how the straight alignment AB is deviated along the hill side pass, thus avoiding a tunnel or heavy cutting.



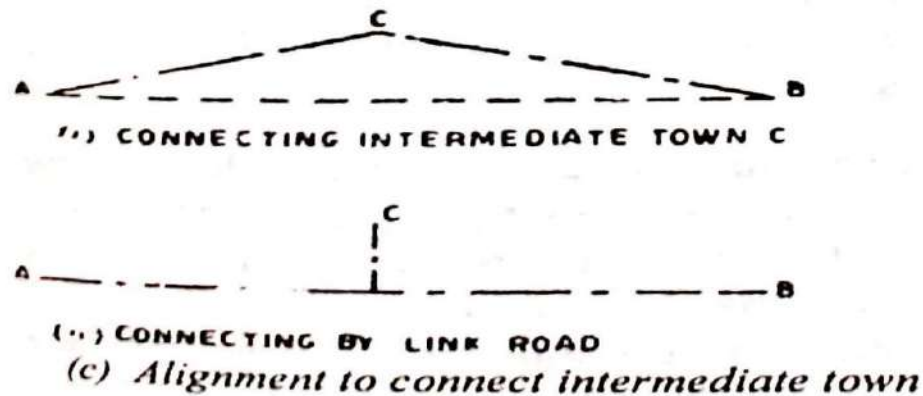
(a) Alignment along a hill side pass

Case 2: the road bridge across a river can be located at a place where the river has straight and permanent path and where there is a bend in the river, also the selected location of the bridge should be such that the abutment and pier can be properly constructed. Figure (b) shows that the straight alignment between stations A and B which crosses the river at the bend is not a suitable location and hence the alignment is to deviated along the path shown (by dash lines).



(b) Alignment to suit proper location of bridge

Case 3: when connecting a road network between two stations, it always beneficial to provide a link road or to connect the proposed alignment through nearby station. The straight alignment AB may be shifted along line ACB, as shown in figure (c) in order to connect the intermediate station C. It is also possible to connect the station C with a link road as shown in figure, thus avoiding the deviation of the straight alignment.



- **Points through which the alignment should not pass**

This may also make it necessary to deviate from the proposed shortest alignment due to the obligatory points through which alignment should not pass such as religious places (temples, church, mosque and grave), very costly structure, unsuitable land (lakes, ponds, marshy soil)

2. Traffic

The alignment should suit traffic requirements. Origin and destination study should be carried out in the area and the desire lines be drawn showing the traffic flow. The new alignment should keep in view of desired lines, flow patterns and future trends.

3. Geometric design

Geometric design factors such as gradient, radius of curve and sight distance, overtaking sight distance, ruling gradient on hilly region also would govern the final alignment of the highway. As far as possible while aligning a new road, the gradient should be flat and less than the ruling or design gradient.

4. Economics

The alignment finalized based on the above factors should be economical compared to other alignment. While working out the economics, the factors to be considered are initial construction cost, regular and periodic maintenance cost of the road and vehicle operation cost in future years. It is essential to work out overall economics based on 'life cycle cost' of the road project and not consider the initial cost of the road project only.

5. Other consideration

Factors like drainage consideration, hydrological factors, water table, seepage flow, high flood level, political considerations and monotony also affect in deciding the alignment. Straight road of very long stretch may be monotonous for driving. Hence, after a few kilometers of straight road, it may be desirable to have a slight bend or to provide some road side amenities, to break the monotony and keep the driver alert.

Special Considerations for Hilly Area Alignment

In hill roads additional care has to be given for

- **Stability**
- **Drainage**
- **Special geometric standards of hill roads**
- **Resisting length.**

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 is that of landslides. The cutting and filling of earth to construct roads on hill side causes steepening of existing slopes and this affects its stability of the hill slopes.

Drainage

Numerous hill side drains should be provided for adequate drainage facility across the road. But the cross drainage structure being costly, attempts should be made to align the road in such a way that the number of very expensive cross drainage structures is kept minimum.

Geometric standard of hill roads

Different sets of geometric design standards are followed on hill roads with reference to gradient, curves and speed and they consequently influence the sight distance, radius of curve and other related features. The route should enable the ruling gradient to be attained in most of the length, minimizing steep gradients, hair pin bends and needless rise and fall.

Resisting length

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

Engineering Surveys for Highway Alignment

The stages of engineering surveys for highway locations are

1. **Map study**
2. **Reconnaissance survey**
3. **Preliminary surveys**
4. **Final location and detailed surveys**

1. Map study

- ❖ By careful study of topographical map, it is possible to have an idea of several possible alternate routes so that further details of these may be studied later at the site.
- ❖ The features like river, hills valleys, and counter intervals can be observed.
- ❖ By knowing these feature it can fairly assign the alignment avoiding valleys, lakes and possible location of bridge (avoiding sharp turns etc.).
- ❖ It is also possible to suggest permissible gradient considering counter intervals.

2. Reconnaissance

It is to examine the general character of the area for deciding the most feasible routes for detailed studies. A field survey party may inspect a fairly broad stretch of land along the proposed alternative routes of the map in the field. Only few simple instruments like abney level tangent clinometers, barometer or GPS are used by the reconnaissance party to collect additional details rapidly. Some of the following details are collected

- ❖ Valleys, ponds, lakes, marshy land, hills, permanent structures and other obstruction along the route which are not available in the map.
- ❖ Approximate values of gradient, length of gradient and radius of curves of alternate alignments.
- ❖ Number and type of cross drainage structures, maximum flood level and natural ground water level along the probable routes.
- ❖ Sources of construction materials, water and location of stone quarries.
- ❖ When the alignment passes through hill, additional details like type of rocks, dip of strata, seepage flow.

3. Preliminary Survey

This survey can be done either by Conventional approach or aerial survey if the area is more.

The main objectives of preliminary survey are

- ❖ To survey the various alternate alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil.
- ❖ To compare the different proposals in view of the requirements of a good alignment.
- ❖ To estimate quantity of earth work materials and other construction aspects and to work out the cost of alternate proposals.
- ❖ To finalize the best alignment from all consideration.

4.Final Location and Detailed survey

- ❖ The alignment finalized at the design office after the preliminary survey is to be located on the field by establishing the centre line.
- ❖ The centre line of the road finalized is to be translated on the ground during the location survey
- ❖ The centre line stakes are driven at suitable intervals say 50 m in plain and rolling terrains and at 20 m in hilly terrain.
- ❖ Temporary bench marks are fixed at intervals of about 250 m and at all drainage and under pass structures.
- ❖ The cross sectional levels are taken at very 50 – 100 m in plain terrain, 50 – 75m in rolling terrain, 50m in built-up area and 20m in hilly areas intervals.
- ❖ The cross section should be taken at curves and where there is a gradient change.
- ❖ The data collected during the detailed survey should be elaborate and complete for preparation of detailed plans, design and estimate of the project.

HIGHWAY GEOMETRIC DESIGN

Geometric design of highways deals with the following elements

- Cross section elements
- Sight distance considerations
- Horizontal alignment details
- Vertical alignment details
- Intersection elements

Design Control and Criteria

The geometric design of highways depends on several design factors. The important factors which control the geometric elements are

1. Design speed
2. Topography or terrain
3. Traffic factors
4. Design hourly volume and capacity
5. Environmental and other factors

1.Design speed

The design speed is the most important factor controlling the geometric design elements of highways. The design speed is decided taking into account the overall requirements of the highway. In India, different standards have been assigned depending upon the importance of the class of road. Further the design speed standards are modified depending upon the terrain or topography. Design of almost every geometric design elements of a road is dependent on the design speed.

The recommended design speed is given in Table .

Table : Design speed in as per IRC (ruling and minimum)				
Type	Plain	Rolling	Hilly	Steep
NS&SH	100-80	80-65	50-40	40-30
MDR	80-65	65-50	40-30	30-20
ODR	65-50	50-40	30-25	25-20
VR	50-40	40-35	25-20	25-20

2.Topography

The topography or the terrain conditions influence the geometric design of highways significantly. The terrains are classified based on the general slope of the country across the alignment as plain, rolling, mountainous and steep terrain. The design standards specified for different classes of roads are different depending on the terrain classification. For example the design speed of NH and SH on plain terrain with general cross slope of 10% is 100kmph whereas on rolling terrain with general slope of 10 to 25% is 80kmph and that on mountainous terrain with cross slope 25 to 60% is 50kmph.

Terrain Classification	Cross slope of the country, percent
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	Greater than 60

3.Traffic factors

The factors associated with traffic that affects geometric design of roads are the vehicular characteristics and human characteristics of road users. It is difficult to decide the design vehicle or the standard traffic lane under the mixed traffic flow condition prevalent especially on urban roads of developing countries like India. This is a complex problem. However, it is often necessary to consider some standard vehicle as the design vehicle. The important human factors which affect traffic behavior include the physical, mental and psychological characteristics of drivers and pedestrians.

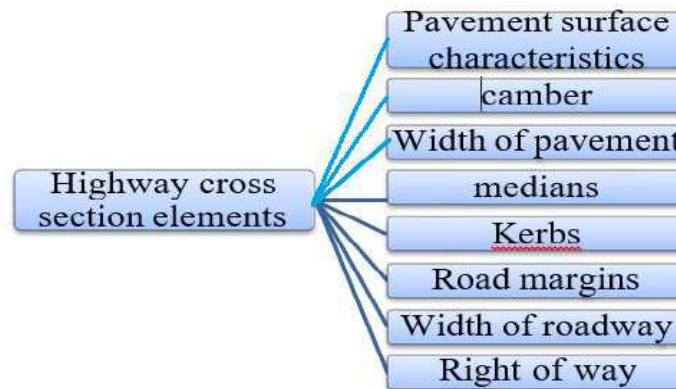
4.Design hourly volume and capacity

The traffic flow or volume keeps fluctuating with time, from a low value during certain off peak hours to the higher flow during the peak hours. It will be uneconomical to design the roadway facilities for the peak traffic flow or the highest hourly traffic volume. Therefore a reasonable value of traffic volume is decided for the design and this is called design hourly volume.

4.Environmental and other factors

The environmental factors such as aesthetics, landscaping, air pollution, noise pollution and other local conditions should be given due consideration in the design of road geometrics. Some of the arterial high speed highways and expressways are designed for higher speed standards and uninterrupted flow of vehicles by providing controlled access and grade separated intersections.

Highway Cross Section Elements



1.Pavement Surface Characteristics

The pavement surface a) depends on the pavement type. The important characteristics of the pavement are

- (i) Friction
- (ii) Unevenness
- (iii) Light reflecting characteristics
- (iv) Drainage of surface water

(i) Friction

The friction or Skid resistance between vehicle tyre and pavement surface is one of the factors determining the operating speed and minimum distance required for stopping the vehicles. When vehicle negotiates a horizontal curve, the lateral friction developed counteracts the centrifugal forces and thus governs the safe operating speed. Frictional force is an important factor in the acceleration and retarding abilities of vehicles. The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f . The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed for calculating stopping sight distance and coefficient of lateral friction as 0.15 for horizontal curve design. Lack of adequate friction can cause skidding or slipping of vehicles.

- a. Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction
- b. Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road.

Factors affecting friction

- ❖ Type of the pavement (like bituminous, concrete, or gravel),
- ❖ Condition of the pavement (dry or wet, hot or cold, etc),
- ❖ Condition of the tyre (new or old)
- ❖ Speed of the vehicle
- ❖ Relative roughness
- ❖ Brake efficiency
- ❖ Load and tyre pressure
- ❖ Temperature of tyre and pavement
- ❖ Type of skid, if any

Below table shows the recommended value of ‘f’ by IRC

Speed, kmph	20 to 30	40	50	60	65	80	100 and above
Longitudinal friction coefficient value, f for SSD	0.40	0.38	0.37	0.36	0.36	0.35	0.35

(ii) Pavement Unevenness

Presence of undulations on the pavement surface is called pavement unevenness which results in

- (i) Increase in discomfort and fatigue to road users
- (ii) Increase in fuel consumption and tyre wear
- (iii) Increase in vehicle maintenance cost
- (iv) Reduction in vehicle operating speed increase in accident rate

Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road. It is measured by an instrument called Bump integrator (BI) in terms of unevenness index. An unevenness index value less than 1500 mm/km is considered as good, a value less than 2500 mm.km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 kmph.

The unevenness may be caused due to the following reasons

- (i) Inadequate or improper compaction of either the fill, subgrade or pavement layers or combination of these
- (ii) Use of improper construction machinery

- (iii) Use of inferior pavement materials
- (iv) Improper surface and subsurface drainage
- (v) Unscientific construction practices
- (vi) Poor maintenance practices
- (vi) Localized failures

(iii) Light Reflecting Characteristics

- (v) Night visibility depends upon the color and light reflecting characteristics of the pavement surface
- (vi) The glare caused by the reflection of head light is high on wet pavement surface than dry
- (vii) White roads have good visibility at night, but caused glare during day time.
- (viii) Black roads has no glare during day, but has poor visibility at night

(iv) Drainage

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

2. Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain off rain water from road surface. The objectives of providing camber are

- a. to prevent the entry of surface water into the pavement layers and subgrade soil
- b. To prevent the entry of water into the bituminous pavement layers
- c. To remove the rain water from the pavement surface as quickly as possible

The required camber of a pavement depends on

- ❖ Type of pavement surface
- ❖ The amount of rainfall

Types of camber

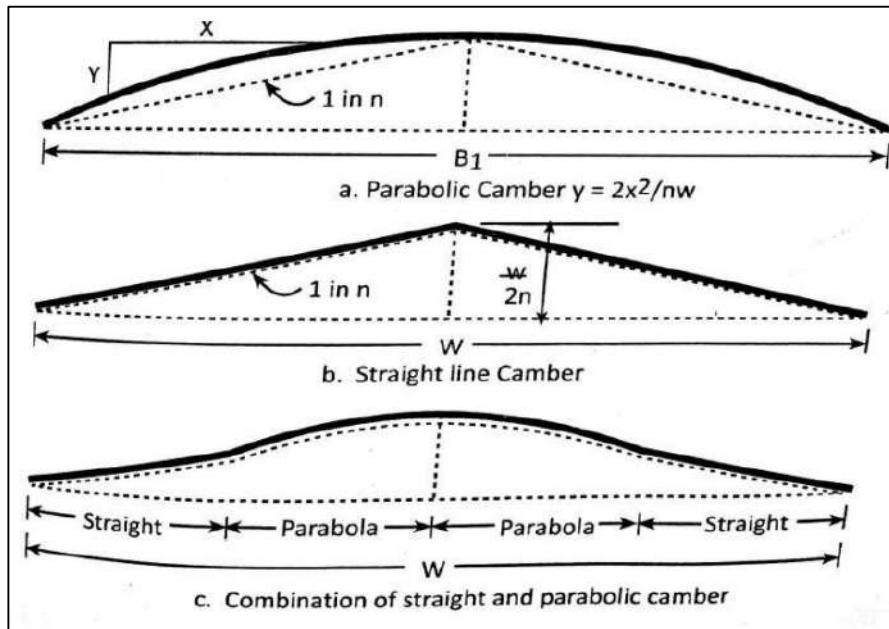
There are generally three types of the cambers

- Straight Camber
- Parabolic Camber
- Combination of straight and parabolic camber

Straight Camber: This type of camber is provided by meeting two straight surfaces at the crown. Crown is the central and top most point on the surface of the road. The edge shape produces inconvenience to the traffic so it is not used in general.

Parabolic Camber: Parabolic camber is provided by providing a parabolic shape to the surface of the road. It is also not used in general because it has steep slopes towards the edges, which can create the outward thrust to the vehicles.

Combination Camber: This camber is formed by use of the straight surfaces at the edges but parabolic surface at the centre. It is mostly used for the road construction because both the problem of the earlier two is solved if we use this camber.



Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (eg. 1 in 50 or 2%) and the value depends on the type of pavement surface. The values suggested by IRC for various categories of pavement is given in Table

S.No	Type of Road Surface	Range of camber in areas of	
		Heavy Rain fall	Low Rain fall
1	Cement concrete and high type bituminous surface	1 in 50 or 2.0%	1 in 60 or 1.7%
2	Thin bituminous surface	1 in 40 or 2.5%	1 in 50 or 2.0%
3	Water bound Macadam and gravel pavement	1 in 33 or 3.0%	1 in 40 or 2.5%
4	Earth road	1 in 25 or 4.0%	1 in 33 or 3.0%

Width of Pavement or Carriage Way

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.5m and the desirable side clearance for single lane traffic is 0.625 m. This require minimum of lane width of 3.75 m for a single lane road (figure a) and 7m for two lane road (figure b). The desirable carriage way width recommended by IRC is given in Table

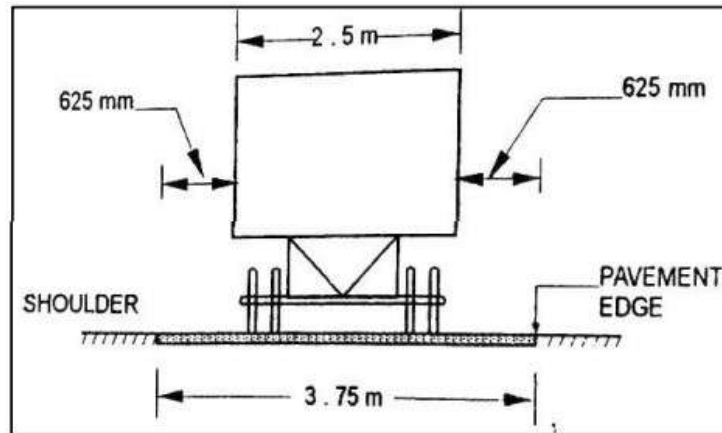


figure a-single lane road

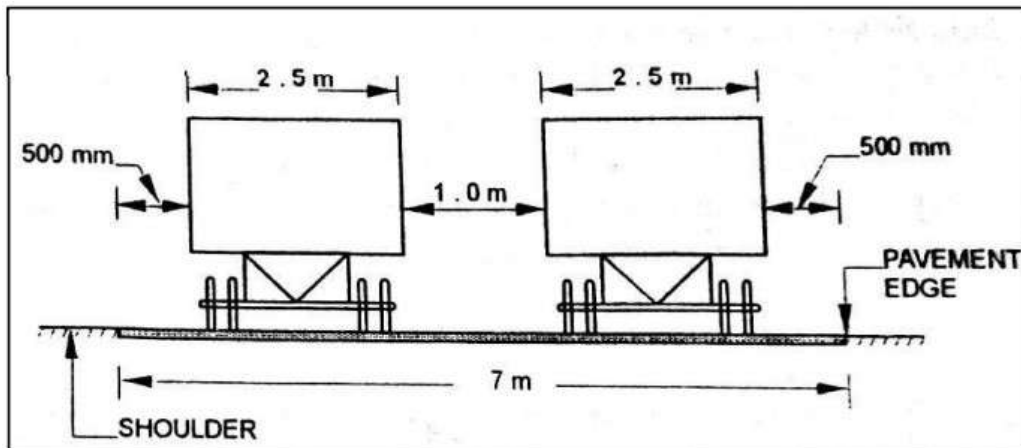
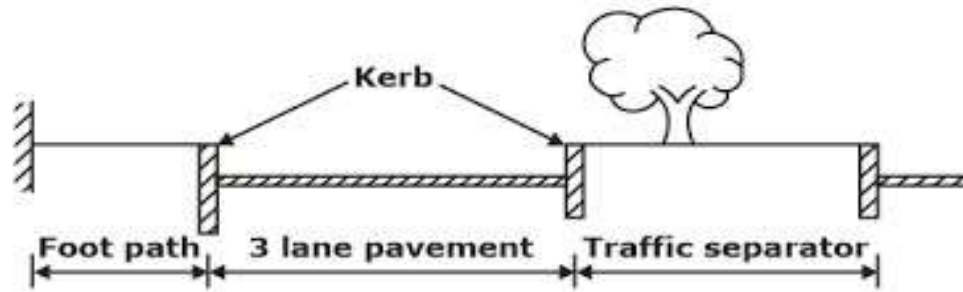


figure b - two lane road

Class Of Road	Width Of Carriageway (m)
Single lane road	3.75
Two lanes, without raised kerbs	7
Two lanes, with raised kerbs	7.5
Intermediate Carriageway	5.5
Multi-lane pavements	3.5 per lane

Medians or traffic separators



In highways with divided carriageway, a median is provided between two sets of traffic lanes intended to divide the traffic moving in opposite direction. The main function of the median is to prevent head on collision between vehicles moving in opposite directions on adjacent lanes. The traffic separators used may be in the form of pavement markings, physical dividers or area separators. The functions of medians are

- a) To channelize traffic into streams at intersections
- b) To shadow the crossing and turning traffic
- c) To segregate slow traffic
- d) To protect pedestrians

The IRC recommends a minimum desirable width of 5m for medians of rural highways, which may be restricted to 3m. The absolute minimum width of median in urban area is 1.2m and desirable minimum is 5m.

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are

❖ **Low or mountable kerbs**

These types of kerbs are provided such that they encourage the 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 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.

❖ **Semi-barrier type kerbs**

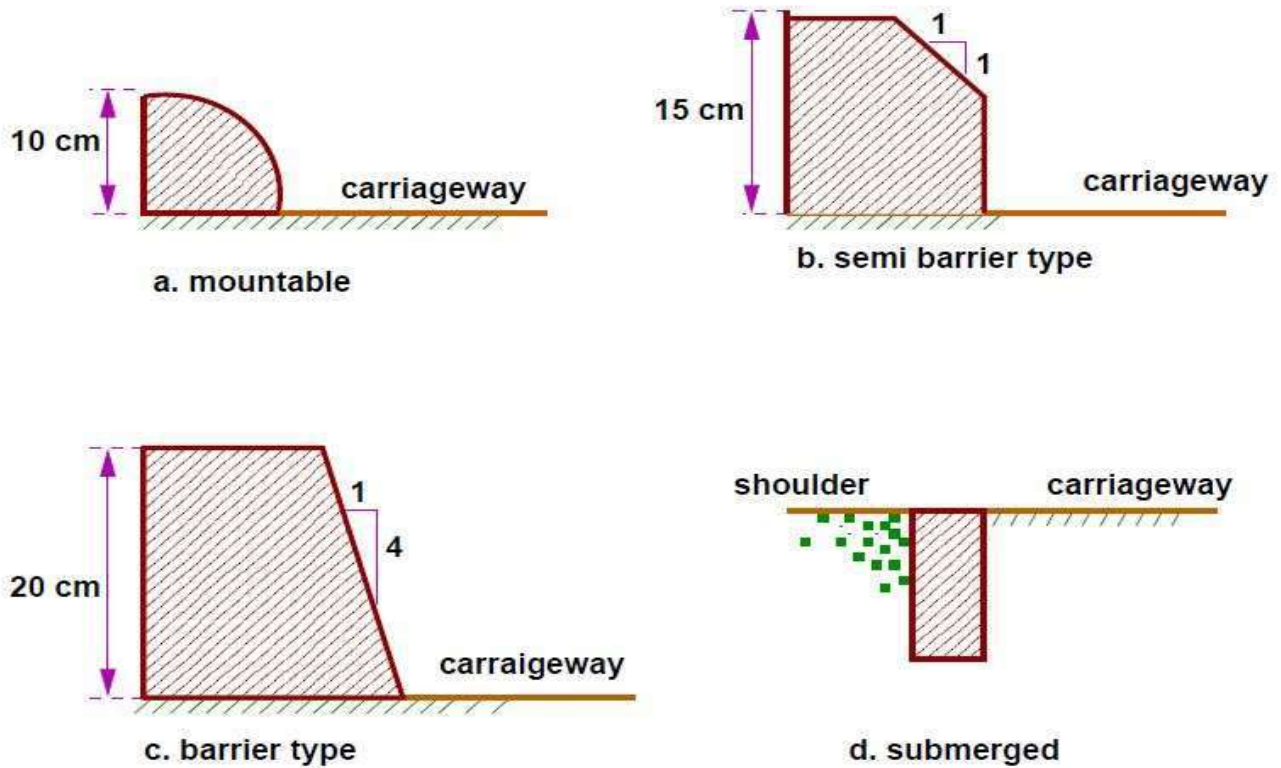
When the pedestrian traffic is high, these kerbs are provided. Their height is 15cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.

❖ **Barrier type kerbs**

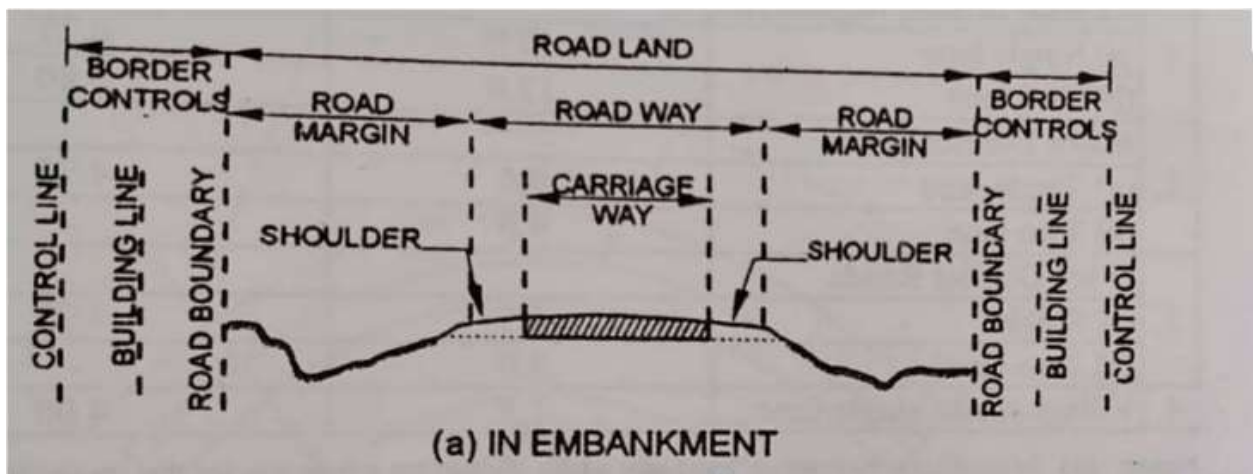
They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.

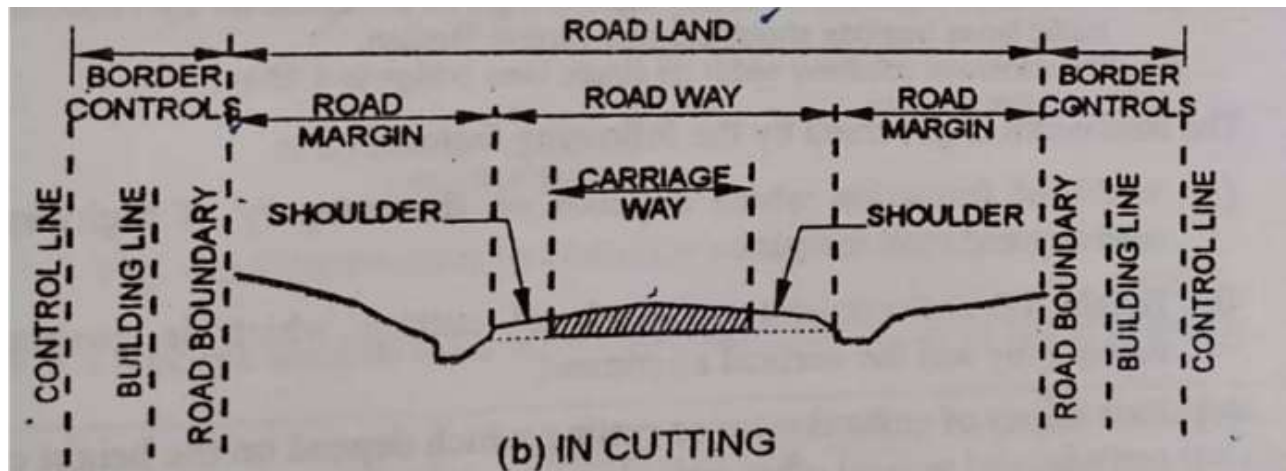
❖ **Submerged kerbs**

They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.



Road Margins





❖ Shoulder

Shoulders are provided along the road edge and are intended for accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses. The shoulder should be strong enough to bear the weight of a fully loaded truck even in wet conditions. The shoulder width should be adequate for giving working space around a stopped vehicle. A minimum width of 2.5 m is recommended by IRC for 2-lane rural highways in India.

The functions of shoulders are

- ❖ Structural ability and support to the edges of the flexible pavements
- ❖ Capacity of carriageway and the operating speeds of vehicles increases
- ❖ Serves as an emergency lane
- ❖ Acts as service lanes for vehicles that are disabled

❖ Parking lanes

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving on the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking. As far as possible parallel parking should be allowed as it is safer for moving vehicles.

❖ Bus-bays

Bus bays are provided by recessing the kerbs for bus stops. They are provided so that they do not obstruct the movement of vehicles in the carriage way. They should be at least 75 meters away from the intersection so that the traffic near the intersections is not affected by the bus-bay.

❖ Cycle track

Cycle tracks are provided in urban areas when the volume of cycle traffic is high. Minimum width of 2 meter is required, which may be increased by 1 meter for every additional track.

❖ Footpath

Footpaths are exclusive right of way to pedestrians, especially in urban areas. They are provided for the safety of the pedestrians when both the pedestrian traffic and vehicular traffic is high. Minimum width is 1.5 meter and may be increased based on the traffic. The footpath should be either as smooth as the pavement or smoother than that to induce the pedestrian to use the footpath.

❖ Guard rails

They are provided at the edge of the shoulder usually when the road is on an embankment. They serve to prevent the vehicles from running o the embankment, especially when the height of the fill exceeds 3m. Various designs of guard rails are in use. Guard stones painted in alternate black and white are usually used. They also give better visibility of curves at night under headlights of vehicles.

❖ Drive ways

Drive ways connect the highway with commercial establishment like fuel stations, servicestations etc. Drive ways should be properly designed and located, fairly away from an intersection. The radius of the drive way curve should be kept as large as possible, but the width of the drive way should be minimized to reduce the crossing distance of pedestrians.

❖ Lay byes

They are provided near public conveniences with guide maps to enable drivers to stop clear off the carriageway. It should normally be 3m width and at least 30m length with 15m end tapers on both sides.

❖ Frontage road

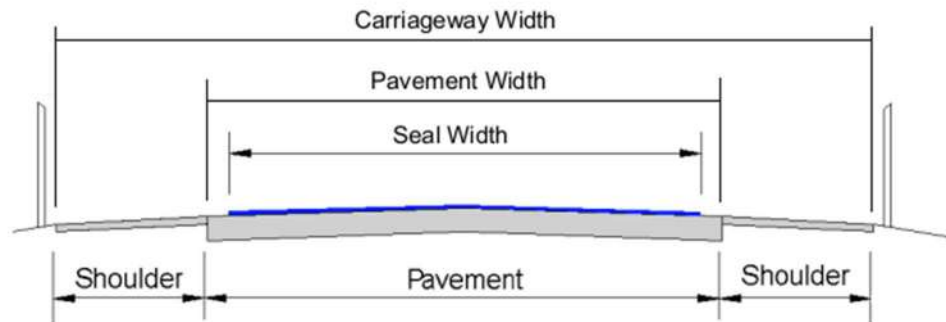
Frontage roads are provided to give access to properties along an important highway with controlled access to express way or free way. The frontage roads may run parallel to the highway and are isolated by a separator, with approaches to the through facility only at selected points, preferably with grade separators.

❖ Embankment slope

Embankment slope should be as flat as possible for the purpose of safe traffic movement and also for aesthetic reasons. For safety considerations, the desirable slope for the embankment is 1 in 3.

Width of Formation or Roadway

Width of formation or roadway is the sum of widths of pavement or carriageway including separators, if any and the shoulders. The width of roadway standardized by the IRC is given in table below



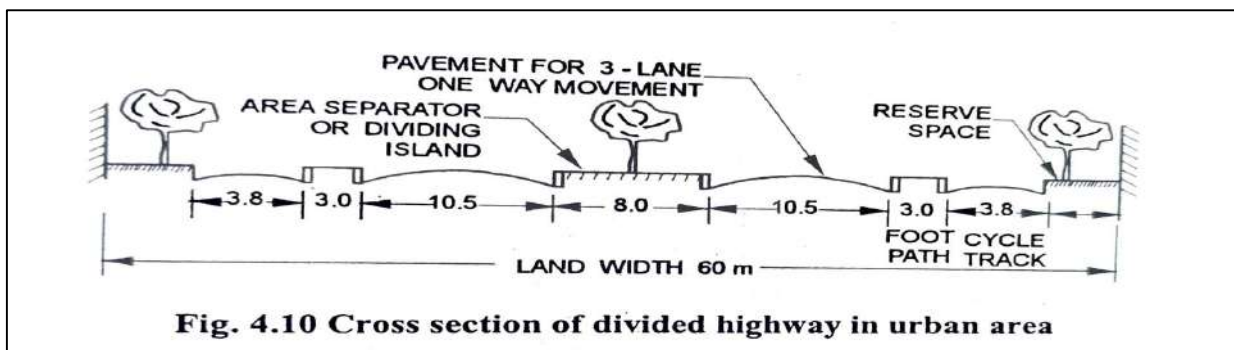
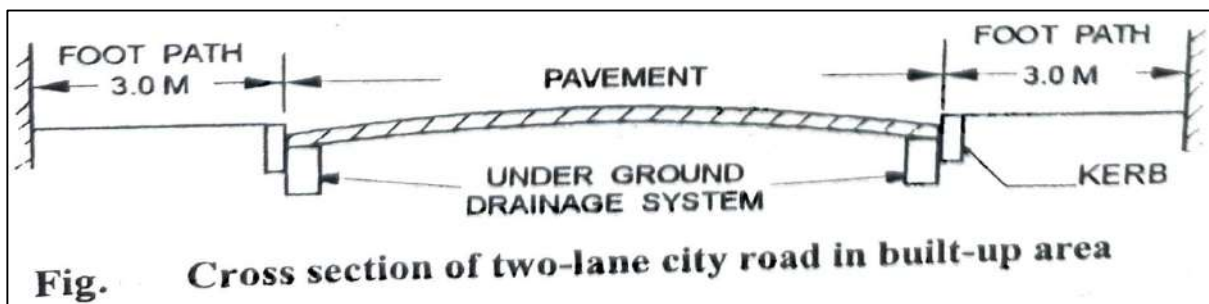
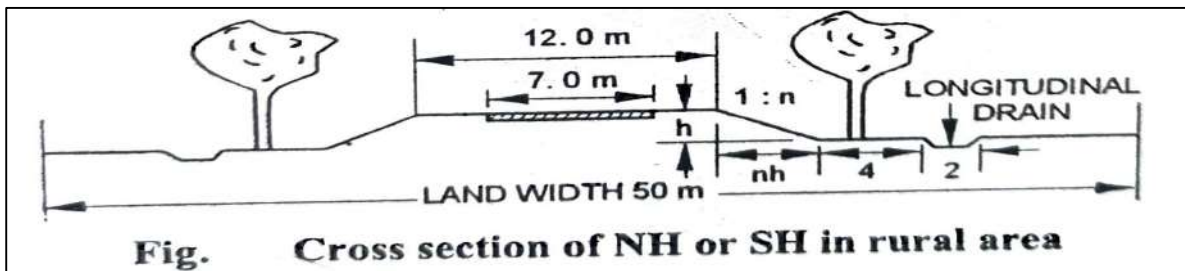
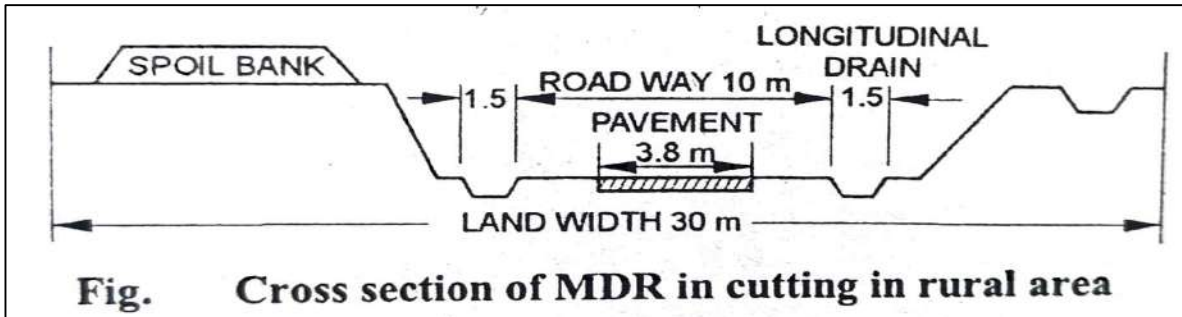
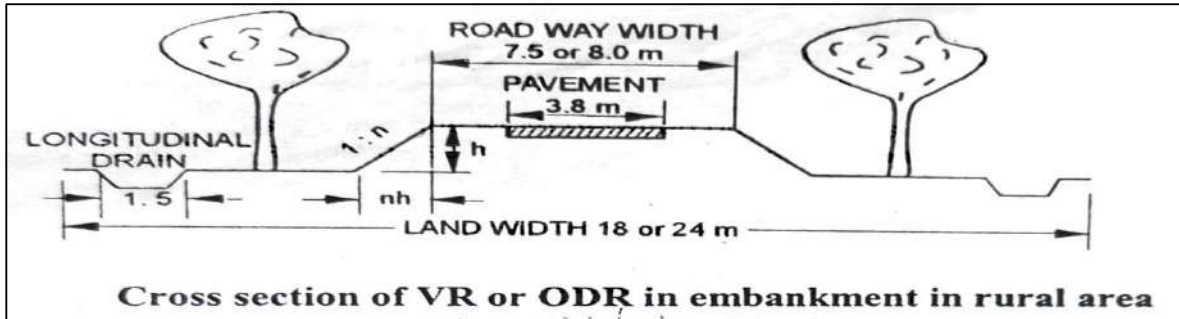
Sr. No	Road Classification	Roadway Width (m)	
		Plain and rolling terrain	Mountainous and steep terrain
1	National & State Highways	12	6.25
	a) Single Lane b) Two lane	12	8.80
2	Major District Roads	9	4.75
	a) Single Lane b) Two lane	9	-
3	Other District Roads	7.5	4.75
	a) Single Lane b) Two lane	9	-
4	Village Roads ,Single Lane	7.5	4

Right of Way and Land Width

Right of way is the area of land acquired for the road, along its alignment. The width of the acquired land for right of way is known as land width and depends on the importance of the road and possible future development. To prevent development along highways, control lines and building lines may be provided. Control line is a line which represents the nearest limits of future uncontrolled building activity in relation to a road. Building line represents a line on either side of the road; between which and the road no building activity is permitted at all. The right of way width is governed by

- ❖ Width of formation: It depends on the category of the highway and width of roadway and road margins.
- ❖ Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.
- ❖ Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
- ❖ Drainage system and their size which depends on rainfall, topography etc.
- ❖ Sight distance considerations on curves etc., there is restriction to the visibility on the inner
- ❖ side of the curve due to the presence of some obstructions like building structures etc.
- ❖ Reserve land for future widening.

Typical Cross Section of Roads

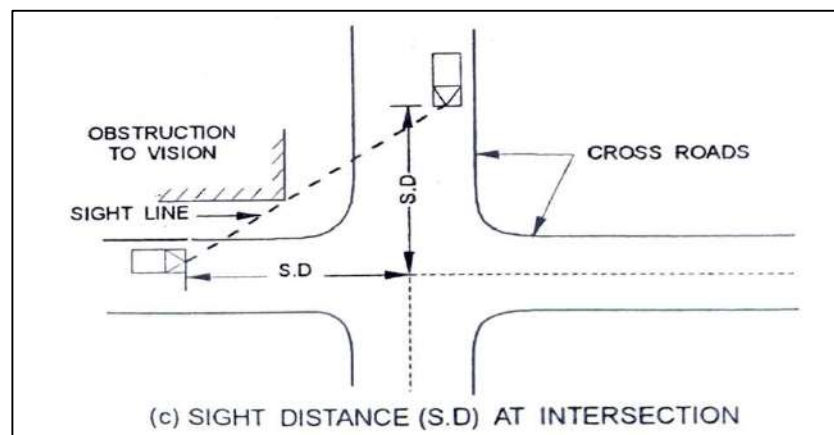
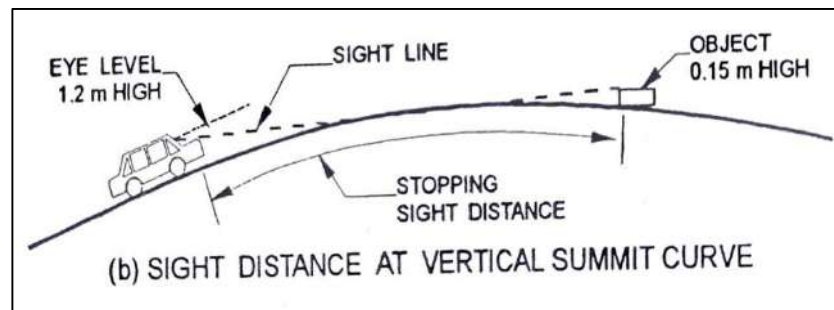
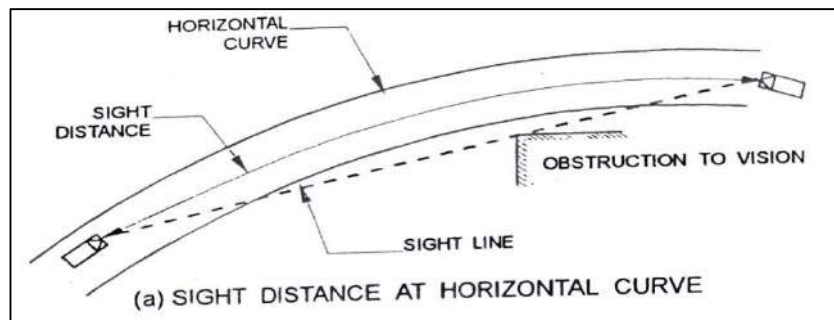


Sight Distance

It is the length of road visible ahead to the driver at any instance. Sight distance available at any location of the carriageway is the actual distance a driver with his eye level at a specified height above the pavement surface has visibility of any stationary or moving object of specified height which is on the carriageway ahead.

Restrictions to Sight Distance

- a) At horizontal curves, when the line of sight is obstructed by objects at the inner side of the curve (fig a)
- b) At a vertical curve the line of sight is obstructed by the road surface of the summit curve (figb)
- c) At an uncontrolled intersection when a driver from one of the approach roads is able to sight a vehicle from another approach road proceeding towards the intersection (fig c)



Types of Sight Distance

Three types of sight distances situations are considered in the design

1. Stopping sight distance (SSD) or Absolute minimum sight distance

2. Safe overtaking sight distance (OSD) or Passing sight distance

3. Safe sight distance for entering into uncontrolled intersections

1. Stopping sight distance (SSD)

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.

2. Safe overtaking sight distance

Driver travelling at the design speed should be able to safely overtake the slower vehicles without causing obstruction or hazard to traffic of opposite direction, at reasonable intervals

3. Safe sight distance for entering into uncontrolled intersections

Driver entering an uncontrolled intersection has sufficient visibility to enable him to take control of his vehicle and to avoid collision with another vehicle

Apart from the three situations mentioned above, the following sight distances are considered by the IRC in highway design

❖ **Intermediate sight distance**

This is defined as twice the SSD. When OSD cannot be provided, intermediate sight distance (ISD) is provided to give limited overtaking opportunities to fast vehicles.

❖ **Head – light sight distance**

This is the distance visible to a driver during night driving under the illumination of the vehicle head lights. This sight distance is critical at up gradient and at ascending stretch of the valley curves

Stopping Sight Distance (SSD)

The minimum distance visible to a driver ahead on a highway at any spot should be of sufficient length to safely stop a vehicle travelling at design speed, without collision with any other obstruction. This is also called as non passing sight distance or absolute minimum sight distance.

The sight distance available to a driver traveling on a road at any instant depends on the following factors

- (i) Features of the road ahead
- (ii) Height of the driver's eye above road surface
- (iii) Height of the object above the road surface

The features of the road ahead which affects the sight distance are the horizontal alignment and vertical profile of the road, the traffic condition and the position of obstructions. For the purpose of measuring the stopping sight distance or visibility ahead, IRC has suggested the height of eye level of driver as 1.2m and the height of the object as 0.15m above the road surface.

Factors on Which Stopping Sight Distance Depends

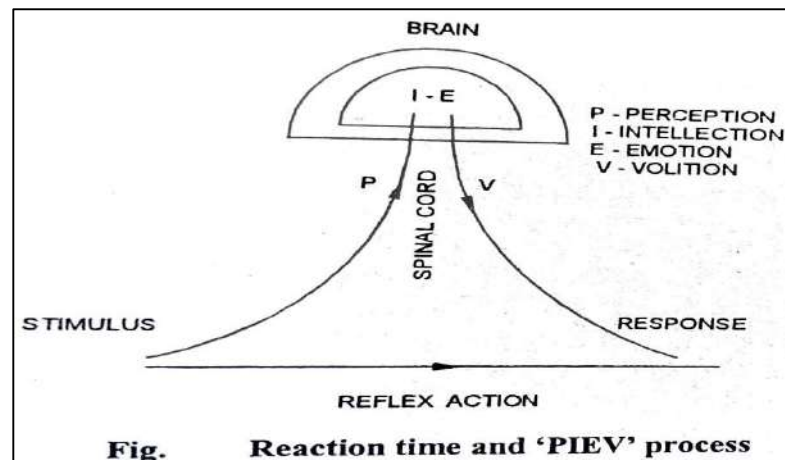
- 1.Total reaction time of the driver**
- 2.Speed of vehicle**
- 3.Efficiency of brakes**
- 4.Frictional resistance between the road and the tyre**
- 5.Gradient of the road, if any**

1.Total reaction time

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 two parts: perception and brake reaction time. The perception time is the time required for a driver to realize that brakes must be applied. It is the time from the instant the object comes on the line of sight of the driver to the instant he realizes that the vehicle needs to be stopped. The brake reaction time depends on several factors including the skill of the driver, the type of the problems and various other environmental factors. The total reaction time may be explained with the help of PIEV theory.

PIEV theory

According to PIEV theory, the total reaction time of the driver is split into four parts



1. Perception time

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

2. Intellection time

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

3. Emotion time

It is the time elapsed during emotional sensations and other mental disturbance such as fear, angry or any other emotional feelings like superstition etc with reference to situation. It varies for different drivers.

4. Volition time

It is the time taken by the driver for the final action, such as brake application.

2. Speed of vehicle

The stopping distance depends very much on the speed of the vehicle. First, during the total reaction time of the driver the distance moved by the vehicle will depend on the speed. Second, 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. Hence it is evident that higher the speed, higher will be the stopping distance. Hence it is evident that higher the speed, higher will be the stopping distance.

3.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 is less.

4.Frictional resistance between road and tyres

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.

5.Gradient of the road

Gradient of the road also affects 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.

Analysis of Stopping Sight Distance

The stopping sight distance of a vehicle is the sum of

- 1.The distance travelled by the vehicle at uniform speed during the total reaction time, t which is known as lag distance
- 2.The distance travelled by the vehicle after the application of the brakes, until the vehicle comes to a dead stop which is known as braking distance

Lag distance

If 'v' is the design speed in m/sec and 't' is the total reaction time of the driver in seconds, then

Lag distance = vt (m)

If the design speed is V kmph, then the lag distance = $0.278Vt \approx 0.28Vt$ (m)

Braking distance

Assuming a level road, the braking distance may be obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle moving at design speed. If the maximum frictional force developed is F (kg) and the braking distance is I (m), then work done

$$F * I = W * f * I$$

Kinetic energy of the vehicle of weight W moving at the design speed of v m/sec = $Wv^2/2g$

Hence

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

Therefore **braking distance**,

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

Where l = braking distance, m

V = speed of vehicle, m/s

f = frictional coefficient

g = acceleration due to gravity = 9.8m/s^2

Stopping distance on level road

Stopping distance, SD = Lag distance + breaking distance

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

If speed is V kmph, the stopping distance

$$SD = 0.278 Vt + \frac{v^2}{254f}$$

Stopping distance at slopes

$$SD = 0.278 Vt + \frac{V^2}{254(f \pm 0.01n)}$$

OVERTAKING SIGHT DISTANCE (OSD)

Over Taking Requirement

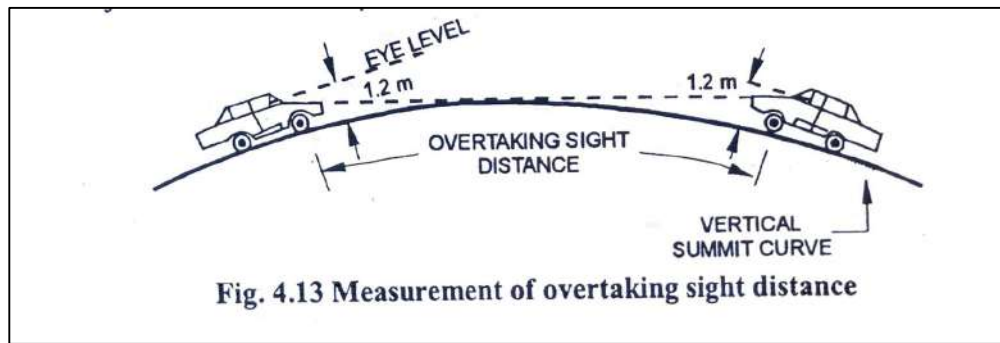
If all the vehicles travel along a road at the design speed, then theoretically there should be no need for any overtaking. In fact, all vehicles do not move at the design speed as each driver is free to travel at lower speeds and this is particularly true under Mixed Traffic conditions. It is necessary for fast moving vehicle to overtake or pass the slow-moving traffic.

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 opposite direction is known as Minimum Overtaking Sight Distance (OSD) or Safe Passing Sight Distance

Overtaking Sight Distance (OSD) or Safe Passing Sight Distance

The OSD is the distance measured along the centre line of the road which a driver with his eye level at

1.2m above the road surface can see the top of an object 1.2m above the road surface



Factor Affecting OSD

> Speeds of

- 1) Overtaking Vehicle
- 2) Overtaken Vehicle
- 3) Vehicle coming from opposite direction

>>Distance between the overtaking and overtaken vehicles, the minimum spacing between vehicles depends on the speeds

>Skill and reaction time of the driver

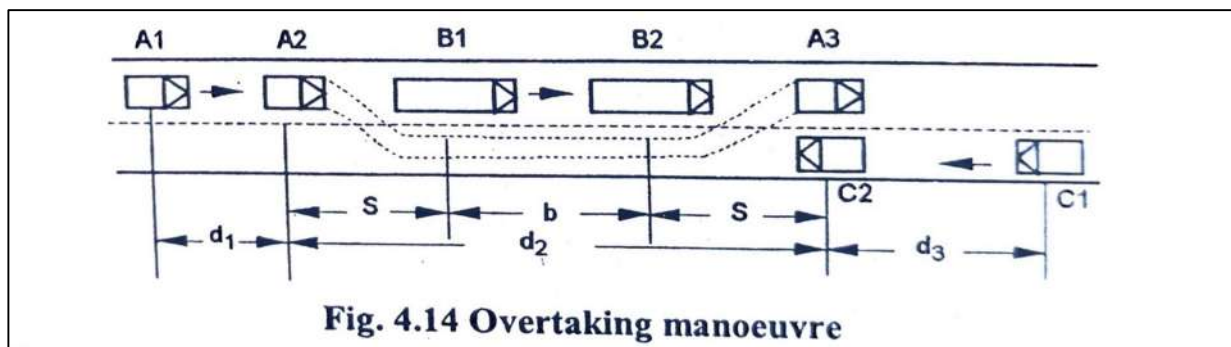
>Rate of acceleration of overtaking vehicle

> Gradient of the road

ANALYSIS OF OSD ON A 2 – WAY ROAD

Simple overtaking process on a 2 – lane highway with 2 – way traffic movement

Vehicle A travelling at the design speed v m/sec or V kmph desires to overtake another slow-moving vehicle B moving at a speed of v_b m/sec or V_b kmph. The vehicle A has to accelerate, shift to the adjacent right-side lane, complete the overtaking manoeuvre and return to the left lane, before oncoming vehicle C approaches the overtaking stretch.



The overtaking manoeuvre may be split up into 3 operations, thus dividing OSD into 3 parts d_1 , d_2 and d_3 .

- d_1 is the distance (m) travelled by the overtaking vehicle A during the reaction time, t (secs) of the driver from position A1 to A2 before starting to overtake the slow vehicle B
- d_2 is the distance travelled (m) travelled by the vehicle A during the actual overtaking operation during T (secs) from position A2 to A3
- d_3 is the distance (m) travelled by oncoming vehicle C during the actual overtaking operation of A during T (secs) from position C1 to C2.

Thus, on a 2-lane road with 2-way traffic the **OSD = $d_1 + d_2 + d_3$ in meters**

Assumptions made in the analysis

Assumptions made to calculate the values of d_1, d_2 and d_3 (m) are given below:

- The overtaking vehicle A is forced to reduce its speed from the design speed v (m/sec) to V_b (m/sec) of the slow vehicle B and move behind it, allowing a space s (m), till there is an opportunity for safe overtaking operation
- When the driver of vehicle A finds sufficient clear gap ahead, decides within a reaction time t (sec) to accelerate and overtake the vehicle B, during which the vehicle A moves at speed v_b (m/sec) through a distance d_1 from position A1 to A2.
- The vehicle A accelerates and overtakes the slow vehicle B within a distance d_2 during the overtaking time, T (sec) between the position A2 to A3
- The distance d_2 is split up into three parts
 - a) Spacing, s (m) between A2 and B
 - b) Distance b (m) travelled by the slow vehicle B between B1 and B2 during the overtaking manoeuvre of A
 - c) Spacing (m) between B2 and A3
- During this overtaking time T (sec), the vehicle C coming from opposite direction travels through a distance d_3 from position C1 to C2

Determination of the components of OSD

a) From position A1 to A2, the distance, d_1 (m) travelled by overtaking vehicle A, at the reduced speed v_b (m/sec) during the reaction time, t (sec) = $v_b t$ (m). The IRC suggests that this reaction time Y of the driver

may be taken as 2.0 sec as an average value, as the aim of the driver is only to find an opportunity to overtake.

Therefore

$$d1 = 2vb$$

b) From position A2, the vehicle A starts accelerating, shifts to the adjoining lane, overtakes the vehicle B, and shifts back to its original lane ahead of B in position A3 during the overtaking time, T (sec). The straight distance between position A2 and A3 is taken as d2 (m), which is further split into three parts, viz.,

$$d2 = (s + b + s)$$

c) The minimum distance between position A2 and B1 may be taken as the minimum spacing s (m) between the two vehicles while moving with the speed vb (m/sec). The minimum spacing between vehicles depends on their speed and is given by empirical formula

$$s = (0.7 vb + 6)$$

d) Now the time T depends on speed of overtaken vehicle B and the average acceleration a (m/sec²) of overtaking vehicle A. The overtaking time T (sec) may be calculated by equating the distance d2 to (vb T + ½ a T²) using the general formula for the distance travelled by a uniformly accelerating body with initial speed vb m/sec and a is the average acceleration during overtaking in m/sec²

$$d2 = (vb T + 2s)$$

e) The distance travelled by vehicle C moving at design speed v (m/sec) during the overtaking operation of vehicle A i.e. during time T (sec) is the distance d3 (m) between positions C1 to C2. Hence,

$$d3 = v T (m)$$

In m/sec units

$$OSD = (d1 + d2 + d3) = (vb t + vb T + 2s + vT)$$

Here

vb = initial speed of overtaking vehicle, m/s

t = reaction time of driver = 2 sec

V = speed of overtaking vehicle or design speed, kmph

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

s = spacing of vehicles = (0.7 vb + 6)

a = average acceleration during overtaking, m/sec.

In kmph units

$$OSD = 0.28 Vb t + 0.28 Vb T + 2s + 0.28 V T$$

Here Vb = initial speed of overtaking vehicle, kmph

t = reaction time of driver = 2 sec

V = speed of overtaking vehicle or design speed, kmph

s = spacing of vehicles = $(0.2 V_b + 6)$

A = average acceleration during overtaking, kmph

In case the speed of overtaken vehicle (v_b or V_b) is not given, the same may be assumed as 4.5 m/sec or 16 kmph less than the design speed of the highway.

Therefore, $v_b = (v - 4.5)$ m/sec

$V_b = (V - 16)$ kmph

where v is the design speed in m/sec

V is the design speed in kmph.

The acceleration of the overtaking vehicle varies depending on several factors such as the make and model of the vehicle, its condition, load and the speed; actual acceleration also depends on the characteristics of the driver. The average rate of acceleration during overtaking manoeuvre may be taken corresponding to the design speed.

Maximum overtaking acceleration at different speeds

Speed		Maximum overtaking acceleration	
V, kmph	v, m/sec	A, kmph/sec	a, m/sec
25	6.93	5.00	1.41
30	8.34	4.80	1.30
40	11.10	4.45	1.24
50	13.86	4.00	1.11
65	18.00	3.28	0.92
80	22.20	2.56	0.72
100	27.80	1.92	0.53

CRITERIA FOR SIGHT DISTANCE REQUIREMENT ON HIGHWAY

Absolute Minimum Sight Distance

Safe stopping distance, SSD for the design speed is the absolute minimum sight distance and this should be made available all along the road stretches irrespective of the category of road. If on any road stretch SSD is not available due to any reason such as obstruction to vision, immediate steps should be taken to either remove the obstruction to the sight line or install suitable regulatory signs to specifying the speed limit along the appropriate warning signs. On horizontal curves the obstruction on the inner side of the curve should be cleared to provide the required set back distance such that the absolute minimum sight distance is invariably available.

Overtaking Zones

It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance cannot be provided. In such zones where overtaking or passing is not safe or is not possible, sign posts should be installed indicating **No Passing or Overtaking Prohibited** before such restricted zones start. However overtaking opportunity for vehicles moving at design speed should be given at as frequent intervals as possible. These zones which are meant for overtaking are called **Overtaking Zones**.

The width of carriageway and the length of overtaking zone should sufficient for safe overtaking. Sign posts should be installed at sufficient distance in advance to indicate the start of the overtaking zones, this distance may be equal to

- **(d1 + d2) for one-way roads**
- **(d1 + d2 + d3) for two-way roads**

The minimum length of overtaking zone = 3 (OSD)

The desirable length of overtaking zones = 5 (OSD)

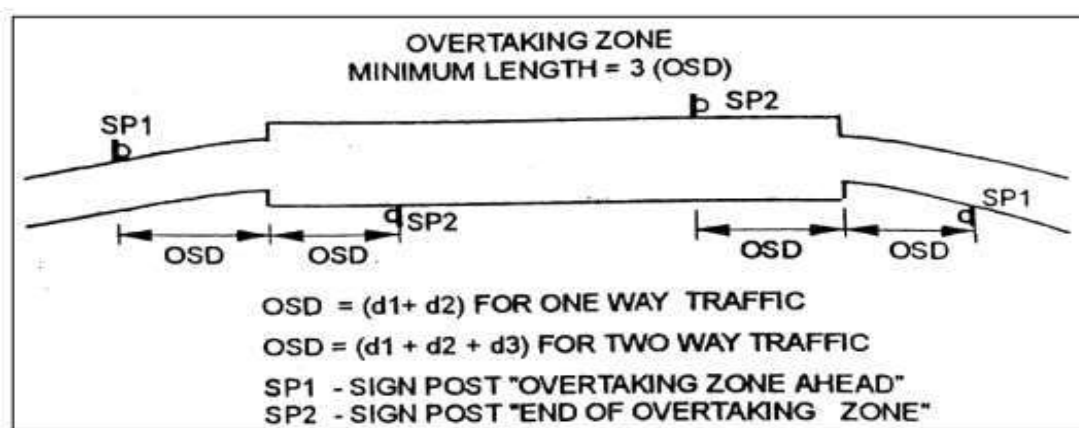
Sight Distance at Uncontrolled Intersections

It is important that on all approaches of intersecting roads, there is a clear view across the corners from a sufficient distance so as to avoid collision of vehicles. The design of sight distance at intersection may be based on three conditions Enabling the approaching vehicle to change speed

Intermediate Sight Distance

At stretches of the road where requires OSD cannot be provided, as far as possible intermediate Sight Distance **ISD** equal to twice **SSD** may be provided. The measurement of the **ISD** may be made assuming both the height of the eye level of the driver and the object to be 1.2 metres above the road surface.

Therefore **ISD = 2 SSD**



DESIGN OF HORIZONTAL ALIGNMENT

General

Often changes in the direction are necessitated in highway alignment due to various reasons such as topographic considerations, obligatory points. The geometric design elements pertaining to horizontal alignment of highway should consider safe and comfortable movement of vehicles at the designated design speed of the highway. It is therefore necessary to avoid sudden changes in direction with sharp curves or reverse curves which could not be safely and conveniently negotiated by the vehicles at design speed. Improper design of horizontal alignment of roads would necessitate speed changes resulting in higher accident rate and increase in vehicle operation cost.

Various design elements to be considered in the horizontal alignment are design speed radius of circular curve, type and length of transition curves, super elevation, widening of pavement on curves and required set-back distance for fulfilling sight distance requirements.

Design Speed

The design speed is the main factor on which geometric design elements depends. In other words, the geometric details of a highway mainly depend on the design speed. All the important geometric elements such as sight distances, radius of horizontal curve, length of horizontal transition curve, rate of super elevation, extra widening of pavement at horizontal curve, length of summit and valley curves are dependent on the design speed.

The design speed of roads depends upon

- 1) Class of the Road
- 2) Terrain

The speed standards of a particular class of road thus depends on the classification of terrain through which it passes. The terrains have been classified as plain, mountainous and steep, depending on the cross slope of the country as given in table below

Terrain classification	Cross slope of the country, percent
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	greater than 60

Two values of design speeds are considered at the design stage of highway geometries namely,

- 1) Ruling design speed
- 2) Minimum design speed

As a general rule, attempt should be made to design all the geometric element of the highway for the 'ruling design speed'. This is because ruling design speeds are guiding criteria for the geometric design. However, 'minimum design speed' may be accepted where site conditions or economic considerations warrant.

The ruling design speeds suggested for the National and State Highways in India passing through plain terrain is 100 kmph and through rolling terrain is 80kmph and minimum design speed values standardized by the IRC for of roads on different terrains in rural (non-urban) areas are given in Table below

Road Classification	Design Speed in kmph							
	Plain		Rolling		Mountainous		Steep	
	Ruling	Min.	Ruling	Min.	Ruling	Min.	Ruling	Min.
Expressway	120	100	100	80	80	60	80	60
NH and SH	100	80	80	65	50	40	40	30
MDR	80	65	65	50	40	30	30	20
ODR	65	50	50	40	30	25	25	20
VR	50	40	40	35	25	20	25	20

The recommended design speeds for different classes of urban roads

- 1) Arterial Roads: 80 Kmph
- 2) Sub-Arterial Roads: 60 Kmph
- 3) Collector Streets: 50 Kmph
- 4) Local Streets: 30 Kmp

SUPERELEVATION

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as **SUPER ELEVATION or CANT or BANKING.**

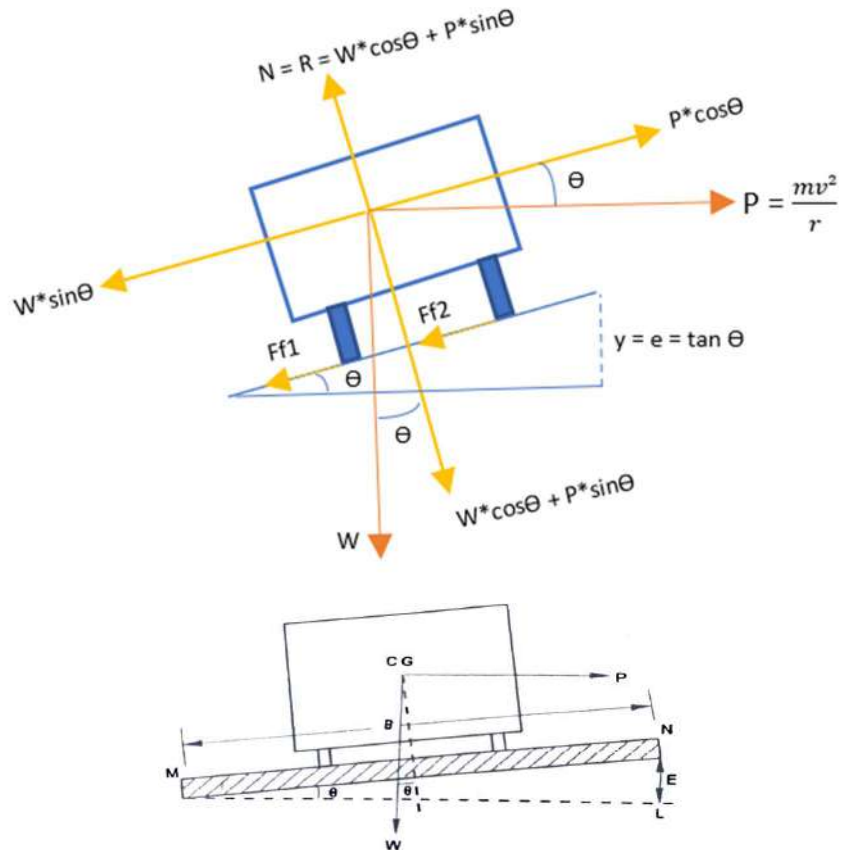


Fig. Super-elevated pavement section

The rate of super elevation, 'e' is expressed as the ratio of the height of outer edge with respect to the horizontal width.

$$e = \tan \theta = \sin \theta = \frac{NL}{ML} = \frac{E}{B}$$

E – Relative elevation of the outer edge

B – Width of the pavement

The general equation for design of super elevation is given by

$$e + f = \frac{v^2}{gR}$$

e = rate of super elevation = $\tan \theta$

f = design value of lateral friction coefficient = 0.15

v = speed of the vehicle, m/sec

R = radius of the horizontal curve, m

g = acceleration due to gravity = 9.8 m/sec²

If the speed of the vehicle is given in kmph then the equation is

$$e + f = \frac{(0.278 V)^2}{9.81R} = \frac{V^2}{127R}$$

The maximum value of super elevation is limited to 7% or 0.07 and the minimum value of lateral friction of coefficient f for highway is 0.15

In some situations, particularly at, some intersections it is not possible to provide super elevation and in such cases the friction counteracts the centrifugal force fully. The allowable speed of vehicle negotiating a turn should be restricted to the condition

$$V = \sqrt{127fR}$$

The super elevation depends upon

- 1) Radius of the curve R,
- 2) Speed of the vehicle V
- 3) The coefficient of lateral friction f

Steps for Super Elevation Design

The steps for the design of super elevation in India from practical considerations (as per the IRC Guidelines) are given below:

- 1) The super elevation is calculated for 75% of design speed (0.75 v m/sec or 0.75 V kmph), neglecting the friction

$$e = \frac{(0.75 V)^2}{gR} = \frac{(0.75 V)^2}{127R}$$

$$e \approx \frac{(0.75 V)^2}{gR}$$

- 2) If the calculated value of 'e' is less than 7% or 0.07 the value so obtained provided. If the value of 'e' as per the above equation exceeds 0.07 then provide the maximum super elevation equal to 0.07 and proceed with steps 3 or 4
- 3) Check the coefficient of friction developed for the maximum value e = 0.07 at the full value of design speed, v m/sec or V kmph

$$f = \left(\frac{v^2}{gR} - 0.07 \right) \text{ or } \left(\frac{V^2}{127R} - 0.07 \right)$$

If the value of f thus calculated is less than 0.15, the super elevation of 0.07 is safe for the design speed and this is accepted as the design super elevation. If not, either the radius of the horizontal curve has to be increased or the speed has to be restricted to the safe value which will be less than the design speed. The restricted speed or the allowable speed is calculated as given in step 4

- 4) The allowable speed or restricted speed (v_a m/sec or V_a kmph) at the $cm1$ ' is calculated by considering the design coefficient of lateral friction and the maximum super elevation. The safe allowable speed

$$V_a = \sqrt{0.22gR} = \sqrt{2.156R} \text{ m/s or } \sqrt{27.94R} \text{ kmph}$$

If the allowable speed, as calculated above is higher than the design speed design, then the design is adequate and provide a super elevation of 'e' equal to 0.07. If the allowable speed is less than the design speed, the speed is limited to the allowable V_a kmph calculated above. If the allowable speed V_a is less than the design speed V , appropriate warning signs and speed limit signs are to be installed.

Attainment of Super elevation in the field

Introduction of super elevation on a horizontal curve in the field is an important feature in construction. The road cross section at the straight portion is cambered with the crown at the center of the pavement and sloping down towards both the edges. But the cross section on the portion of circular curve of the road is super elevated with a uniform tilt sloping down from the outer edge of the pavement up to inner edge.

Thus, the crowned camber sections at the straight before the start of the transition curve should be changed to a single cross slope equal to the desired superelevation at the beginning of the circular curve. This change may be conveniently attained at a gradual and uniform rate through the length of horizontal transition curve. The full superelevation is attained by the end of transition curve or at the beginning of the circular curve.

The attainment of superelevation may be split up into two parts:

- (a) Elimination of crown of the cambered section
- (b) Rotation of pavement to attain full superelevation

EXTRA WIDENING OF PAVEMENT ON HORIZONTAL CURVES

Objectives

- 1) An automobile such as car, bus or truck has a rigid wheel base and only the front wheels can be turned.

When the vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of the front wheels. This phenomenon is called 'off tracking'. Normally at low speeds and up to the design speed when no lateral slipping of rear wheels take place, the rear wheels 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 shoulder. The off-tracking depends on

 - a) The length of the wheel base of the vehicle
 - b) The turning angle or the radius of the horizontal curve negotiated
- 2) At speeds, higher than the design speeds when the superelevation and lateral friction developed are not fully able to counteract the outwards thrust due to the centrifugal force, some transverse skidding may occur and the rear wheels may take paths on the outside of those traced by the front wheels on the horizontal curves. However, this occurs only at excessively high speeds
- 3) The path traced by the wheels of a trailer in the case of trailer units, is also likely to be on either side of the central path of the towing vehicle, depending on the speed, rigidity of the universal joints and pavement roughness
- 4) In order to take curved 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 beginning of a curve
- 5) While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain a greater clearance between the vehicles, than on straights for increase safety

Thus, the required extra widening of the pavement at the horizontal curves, We depends on

- a) The Length of wheel based of the vehicle l ,
- b) Radius of the curve negotiated R
- c) The psychological factor which is a function of the speed of the vehicle 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 Horizontal Curves

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

1. Mechanical Widening
2. Psychological Widening

Mechanical Widening

The widening required to account for the off-tracking due to rigidity of wheel base is called as ‘ MechanicalWidening’ (W_m) and is given by

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

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.

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

Hence Total Widening W_e is given by $W_e = W_m + W_{ps}$

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

R – Radius of the curve

n – No of lanes

l – length of wheel base of longest vehicle, m

Radius of Curve, m	Up to 20	20 to 40	41 to 60	61 to 100	101 to 300	Above 300
Extra width on two-lane pavement, m	1.5	1.5	1.2	0.9	0.6	Nil
Extra width on single lane pavement, m	0.9	0.6	0.6	Nil	Nil	Nil

Note: For multi lane roads, the pavement widening is calculated by adding half extra width of two lane roads to each lane of the multi lane road.

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)

Thus, the functions of transition curve in the horizontal alignment are given below:

- 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.
- To enable the driver, turn the steering gradually for his own comfort and safety
- To enable gradual introduction of the designed super elevation and extra widening of pavement at the start of the circular curve.
- To improve the aesthetic appearance of the road

Type of transition curve

Different types of transition curves are

- a) Spiral or Clothoid
- b) Cubic Parabola
- c) Lemniscates

IRC recommends spiral as the transition curve because:

- 1) It full fills the requirement of an ideal transition, as the rate of change of centrifugal acceleration is uniform throughout the length.
- 2) The geometric property of spiral is such that the calculation and setting out the curve in the field is simple and 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) An Empirical Formula Given by IRC

1. Rate of Change of Centrifugal Acceleration

At the tangent point, radius is infinity and hence centrifugal acceleration (v^2/R) is zero, as the radius is infinity. At the end of the transition, the radius R has minimum value R_m . Hence the rate of change of centrifugal acceleration is distributed over a length L_s

Let the length of transition curve be L_s m. If 't' is the time taken in seconds to traverse this transition length at uniform design speed of v m/sec, $t = L_s/v$. The maximum centrifugal acceleration of v^2/R is

introduced in time t through the transition length L_s and hence the rate of centrifugal acceleration C is given by

$$C = \frac{v^2}{Rt} = \frac{\frac{v^2}{RL_s}}{v} = \frac{v^3}{L_s R}$$

The IRC has recommended the following equation

$$C = \frac{80}{(75 + V)}$$

The minimum and maximum value of C are limited to 0.5 and 0.8

The length of the transition curve L_s is given by

$$L_s = \frac{v^3}{CR}$$

Transition Curves

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$$C = \frac{v^2}{Rt} = \frac{\frac{v^2}{RL_s}}{v} = \frac{v^3}{L_s R}$$

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$$C = \frac{80}{(75 + V)}$$

The minimum and maximum value of C are limited to 0.5 and 0.8

The length of the transition curve L_s is given by

$$L_s = \frac{v^3}{CR}$$

If the design speed is given in kmph

$$L_s = \frac{V^3}{46.5 CR}$$

C - rate of change of centrifugal acceleration, m/sec³

Ls – length of transition curve

R – radius of the circular curve, m

Rate of introduction of super-elevation

Raise (E) of the outer edge with respect to inner edge is given by

$$E = eB = e(W + W_e)$$

If it is assumed that the pavement is rotated about the centre line after neutralizing the camber, then the max amount by which the outer edge is to be raised at the circular curve with respect to the centre = E/2. Hence 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 Ls is given by

$$L_s = \frac{EN}{2} = \frac{eN}{2} (W + W_e)$$

However, if the pavement is rotated about the inner edge, the length of transition curve is given by

$$L_s = EN = eN (W + W_e)$$

By Empirical Formula

According to IRC standards the length of horizontal transition curve Ls should not be less than the value given by the following formulas for two terrain classification

a) For plain and rolling terrain

$$L_s = \frac{2.7 V^2}{2}$$

b) For mountainous and steep terrain

$$L_s = \frac{V^2}{2}$$

Setting out Transition Curve

Transition curves are introduced between the tangent points of the straight stretches and the end of the circular curve on both sides. If the length of transition curve is L_s and the radius of the circular curve is R , the shift S of the transition curve is given by the formula

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

Setback Distance on Horizontal Curves

Setback distance m or the clearance distance is the distance required from the centreline 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:

- a) Required Sight Distance, S
- b) Radius of Horizontal Curve, R
- c) Length of the curve, L_c which may be greater or lesser than S

a) When $L_c > S$

When the length of curve L_c is greater than the sight distance S , let the angle subtended by the arc length S at the curve be α . On narrow roads such as single lane roads, the sight distance is measured along the centre line of the road and the angle subtended at the centre, α is equal to S/R radians. Therefore, half central angle is given by

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

The setback distance m , required from the centre line on narrow road is given by

$$m = R - R \cos \frac{\alpha}{2}$$

In case of wide roads with 2 or more lanes, if d is the distance between the centre line of the road and the centre line of the inside lane in meters, the sight distance is measured along the middle of the inner side lanes and the setback distance m' is given by

$$m' = R - (R - d) \cos \frac{\alpha'}{2}$$

Where

$$\frac{\alpha'}{2} = \frac{180 S}{2 \pi (R - d)} \text{ degrees}$$

b) When $L_c < S$

If the length of the curve L_c is less than the required sight distance S , then the angle α subtended at the center is determined with reference to the length of circular curve L_c and the setback distance m' is worked out in 2 parts

$$\frac{\alpha'}{2} = \frac{180 L_c}{2 \pi(R - d)} \text{ degrees}$$

The setback distance is given by

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

Curve Resistance

When the vehicle negotiates a horizontal curve, the direction of rotation of the front and the rear wheels are different. The front wheels are turned to move the vehicle along the curve, whereas the rear wheels seldom turn. The rear wheels exert a tractive force T in the PQ direction. The tractive force available on the front wheels is $T \cos \theta$ in the PS direction. 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:

$$CR = T - T \cos \alpha = T (1 - \cos \alpha)$$

Vertical Curves

Due to changes in grade in the vertical alignment of highway, it is necessary to introduce vertical curve at the intersections of different grades to smoothen out the vertical profile and thus ease off the changes in gradients for the fast moving vehicles. **The vertical curves used in highway may be classified into two categories:**

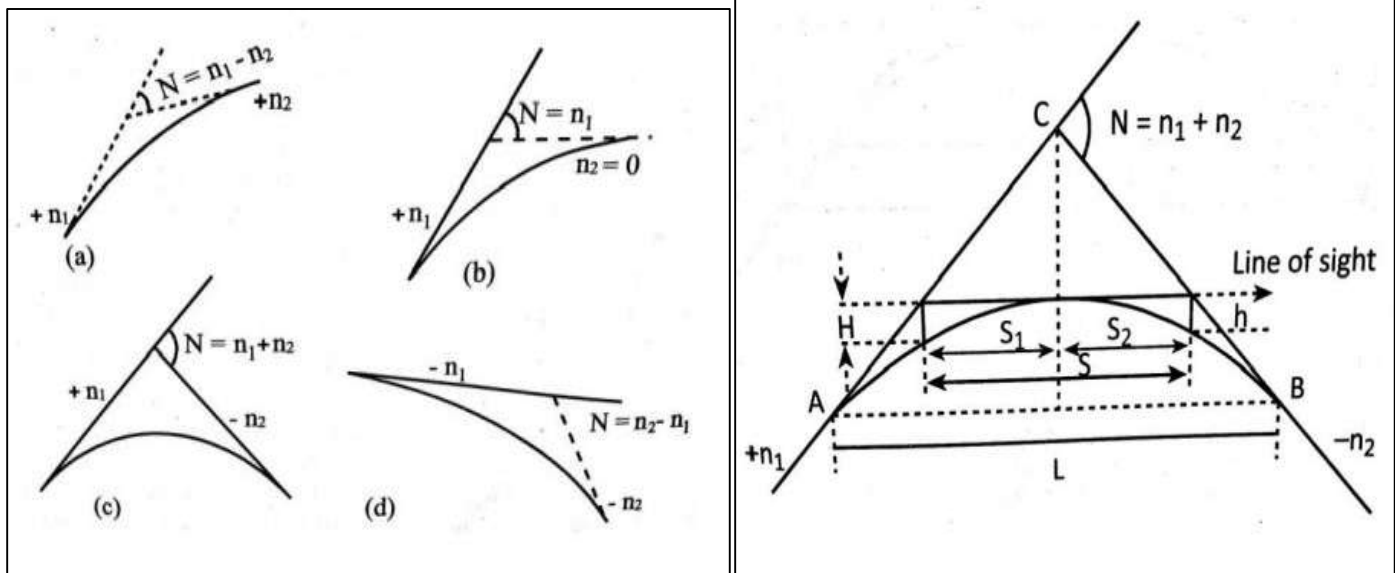
(a) Summit curves or crest curves with convexity upwards

(b) Valley curves or sag curves with concavity upwards

Summit curves

Summit curves with convexity upwards are formed in any one of the cases as given below

- When a positive gradient meets another positive gradient
- When positive gradient meets a at gradient
- When an ascending gradient meets a descending gradient.
- When a descending gradient meets another descending gradien



DESIGN CONSIDERATION :

- In determining the type and length of the vertical curve, the design considerations are comfort and security of the driver, and the appearance of the profile alignment.
- Among these, sight distance requirements for the safety is most important on summitcurves.

- The stopping sight distance or absolute minimum sight distance should be provided on these curves and where overtaking is not prohibited, overtaking sight distance or intermediate sight distance should be provided as far as possible.
- When a fast moving vehicle travels along a summit curve, there is less discomfort to the passengers.
- This is because the centrifugal force will be acting upwards while the vehicle negotiates a summit curve which is against the gravity and hence a part of the tyre pressure is relieved.

DESIGN CONSIDERATION FOR LENGTH OF THE SUMMIT CURVE:

- If the curve is provided with adequate sight distance, the length would be sufficient to ease the shock due to change in gradient. Circular summit curves are identical since the radius remains same throughout and hence the sight distance.
- From this point of view, transition curves are not desirable since it has varying radius and so the sight distance will also vary.
- The deviation angle provided on summit curves for highways are very large, and so the a simple parabola is almost congruent to a circular arc, between the same tangent points.
- Parabolic curves is easy for computation and also it had been found out that it provides good riding comfort to the drivers.
- It is also easy for field implementation.
- Due to all these reasons, a simple parabolic curve is preferred as summit curve.

LENGTH OF THE SUMMIT CURVE

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration

Length of the summit curve for SSD

a) When L > SSD

The equation for length L of the parabolic curve is given by

$$L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

Here

L – length of summit curve, m

S – SSD, m

N – Deviation angle, equal to algebraic difference in grades, radians, or tangent of deviation angle

H - Height of eye level of driver above road surface, m = 1.2m

h – Height of subject above the pavement surface, m = 0.15m

As per IRC

$$L = \frac{NS^2}{4.4}$$

b) When $L < SSD$

The equation for length L of the parabolic curve is given by

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

As per IRC

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

The minimum radius of parabolic summit curve is given by R/N

Length of the summit curve for OSD or ISD

a) When $L > OSD$ or ISD

The equation for length L of the parabolic curve is given by

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

As per IRC

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

S – OSD or ISD, m

b) When $L < OSD$ or ISD

The equation for length L of the parabolic curve is given by

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

As per IRC

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

Valley curve

Valley curve or sag curves are vertical curves with convexity downwards. The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them. Among all the cases, the deviation angle will be maximum when a descending gradient, $(-n_1)$ meets with an ascending gradient, $(+n_2)$.

Therefore, deviation angle, $N = -n_1 - (+n_2) = -(n_1 + n_2)$

They are formed when two gradients meet as illustrated in figure below in any of the following four ways:

- 1) When a descending gradient meets another descending gradient
- 2) When a descending gradient meets a at gradient
- 3) When a descending gradient meets an ascending gradient
- 4) When an ascending gradient meets another ascending gradient

Length of the valley curve

The length of the valley transition curve is designed to fulfil two criteria

- a) Allowable rate change of centrifugal acceleration
- b) The required HSD for night driving