Program : **B.Tech**

Subject Name: **Transportation Engg II**

Subject Code: **CE-502**

Semester: **5th**

Unit I

Highway planning, Alignment & Geometric Design

Principles of highway planning, road planning in India and financing of roads, classification patterns. Requirements, engineering Surveys for highway location.

Cross sectional elements- width, camber, super-elevation, sight distances, extra widening at curves, horizontal and vertical curves and numerical problems.

Introduction to Highway Planning:

Planning is a prerequisite for any engineering activity or project; this is particularly true for the development of a highway network or system in a country.

Role of transportation in society

Transportation is a non-separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations. This chapter conveys an understanding of the importance of transportation in the modern society by presenting selected characteristics of existing transportation systems, their use and relationships to other human activities.

Transportation is responsible for the development of civilizations from very old times by meeting travel requirement of people and transport requirement of goods. Such movement has changed the way people live and travel. In developed and developing nations, a large fraction of people travel daily for work, shopping and social reasons. But transport also consumes a lot of resources like time, fuel, materials and land.

The objectives of highway planning are:

i. **Planning a highway network for safe, efficient and fast movement of people and goods.**
ii. **Keeping the overall cost of construction and maintenance of the roads in the network to a minimum.**
iii. **Planning for future development and anticipated traffic needs for a specific design period.**
iv. **Phasing road development programmes from considerations of utility and importance as also of financial resources.**
v. **Evolving a financing system compatible with the cost and benefits.**

To fulfill these objectives, the following principles have to be borne in mind:

i. **The proposed road links should be a part of the planned road network for the state/nation.**

ii. **The importance of the road shall be based on the traffic demand, and hence its type should fall under the standard classification.**
iii. **The maintenance needs of the roads should receive prompt attention by setting aside funds for this purpose.**
iv. **Statutory provisions for traffic regulation should be in place.**

From the beginning of history, human sensitivity has revealed an urge for mobility leading to a measure of Society's progress. The history of this mobility or transport is the history of civilization. For any country to develop with right momentum modern and efficient Transportation basic infrastructure is a must.

Modes of Transportation:

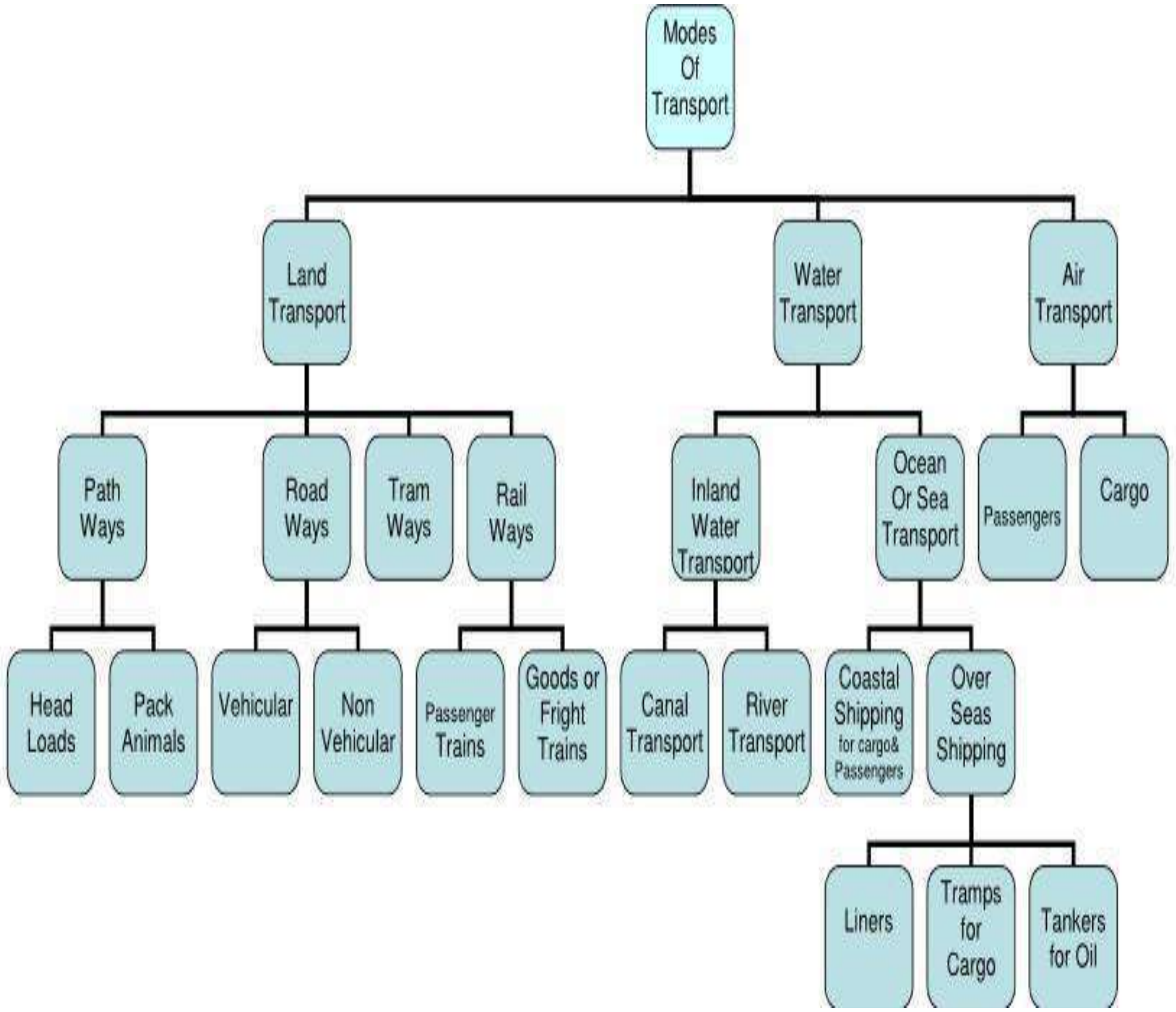

Fig:1 Modes of transportation

Advantage and Disadvantage Road Transportation:

Table:1 Advantage and disadvantages of road transportation

Advantages	Disadvantages
1. Less Capital Outlay	1. Seasonal Nature
2. Door to Door Service	2. Accidents and Breakdowns
3. Service in Rural Areas	3. Unsuitable for Long Distance and Bulky Traffic
4. Flexible Service	4. Slow Speed
5. Suitable for Short Distance	5. Lack of Organization
6. Lesser Risk of Damage in Transit	
7. Saving in Packing Cost	
8. Rapid Speed	

History of Highway Engineering

The history of highway engineering gives us an idea about the roads of ancient times. Roads in Rome were constructed in a large scale and it radiated in many directions helping them in military operations. Thus they are considered to be pioneers in road construction. Here we will see in detail about Ancient roads, Roman roads, British roads, French roads etc.

Ancient Roads

The most primitive mode of transport was by foot. These human pathways would have been developed for specific purposes leading to camp sites, food, streams for drinking water etc. The invention of wheel in Mesopotamian civilization led to the development of animal drawn vehicles. To provide adequate strength to carry the wheels, the new ways tended to follow the sunny drier side of a path. After the invention of wheel, animal drawn vehicles were developed and the need for hard surface road emerged. Traces of such hard roads were obtained from various ancient civilization dated as old as 3500BC.The earliest authentic record of road was found from Assyrian empire constructed about 1900BC.

Roman roads

The earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome. Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship. Their roads were very durable and some still exist. The roads were bordered on both sides by longitudinal drains. A typical cross section is shown in Fig below. This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during the side drain construction. This was then topped with a sand leveling course. In the case of heavy traffic, a surface course of large 250 mm thick hexagonal stones were provided. They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

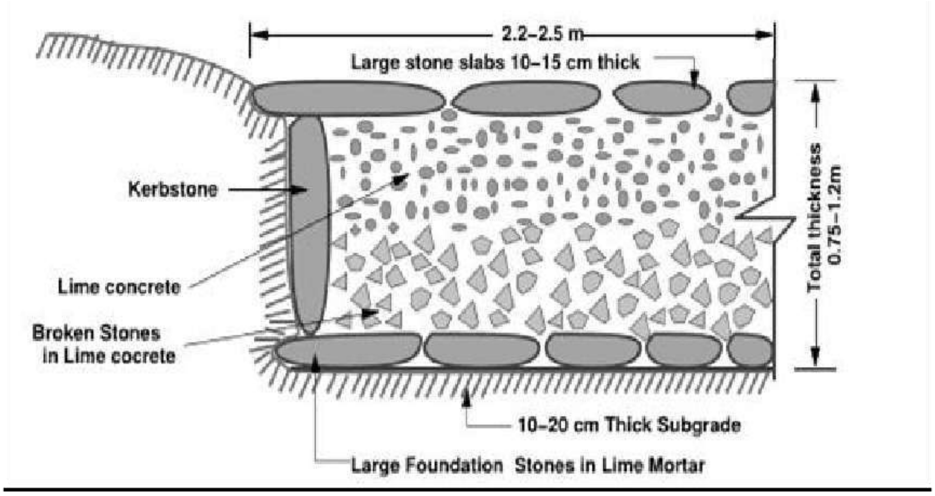

Fig:2 Roman roads

French roads

The significant contributions were given by Tresaguetin 1764 and a typical cross section of this road is given in Figure below. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200mm pieces of quarried stone of a more compact form and shaped such that they had at least one at side which was placed on a compact formation. Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally the running layer was made with a layer of 25 mm sized broken stone. All this structure was placed in a trench in order to keep the running surface level with the surrounding countryside. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

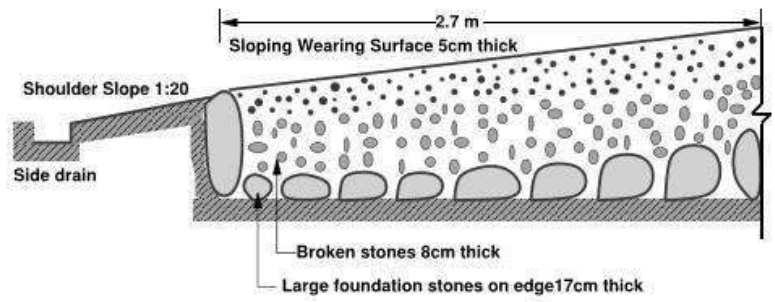

Fig3: French roads

British roads

The British government also gave importance to road construction. The British engineer John Macadam introduced what can be considered as the first scientific road construction method. Stone size was an important element of Macadam recipe. By empirical observation of many roads, he came to realize that 250mm layers of well compacted broken angular stone would provide the same strength a better running surface than an expensive pavement founded on large stone blocks. Thus he introduced an economical method of road construction.

Modern roads

The modern roads by and large follow Macadam's construction method. Use of bituminous concrete and cement concrete are the most important developments. Development of new equipments helps in the faster construction of roads. Many easily and locally available materials are tested in the laboratories and then implemented on roads for making economical and durable pavements.

Road Development in India

Excavations in the sites of Indus valley revealed the existence of planned roads in India as old as 2500-3500BC.TheMauryan kings also built very good roads. During the time of Mughal period, roads in India were greatly improved. Roads linking North-West and the Eastern areas through gangetic plains were built during this time. The construction of Grand-Trunk road connecting North and South is a major contribution of the British.

Modern developments

The First World War period and that immediately following it found a rapid growth in motor transport. So need for better roads became a necessity. For that, the Government of India appointed a committee called Road development Committee with Mr.M.R. Jayakar as the chairman. This committee came to be known as Jayakar committee.

Jayakar Committee

In 1927 Jayakar committee for Indian road development was appointed. The major recommendations and the resulting implementations were:

- Committee found that the road development of the country has become beyond the capacity of local governments and suggested that Central government should take the proper charge considering it as a matter of national interest.
- They gave more stress on long term planning program, for a period of 20years (hence called twenty year plan) that is to formulate plans and implement those plans within the next 20years.
- One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official technical body called Indian Road Congress(IRC) in1934
- The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation and license fees for vehicles plying for hire. This led to the introduction of a development fund called Central road fund in 1929. This fund was intended for road development.

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Nagpur road congress (1943-1963)

A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a co-ordinate 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 committee planned to construct 2 lakh kilometers of road across the country within 20 years. They recommended the construction of star and grid pattern of roads throughout the country. One of the objective was that the road length should be increased so as to give a road density of 16kmsper 100sq.km

Bombay road congress (1961-1981)

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. Accordingly a 20-yearplan was drafted by the Road swing 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 10lakhs.
- Rural roads were given specific attention.
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100sq.km

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

Lucknow road congress (1981-2001)

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 kilometers by the year 1981 resulting in a road density of 82kms/100sq.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.

Current Scenario:

About 60 % of freight and 87 % passenger traffic is carried by road. Although National Highways constitute only about 2 % of the road network, it carries 40 % of the total road traffic. Easy availability, adaptability to individual needs and cost savings are some of the factors which go in favor of road transport. Road transport also acts as a feeder service to railway, shipping and air traffic. The number of vehicles has been growing at an average pace of around 10 % per annum. The share of road traffic in total traffic has grown from 13.8 per cent of freight traffic and 15.4 percent of passenger traffic in 1950-51 to an estimated 62.9 per cent of freight traffic and 90.2 percent of passenger traffic by the end of 2009-10.Therapid expansion and strengthening of the road network, therefore, is imperative, to provide for both present and future traffic and for improved accessibility to the hinterland.

Highway Planning:

Highway design is only one element in the overall highway development process. Historically, detailed design occurs in the middle of the process, linking the preceding phases of planning and project development with the subsequent phases of right-of-way acquisition, construction and maintenance. It is during the first three stages, planning, project development and design, that designers and communities, working together, can have the greatest impact on the final design features of the project. In fact the flexibility available for highway design during the detailed design phase is limited a great deal by the decisions made at the earliest ages of planning and project development.

Stages of highway development:

- Planning
- Project development
- Final design
- Right of way
- Construction

Planning

The initial definition of the need for any highway or bridge improvement project takes place during the planning stage. This problem definition occurs at the State, regional, or local level, depending on the scale of the proposed improvement. This is the key time to get the public involved and provide input into the decision making process. The problems identified usually fall into one or more of the following four categories:

1. The existing physical structure needs major repair/replacement (structure repair).

2. Existing or projected future travel demands exceed available capacity, and access to transportation and mobility need to be increased (capacity).
3. Therouteisexperiencinganinordinatenumberofsafetyandaccidentproblemsthatcan only be resolved through physical, geometric changes (safety).
4. Developmentalpressuresalongtheroutemakeareexaminationofthenumber, location, and physical design of access points necessary (access).

Factors to Consider During Planning

It is important to look ahead during the planning stage and consider the potential impact that a proposed facility or improvement may have while the project is still in the conceptual phase. During planning, key decisions are made that will affect and limit the design options in subsequent phases.

Project Development

After a project has been planned and programmed for implementation, it moves into the project development phase. At this stage, the environmental analysis intensifies. The level of environmental review varies widely, depending on the scale and impact of the project. It can range from a multiyear effort to prepare an Environmental Impact Statement (a comprehensive document that analyzes the potential impact of proposed alternatives) to a modest environmental review completed in a matter of weeks. Regardless of the level of detail or duration, the product of the project development process generally includes a description of the location and major design features of the recommended project that is to be further designed and constructed, while continually trying to avoid, minimize, and mitigate environmental impact.

Final Design

After a preferred alternative has been selected and the project description agreed upon as stated in the environmental document, a project can move into the final design stage. The product of this stage is a complete set of plans, specifications, and estimates (PS&Es) of required quantities of materials ready for the solicitation of construction bids and subsequent construction. Depending on the scale and complexity of the project, the final design process may take from a few months to several years.

Right-of-way, Construction and Maintenance

Once the final designs have been prepared and needed right-of-way is purchased, construction bid packages are made available, a contractor is selected and construction is initiated. During the right-of-way acquisition and construction stages, minor adjustments in the design may be necessary; therefore, there should be continuous involvement of the design team throughout these stages. Construction may be simple or complex and may require a few months to several years. Once construction has been completed, the facility is ready to begin its normal sequence of operations and maintenance.

Even after the completion of construction, the character of a road can be changed by inappropriate maintenance actions. For example, the replacement of sections of guardrail damaged or destroyed in crashes commonly utilizes whatever spare guardrail sections maybe available to the local highway maintenance personnel at the time.

Stages of Highway Development

Summaries of the five basic stages in highway planning and development.

Table: 2Stages of the highway design

Stages	Description of Activity
Planning	Identification of transportation needs and program project to be built Within financial constraints.
Project Development	The transportation project is more clearly defined. Alternative locations and design features are developed and an alternative is selected.
Design	The design team develops detailed design and specification.
Right-of-way	Land needed for the project is acquired.
construction	Selection of contractor, who then builds the project.

Geometric Design:

Geometric design for transportation facilities includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections, and various design details. These basic elements are common to all linear facilities, such as roadways, railways, and airport runway sand taxiways. Although the details of design standards vary with the mode and the class of facility, most of the issues involved in geometric design are similar for all modes. In all cases, the goals of geometric design are to maximize the comfort, safety, and economy of facilities, while minimizing their environ-mental impacts. This chapter focuses on the fundamentals of geometric design, and presents standards and examples from different modes.

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The features normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection. The design of these features is to a great extend influenced by driver behavior and psychology, vehicle characteristics, traffic characteristics such as speed and volume. Proper geometric design will help in the reduction of accidents and their severity. Therefore, the objective of geometric design is to provide optimum efficiency in traffic operation and maximum safety at reasonable cost.

The planning cannot be done stage wise like that of a pavement, but has to be done well in advance. The main components that will be discussed are:

1. Highway alignment
2. Road classification,
3. Pavement surface characteristics,

4. Cross-section elements including cross slope, various widths of roads and features in the road margins.
5. Sight distance elements including cross slope, various widths and features in the road margins.
6. Horizontal alignment which includes features like super elevation, transition curve, extra widening and set back distance.
7. Vertical alignment and its components like gradient, sight distance and design of length of curves. Intersection features like layout, capacity, etc

Factors affecting geometric design:

- **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.
- **Traffic factors:** It is of crucial importance in highway design, is the traffic data both current and future estimates. Traffic volume indicates the level of services (LOS)for which the highway is being planned and directly affects the geometric features such as width, alignment, grades etc., without traffic data it is very difficult to design any highway
- **Design Hourly Volume and Capacity:** The general unit for measuring traffic on highway is the Annual Average Daily Traffic volume, abbreviated as AADT. The traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to the highest value during the peak hour. It will be uneconomical to design the roadway facilities for the peak traffic flow
- **Environmental and other factors:** The environmental factors like air pollution, noise pollution, landscaping, aesthetics and other global conditions should be given due considerations in the geometric design of roads.

Road classification

The roads can be classified in many ways. The classification based on speed and accessibility is the most generic one. Note that as the accessibility of road increases, the speed reduces. Accordingly, the roads can classify as follows in the order of increased accessibility and reduced speeds.

- **Freeways:** Freeways are access controlled divided highways. Most freeways are four lanes, two lanes each direction, but many freeways widen to incorporate more lanes as they enter urban areas. Access is controlled through the use of interchanges, and the type of interchange depends upon the kind of intersecting road way (rural roads, another freeway etc.)
- **Expressways:** They are superior type of highways and are designed for high speeds (120km/hr is common), high traffic volume and safety. They are generally provided with grade separations at intersections. Parking, loading and unloading of goods and pedestrian traffic is not allowed on expressways.
- **Highways:** They represent the superior type of roads in the country. Highways are of two types - rural highways and urban highways. Rural highways are those passing through rural areas (villages) and urban highways are those passing through large cities and towns, i.e. urban areas.
- **Arterials:** It is a general term denoting a street primarily meant for through traffic usually on a

continuous route. They are generally divided highways with fully or partially controlled access. Parking, loading and unloading activities are usually restricted and regulated. Pedestrians are allowed to cross only at intersections/designated pedestrian crossings.

- Local streets: A local street is the one which is primarily intended for access to residence, business or abutting property. It does not normally carry large volume of traffic and also it allows unrestricted parking and pedestrian movements.
- Collector streets: These are streets intended for collecting and distributing traffic to and from local streets and also for providing access to arterial streets. Normally full access is provided on these streets. There are few parking restrictions except during peak hours.

Based on usage

This classified is based on whether the roads can be used during different seasons of the year.

- All-weather roads: Those roads which are negotiable during all weathers, except at major river crossings where interruption of traffic is permissible up to a certain extent are called all weather roads.
- Fair-weather roads: Roads which are negotiable only during fair weather are called fair weather roads.

Based on carriageway

This classification is based on the type of the carriage way or the road pavement.

- Paved roads with hard surface: If they are provided with a hard pavement course such roads are called paved roads.(eg: stones, Water bound macadam(WBM),Bituminous macadam (BM), concrete roads)
- Unpaved roads: Roads which are not provided with a hard course of at least a WBM layer is called unpaved roads. Thus earth and gravel roads come under this category.

Based on pavement surface

Based on the type of pavement surfacing provided, they are classified as surfaced and un-surfaced roads.

- Surfaced roads (BM, concrete): Roads which are provided with a bituminous or cement concreting surface are called surfaced roads.
- Un-surfaced roads (soil/gravel): Roads which are not provided with a bituminous or cement concreting surface are called un-surfaced roads.

Highway alignment

Once the necessity of the highway is assessed, the next process is deciding the alignment. The highway alignment can be either horizontal or vertical and they are described in detail in the following sections.

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.

Requirements

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 alignment should be easy to construct and maintain. It should be easy for the operation of vehicles. So to the maximum extend easy gradients and curves should be provided.
- 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.
- 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:

We have seen the requirements of an alignment. But it is not always possible to satisfy all these requirements. Hence we have to make a judicial choice considering all the factors.

The various factors that control the alignment are as follows:

- Obligatory points: These are the control points governing the highway alignment. These points are classified into two categories. Points through which it should pass and points through which it should not pass. Some of the examples are:
- 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.
- **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 the traffic requirements. Based on the origin- destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.

Geometric design: Geometric design factors such as gradient, radius of curve, sight distance etc. also governs the alignment of the highway. To keep the radius of curve minimum, it may be required to change the alignment of the highway. The alignments should be finalized such that the obstructions to visibility do not restrict the minimum requirements of sight distance. The design standards vary with the class of road and the terrain and accordingly the highway should be aligned.

Cross sectional elements:

The primary consideration in the design of geometric cross sections for highways, run-ways and taxiways is drainage. Details vary depending on the type of facility Highway cross sections consist of traveled way, shoulders (or parking lanes) and drainage channels. Shoulders are intended primarily as a safety feature. They provide for accommodation of stopped vehicles, emergency use and lateral support of the pavement. Shoulders may be either paved or unpaved. Drainage channels may consist of ditches (usually grassed swales) or of paved shoulders with berms or curbs and gutters. Cross sections of various roads are given below.

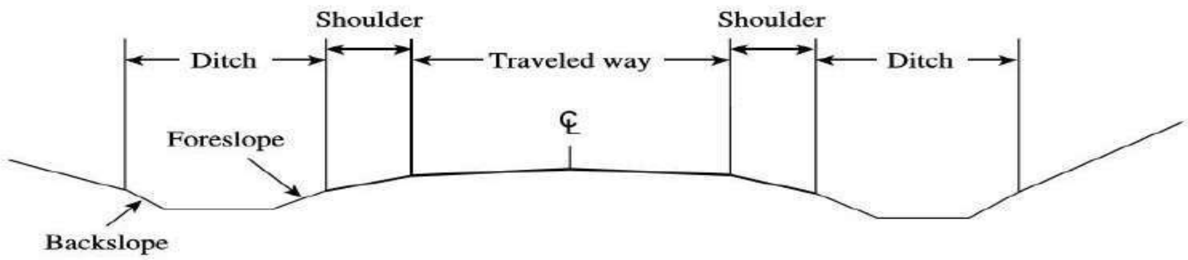


Fig:4 Two-lane highway cross section

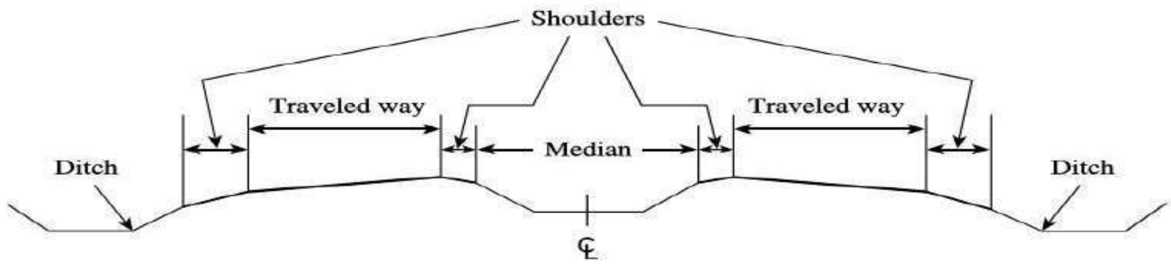


Fig:5 Divided highway cross section, depressed median, with ditches

Pavement surface characteristics:

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 traveled along the road surface is more than the circumferential movement of the wheels due to friction

Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road. Various factors that affect friction are:

The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f. The choice of the value of f is a very complicated issues it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of lateral friction as 0.15. The former is useful in sight distance calculation and the latter in horizontal curve design.

Unevenness

It is always desirable to have an even surface, but it is seldom possible to have such one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires.
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 than2500 mm.km is satisfactory up to speed of 100 Kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55kmph.

Drainage

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

Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain o rain water from road surface.

Too steep slope is un-desirable for it will erode the surface. Camber is measured in 1 in n % (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface.

Width of carriageway

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety.

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or foot paths.
Types:

- **Low or mountable kerbs:**
- **Semi-barrier type kerbs:**
- **Barrier type 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
Shoulders, parking lanes, bus-bays, service roads, cycle track, footpath and guard rails.

Sight Distances:

Sight Distance is a length of road surface which a particular driver can see with an acceptable level of clarity. Sight distance plays an important role in geometric highway design because it establishes an acceptable design speed, based on a driver's ability to visually identify and stop for aparticular, unforeseen roadway hazard or pass as lower vehicle without being in conflict with opposing traffic. As velocities on a roadway are increased, the design must be catered to allowing additional viewing distances to allow for adequate time to stop.

Types of sight distance
- **Stopping sight distance (SSD) or the absolute minimum sight distance**
- **Intermediate sight distance (ISD) or is the as twice SSD**
- **Overtaking sight distance (OSD) for safe overtaking operation**

The computation of sight distance depends on:
1. **Reaction time of the driver**
2. **Speed of the vehicle**
3. **Efficiency of brakes**

PIEV Process

The perception-reaction time for a driver is often broken down into the four components that are assumed to make up the perception reaction time. These are referred to as the PIEV time or process.

- **Perception** — the time to see or discern an object or event
- **Intellection** — the time to understand the implications of the object's presence or event
- **Emotion** — the time to decide how to react
- **Volition** — the time to initiate the action, for example, the time to engage the brakes

Stopping sight distance

Stopping sight distance is defined as the distance needed for drivers to see an object on the roadway ahead and bring their vehicles to safe stop before colliding with the object. The distances are derived for various design speeds based on assumptions for driver reaction time, the braking ability of most vehicles under wet pavement conditions, and the friction provided by most pavement surfaces, assuming good tires. A roadway designed to criteria employs horizontal and vertical alignment and a cross section that provides at least the minimum stopping sight distance through the entire facility.

The stopping sight distance is comprised of the distance to perceive and react to a condition plus the distance to stop:

$$SSD = 0.278\,Vt + \frac{V2}{254\,f} \quad \text{(V is in Kmph)}$$

$$SSD = Vt + \frac{V^2}{2gf} \quad \text{(V is in m/sec)}$$

Where, SSD = Required stopping sight distance, (m)
V = Speed vehicle ()
t = Reaction time of driver (seconds)
f = coefficient of friction
g = acceleration due to gravity ($9.8 m/s^2$)

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 high sea 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.**
- **Spacing between vehicles, which in-turn depends on the speed**
- **Skill and reaction time of the driver**
- **Rate of acceleration of overtaking vehicle**

Horizontal curves

- **A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road. When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the center of gravity of the vehicle.**

$$P = W v^2/gR$$

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 = 9.8 m/sec**

Super elevations

Super elevation is the transverse slope provided to counteract the effect of centrifugal force and reduce the tendency of vehicle to overturn and to skid laterally outwards by raising the pavement outer edge with respect to inner edge. super elevation is represented by " e ".

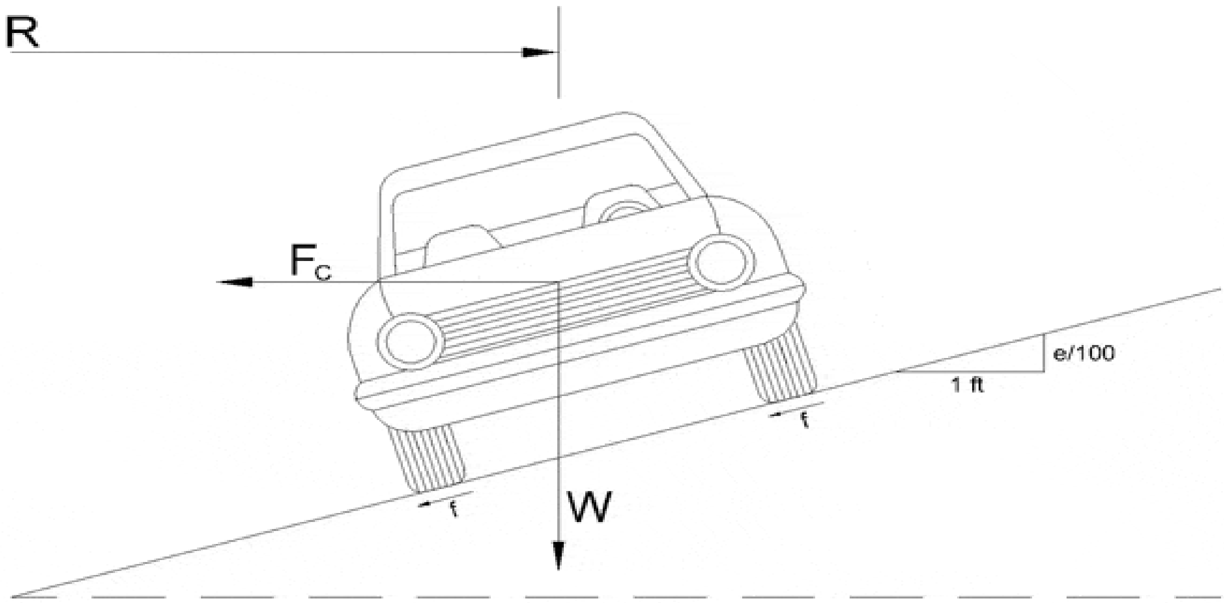
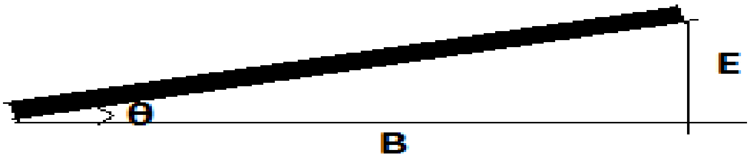


Fig6 :Super elevation in Highway Engineering

Analysis of super elevation



From above fig: $\tan\theta = e = E/B$ .... (1)

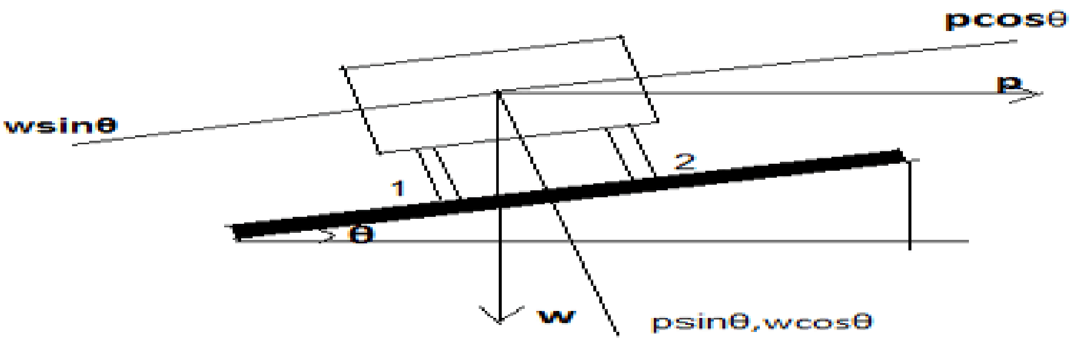


Fig 7:- Super elevation in Highway Engineering

Let us say Design speed = V m/s

Radius = R m

Various forces acting on the vehicle:

IRC Recommendations for Camber

Type of pavement	Light rainfall intensity	Heavy rainfall intensity
C.C pavements and thick bituminous pavements	1 in 60	1 in 50
Thin Bituminous Pavements	1 in 50	1 in 40
W.B.M and Gravel Pavements	1 in 40	1 in 33
Earthen Pavements	1 in 33	1 in25

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.

Offtracking
- 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.
  - It is divided into two parts;

Mechanical widening (Wm): the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening
Psychological widening (Wps): 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 = Wps+ Wm

$W_m = R_2 - R_1$

From Δ OAB, $OA^2 = OB^2 - BA^2$ $R_1^2 = R_2^2 - l^2$

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

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

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

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

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 remainin 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
-

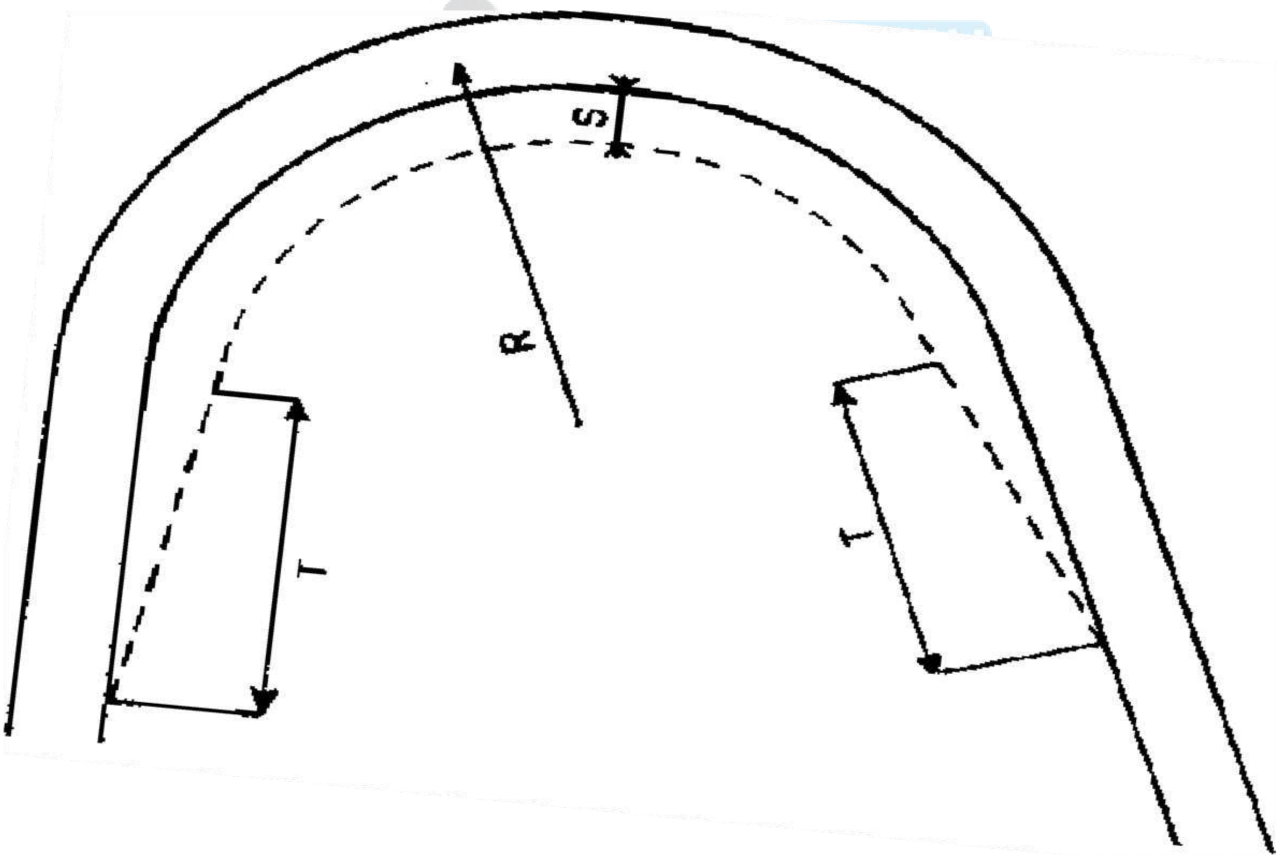


Fig7:- widening of curves

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.

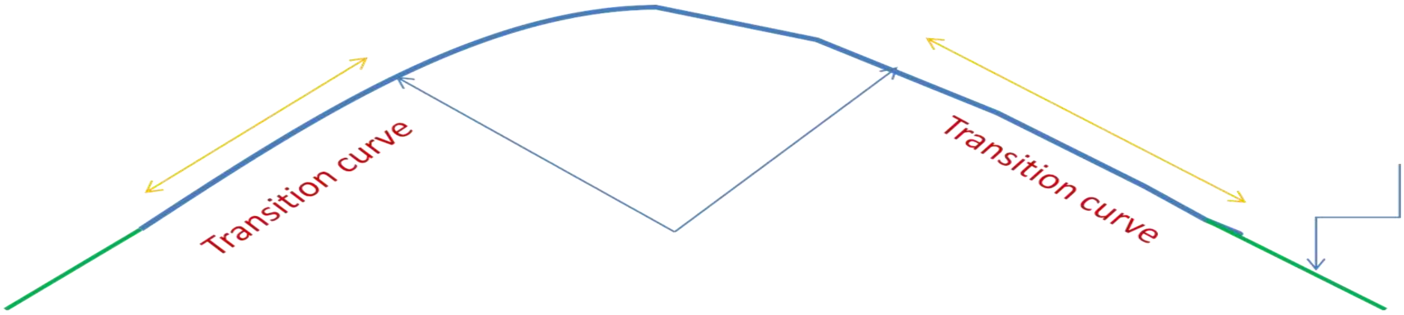


Fig:-8 Horizontal transition curve

Objectives for providing transition curve

- 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.

Shift of the transition curve 'S'

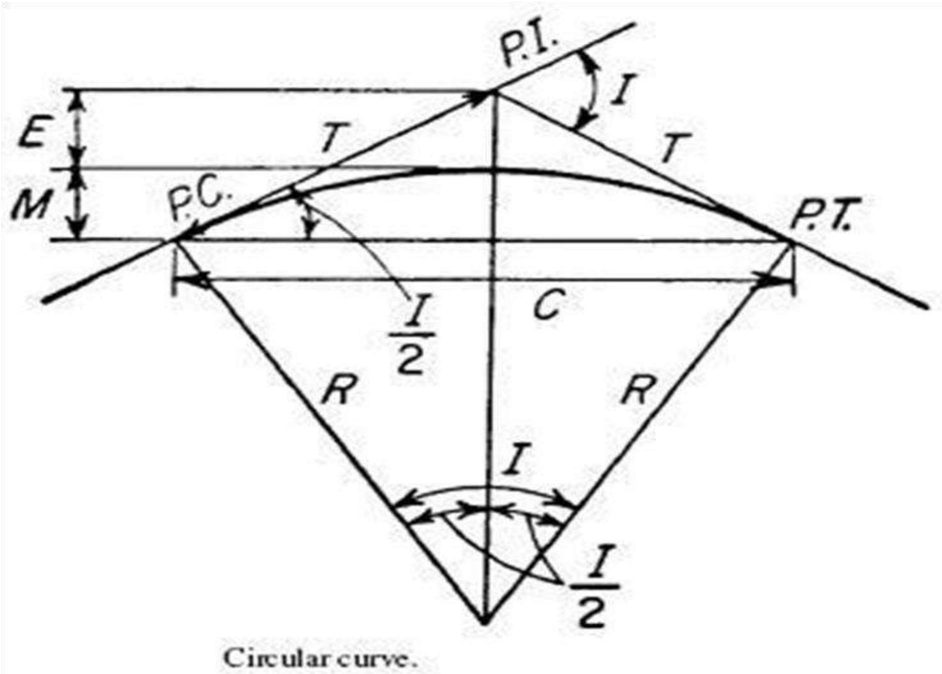


Fig 9:- Shift of Transition curves

Vertical curves:-

It is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal unit). Some times the gradient is also expressed as a percentage i.e. n% (n in 100).

Represented by:

n % + 1 in X (+ve or Ascending) or

-n% - 1 in X (-ve or descending

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 depends 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.

Terrain	Ruling gradient	Limiting gradient	Exceptional gradient
Plain and Rolling	3.3% (1 in 30)	5%	6.70%
Mountainous terrain	5% (1 in 20)	6%	7%

critical length of the grade:

- The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, initial speed.

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 rain fall, type of soil and other site conditions.

A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains

Table 3:- Terrain and various gradient

Steep terrain up to 3000m (MSL)	5% (1 in 20)	6%	7%
Steep terrain (>3000m)	6% (1 in 16.7)	7%	8%

Grade compensation:-

At the horizontal curve ,due to the turning angle α of the vehicle, the curve resistance develop is equal to T(1-Cos α). When there is a horizontal curve in addition to the gradient, there will be a increase in resistance to fraction due to both gradient and curve. It is necessary that in such cases the total resistance due to grade and the curve should not exceeded the resistance due to maximum value of the gradient specified.

Maximum value generally taken as ruling gradient

- Thus grade compensation can be defined as the reduction in gradient at the horizontal curve because of the additional tractive force required due to curve resistance (T−Tcosα), which is intended to offset the extra tractive force involved at the curve.
- IRC gave the following specification for the grade compensation.
    1. Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.
    2. Grade compensation is (30+R)/R %, where 'R' is the radius of

the horizontal curve in meters.

1. The maximum grade compensation is limited to 75/R%.

Velly carve:-

Sag vertical curves are curves that connect descending grades, forming a bowl or a sag. Designing them is is very similar to the design of crest vertical curves. Once again, the sight distance is the parameter that is normally employed to find the length of the curve. When designing a sag vertical curve, however, the engineer must pay special attention to the comfort of the drivers. Sag vertical curves are characterized by a positive change in grade, which means that vehicles traveling over sag vertical curves are

accelerated upward. Because of the inertia of the driver's body, this upward acceleration feels like a downward thrust. When this perceived thrust and gravity combine, drivers can experience discomfort.

The length of sag vertical curves, which is the only parameter that we need for design, is determined by considering drainage, driver comfort, aesthetics, and sight distance. Once again, the aesthetics and driver comfort concerns are normally automatically resolved when the curve is designed with adequate sight distance in mind. Driver comfort, for example, requires a curve length that is approximately 50% of the curve length required for the sight distance. Drainage may be a problem if the curve is quite long and flat, or if the sag is within a cut. For more information on these secondary concerns, see your local design manuals.

The theory behind the sight distance calculations for sag vertical curves is only slightly different from that for crest vertical curves. Sag vertical curves normally present drivers with a commanding view of the roadway during the daylight hours, but unfortunately, they truncate the forward spread of the driver's headlights at night. Because the sight distance is restricted after dark, the headlight beams are the focus of the sight distance calculations. For sight distance calculations, a 1° upward divergence of the beam is normally assumed.

In addition, the headlights of the vehicle are assumed to reside 2 ft above the roadway surface. As with crest vertical curves, these assumptions lead to two possible configurations, one in which the sight distance is greater than the curve length, and one in which the opposite is true. The figure below illustrates these possibilities.

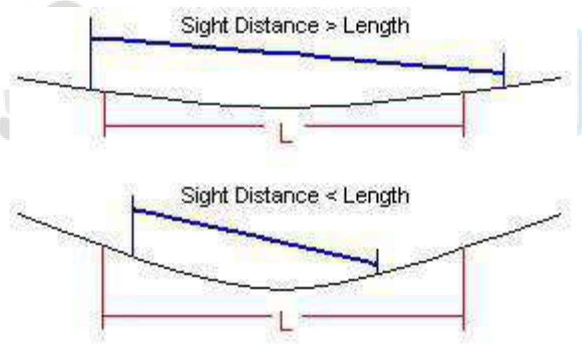


Fig-10 Velly curves

As with crest vertical curves, each possibility has a different design equation. All that you need to do, therefore, is make sure that the results from the equation that you use are consistent with that equation's assumptions. For example, if you employ the equation that assumes the sight distance is greater than the curve length, you should make sure that the resulting curve length is less than the sight distance. The equations for each possibility are given below.

If S > L then

$$L = 2S - \frac{200(H + S*\tan(B))}{A}$$

If S < L then

$$L = \frac{AS^2}{200(H + S*\tan(B))}$$

Where:

L = Curve length (ft)

S = Sight distance (ft) (normally the stopping sight distance)
B = Beam upward divergence (°) (normally assumed as 1°)
H = Height of the headlights (ft) (normally assumed as 2 ft)
A = Change in grade (|G2-G1| as a percent)

The stopping sight distance is normally the controlling sight distance for sag vertical curves. At decision points, the roadway should be illuminated by other means so that the sight distance of the driver is extended. Where possible, increased curve length may also be provided.

Highway overpasses or other obstacles can occasionally reduce the sight distance on sag vertical curves. In these instances, separate equations should be used to determine the correct curve length. These equations are readily available in design manuals.

At this point, you have all of the information that you need to develop the precise layout of your vertical curve. The parabolic curve calculations are identical for sag and crest vertical curves. Just remember to use the appropriate positive or negative values for the participating grades.

Summit curve:-

Crest vertical curves are curves which, when viewed from the side, are convex upwards. This includes vertical curves at hill crests, but it also includes locations where an uphill grade becomes less steep, or a downhill grade becomes steeper.

The most important design criterion for these curves is stopping sight distance. This is the distance a driver can see over the crest of the curve. If the driver cannot see an obstruction in the roadway, such as a stalled vehicle or an animal, the driver may not be able to stop the vehicle in time to avoid a crash. The desired stopping sight distance (S) is determined by the speed of traffic on a road. By first finding the stopping sight distance (S) and then solving for the curve length (L) in each of the equations below, the correct curve length can be determined. The proper equation depends on whether the vertical curve is shorter or longer than the available sight distance. Normally, both equations are solved, then the results are compared to the curve length.

Length of summit curve greater than sight distance($L > S$)

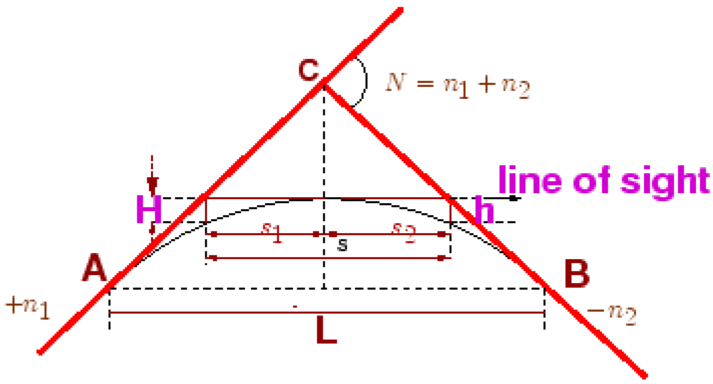


Figure 11: Length of summit curve ($L > S$)

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

The second case is illustrated in fig 12

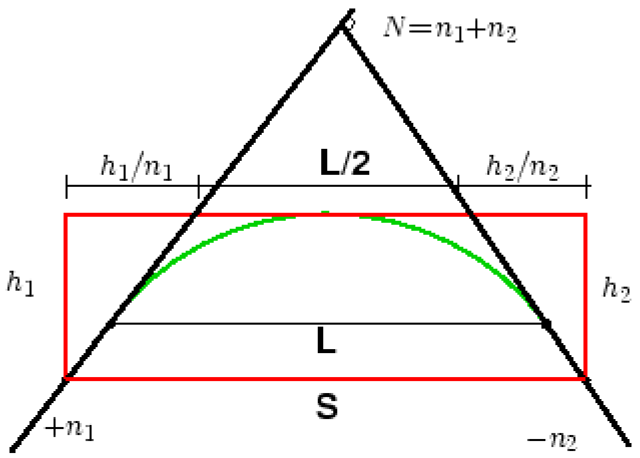


Figure 12: Length of summit curve ($L < S$)

From the basic geometry, one can write

$$S=\frac{L}{2}+\frac{h_1}{n_1}+\frac{h_2}{n_2}=\frac{L}{2}+\frac{h_1}{n_1}+\frac{h_2}{N-n_2} \tag{1}$$

Therefore for a given L, h_1 and h_2 to get minimum S, differentiate the above equation with respect to h_1 and equate it to zero. Therefore,

$$\frac{dS}{dh_1}=\frac{-h_1}{n_1^2}+\frac{h_2}{N-n_1{}^2}=0 h_1\left(N-n_1\right)^2= \qquad h_2 n_1^2$$

$$h_1\left(N^2+n_1^2-2Nn_1\right)= \qquad h_2 n_1^2$$

$$h_1N^2+h_1n_1^2-2Nn_1h_1=h_2n_1^2$$

$$\left(h_2-h_1\right)n_1^2+2Nh_1n_1-h_1N^2=0$$

Solving the quadratic equation for n_1,

$$n_1=\frac{-2Nh_1\pm\sqrt{\left(2Nh_1\right)^2-4\left(h_2-h_1\right)\left(-h_1N^2\right)}}{2\left(h_2-h_1\right)}$$

$$=\frac{-2Nh_1+\sqrt{4N^2h_1^2+4h_1N^2h_2-4h_1^2N^2}}{2\left(h_2-h_1\right)}$$

$$=\frac{-2Nh_1+2N\sqrt{h_1h_2}}{2\left(h_2-h_1\right)}$$

$$n_1 = \frac{N\sqrt{h_1 h_2} - h_1 N}{h_2 - h_1} \qquad \textbf{(2)}$$

Now we can substitute n back to get the value of minimum value of L for a given n_1, n_2, h_1 and h_2. Therefore,

$$S = \frac{L}{2} + \frac{h_1}{\frac{N\sqrt{h_1h_2} - Nh_1}{h_2 - h_1}} + \frac{h_2}{N - \frac{N\sqrt{h_1h_2} - Nh_1}{h_2 - h_1}}$$

Solving for L,

$$= \frac{L}{2} + \frac{h_1(h_2 - h_1)}{N\left(\sqrt{h_1h_2} - h_1\right)} + \frac{h_2(h_2 - h_1)}{Nh_2 - Nh_1 - N\sqrt{h_1h_2} + Nh_1}$$

$$= \frac{L}{2} + \frac{h_1(h_2 - h_1)}{N\left(\sqrt{h_1h_2} - h_1\right)} + \frac{h_2(h_2 - h_1)}{N\left(h_2 - \sqrt{h_1h_2}\right)}$$

$$= \frac{L}{2} + \frac{h_1(h_2 - h_1)\left(h_2 - \sqrt{h_1h_2}\right) + (h_2 - h_1)h_2\left(\sqrt{h_1h_2} - h_1\right)}{N\left(\sqrt{h_1h_2} - h_1\right)\left(h_2 - \sqrt{h_1h_2}\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(h_1h_2 - h_1\sqrt{h_1h_2} + h_2\sqrt{h_1h_2} - h_1h_2\right)}{N\left(\sqrt{h_1h_2} - h_1\right)\left(h_2 - \sqrt{h_1h_2}\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\left(\sqrt{h_1h_2}(h_2 - h_1)\right)}{N\left(h_2\sqrt{h_1h_2} - h_1h_2 + h_1\sqrt{h_1h_2} - h_1h_2\right)}$$

$$= \frac{L}{2} + \frac{(h_2 - h_1)\sqrt{h_1h_2}\left(\sqrt{h_2} + \sqrt{h_1}\right)\left(\sqrt{h_2} - \sqrt{h_1}\right)}{N\sqrt{h_1h_2}\left(h_2 - 2\sqrt{h_1h_2} + h_2\right)}$$

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

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

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

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

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

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

When stopping sight distance is considered the height of driver's eye above the road surface (h_1) is taken as 1.2 metres, and height of object above the pavement surface (h_2) is taken as 0.15 metres. 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 metres.

