MODULE- I

INTRODUCTION

Basic Definition: The latin word transporate means carry across. A facility consisting of the means and equipment necessary for the movement of passengers or goods. At its most basic, the term “transportation system” is used to refer to the equipment and logistics of transporting passengers and goods. It covers movement by all forms of transport, from cars and buses to boats, aircraft and even space travel. Transportation systems are employed in troop movement logistics and planning, as well as in running the local school bus service.

Transportation engineering: Transportation engineering is the application of technology and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods. and : It is the phase of transportation engineering that deals with the planning, geometric design and traffic operations of roads, streets and highways, their networks, terminals, abutting lands, and relationships with other modes of transportation.

Transportation covers three elements

- Vehicle in which people and goods are transported
- Paths over which vehicle moves.
- Terminals where people and goods are received and dispatched.

Traffic Engineering: Traffic engineering is that branch of engineering which deals with planning and geometric design of streets, highway, abutting lands, and operating traffic systems to achieve safe, economical, convenient and efficient movement of persons and goods.

ROLE OF TRANSPORTATION IN NATIONAL DEVELOPMENT:

Transportation contributes to the economic, industrial, social and cultural development of any country. It is the vital for the economic development of any region since every commodity produced whether it is food, polythene, industrial products or medicine needs transport at all stages from production to distribution. In the production stage transportation is region for carrying raw material. In the distribution stage transportation is required from the production center to the consumer.

1. Economic development - links places of production and consumption
2. Social development – Education, health etc.
3. Spatial development – Induces area development

4. Cultural development – Cultivates civilization, urbanization, education, and enlightment
5. Political – Strengthens national defence

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 three major modes of transportation are:

- Land
    1. Roadways/Highways
    2. Railways
- Air way
- Water
    1. Shipping
    2. Inland waterway

The minor mode of transportation

- Pipeline
- Ropeways
- Elevator

Roadways: The transportation by road is the only mode which could give maximum service to one and all. Road transport carries 80 % of the passenger and 60 % of good movement. The road or highways not only include the modern highway system but also the city streets, feeder roads and village roads, catering for a wide-range of road vehicles and the pedestrians. This mode has also maximum flexibility for travel with reference to route, direction, time and speed of travel etc. through any mode of road vehicle. It is possible to provide door to door service by road transport. The other three modes (railways; water ways; airways) has to depend on the roadway for the service.

Ultimately, road network is therefore needed not only to serve as feeder system for other modes of transportation and to supplement them, but also to provide independent facility for road travel by a well-planned network of roads throughout

Railways: The transportation along the railway track could be advantageous by railways between the stations both for the passengers and goods, particularly for longer distances. The energy requirement to haul unit load through unit distance by the railway is only a fraction (one fourth to one sixth) of the required by road. Hence, full advantage of this mode of transportation should be taken for the transportation of bulk goods along land where the railway facilities are available.

Airways: The transportation by air is the fastest among the four modes. Air also provides more comfort apart from saving in transportation time for the passengers and the goods between the airports.

Waterways: Transportation by water is the slowest among the three modes. This mode needs minimum energy to haul load through unit distance.

The transportation by water is possible between the ports on the sea routes or along the rivers or canals where inland transportation facilities are available.

Shipping: Most international trade in goods takes place through overseas shipping.

Inland water transport(IWT): This mode takes place inside a country along the perennial river. Here both passenger and goods are moved.

Pipelines: Pipelines are laid for long distance transport of petroleum product and gas.

Ropeways: Ropeway having application in extremely difficult hilly location both for goods and passenger movement.

CHARACTERISTICS AND COMPARISON OF DIFFERENT MODES

It is accepted that the fact road transport is the nearest to the people. The passengers and goods have to be first transported by road before reaching a railway station or an airport. It is seen that road network alone could serve the remotest villages of the vast country like occurs. The various characteristics (advantages) and disadvantages of different mode of transport are briefly listed here:

Sl No.	Mode	Advantage	Disadvantage
1	Roads	1. Accessible to remote parts. 2. Flexibility to deal with changes in demand. 3. Provides personal transport 4. Generates high employment 5. Reasonable good speed (upto 120km/h) 6. Cheap and good mode	1. Very poor safety record. About 90,000 people get killed every year in India 2. High environmental pollution(air quality, noise etc.) 3. High consumption of fuel particularly liquid petroleum products.
2	Railways	1. Good safety record. 2. Good emergency efficiency 3. Non polluting 4. Good comfort 5. Reasonable good speed 6. Cheap mode 7. Can run on electricity	1. Cannot reach remote parts. 2. Lacks flexibility to deal with change in demand 3. There is government monopoly leading take efficiency.
3	Air ways	1. Very high speed (1000km/h) 2. Very good comfort 3. Good record of safety 4. Low pollution	1. High energy consumption and solely depend on petroleum products 2. Very costly
4	Shipping	1. Good energy efficiency 2. Non polluting 3. Good safety & comfort	1. Low speed particularly for international passanger travel.
5	Inland water transport	1. Non-polluting 2. Good energy efficiency 3. Good employment generation 4. Cheap	5. Slow speed of travel 6. Can operate only on perennial rivers and channels.
6	Pipelines	1. Non-polluting 2. Good safety 3. Cheap 4. Good energy efficiency	1. Can handle only liquids and gas

Importance of roads in India:

No planned development of roads in first 20 year road plan. An 5 year plan 1951 the development of work speed up.

- The road development in India started receiving its marginal initiation 1943 by Nagpur road plan.
- Then the total road length increases by 4 lakhs kilometer in year 1951 to about increases 33 lakh km by 2001. But now it is increases 42 lakhs km.
- Paved surfaced now not in good condition can contribute (15 to 40 % saving in vehicle operation cost).
- Only 35 to 40 % of total revenue of road transport section has been inverted on road maintenance work.

History of Road construction:-

It is directly linked with the history and development of human civilization. Slaves were used as labourers in some ancient civilization. Pyramids of Egypt (300 BC) were possible due to availability of good roads for transporting materials.

The existence of highways called MAHAPATHAS are mentioned in Rigveda (5000BC).

Indians knew the science of well drained and properly aligned construction from early 3500 BC.

The early development oldest mode of travel was foot track.

- Then animals are then used to travel from one place to another place
- Then in roman era road construction was done in a large scale by roman road technique.

Important facts about Ancient Historical roads

- Roads were provided with trees(Because to protect the road from being washed away by flood) as border line in around 1900 BC.
- At the time of Mughals roads were been constructed which connects Delhi to Daulatabad.
- Babar (1500 AD) made the Grand trunk road which connects the North India to North West India.
- Sher Shah Suri (1540-1545 AD) constructed the longest road from Lahore to West Bengal.
- In British period roads were built by British militaryengineers.

- Lord Dalhousie (1855)was responsible for the opening of the first railways and setting of the PWDS.
- IRTDA (Indian Road and Transport Development Association) came to existence in 1927. It was made to study the transport problems of the country.

1. Roman Road:-

A. First time Roman started construction of roads in large scale.
B. In 312 BC, they constructed “Appian way” of length over 580 km.

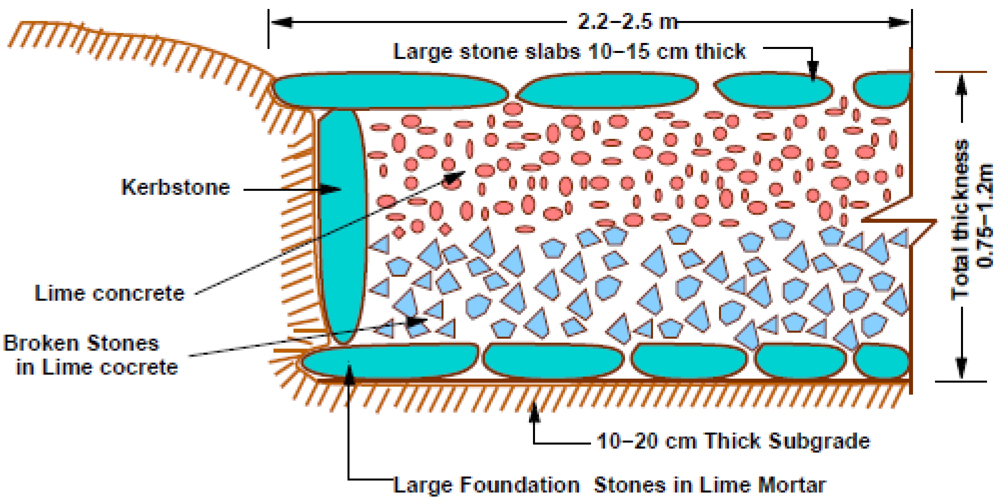
Layer of Roman roads –

1. Large foundation stones in lime mortar (10 to 20 cm thick)
2. Broken stones in Lime mortar (25 to 40 cm thick)
3. Lime concrete (25 to 40 cm thick)
4. Large stone slabs in lime mortar (10 to 15 cm thick)

Total thickness – 0.75 to 1.2 m

Main features of Roman Roads –

i. They were built straight regardless of gradient
ii. Total thickness was as high as 0.75 to 1.2 m.
iii. The wearing course consisted of large dressed stone blocks in lime mortar.



2. Tresaguet construction:

Pierre Tresaguet (1716-1796) developed an improved method of construction in France by the year 1964.The main feature of his proposal was that the thickness of construction need be only in the order of 30 cm.

Tresaguet was the inspector General of roads in France from 1775 to 1785.So his method of construction was implemented in that country in 1775.

Layers of Treasaguet construction-

a. Large foundation stone on edge (17 cm thick)
b. Broken stones (8 cm thick)
c. Sloping wearing surface (5 cm thick and slope 1 in 45)

Total thickness = 30 cm

Main features of Tresaguet construction-

i) The thickness was of the order of 30 cm

ii) Consideration was given to subgrade moisture and drainage of surface water.

iii) Shoulder sloping was provided of order of 1 in 20.

The typical cross section of tresaguets road construction is given in fig. and the construction steps may be enumerated as below.

i) The sub grade was prepared and layers of large foundation stones were laid on edge by hand. At the two edges of the pavement large stones were embedded edge wise to serve as submerged kerbs stones.

ii) The corners of the heavy foundation stones were hammered and then the interstices filled with smaller stones.

iii) The top-wearing course was made of smaller stones and compacted to a thickness of about 5 cm at the edges and gradually increased towards the center.

iv) The shoulders were also provides cross slope to drain the surface water to the side drain.

3. Metcalf Construction:-

i) John Metcallf was working in England during the period of “Tresguet”.

ii) He followed the recommendation of “Robert Phillips” and was responsible for construction of about 290 km of road in the northern region of England.

4. Telford Construction:-

“Thomas Telford” founder of Institution of civil engineering at London, began his work in early 19th century

Layers of Telford Construction-

i) Foundation stones of varying size (17 to 22 cm)

ii) Broken stone in Lime mortar at the edge (15 cm thick)

iii) Plus two layers of angular broken stone (7 cm size and 10 cm & 5 cm thickness)

iv) Binding layer of wearing course 4 cm thick with cross slope of 1 in 45

Main features of Telford Construction

i) In this construction leveled subgrade of width 9 m was provided

ii) Wearing course slope of about 1 in 45

5. Macadam Construction:-

"John Macadam", Surveor General of roads in England, put forward an entirely new method of road construction.

- This was first method based on scientific thinking
- This new concept came in the year 1827

Construction steps:-

i) Subgrade is computed and prepared with a cross slope of 1 in 36 upto a desired width of 9 m

ii) Broken stones, all passing through 5 cm sieve size were compacted to a uniform thickness of 10 cm

iii) The 2nd layer of broken stone of size 3.75 cm was compacted to thickness of 10 cm

iv) The top layer consisted of stones of size less than 2 cm and compacted to a thickness of about 5 cm and maintaining the slope of about 1 in 36.

Main features are –

i) Importance was given to subgrade drainage and compaction so that subgrade was compacted and prepared with cross slope of 1 in 36

ii) The size of broken stones for top layers was decided on the basis of stability under animal drawn vehicles

iii) The thickness of each layer was kept uniform from edge to the center and the total thickness also kept uniform to a minimum value of 25 cm.

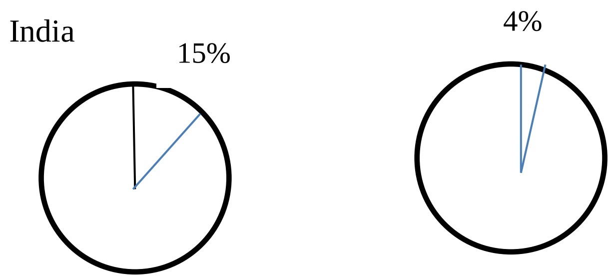
iv) The pavement surface was also given the cross slope of 1 in 36.

The two methods have been compared here:

Macadam method	**Telford method**
i) The subgrade was given a cross slope of 1 in 36 to facilitate subgrade drainage.	The subgrade was kept horizontal and hence subgrade drainage was not proper.
ii) The bottom layer of pavement or the subbase course consisted of broken stones of less than 5 cm.	Heavy foundation stones of varying sizes, about 17 cm towards the edges and 22 cm towards the centre were hand packed and prepared to serve as sub base course.
iii) Base and surface courses consisted of	Two layers of broken stones were

broken stones of smaller sizes to compacted thickness of 10 and 5 cm respectively.	compacted over the foundation stones before laying the wearing course.
iv) The total thickness of pavement construction was kept uniform from edge t centre to a minimum value of only 25cm.	The total thickness of construction varied from about 35 cm at the edge to about 41 cm at the centre.

PRINCIPLE OF HIGHWAY PLANNING



Population in world Road network

Result → Accidents and deaths

Principle Of Highway Planning

The following are the major principles should be kept in mind while planning

- The proposal road should form an integral part of the road network of country.
- The importance of a road should be determined only on the basis of traffic demand.
- The roads should be free to all.
- The roads should form a part development scheme.
- All roads should be given a due priority of maintenance over construction.
- All roads should have provision of maintenance funds on sure and sustained basis.
- All roads should have provision for traffic regulation. Example Traffic signals should be provided at major and minor junctions.

HIGHWAY DEVELOPMENTS IN INDIA

i) Ancient period (3500BC)
ii) Mughal period (15th century)
iii) British period (17th & 18th century)
iv) Free India (1950 onwards)

Jayakar Committee - 1927

Recommendations And Implementation 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 when not capable to 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.

REALISATION OF THE RECOMMENDATION OF THE JAYAKAR COMMITTEE

(i) 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.

(ii) Indian Road Congress (IRC):

(a) Background:

Indian road congress is the premier technical body of highway engineers in the country. On the recommendations of Jayakar committee, Indian road congress was set up in December 1934. As the activities of the IRC expanded; it was formally registered as a society's registration act of 1860.

Role of IRC

- The following are the major roles of the congress.
- To promote and encourage the science and practice of construction and maintenance of roads.
- To suggest improved methods of administration, planning, design, construction, operation, use and maintenance of roads.
- To promote the use of standard specifications and to propose specifications.
- To advice regarding education, experience and research connected with roads.
- To establish, furnish and maintain libraries and museums for furthering the science of road making.

The objectives are IRC highway research Board is:

a. To ascertain the nature and extent of research required.
b. To correlate research information from various organizations in India and abroad.
c. To co-ordinate and conduct correlation services.
d. To collect and disseminate results on research.
e. To channelize consultative services.

(b) Committees and sub committees:

The IRC has many Committees and sub committees under its fold.

Committee:

- Bituminous committee
- Cement concrete committee
- Road Transport Development committee
- Research organization committee

- Transport operation cost committee
- Specification standard committee

Sub Committee:

- Cement concrete road surfacing
- Education of road engineers
- Prevention of ribbon developement
- Soil research
- Stabilised soil roads
- Traffic engineering

(c) Primary functions

- Sharing of ideas and experience in matters concerned with planning, construction and maintenance of roads
- To provide a platform for expression of professional opinion on road engineering
- Formulation of 20 year road development plans in India
- Prescription of specifications and standards for urban and rural roads
- Annual meeting for convey the problems.

(d) Significant contributions of IRC:

- 20 year road development plans
- Specific classification of urban and rural roads based on location and function.
- Publications of journals, research records, guide lines and other matters on various aspects.

(iii) 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.

National highway authority of India

National highway authority of India was constituted in 1988 by an act of parliament. The responsibility of the authority is for development, maintenance and management of national highways and for matters connected to or incidental there to. The authority was operationalised in February 1995.

Role of NHAI

National highways in India have a total length of about 70500km running in every direction of the country to serve as an arterial network of the country. The national highways authority of India rest as with government of India through the national highway authority of India. It is empowered to implement the national highway development project.

ROAD DEVELOPMENT PLANS

I Plan Nagpur 1943-1963

II Plan Bombay 1961-1981

III Plan Lucknow 1981-2001

Nagpur road congress 1943

The second World War saw a rapid growth in road traffic and this led to the deterioration in the condition of roads. To discuss about improving the condition of roads, the government convened a conference of chief engineers of provinces at Nagpur in 1943. The result of the conference is famous as the Nagpur plan.

- A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a co-ordinated road development programme in a planned manner.
- The roads were divided into four classes:

- National highways which would pass through states, and places having national importance for strategic, administrative and other purposes.
- State highways which would be the other main roads of a state.
- District roads which would take traffic from the main roads to the interior of the district. According to the importance, some are considered as major district roads and the remaining as other district roads.
- Village roads which would link the villages to the road system.

The total length of the surfaced roads for NH,SH and MDR in km

Length of (NH+SH+MDR) in km = $\left[\frac{A}{8}+\frac{B}{32}+1.6N+8T\right]+D-R$

Where

A = Agricultural area, km^2

B = Non-agricultural area, km^2

N = Number of towns and villages with population range 2001-5000

T = Number of towns and villages with population over 5000

D = Development allowance of 15 percent of road length calculated for agricultural and Industrial development during the next 20 years

R = Existing length of railway track, km

The total length of the un- surfaced roads for ODR and VR in km

Length of (ODR+VR) in km = [0.32V+0.8Q+1.6P+3.2S]+D

Where

V = Number of villages with population 500 or less

Q = Number of villages with population range 501 – 1000

P = Number of villages with population range 1001 – 2000

S = Number of villages with population range 2001 – 5000

D = Development allowance of 15 percent for next 20 years

Bombay road congress 1961

The length of roads envisaged under the Nagpur plan was achieved by the end of it, but the road system was deficient in many respects. The changed economic, industrial and agricultural conditions in the country warranted a review of the Nagpur plan. Accordingly a 20-year plan was drafted by the Roads wing of Government of India, which is popularly known as the Bombay plan. The highlights of the plan were:

_ It was the second 20 year road plan (1961-1981)

_ The total road length targeted to construct was about 10 lakhs.

_ Rural roads were given specific attention. Scientific methods of construction was proposed for the rural roads. The necessary technical advice to the Panchayaths should be given by State PWD's.

_ They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km

_ The construction of 1600 km of expressways was also then included in the plan.

Second Twenty-Year Road Plan (1961-81): -

The Nagpur road plan was intended for the period 1943-63,but the target road length was nearly completed earlier in 1961.Hence the next long term plan for the twenty year period commencing from 1961 was initiated by the IRC and was finalized by the subcommittee and this was approved by the Chief Engineers. The Second Twenty Year Road Development plan 1961-81 is also Called Bombay Road Plan.

Salient features of the second 20-year plan (1961-81):-

- This plan is considered to be draw more scientifically in view of development needed in under-developed areas.
- Maximum distance of any place in a developed or agricultural area would be 6.4 km from a metalled road and 2.4 km from any category of roads.
- The maximum distance from any place in a semi-developed area would be 12.8 km from a mettaled road and 4.8 km from any road.
- Every town with population above 2000 in plains and above 1000 in semi-hill areas and above 500 in hilly areas should be connected by a metalled road.
- Expressways have also been considered in this plan and 1600 km of length has been included in the proposed target of national highways
- Length of railway track is considered independent of the road system and hence it is not subtracted to get the road length.
- The development factor of only 5 percent is provided for future development and unforeseen factors.

Five different formulae were framed to calculate the lengths of NH, SH, MDR, ODR, VR. These five formulae are given below:

a) National highway (km)

$$\left[\frac{A}{64}+\frac{B}{80}+\frac{C}{96}\right]+\left[32k+8M\right]+D$$

b) National Highways + State Highways (km)

$$\left[\frac{A}{20}+\frac{B}{24}+\frac{C}{32}\right]+\left[48k+24M+11.2N+1.6P\right]+D$$

c) National Highways + State Highways + Major district roads (km)

$$\left[\frac{A}{8}+\frac{B}{16}+\frac{C}{24}\right]+\left[48k+24M+11.2N+9.6P+6.4Q+2.4R\right]+D$$

d) National Highways + State Highways + Major district roads + Other District roads (km)

$$\left[\frac{3A}{16}+\frac{3B}{32}+\frac{C}{16}\right]+\left[48k+24M+11.2N+9.6P+12.8Q+4R+0.8S+0.32T\right]+D$$

e) National Highways + State Highways + Major district roads + Other District roads + Village roads

$$\left[\frac{A}{4}+\frac{B}{8}+\frac{C}{12}\right]+\left[48k+24M+11.2N+9.6P+12.8Q+5.9R+1.6S+0.64T+0.2V\right]+D$$

Where

A= Developed and agricultural areas; km^2

B = Semi-Developed area, km2

C = Undeveloped area, km2

K = Number of towns with population over 1,00,000

M = Number of towns with population range 1,00,000-50,000

N = Number of towns with population range 50,000-20,000

P = Number of towns with population range 20,000-10,000

Q = Number of towns with population range 10,000-5,000

R= Number of towns with population range 5,000-2000

S = Number of towns with population range 2,000-1,000

T = Number of towns with population range 1000-500

V = Number of towns with range below 500

D = Development allowance of 5 percent of road length calculated for further development and other unforeseen factors.

Lucknow road congress 1984

This plan has been prepared keeping in view the growth pattern envisaged in various _elds by the turn of the century. Some of the salient features of this plan are as given below:

_ This was the third 20 year road plan (1981-2001). It is also called Lucknow road plan.

_ It aimed at constructing a road length of 12 lakh kilometres by the year 1981 resulting in a road density of 82kms/100 sq.km

_ The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth five year plan periods.

_ It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.

_ One of the goals contained in the plan was that expressways should be constructed on major traffic corridors to provide speedy travel.

_ Energy conservation, environmental quality of roads and road safety measures were also given due importance in this plan.

Third Twenty-Year Road Development Plan 1981-2001: -

Policies and objectives:

The Third Twenty Year Road development Plan 1981-2001(also Known as Lucknow Road Plan) was finalized and the plan document was published by the year 1984.The major policies and objectives of this road plan are listed below:

a) The feature road development should be based on the revised classification of road system consisting of primary, secondary and tertiary road systems.

b) The road network should be developed so as to preserve the rural oriented economy and to develop small towns with all the essential facilities.

c) The overall road density in the country should be increased to 82 km per 100-sq.km areas by the year 2001.

d) The national highway network should be expanded to form square grids of 100 km sides so that no part of the country is more than 50 km away from a NH.

e) The lengths of SH and MDR required in a state or region should be decided based on both areas and number of towns with population above 5,000 in the state or region.

f) Expressways should be constructed along major traffic corridors to provide fast travel.

g) Roads should also be built in less industrialized areas to attract the growth of industries.

h) There should be improvements in environmental quality and road safety.

VISION 2021:

TYPES OF ROAD:

Basically, different types of roads can be classified into two categories namely,

- All-weather roads
- Fair-weather roads.

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.

CLASSIFICATION OF ROADS:

Roads are classified based on various aspects namely,

1) 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 unpaved roads.

2) Based on Surface pavement provided

Surface Roads: These roads are provided with a bituminous or cement concrete surfacing. **Unsurfaced Roads**: These are not provided with bituminous or cement concrete surfacing. Roads which are provided with bituminous surfacing are called as black toped roads and that of concrete are referred to as concrete roads respectively.

3) Based on Traffic Volume:

-Heavy Medim

- Light traffic roads.

4) Based on Load transported or tonnage:

- Class-I or Class-A
- Class-II orClassB.

5) Based on location and Function:

The classification of urban roads in India:

- National highways
- State highways
- Major district roads
- Other district roads
- Village roads

National highways

National highways are the main highways running through the length and breadth of India, connecting major parts, forgein highways, capital of large states and industrial and tourist centres including roads required for strategic movements for the defense of India.

It was agreed that a first step national trails should be constructed by the centre and that latter's these should be converted into roads to suit the traffic conditions. It was specified that national highways should be the frame on which the entire road communication should be based on that these highways may not necessarily be of same specification, but they must give an uninterrupted road communication through India and should connect the entire road network.

State highways

State highways are the arterial roads of a state, connecting up with the national highways of adjacent state, district headquarters and important cities within the state and serving as the main arteries for traffic to and from district roads.

These highways are considered as main arteries of commerce by roads within a state or a similar geographical unit. In some places they may be even carry heavier traffic than some of the national highways but this will not alter their designation or function. The NH and SH have some design speed and geometric design specification.

Major district roads

Major district roads are the important roads within a district serving areas of production and markets and providing them with outlet to markets and connecting those with each other or with the main highways of a district. the MDR has lower speed and geometric design specifications than NH/SH.

Other district roads

Other district roads are roads serving rural areas of production and providing them with outlet to market Centre’s taluk headquarters block development headquarters or other main roads. These are of lower design specifications then MDR.

Village roads

Village roads are road connecting villages or groups of villages with each other to the nearest road of a higher category.

It was specified that these villages roads should be in essence farm tracks, but it was desired that the prevalent practice of leaving such tracks to develop and maintain by themselves should be replaced by a plan for a designed and regulated system.

6) 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).

7) Based on Urban Roads:

-Arterial roads

- Sub-arterial roads

-Collector Streets

-Local Streets

Arterial and Sub-arterial roads are primarily for through traffic on a continuous route, but sub-arterials have a lower level of traffic mobility than the arterials.

Collector streets provide access to arterial streets and they collect and distribute traffic from and to local streets which provide access to abutting property.

ROAD PATTERNS:

There are various types of road patterns and each pattern has its own advantages and limitations. The choice of the road pattern depends upon the various factors such as:

- Locality
- Layout of the different towns, villages, industrial and production centres.
- Planning Engineer.

The various road patterns may be classified as follows:

Rectangular or block pattern: In this, entire area is divided into rectangular segments having a common central business and marketing area. This area has all the services located in the central place. This pattern is not convenient or safe from traffic operation point of view and it results into more number of accidents at intersections. Eg: Chandigarh city.

Radial or star and block pattern: In this, roads radially emerge from the central business area in all directions and between two built-up areas will be there. The main advantage in this, central place is easy accessible from all the directions. Eg: Nagpur

Radial or star and circular pattern: In this roads radiate in all the directions and also circular ring roads are provided.

Advantages: Traffic will not touch the heart of the city and it flows radially and reaches the other radial road and thereby reducing the congestion in the centre of the city. This ring road system is well suited for big cities where traffic problems are more in the heart of the city. Eg: Connaught place in New Delhi.

Radial or star and grid pattern: It is very much similar to star and the circular pattern expects the radial roads are connected by grids. In this pattern a grid is formed around the central point which is a business centre. Eg: Nagpur road plan.

Hexagonal pattern: In this entire zone of planning is divided into hexagonal zones having separate marketing zone and central services surrounded by hexagonal pattern of roads. Each hexagonal element is independent. At each corner of hexagon three roads meet.

Minimum travel pattern: In this type, city is divided into number of nodal points around a central portion by forming sectors. And each sector is divided again in such a way that from each of the nodal centre, the distance to the central place is minimum.

HIGHWAY ALIGNMENT

Alignment The position or the layout of the central line of the highway on the ground is called the alignment. Horizontal alignment includes straight and curved paths. Vertical alignment includes level and gradients. Alignment decision is important because a bad alignment will enhance the construction, maintenance and vehicle operating cost. Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside.

Disadvantages of improper alignment:-

- Increase in construction cost
- Increase in maintenance cost
- Increase in vehicle operating cost
- Increase in accident rate

Requirements of Alignment

The requirements of an ideal alignment are

The alignment between two terminal stations should be short and as far as possible be straight, but due to some practical considerations deviations may be needed.

The basic requirement of an ideal alignment between two terminal stations is that it should be:

- Short
- Easy
- Safe
- Economical

Short

The alignment should be easy to construct and maintain.

Easy

It should be easy for the operation of vehicles. So to the maximum extend easy gradients and curves should be provided.

Safe

It should be safe both from the construction and operating point of view especially at slopes, embankments, and cutting. It should have safe geometric features.

Economical

The alignment should be economical and it can be considered so only when the initial cost, maintenance cost, and operating cost is minimum.

Factors controlling alignment

The various factors which control the highway alignment in general may be listed as:

a) Obligatory points

b) Traffic

c) Geometric design

d) Economics

e) Other considerations

Obligatory points

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

(i) Point through which the alignment is to pass.

(ii) Points through which the alignment should not pass.

Points through which the alignment should pass

- Mountain pass
- Suitable location of a bridge to cross the river
- Intermediate town
- Religious places
- Very costly structures
- Lakes/ponds
- Unsuitable land

Bridge site: The Bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.

Mountain: While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills. The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.

Intermediate town: The alignment may be slightly deviated to connect an intermediate town or village nearby. These were some of the obligatory points through which the alignment should pass. Coming to the second category that is the points through which the alignment should not pass are.

Religious places: These have been protected by the law from being acquired for any purpose. Therefore, these points should be avoided while aligning.

Very costly structures: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.

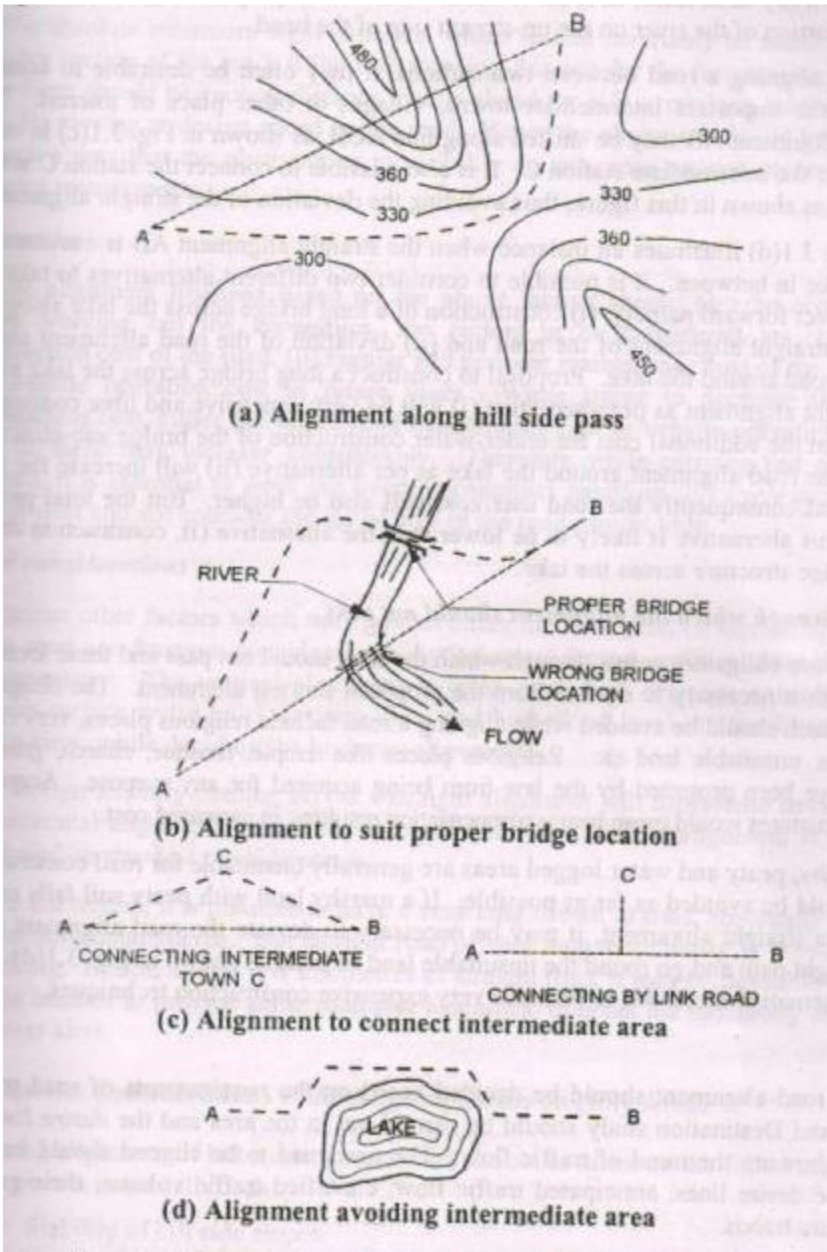


Figure: Obligatory points controlling alignment of road

Lakes/ponds etc: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.

Traffic

The alignment should suit traffic requirements .origin and destination study should be carried out in the area and the desire lane be drawn shown in the trend of traffic flow. The new road to be aligned should keep in view the desired lines, traffic flow patterns and future trends.

Geometric design

Geometric design factors such as gradient, radius of curve and sight distance also would govern the final alignment of the highway. If straight alignment is aimed at, often it may be necessary to provide very steep gradients. As far as possible while aligning a new road, the gradient should be flat and less than the ruling or design gradient.

Thus it may be necessary to change the alignment in view of the design speed, maximum allowable super elevation and coefficient of lateral friction. It may be necessary to make adjustment in the horizontal alignment of roads keeping in view the minimum radius of curve and the transition curves.

Economics

The alignment finalized based on the above factors should also be economical. In working out the economics, the initial cost the cost of maintenance and vehicle operation should be taken into account. The initial cost of construction can be decreased if high embankments and deep cuttings are avoided and alignment is chosen in a manner to balance the cutting and filling.

Other consideration

Various other factors which may govern the alignment are drainage considerations, hydrological factors, political considerations and monotomy. The vertical alignment is often guided by drainage considerations. The subsurface water level, seepage flow and high flood level are the factors to be kept in view.

Special considerations while aligning Roads on Hilly area:-

Special care should be taken on the following points

a) Stability of hill side slopes

b) Drainage of surface &subsurface water on hill

c) Geometric Standards for hill roads

d) Resisting Length

Stability

•A common problem in hilly roads is land sliding

•The cutting and filling of the earth to construct the roads on hilly sides causes steepening of existing slope and affect its stability.

Drainage

•Avoid the cross drainage structure

•The number of cross drainage structure should be minimum.

Geometric standard of hilly road

•Gradient, curve and speed

•Sight distance, radius of curve

Resisting length

•The total work to be done to move the loads along the route taking horizontal length, the actual difference in level between two stations and the sum of the ineffective rise and fall in excess of floating gradient should kept as low as possible.

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

Before a highway alignment is finalized in highway project, the engineering survey are to be carried out. The various stages of the engineering surveys are:

a) Map study.

b) Reconnaissance.

c) Preliminary surveys.

d) Final location and detailed surveys.

Drawings and report required for a highway:-

(i) KEY MAP: It will show existing road network and important places to be connected.

(ii) Index Map: It will give the general topography of the area and the details are symbolically represent.

(iii) Preliminary survey plan

(iv) Detailed plan & Longitudinal section

(v) Detailed cross section

(vi) Land acquisition plan

(vii) Drawings of cross drainage and other retaining structures.

(viii) Drawings of road intersection

(ix) Land plans showing quarries

Steps in a New highway project:-

i) Map study
ii) Reconnaissance survey
iii) Preliminary survey
iv) Location of final alignment
v) Detailed survey
vi) Material survey
vii) Design
viii) Earthwork
ix) Pavement construction
x) Construction controls

Planning Survey:

There are 4 planning survey are there

1. Economic studies
2. Financial studies
3. Traffic or road use studies
4. Engineering studies

ECONOMIC STUDIES:

It includes the desirable to find service given by each road system to the population & the product of the area.

- The details to be collected during economic studies are population, distribution each village, town, other locality each area classified in group.
- The trend, population growth
- Agricultural & Industrial product in different area
- Agricultural & Industrial development on future trends.
- For capital Income

FINANCIAL STUDIES:

The financial includes the source of income, estimated revenue and for taxation on road transport, the living standards.

TRAFFIC OR ROAD USE STUDIES:

The points are traffic volumes in vehicle per day

- Annual average daily traffic
- Peak & design hourly traffic volume
- Origin & destination of survey
- Traffic flow pattern
- Accident causes & higher cost analysis
- Growth of passenger trip

ENGINEERING STUDIES:

Topographic Survey

That includes gathering the survey that about natural & manmade features of land & elevation.

Soil Survey

- Location & classification of existing road
- Special problem related to drainage, construction & maintenance of the road

SURVEY FOR HIGHWAY LOCATION:

Map study: -

With the help of topographic map, it is possible to suggest the likely routes of the roads. In India, topographic maps are available from the survey of India with 15m or 30m contour interval. The main features like rivers, hills, valleys, etc. are also shown on these maps.

The main feature like rivers, hills, and valleys etc. The probable alignment can be located on the map from the following details available on the map.

- Alignment avoiding valleys, ponds or lakes
- When the road has to cross a row of hills, possibility crossing through a mountain pass.
- Approximate location of bridge site for crossing rivers, avoiding bend of the river.
- When a road is to be connected between two stations one of the top and the other on the foot of the hill then alternate routes can be suggested keeping in view the permissible alignment.
- Suppose the scale of the contour map is known, and then the contour intervals it is possible to decide the length of road required between two consecutive contours keeping the gradient within allowable limits.
- In the figure Let A and B be two stations to be connected by road. AB is the shortest route (Straight line) APQB is a steep route in which the gradient positively exceeds 1 in 20 as the distance between the contour intervals is only about 200 meter.

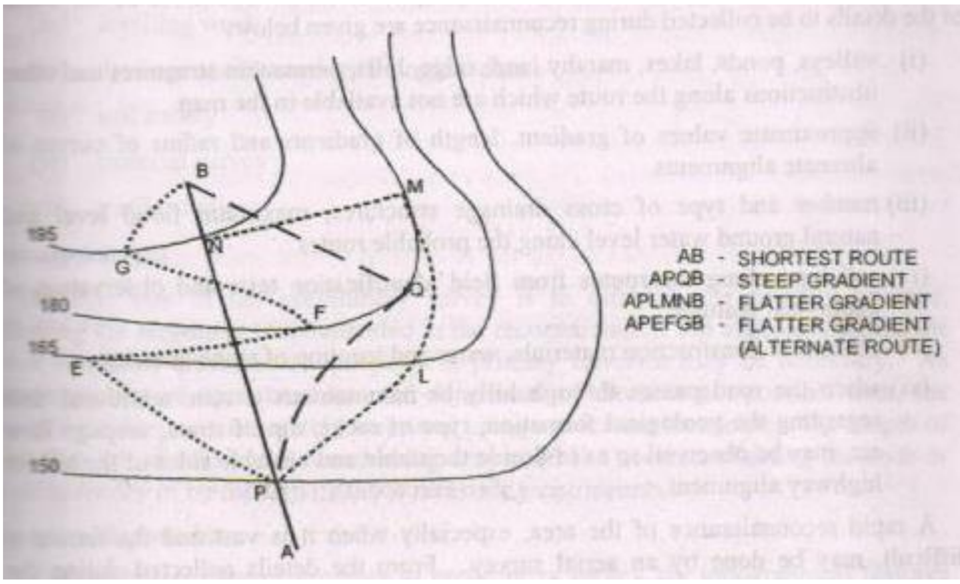


Figure: Alignment with allowable gradients

- APLMNB is a route with an approximate slope of 1 in 20 whereas APEFGB is an alternate alignment with the same gradient.
- Thus the map study also is possible to drop a certain route in view of any unavoidable obstructions (or) undesirable ground reroute.

Reconnaissance:-

The second stage of surveys for highway location is the reconnaissance to examine the general character of the area for deciding the most feasible routes for detailed studies.

It is a rapid and rough survey. During the survey, the physical characteristics of the areal are inspected and the proposed route is thoroughly examined. It is done without accurate instruments. Clinometers are used to determine the slopes of the ground. It provides additional information not available in top sheets

Some of the details to be collected during reconnaissance are given below:

- Valleys, ponds, lakes, marshy, land, ridge, hills, permanent structures and other obstructions along the route, which are not available in the map.
- Approximate values of gradient, length of gradients and radius of curves of alternate alignments.
- Number and types of cross drainage structures maximum flood level and natural groundwater level along the probable routes.
- Soil type along the routes from field identification tests and observation of geological features.
- Sources of construction materials water and location of stone quarries.
- When the road passes through hilly or mountainous terrain, additional data regarding the geological formation types of rocks, dip of strata, seepage flow etc.

Objectives:-

a. To study the feasibility or practicability of the proposed rout.
b. To reduce the number of alternative routes to the minimum to select the best two or three routes.
c. Source of construction materials, water and location of stone quarries.
d. Number and type of cross drainage structure, maximum flood level and natural ground water along the probable routes.

Preliminary survey: - This survey can be started on the basis of reconnaissance. It consists of detailed survey of the alternative routes selected. After reconnaissance, it is done by using the instruments such as chain, compass, tape, level and theodolite.

The main objectives of the preliminary surveys 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 collect all additional information found necessary after reconnaissance.
- To compare the different proposals in view of the requirements of a good alignment.
- To estimate quantity of earthwork materials and other construction aspects and to work out the cost of alternate proposals.
- To finalize the best alignment from all considerations/ to select the best route.
- To determine the center line to be followed

The procedure of the conventional methods of preliminary surveys the given steps:

Primary survey: -

For alternate alignments either secondary traverses (or) independent primary traverses may be necessary.

Topographical features: -

All geographical and other man made features along the traverse and for a certain width on either side surveyed and plotted.

Leveling work: -

Levelling work is also carried out side by side to give the centerline profiles and typical cross sections. The leveling work in the preliminary survey is kept to a minimum just sufficient to obtain the approximate earthwork in the alternate alignments.

Drainage studies: -

Drainage investigations and hydrological data are collected so as to estimate the type, number and approximate size of cross and drainage structures.

Soil survey: -

The soil survey conducted at this stage helps to working out details of earthwork, slopes, suitability of materials, subsoil and surface drainage requirements and pavement type and the approximate thickness requirements.

Material survey: -

The survey for naturally occurring materials like stone aggregates, soft aggregates etc and identification of suitable quarries should be made.

Traffic survey: -

Traffic surveys conducted in the region from basis for deciding the number of traffic lanes and roadway width, pavement design and economic analysis of highway project.

Final location and detailed survey: -

The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centerline. The detailed survey should be carried out for collecting the information technology for the preparation of plans and construction details.

Location: -

The centerline of the road finalized in the drawings to be translated on the ground during the location survey.

Major and minor control points are established on the ground and center pegs are driven, checking the geometric design, requirements.

Detailed survey: -

Levels along his final centerline should be taken at all staked points. Leveling work is to great importance as the vertical alignment.

A detailed soil survey is carried out to enable drawing of the soil profile.

The data during the detailed survey should be elaborate and complete for preparing detailed plans, design and estimates of the project.

This is done accurately by using instruments. The final route selected after the preliminary survey is surveyed and located on the ground.

Objectives:

1. To establish temporary bench marks.
2. To collect information required for
3. The preparation of working drawings
4. The preparation of detailed estimates
5. The design of road and bridges
6. Preparing specifications
7. Land acquisition

Objectives of engineering surveys for alignment:

The aim of location survey is to select a route with the following points kept in mind.

- With reasonable economy it should meet the minimum requirement regarding curvature and grades.
- To produce an easy riding (travelling), free flowing traffic artery that has a high capacity and it meets all the safety standards.

- The location survey should recognize and evaluate the routes impact on already existing industries, business and residential values and on future development.

Before field survey for any highway location is started, tentative decision, regarding the design speed of the route, its cross-section and the maximum grade must be made. These decision made are based on the; Estimated of amount, character and hourly distribution of traffic, along with knowledge of the area is traversed.

Modern methods of highway alignment:

1. Provisional alignment identification (Map study)
2. Reconnaissance survey
3. Hand held GPS giving 3D positions to an accuracy of 10-20m
4. Preliminary survey

- Mapping of topography and relief
- Use of aerial photos
- Airborne laser terrain mapping

5. Final location and detailed survey

Modern Equipments for surveying:

- EDM-Electronic Distance Measurement
- Auto level
- Digital level
- Total station
- GPS-global positioning system

Data from Aerial survey:

- Mosaic for longitudinal and lateral overlaps
- Control points
- Examination of photos for spot levels and contour lines
- Topo details
- Photo interpretation for geological features, soil and drainage for the study area.

Elements of comparison	**Conventional**	**Modern**
Maps-Base material	Topo sheet	RS data, Aerial photos, Satellite imageries
Instruments	Chain/Tapes, Theodolite,	Electromagnetic distance

	dumpy levels	measurement (EDM), Total station(TS), GPS, Auto and digital level, Photogrammetry
Accuracy	Chain/Tape 1 in 3000 to 1 in 30000 Tachometer 1 in 1000 to 1 in 10000	EDM/TS 1 in 10000 to 1 in 100000 Photogrammetry 1 in 10000 to 1 in 100000
Plotting	CAD systems	Software
Errors	Human errors	Closing errors hence re-measuring is required

HIGHWAY GEOMETRIC DESIGN

Importance of Geometric design:

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc. The features normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection.

Geometrics of highway should be design to provide optimum efficiency the traffic operation with maximum safety at reasonable cost. It may be deals with planning of new highway network or improvement of existing.

Geometric design of Highway deals with following element

1. Cross section element
2. Sight distance consideration
3. Horizontal alignment details
4. Vertical alignment details
5. Intersection element
6. Lateral and vertical clearances
7. Control of access

The factor which controls the highway geometric design requirements are speed, road user, vehicular characteristics, design traffic, traffic capacity and benefit cost consideration. However speed is the most important criteria among the all.

Design control and criteria: The geometric of highway depends on several design factors. The important factors are

- Design speed
- Topography
- Traffic factors
- Design hourly volume and capacity
- Environmental and other factors

Factors affecting geometric design

Factors affecting the geometric designs are as follows

Design speed:

- Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.

Topography:

It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain. Classified based on the general slope of the country.

- Plane terrain <10%
- Rolling terrain 10-25%
- Mountainous terrain 25-60%
- Steep terrain >60%

Traffic:

It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is determined from the various traffic data collected..

- Vehicular characteristics and human characteristics of road users.
- Different vehicle classes have different speed and acceleration characteristics, different dimensions and weight .
- Human factor includes the physical, mental and psychological characteristics of driver and pedestrian.

Environmental:

Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.

Economy:

The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.

Other factors:

Geometric design should be such that the aesthetics of the region is not affected.

HIGHWAY CROSS SECTIONAL ELEMENT:

The feature of the cross-section of the pavement influences the life of the pavement as well as the riding comfort and safety.

Pavement surface characteristics For a safe and comfortable driving four aspects of the pavement surface are important;

Friction : Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affects the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.

Skidding happens when the path travelled along the road surface is more than the circumferential movement of the wheels due to friction.

Slipping occurs when the wheel revolves more than the longitudinal movement of the road

Various factors that affect friction are:

- Type of the pavement surface (like bituminous, concrete, or gravel)
- Macro texture of the pavement surface
- Condition of the pavement (dry or wet, hot or cold, etc)
- Type and Condition of the tire (new or old)
- Speed and load of the vehicle.
- Extent of brake application or brake efficiency
- Load and tyre pressure
- Temperature of tyre and pavement
- Type of skid if any

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 and coefficient of later friction as 0.15.

Pavement Unevenness:

Higher operating speed are possible on even surface than uneven surface. It affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires. It is commonly measure by an equipment call “Bump Integrator”

Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road. 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.

Light reflecting characteristics:

- White roads have good visibility at night, but caused glare during day time.
- Black roads has no glare during day, but has poor visibility at night.
- Concrete roads has better visibility and less glare.

Drainage: The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers.

Camber:

Camber (or) cross slope is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface. The pavement surface by providing cross slope is considered important because of two reasons.

i) To prevent the entry of surface water into the sub grade soil through pavement.

ii) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping.

iii) To improve the rainwater from the pavement surface as quickly as possible and to allow the pavement to get dry soon after the rain.

The rate of camber or cross slope is usually designated by 1 in n which means that the transverse sloe is in ratio 1 vertical to n horizontal. Camber is also expressed as a percentage.

The required camber of a pavement depends on:

i) The type of pavement surface

ii) The amount of rainfall

The minimum camber needed to drain off surface water may be adopted keeping in view the type of pavement surface and the amount of rainfall in the locality.

Too step cross slope is not desirable because of the following reasons:

i) Transverse of flit of vehicles causes uncomfortable side thrust and a drag on the steering of automobiles.

ii) Discomfort causing throw of vehicle when crossing the crown during overtaking operations.

iii) Problems of toppling over of highly laden bullock carts and trucks.

iv) Formation of cross ruts due to rapid flow of water.

v) Tendency of most of the vehicles to travel along the center line.

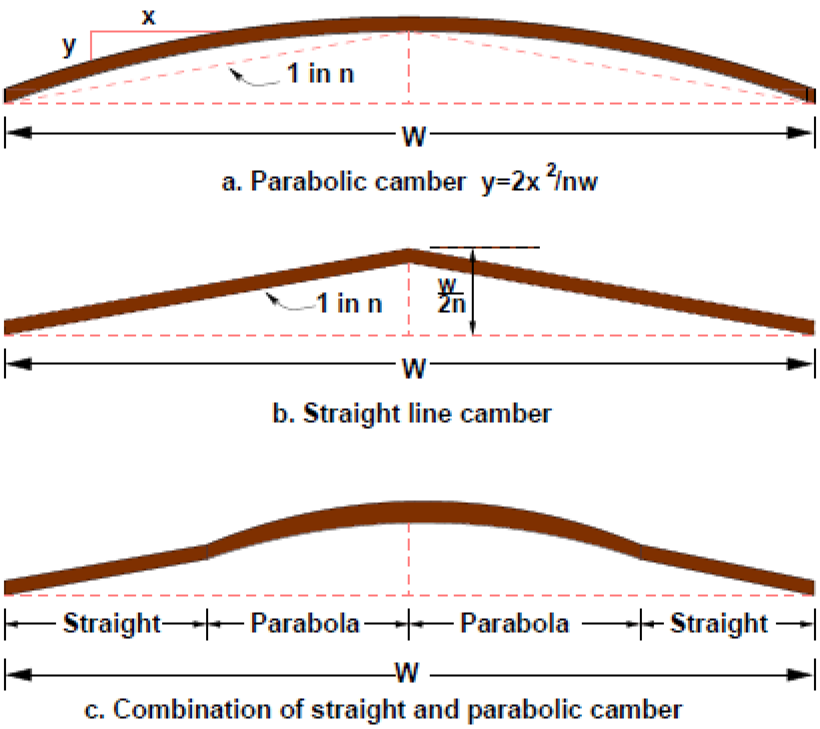


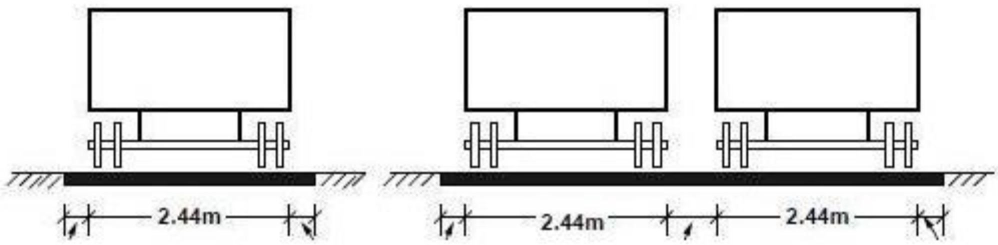
Figure: Different types of camber

Table IRC values for camber

Type of surface	Heavy rainfall	Light rainfall
Concrete/Bituminous	2 %	1.7%
Gravel/WBM	3 %	2.5 %
Earthen	4 %	3.0 %

IRC Specification for carriage way width

Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5



Carriage way (or) Width of pavement:

The pavement or carriageway width depends on the width of traffic lane and number of lanes. The carriage way intended for one line of traffic movement may be called a traffic lane.

Keeping all these in view a width of 3.75m is considered desirable for a road having single lane for vehicles of maximum width 2.44m. For pavements having two or more lanes, width 0f 3.5m per lane is considered sufficient.

The maximum width of vehicle as per IRC specification is 2.44m.If a single carriageway of width 3.8m is provided, a side clearance of 0.68m would be obtained in figure.

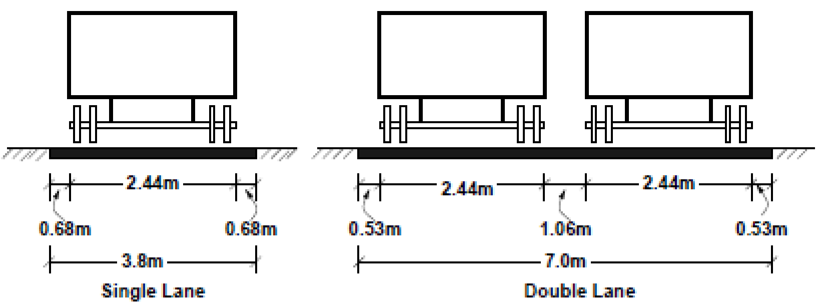


Figure: Lane width for single and two lane roads

Table: IRC Specification carriage way width

Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5

In the case of two lane pavement of width 0.7m a minimum clearance between two lanes of traffic would be 1.06m for the widest vehicles on the road. The number of lanes required in a highway depends on the predicted traffic volume and the design traffic volume of each lane.

Kerbs:

Kerbs indicate the boundary between the pavement and shoulder (or) sometimes island or foot path or kerb parking space.

There is variety of kerb designs; kerbs may be mainly divided in to three groups based on their functions.

- Low or mountable kerb
- Semi-barrier type kerb
- Barrier type kerb

i) Low (or) mountable type kerbs which though encourage traffic to remain in the through traffic lanes, yet allow the driver to enter the shoulder area with little difficulty. This type of kerb is provided at medians and channelization schemes and is also useful for longitudinal drainage system.

ii) Semi-barrier type kerb is provided on the periphery of roadway where the pedestrian traffic is high.This type of kerb has a height of about 15cm above the pavement edge with a batter of 1:1 on the top 7.5 cm.This kerb prevents encroachment of parking vehicles. But at acute emergency it is possible to drive over this kerb with some difficulty.

iii) Barrier type kerb is provided in built up areas adjacent t foot paths with considerable pedestrian traffic. The height of kerb stone is about 20 cm above the pavement edge with a steep batter of 1.0 vertical 0.25 horizontal.

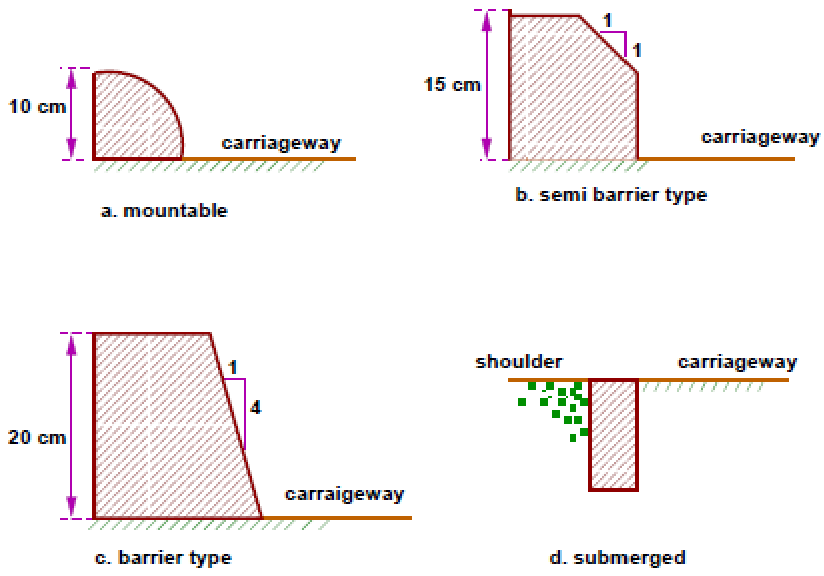


Figure: Different types of kerbs

.

ROAD MARGINS

The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are given below.

Shoulders:

A shoulder are provided along the road edge and is 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. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane rural highways in India.

Parking lanes:

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

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.

Service roads:

Service roads or frontage roads give access to access controlled highways like freeways and expressways. They run parallel to the highway and will be usually isolated by a separator and access to the highway will be provided only at selected points.

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.

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 On the embankment, especially when the height of the fill exceeds 3 m.

Width of formation:

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders. This does not include the extra land in formation/cutting. The values suggested by IRC are given in Table

Table Width of formation for various class of roads

Road classification	**Roadway width in m**	
	Plain and rolling terrain	Mountainous and steep terrain
NH/SH	12	6.25-8.8
MDR	9	4.75
ODR	7.5-9.0	4.75
VR	7.5	4.0

Right of way:

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development.

Right of way is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development.

A minimum land width has been prescribed for each category of road. The land width is governed by the following factor:

a. Width of formation depending on the category of highway and width of roadway and road margins.
b. Height of embankment or depth of cutting which is governed by the topography and the vertical alignment.
c. Side slopes of embankment (or) cutting which depend on the height of the slope.
d. Drainage system and their size which depends on the rainfall, topography and runoff.
e. 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.
f. Reserve land for future widening: Some land has to be acquired in advance anticipating future developments like widening of the road.

Table Normal right of way for open areas

Road classification	Roadway width in m	
	Plain and rolling terrain	Mountainous and steep terrain
Open areas		
NH/SH	45	24
MDR	25	18
ODR	15	15
VR	12	9
Built-up areas		
NH/SH	30	20
MDR	20	15
ODR	15	12
VR	10	9

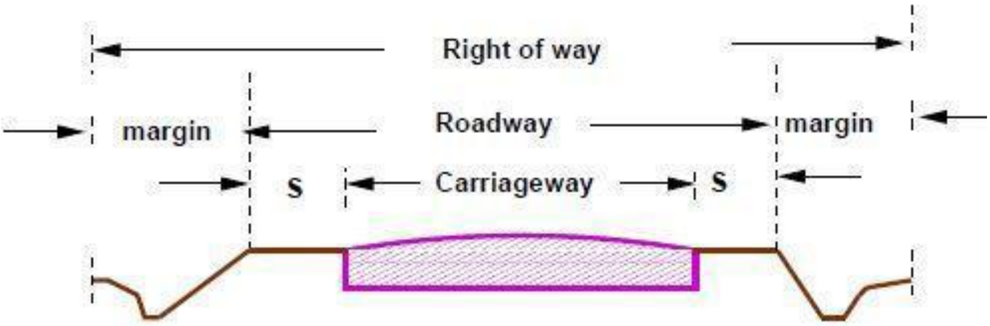


Figure: A typical Right of way

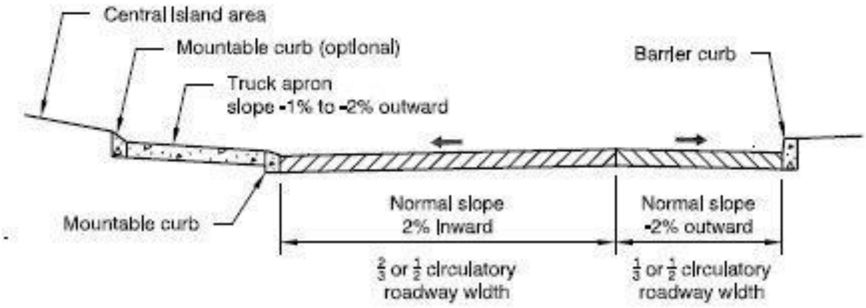
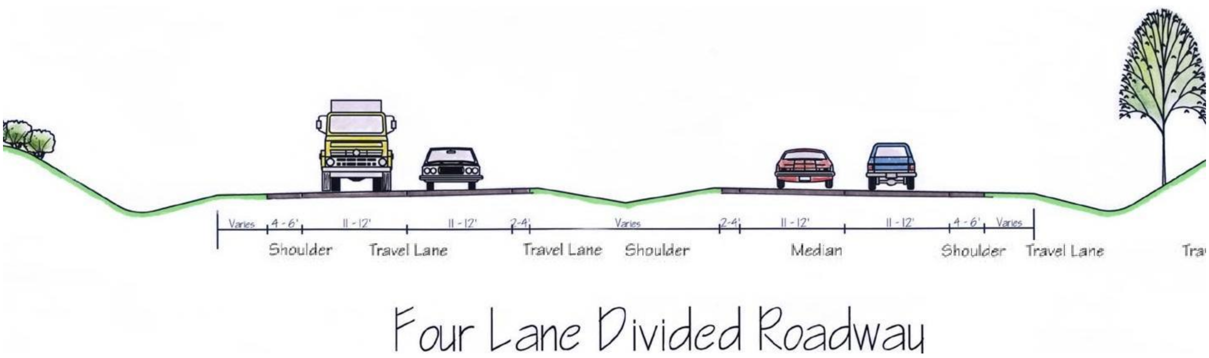


Figure Cross-section of road in built of area



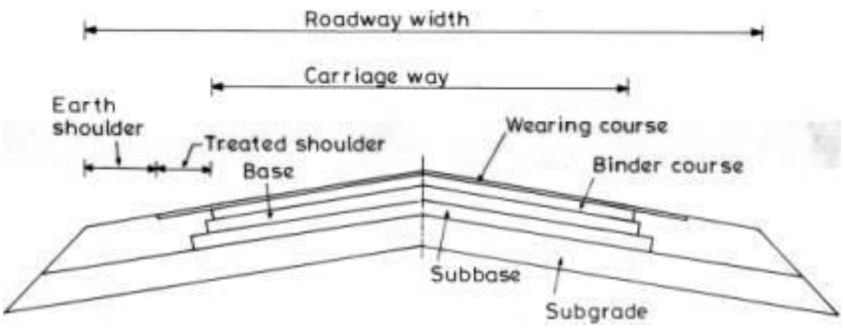


Figure Cross-section Flexible pavement

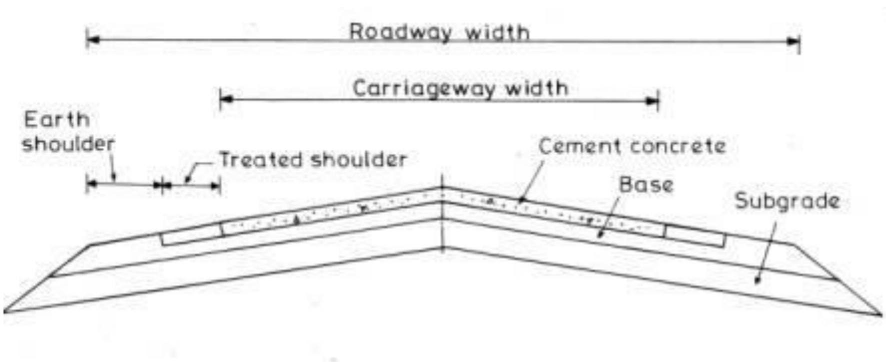


Figure Cross-section Rigid pavement

SIGHT DISTANCE

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead. This distance is said to be the sight distance.

Types of sight distance

Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects. Three sight distance situations are considered for design:

_ Stopping sight distance (SSD) or the absolute minimum sight distance

_ Intermediate sight distance (ISD) is defined as twice SSD

_ Overtaking sight distance (OSD) for safe overtaking operation

_ Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights

_ Safe sight distance to enter into an intersiection.

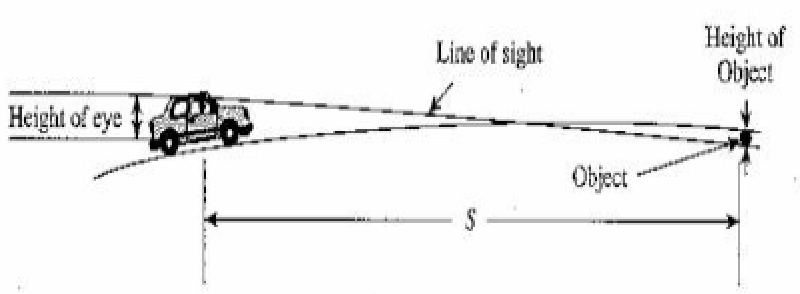


Figure: Sight distance at vertical summit curve

Stopping sight distance:

The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

Over taking sight distance:

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 the minimum overtaking sight distance (OSD) or the safe passing sight distance.

Sight distance at intersection:

Driver entering an uncontrolled intersection (particularly un-signalised Intersection) has sufficient visibility to enable him to take control of his vehicle and to avoid collision with another vehicle.

Intermediate sight distance:

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

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-gradients and at the ascending stretch of the valley curves.

The following are the factor affecting sight distance:

Total reaction time of the driver

- Speed of the vehicle
- Efficiency of breaks
- Frictional resistance between the road and the tyres
- Gradient of the road

Total reaction time of the driver

Reaction time of the driver is the time taken from the instant the object is visible to the driver to the breaks are effectively applied. The amount of time gap depends on several factors. During this time the vehicle travels a certain distance at the original speed or the design speed. Thus stopping distances increases in reaction time of the driver. The total reaction time may be split up into two parts.

- Perception time
- Break reaction time

The perception time is the time required for a driver to realize that breaks 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 break reaction time also depends on several factors including the skill of the driver, the type the problems and various other environmental factors.

Total reaction time of driver can be calculated by "PIEV" theory.

"PIEV" Theory

Total reaction time of driver is split into four parts:

- P-perception
- I-intellection
- E-Emotion
- V-Volition

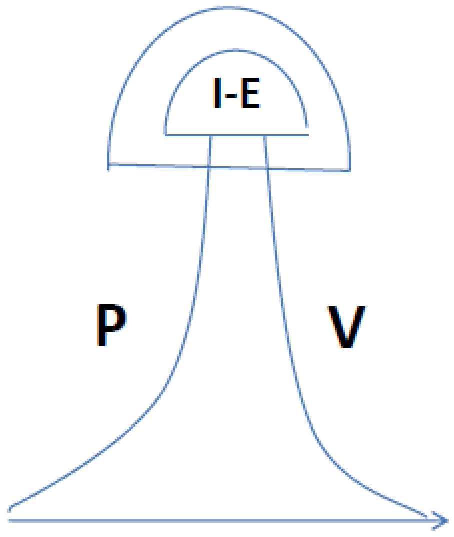


Figure: Reaction time and PIEV Process

Perception:

It is the time required for the sensation received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord.

Intellection:

It is the time required for understanding the situation.

Emotion:

It is the time elapsed during emotional sensation and disturbance such as fear, anger or any other emotional feeling such as superstition etc, with reference to the situation.

Volition:

It is the time taken for the final action

Total reaction time of driver may be vary from 0.5 sec to 4 sec

Speed of the 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 breaking distance or the distance moved by the vehicle after applying breaks, before coming to a stop depends also on the initial speed of the vehicle. Hence it is evident that higher the speed, the higher will be the stopping distance.

Efficiency of breaks

The breaking efficiency is said to be 100 percent if the wheels are fully locked preventing them from rotating on application of the breaks.

This will result in 100 percent skidding which is normally undesirable, except in utmost emergency. Also skidding is considered to be dangerous, as it is not possible to control a skidding vehicle.

Hence avoid skid, the breaking forces should not exceed the frictional force between the wheels and tyres.

Frictional resistance between road and tyres

The frictional resistance developed between road and tyres or the skid resistance depends on the tyre and condition of the road surface and the tyres.

The breaking distance increases with decrease in skid resistance. IRC has specified a design friction co efficient of 0.35 to 0.4 depending upon the speed to be used for finding the breaking distance in the calculation of stopping sight distance.

This value apart from having sufficient safety factor permits a rate of retardation which is fairly comfortable for passengers.

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.

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.

Lag distance is the distance the vehicle traveled during the reaction time t.

If ‘V’ is the design speed in m/sec and ‘t’ is the total reaction time of the driver in seconds,

Lag distance = v.t metres

Where “v” in m/sec

t=2.5 sec

Lag distance = 0.278 V.t meters

Where "v" in Kmph,

T= time in sec=2.5 sec

Braking distance :

- It is the distance traveled by the vehicle after the application of brake. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.
- If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is F l = fW l where W is the total weight of the vehicle. The kinetic energy at the design speed is
- The kinetic energy at the design speed of v m/sec will be ½ m. v^2

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

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

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

Therefore, the SSD = lag distance + braking distance and given by:

SSD = vt + v^2/2gf

Where v is the design speed in m/sec, t is the reaction time in sec, g is the acceleration due to gravity and f is the coefficient of friction. The coefficient of friction f is given below for

Table: Coefficient of longitudinal friction

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

When there is an ascending gradient of say +n%, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the braking force is equal to W sin α = W tanα = Wn=100. Equating kinetic energy and work done:

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

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

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

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

Table: Coefficient of longitudinal friction

	Coefficient of longitudinal friction				
Speed, kmph	30	40	50	60	>80
Longitudinal coefficient of friction	0.40	0.38	0.37	0.36	0.35

Two-way traffic single lane road: SSD=2*SSD

In one-way traffic with single or more lane or two-way traffic with more than single lane: Minimum SSD = SSD

OVERTAKING SIGHT DISTANCE

The overtaking sight distance is the minimum distance open to the vision of the driver of a vehicle intending to overtake the slow vehicle ahead safely against the traffic in the opposite direction. The overtaking sight distance or passing sight distance is measured along the center line of the road over which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2 m above the road surface. The factors that affect the OSD are: Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.

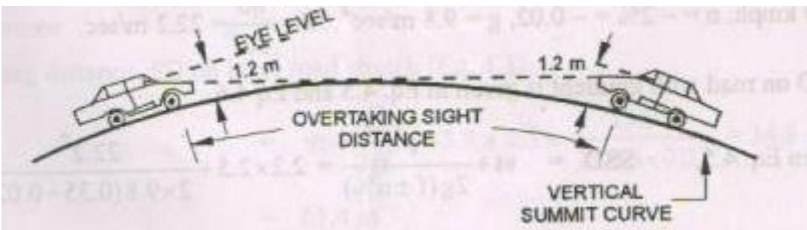


Figure: Measurement of overtaking sight distance

The following are the factors affecting overtaking sight distance:

- Speeds of overtaken and overtaking vehicles.
- Other vehicles coming from the opposite direction.
- Space between overtaking and overtaken vehicles.
- Skill and reaction time of the driver.
- Rate of acceleration of overtaking vehicle.
- Slope of the road.

Analysis of OSD

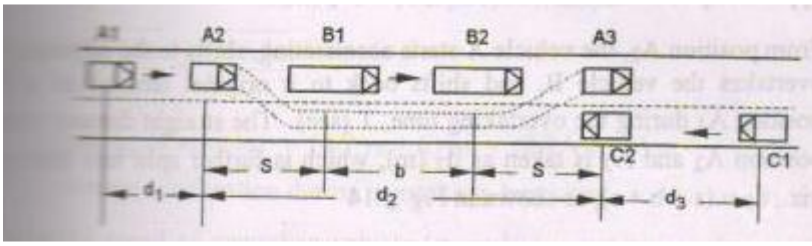


Figure: Overtaking manoeuvre

- d_1 is the distance traveled by overtaking vehicle “A”during the reaction time tsec of the driver from position A_1 to A_2.
- d_2 is the distance traveled by the vehicle AfromA2toA3duringtheactual overtaking operation, in time T sec.
- d_3 is the distance traveled by on-coming vehicleCfromC1to C2during the overtaking operation of A, i.e. Tsec.
- B is the overtaken or slow moving vehicle.
- B is the overtaken or slow moving vehicle moving with uniform speed V_b m/sec or V_b Kmph.
- C is a vehicle coming from opposite direction at the design speed V m/sec or V kmph
- The distance traveled by the vehicle A during this reaction time is d1and is between the positions A_1 and A_2. this distance will be equal to V_b.t meter

where t is the reaction time of the driver in second= 2 sec.

OSD = $d_1 + d_2 + d_3$

OSD = $0.28V_b. t + 0.28V_b .T + 2s + 0.28V.T$

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

$T = \sqrt{4x3.6s/ A} = \sqrt{14.4s /A}$

If the speed of the overtaken vehicle is not given

Vb=(V-16) kmph,

where V= speed of overtaking vehicle in kmph

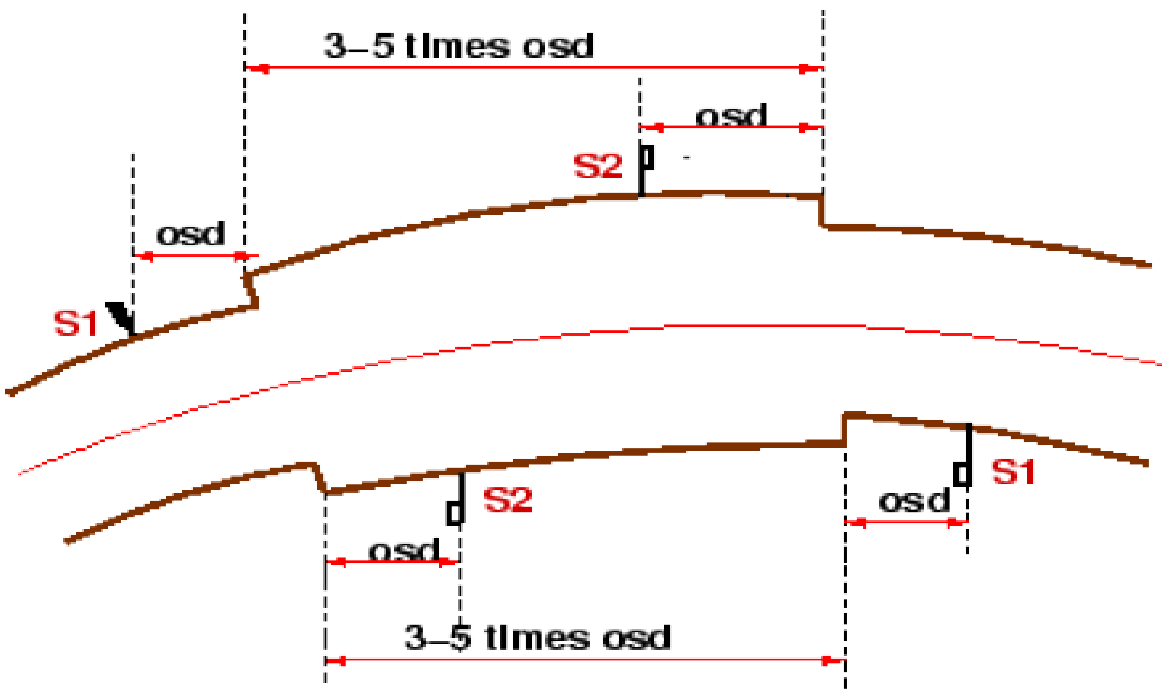
- The minimum overtaking sight distance = $d_1 + d_2 + d_3$ for two-way traffic.
- On divide highways and on roads with one way traffic regulation, the overtaking distance = $d_1 + d_2$ as no vehicle is expected from the opposite direction.

Overtaking Zones

It is desirable to construct highways in such a way that the length of road visible a head 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. But the overtaking opportunity for vehicles moving at design speed should be given at frequent intervals. These zones which are meant for overtaking are called overtaking zones.

The minimum length of overtaking zone should be three time the safe overtaking distance i.e.,$3(d_1+d_2)$ for one-way roads and $3(d_1+d_2+d_3)$ for two-way roads.

Desirable length of overtaking zones is kept five times the overtaking sight distance .i.e., $5(d_1+d_2)$ for one-way roads and 5(d1+d2+d3) for two-way roads.



S1—– Overtaking zone begin
S2—–End of Overtaking zone

Sight distance at intersections:

At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either sides. They should be able to perceive a hazard and stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other. This is illustrated in the figure

Design of sight distance at intersections may be used on three possible conditions:

_ Enabling approaching vehicle to change the speed

_ Enabling approaching vehicle to stop

_ Enabling stopped vehicle to cross a main road

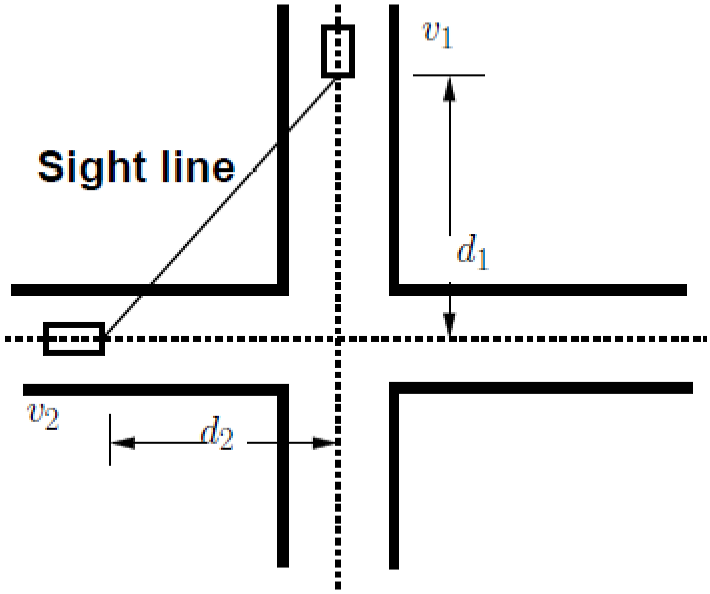


Figure: Sight distance at intersections

HORIZONTAL ALIGNMENT

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. A poor design will result in lower speeds and resultant reduction in highway performance in terms of safety and comfort. In addition, it may increase the cost of vehicle operations and lower the highway capacity. Horizontal alignment design involves the understanding on the design aspects such as design speed and the effect of horizontal curve on the vehicles. The horizontal curve design elements include design of super elevation, extra widening at horizontal curves, design of transition curve, and set back distance.

Design speed

The overall design of geometrics of any highway is a function of the design speed.

The design speed is the main factor on which geometric design elements depends. The sight distances, radius of horizontal curve, super elevation, extra widening of pavement, length of horizontal transition curve and the length of summit curve are all dependent on design speed.

The design speed of roads depends upon

- Class of the road

- Terrain

The speed standard of particular class of road thus depends on the classification of the terrain through its passes. The terrain have been classified as plain, rolling, mountainous and steep, depending on the cross slope of the country as given below.

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

HORIZONTAL CURVE

The presence of horizontal curve imparts centrifugal force which is a reactive force acting outward on a vehicle negotiating it. Centrifugal force depends on speed and radius of the horizontal curve and is counteracted to a certain extent by transverse friction between the tyre and pavement surface. On a curved road, this force tends to cause the vehicle to overrun or to slide outward from the centre of road curvature. For proper design of the curve, an understanding of the forces acting on a vehicle taking a horizontal curve is necessary. Various forces acting on the vehicle are illustrated in the figure.

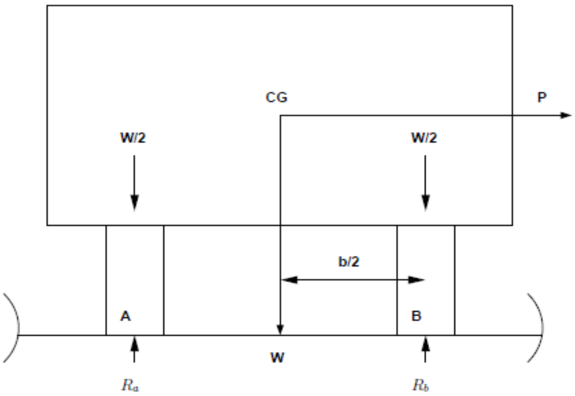


Figure Effect of Horizontal curve

They are the centrifugal force (P) acting outward, weight of the vehicle (W) acting downward, and the reaction of the ground on the wheels (RA and RB). The centrifugal force and the weight is assumed to be from the centre of gravity which is at h units above the ground. Let the wheel base be assumed as b units. The centrifugal force P in kg = m^2 is given by

P = W v²⁄gR

Where,

P = centrifuge force, kg

W = weight of the vehicle, kg

R = radius of the circular curve, m

v = speed of vehicle, m/sec

g = acceleration due to gravity = 9.8m/sec

P/W is known as the centrifugal ratio or the impact factor. The centrifuge ratio is thus equal to **v²⁄gR**

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

- Tendency to overturn the vehicle outwards about the outer wheels
- Tendency to skid the vehicle laterally, outwards

Overturning effect

The equilibrium condition for overturning will occur

when $Ph = \frac{Wb}{2} \text{ or } \frac{P}{W} = \frac{b}{2h}$

This means that there is danger of overturning when the centrifugal when the centrifugal ratio

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

for safety the following condition must satisfy:

$$\frac{b}{2h} \rangle \frac{v^2}{gR}$$

Transverse skidding effect

P = FA+ FB= f(RA+RB) = f W

Since P = f W, the centrifugal ratio P/W is equal to ‘f ‘. In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction there is a danger of lateral skidding.

Thus to avoid overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than b/2h and also ‘f’

f < b/2h - The vehicle would skid and not overturn.

b/2h < f -The vehicle would overturn on the outer side before skidding

ANALYSIS OF SUPER-ELEVATION

Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counter acting the effect of centrifugal force. In order to find out how much this raising should be, the following analysis may be done. The forces acting on a vehicle while taking a horizontal curve with superelevation is shown in figure

Forces acting on a vehicle on horizontal curve of radius R m at a speed of v m/sec^2 are:

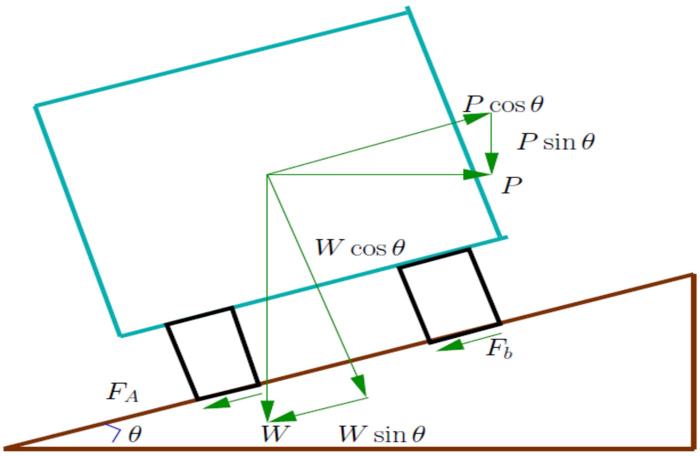


Figure: Analysis of Superelevation

- P the centrifugal force acting horizontally out-wards through the center of gravity,
- W the weight of the vehicle acting down-wards through the center of gravity, and
- F the friction force between the wheels and the pavement, along the surface inward.

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

$P\cos\theta = W\sin\theta + F_A + F_B$

$= W\sin\theta + f(R_A + R_B)$

$= W\sin\theta + f(W\cos\theta + P\sin\theta)$

where W is the weight of the vehicle, P is the centrifugal force, f is the coefficient of friction, θ is the transverse slope due to superelevation. Dividing by W cosθ, we get:

$$\begin{aligned}\frac{P\cos\theta}{W\cos\theta} &= \frac{W\sin\theta}{W\cos\theta}+\frac{fW\cos\theta}{W\cos\theta}+\frac{fPsin\theta}{W\cos\theta}\\ \frac{P}{W} &= \tan\theta+f+f\frac{P}{W}\tan\theta\\ \frac{P}{W}(1-f\tan\theta) &= \tan\theta+f\\ \frac{P}{W} &= \frac{\tan\theta+f}{1-f\tan\theta}\end{aligned}$$

We have already derived an expression for P/W. By substituting this in above equation , we get:

$$\frac{v^2}{gR}=\frac{\tan\theta+f}{1-f\tan\theta}$$

This is an exact expression for superelevation. But normally, f = 0:15 and $\theta < 4^o$, $1 - f\tan\theta \approx 1$ and for small θ, $\tan\theta \approx \sin\theta = E/B = e$, then :

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

where, e is the rate of super elevation, f the coefficient of lateral friction 0:15, v the speed of the vehicle in m/sec^2, R the radius of the curve in m and g = 9:8m/sec^2.

Three specific cases that can arise from above equation are as follows:

1 If there is no friction due to some practical reasons, then f = 0 and above equation becomes $e = v^2/gR$. This results in the situation where the pressure on the outer and inner wheels are same; requiring very high super-elevation e.

2 If there is no super-elevation provided due to some practical reasons, then e = 0 and equation becomes $f = v^2/gR$. This results in a very high coefficient of friction.

3 If e = 0 and f = 0:15 then for safe traveling speed from equation is given by $v_b = \sqrt{fgR}$ where v_b is the restricted speed.

DESIGN OF SUPER-ELEVATION:

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

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

Step 2 If $e_1 \leq$ 0:07, then e = $e_1 = \frac{(0.75v)^2}{gR}$, else if $e_1 > 0.07$ go to step 3.

Step 3 Find f_1 for the design speed and max e, i.e $f_1 = \frac{(0.75v)^2}{gR} - e = \frac{(0.75v)^2}{gR} - 0.07$

If $f_1 < 0.15$, then the maximum e = 0.07 is safe for the design speed, else go to step 4.

Step 4 Find the allowable speed v_a for the maximum e = 0.07 and f = 0.15, $v_a = \sqrt{0.22gR}$

- If the allowed speed, as calculated above is higher than the design speed, then the design is adequate and provides a Superelevation of ‘e’ equal to 0.07.
- If the allowable speed is less than the design speed, the speed is limited to the allowed speed v_a kmph calculated above and Appropriate warning sign and speed limit regulation sign are installed to restrict and regulate the speed.

If $v_a \geq v$ then the design is adequate, otherwise use speed adopt control measures or look for speed control measures.

Maximum and minimum super-elevation

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

Attainment of super-elevation

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

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

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

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

(a) Rotation about the center line: The pavement is rotated such that the inner edge is depressed and the outer edge is raised both by half the total amount of superelevation, i.e., by E =2 with respect to the centre.

(b) Rotation about the inner edge: Here the pavement is rotated raising the outer edge as well as the centre such that the outer edge is raised by the full amount of superelevation with respect to the inner edge.

Radius of Horizontal Curve

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

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

Hence the radius of the curve should be higher than R_{ruling}.

Widening of Pavement on Horizontal Curves

On horizontal corves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width,

•Widening is needed for the following reasons :

- The driver experience difficulties in steering around the curve.
- The vehicle occupies a greater width as the rear wheel don't track the front wheel. known as 'Off tracking'
- For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.
- While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

Off tracking

- An automobile has a rigid wheel base and only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.
- The required extra widening of the pavement at the horizontal curves depends on the length of the wheel base of the vehicle 'l', radius of the curve 'R' and the psychological factors.

Analysis of extra widening on curves:

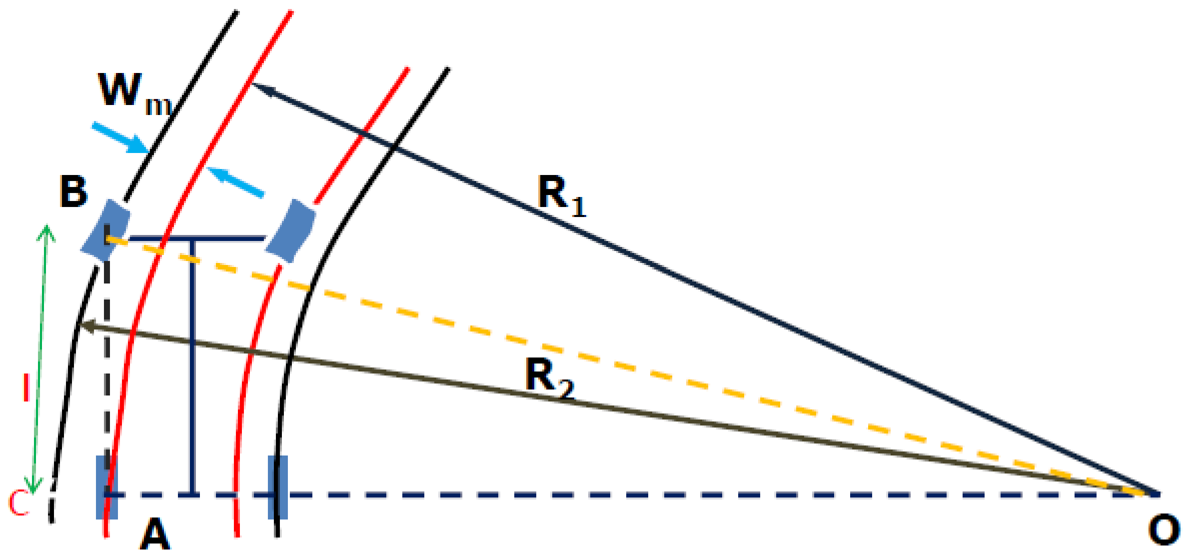
It is divided into two parts;

➢ Mechanical widening (W_m): the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening

- Psychological widening (W_{ps}): extra width of the pavement is also provided for psychological reasons such as , to provide for greater maneuverability of steering at high speed, to allow for the extra space for overhangs of vehicles and to provide greater clearance for crossing and overturning vehicles on curve.

Total widening $W = W_{ps} + W_m$

Mechanical Widening



$W_m = R_2 – R_1$

From Δ OAB, $OA^2 = OB^2 – BA^2$

$R_1^2 = R_2^2 – l^2$

$(R_2 – W_m)^2 = R_2^2 – l^2$

$l^2 = W_m (2 R_2 – W_m)$

$W_m = l^2 / 2R$ (Approx.)

or $W_m = nl^2/2R$

Where, R = Mean radius of the curve in m,

n = no. of traffic lanes

R = Mean radius of the curve, m

l = Length of Wheel base of longest vehicle , m (l = 6.0 m or 6.1m for commercial vehicles)

V= design speed, kmph

Psychological Widening

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$ (Empirical formula)

V = Design speed of the vehicle, km/h

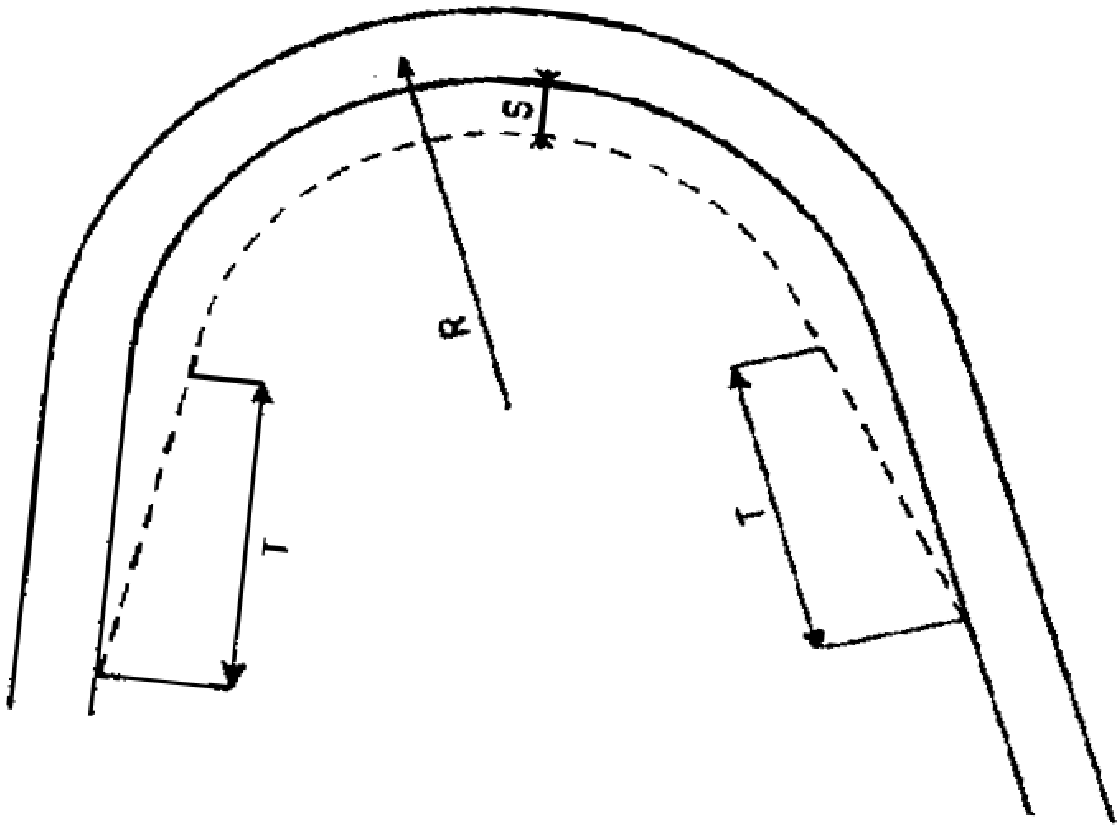
R = Radius of the curve, m

Total extra widening = Mechanical widening + Psychological Widening

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

Method of introducing extra widening

- With transition curve: increase the width at an approximately uniform rate along the transition curve -the extra width should be continued over the full length of circular curve
- Without transition curves: provide two-third widening on tangent and the remaining one-third on the circular curve beyond the tangent point
- With transition curve: Widening is generally applied equally on both sides of the carriageway
- Without transition curve: the entire widening should be done on inner side
- On sharp curves of hill roads: the entire widening should be done on inner side



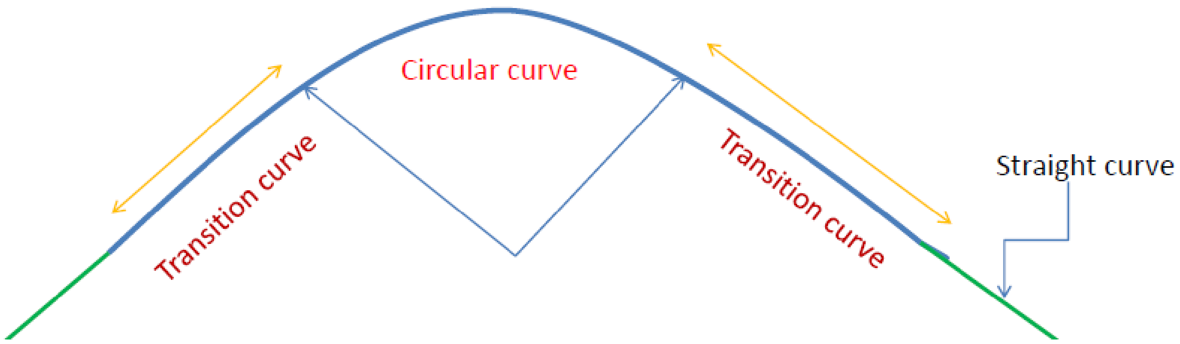
HORIZONTAL TRANSITION CURVES

When a non-circular curve is introduce between a straight and a circular curve has a varying 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) for the gradual introduction of centrifugal force is known as transition curve.

Or

It is an arc between a straight and a circular curve or between two arcs of a compound curve. The radius of a transition curve varies from infinity to a fixed value.

Vehicles passing from straight into a circular curve experience jerk due to the effect of centrifugal force. The centrifugal force always acts in a direction perpendicular to the axis of rotation. In order to counter act the above effect the outer edge of the road or the rail is raised which is called the super elevation or cant. This super elevation is provided gradually along the transition curve.



There are five objectives for providing transition curve and 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 security
- To provide gradual introduction of super elevation
- To provide gradual introduction of extra widening.
- To enhance the aesthetic appearance of the road.

Advantages:

- Introduces super elevation gradually from zero at the tangent point to the value on the circular curve.
- Maintains a constant proportional between super elevation and rate of change of curvature.
- Eliminates discomfort overturning and side slipping vehicles.

- Eliminates discomfort to passengers.

Requirements

- The transition should be tangential to the straight.
- The curvature amount of super elevation should be zero at the origin of the straight.
- The curvature of the transition curve should increase at the same rate as that of the super elevation.
- The exact amount of super elevation should be attained at the junction with the circular curve.

Type of transition curve

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

1. It full fills the requirement of an ideal transition curve, that is;

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

(b) Radius of the transition curve is infinity at the straight edge and changes to R at the curve point (Ls α1/R)and calculation and field implementation is very easy.

Length of transition curve

The length of the transition curve should be determined as the maximum of the following three criteria: rate of change of centrifugal acceleration, rate of change of super elevation, and an empirical formula given by IRC.

1. Rate of change of centrifugal acceleration At the tangent point, radius is infinity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. If c is the rate of change of centrifugal acceleration, it can be written as:

The length of the transition curve Ls in m is

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

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

$$C = \frac{80}{(75+v)} \qquad 0.5 < C < 0.8$$

Where,

L_s = length of transition curve in 'm'

C= allowable rate of change of centrifugal accleration, m/ sec²

R= Radius of the circular curve in ‘m’

2. Rate of introduction of super-elevation

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:

If the pavement is rotated about the center line

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

If the pavement is rotated about the inner edge or Raise (E) of the outer edge with respect to inner edge

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

Where

- W is the width of pavement
- We is the extra widening
- Rate of change of superelevation of 1 in N

3. By empirical formula

According to IRC standards:

- For plane and rolling terrain:

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

For mountainous and steep terrain:

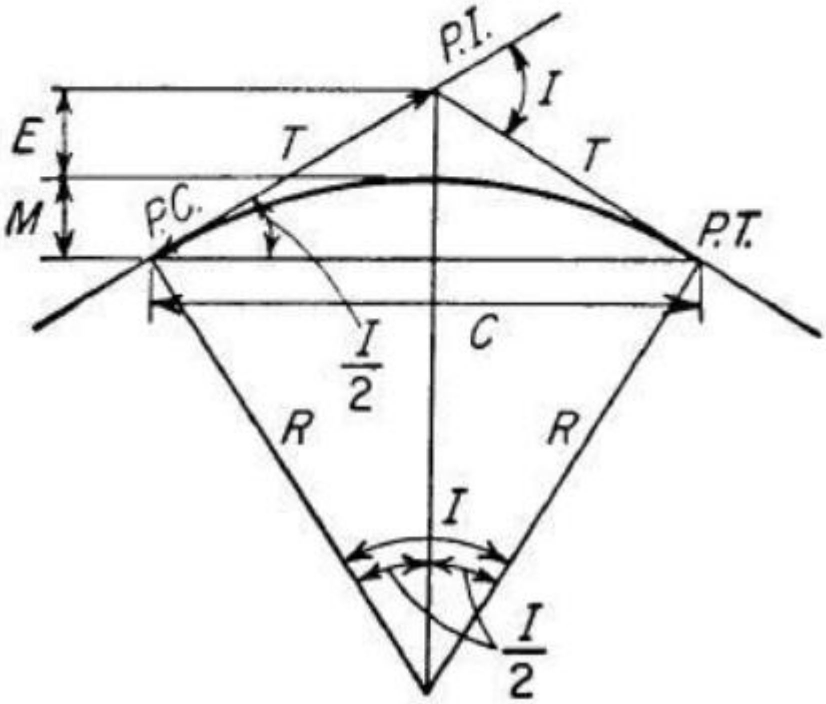
$$L_s = \frac{V^2}{R}$$

The design length of transition curve(Ls) will be the highest value of case-1,2 and 3

Shift of the transition curve

Shift of the transition curve ‘S’

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



Circular curve.

Vertical alignment

The vertical alignment of a transportation facility consists of *tangent grades* (straight lines in the vertical plane) and *vertical curves*. Vertical alignment is documented by the *profile*. Just as a circular curve is used to connect horizontal straight stretches of road, vertical curves connect two gradients. When these two curves meet, they form either convex or concave. The former is called a summit curve, while the latter is called a valley curve. The vertical alignment consists of grade and vertical curve and it influence the vehicle speed, acceleration, sight distance and comfort in vehicle movements at high speed.

Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. Before nalizing the gradients, the construction cost, vehicular operation cost and the practical problems in the site also has to be considered. Usually steep gradients are avoided as far as possible because of the difficulty to climb and increase in the construction cost. More about gradients are discussed below.

Effect of gradient

The effect of long steep gradient on the vehicular speed is considerable. This is particularly important in roads where the proportion of heavy vehicles is significant. Due to restrictive sight distance at uphill gradients the speed of traffic is often controlled by these heavy vehicles. As a result, not only the operating costs of the vehicles are increased, but also capacity of the roads will have to be reduced. Further, due to high differential speed between heavy and light vehicles, and between uphill and downhill gradients, accidents abound in gradients.

Representation of gradient

The positive gradient or the ascending gradient is denoted as +n and the negative gradient as n. The deviation angle N is: when two grades meet, the angle which measures the change of direction and is given by the algebraic difference between the two grades $(n_1 - (-n_2)) = n_1 + n_2 = \alpha_1 + \alpha_2$. Example: 1 in 30 = 3.33% 2^o is a steep gradient, while 1 in 50 = 2% $1^o\ 10'$ is flatter gradient.

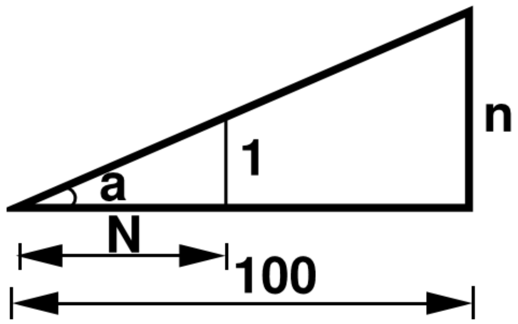


Figure : Representation of gradient

Types of gradient

Many studies have shown that gradient up to seven percent can have considerable effect on the speeds of the passenger cars. On the contrary, the speeds of the heavy vehicles are considerably reduced when long gradients as at as two percent is adopted. Although, atter gradients are desirable, it is evident that the cost of construction will also be very high.

Table : IRC Specifications for gradients for different roads

Terrain	Ruling	Limiting	Exceptional
Plain/Rolling	3.3	5.0	6.7
Hilly	5.0	6.0	7.0
Steep	6.0	7.0	8.0

Typical Gradients (IRC)

- Ruling Gradient
- Limiting Gradient
- Exceptional gradient
- Minimum Gradient

Ruling gradient (design gradient):

It is the maximum gradient within which the designer attempts to design the vertical profile of road, it depends on

- Type of terrain
- Length of grade
- Speed
- Pulling power of vehicles
- Presence of horizontal curves
- Mixed traffic

Limiting Gradient:

Steeper than ruling gradient. In hilly roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient, it depend on

- Topography
- Cost in constructing the road

Exceptional Gradient:

Exceptional gradient are very steeper gradients given at unavoidable situations. They should be limited for short stretches not exceeding about 100 m at a stretch.

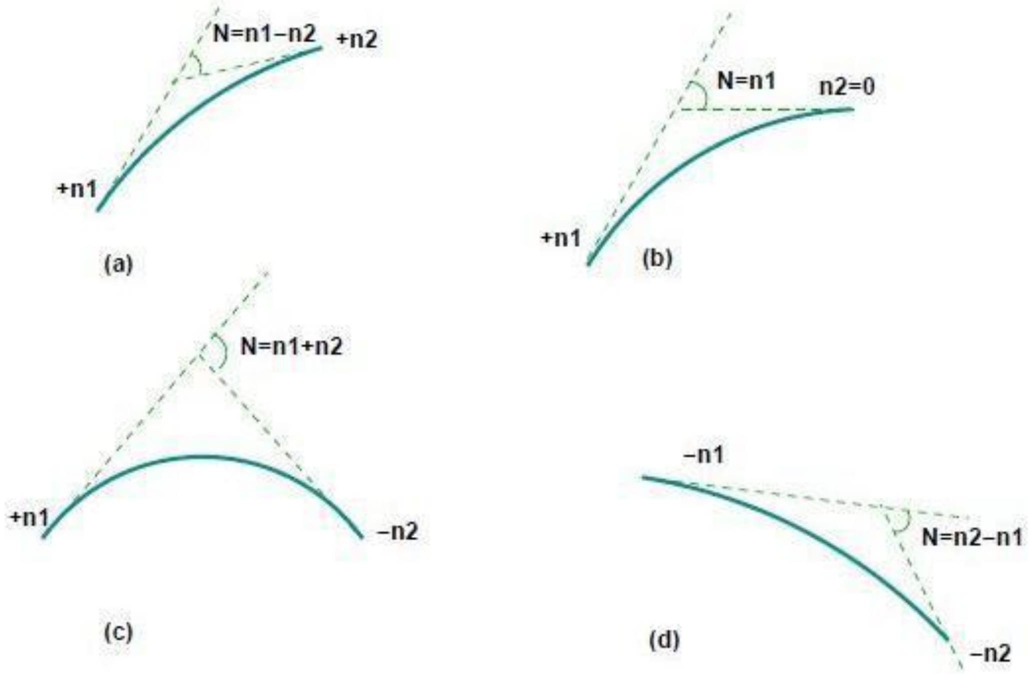
Minimum gradient:

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains require some slope for smooth flow of water. Therefore minimum gradient is provided for drainage purpose and it depends on the rainfall, type soil and other site conditions.

SUMMIT CURVE

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illustrated in figure below in any of the following four ways:

1. When a positive gradient meets another positive gradient
2. When positive gradient meets a at gradient
3. When an ascending gradient meets a descending gradient.
4. When a descending gradient meets another descending gradient



Types of summit curves

Type of Summit Curve

Many curve forms can be used with satisfactory results; the common practice has been to use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another.

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.

Distance Let L is the length

Case a: Length of summit curve greater than sight distance

The situation when the sight distance is less than the length of the curve

$$
\begin{aligned}
y &= ax^2 \\
a &= \frac{N}{2L} \\
h_1 &= aS_1^2 \\
h_2 &= aS_2^2 \\
S_1 &= \sqrt{\frac{h_1}{a}} \\
S_2 &= \sqrt{\frac{h_2}{a}} \\
S_1 + S_2 &= \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}} \\
S^2 &= \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
S^2 &= \frac{2L}{N} \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
L &= \frac{NS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}
\end{aligned}
$$

Case b: Length of summit curve less than sight distance

$$L = 2S - \frac{\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}{N}$$

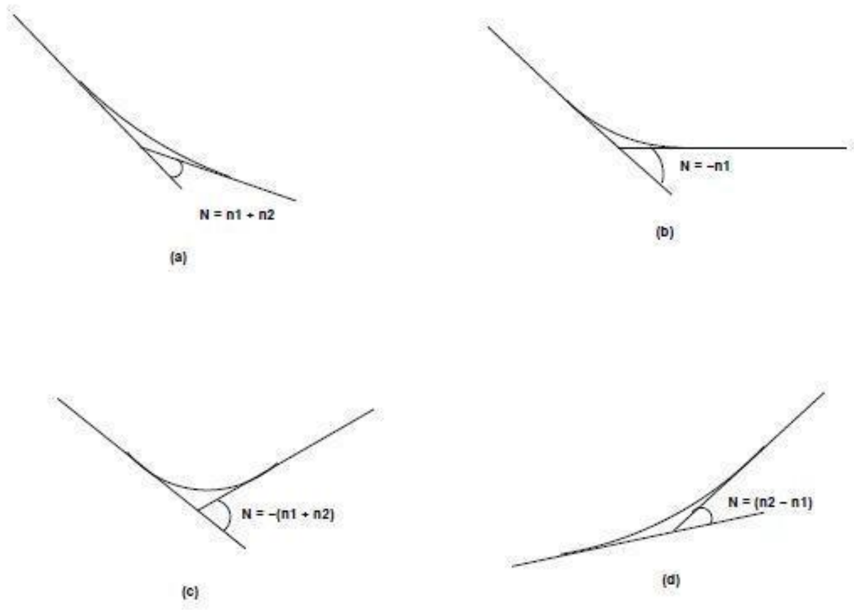
When stopping sight distance is considered the height of driver's eye above the road surface (h_1) is taken as 1.2 meters, and height of object above the pavement surface (h_2) is taken as 0.15 meters. If overtaking sight distance is considered, then the value of driver's eye height (h_1) and the height of the obstruction (h_2) are taken equal as 1.2 meters.

Valley curve

Valley curve or sag curves are vertical curves with convexity downwards. 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



Types of valley curve

Length of the valley curve

The valley curve is made fully transitional by providing two similar transition curves of equal length The transitional curve is set out by a cubic parabola $y = bx^3$ where $b = 2N^3/L2$ The length of the valley transition curve is designed based on two criteria:

1. Comfort criteria; that is allowable rate of change of centrifugal acceleration is limited

to a comfortable level of about 0:6m=sec3.

2. Safety criteria; that is the driver should have adequate headlight sight distance at any part of the country.

Comfort criteria

The length of the valley curve based on the rate of change of centrifugal acceleration that will ensure comfort: Let c is the rate of change of acceleration, R the minimum radius of the curve, v is the design speed and t is the time, then c is given as:

$Ls = v^3/CR$

For a cubic parabola, the value of R for length Ls is given by:

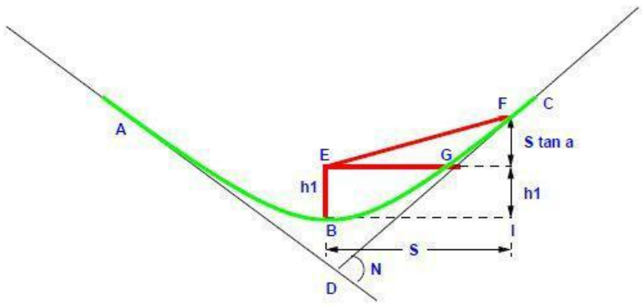
R = Ls N

Safety criteria

Length of the valley curve for headlight distance may be determined for two conditions: length of the valley curve greater than stopping sight distance and Length of the valley curve less than the stopping sight distance.

Case 1: Length of valley curve greater than stopping sight distance (L > S)

The total length of valley curve L is greater than the stopping sight distance SSD. The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve.



Valley curve, case1, $L > S$

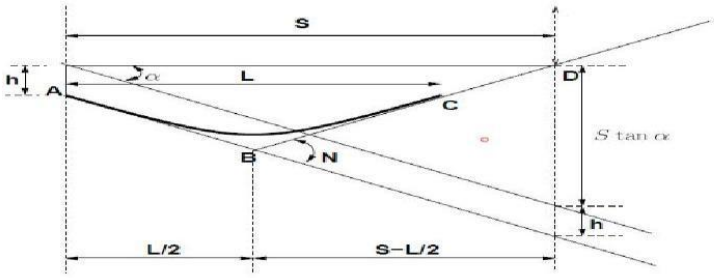
Where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as 0:6m/sec^3.

$$\begin{aligned} h_1 + S\tan\alpha &= aS^2 \\ &= \frac{NS^2}{2L} \\ L &= \frac{NS^2}{2h_1 + 2S\tan\alpha} \end{aligned}$$

Where N is the deviation angle in radians, h1 is the height of headlight beam, α is the head beam inclination in degrees and S is the sight distance. The inclination α is = 1 degree.

Case 2 Length of valley curve less than stopping sight distance (L < S)

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve. The case is shown in figure below.



Valley curve, case 2, $S > L$

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

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

The gradients are very small and are acceptable for all practical purposes. We will not be able to know prior to which case to be adopted. Therefore both has to be calculated and the one which satisfies the condition is adopted.