TRANSPORTATION ENGINEERING

COURSE CODE- RCI4C002

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SYLLABUS

Module-I (10 hrs)

Modes of transportation, importance of highway transportation, history of road construction. Principle of highway planning, road development plans, highway alignments requirements, engineering surveys for highway location. Geometric design- Design controls, highway cross section elements, cross slope or camber, road width, road margins, typical cross sections of roads, design speed, sight distance, design of horizontal and vertical alignments, horizontal and vertical curves.

Module-II (10 hrs)

Highway Materials:- Properties of subgrade , sub-base , base course and surface course materials , test on subgrade soil, aggregates and bituminous materials. Traffic Engineering:- definition , fundamentals of traffic flow , traffic management, prevention of road accidents , elements of transport planning , highway drainage

Module-III (9 hrs)

Design of Highway Pavements: Flexible pavements and their design, review of old methods, CBR method, IRC:37-2012, equivalent single wheel load factor, rigid pavements, stress in rigid pavement, IRC design method (IRC:58-2011).

Module-IV (9 hrs)

Highway Construction: Construction of various layers, earthwork, WBM, GSB, WMM, various types of bituminous layers, joints in rigid pavements, Hot Mix Plants, Construction of Rigid Pavements

Module-V (7 hrs)

Highway Maintenance: Various type of failures of flexible and rigid pavements.

Books:

- Highway Engineering, by S.K.Khanna and CEG Justo, Nem Chand & Bros.
- Transportation Engineering-Highway Engineering by C Venkatramaiah, Universities Press.
- A course in Highway Engineering by Dr. S.P. Bindra, Dhanpat Rai Publications.
- Principles of Highway Engineering and Traffic Analysis by Mannering Fred L., Washburn Scott S. and Kilaresk Walter P., Wiley India Pvt. Ltd
- Traffic Engineering and Transportation Planning by Kadiyali, L.R.,Khanna Publishers
- Transportation Engineering and Planning by Papacostas, C.S. and Prevedouros, P.D.,Prentice Hall.

ACKNOWLEDGEMENT

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Module I

Lecture-1

INTRODUCTION

Overview

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 Transport as a basic infrastructure is a must. **Transport** (British English) or **transportation** (American English) is the movement of people and goods from one place to another. The term is derived from the Latin *trans* ("across") and *portare* ("to carry").

Means of Transport

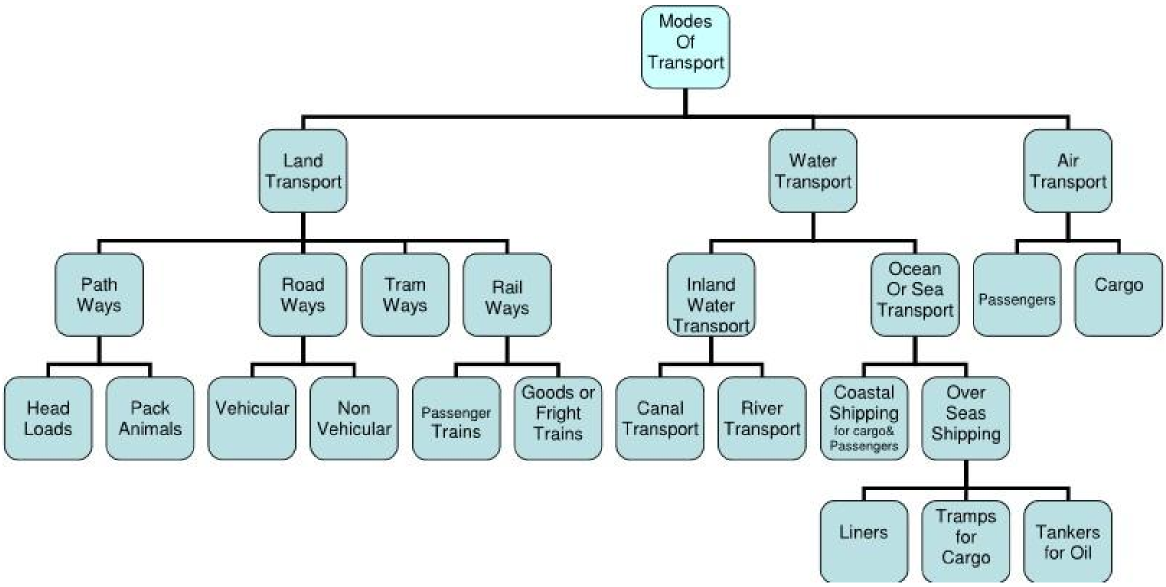

Fig.1.1 Means of Transport

Advantage and Disadvantage Different Modes of Transport

(A) Road Transport

Advantages	Disadvantages
1. Less Capital Outlay 2. Door to Door Service 3. Service in Rural Areas 4. Flexible Service 5. Suitable for Short Distance 6. Lesser Risk of Damage in Transit 7. Saving in Packing Cost 8. Rapid Speed 9. Less Cost	1. Seasonal Nature 2. Accidents and Breakdowns 3. Unsuitable for Long Distance and Bulky Traffic 4. Slow Speed 5. Lack of Organisation

10. Private Owned Vehicles 11. Feeder to other Modes of Transport	

(B) Railway Transport

Advantages	Disadvantages
1. Dependable 2. Better Organised 3. High Speed over Long Distances 4. Suitable for Bulky and Heavy Goods 5. Cheaper Transport 6. Safety 7. Larger Capacity 8. Public Welfare 9. Administrative Facilities of Government 10. Employment Opportunities	1. Huge Capital Outlay 2. Lack of Flexibility 3. Lack of Door to Door Service 4. Monopoly 5. Unsuitable for Short Distance and Small Loads 6. Booking Formalities 7. No Rural Service 8. Under-utilised Capacity 9. Centralised Administration

(C) Air Transport

Advantages	Disadvantages
1. High Speed 2. Comfortable and Quick Services 3. No Investment in Construction of Track 4. No Physical Barriers 5. Easy Access 6. Emergency Services 7. Quick Clearance 8. Most Suitable for Carrying Light Goods of High Value 9. National Defence 10. Space Exploration	1. Very Costly 2. Small Carrying Capacity 3. Uncertain and Unreliable 4. Breakdowns and Accidents 5. Large Investment 6. Specialised Skill 7. Unsuitable for Cheap and Bulky Goods 8. Legal Restrictions

Elements of transport

The movement of goods or passenger traffic, through rail, sea, air or road transport requires adequate infrastructure facilities for the free flow from the place of origin to the place of destination. Irrespective of modes, every transport system has some common elements:

a) Vehicle or carrier to carry passenger or goods
b) Route or path for movement of carriers
c) Terminal facilities for loading and unloading of goods and passengers from carriers
d) Prime Mover
e) Transit time and cost
f) Cargo

These elements influence the effectiveness of different modes of transport and their utility to users.

• **Vehicles:** The dimension of vehicles, its capacity and type are some of the factors, which influence the selection of a transport system for movement of goods from one place to the other.

• **Routes:** Routes play an important role in movement of carriers from one point to another point. It may be surface roads, navigable waterways and roadways. Availability of well-designed and planned routes without any obstacle for movement of transport vehicles in specific routes, is a vital necessity for smooth flow of traffic.

• **Terminal Facilities:** - The objective of transportation cant be fulfilled unless proper facilities are available for loading and unloading of goods or entry and exit of passengers from carrier. Terminal facilities are to be provided for loading and unloading of trucks, wagons etc on a continuous basis.

• **Prime Mover: -** The power utilized for moving of vehicles for transportation of cargo from one place to another is another important aspect of the total movement system.

• **Transit time and cost: -** Transportation involve time and cost. The time element is a valid factor for determining the effectiveness of a particular mode of transport. The transit time of available system of transportation largely determines production and consumption pattern of perishable goods in an economy.

• **Cargo: -** Transportation basically involves movement of cargo from one place to another. Hence, nature and size of cargo constitute the basis of any goods transport system.

Major disciplines of transportation

Transportation engineering can be broadly consisting of the four major parts:

1. Transportation Planning
2. Geometric Design
3. Pavement Design
4. Traffic Engineering

Lecture 2

HIGHWAY DEVELOPMENT IN INDIA

Overview

Road network provides the arterial network to facilitate trade, transport, social integration and economic development. It facilitates specialization, extension of markets and exploitation of economies of scale. It is used for the smooth conveyance of both people and goods. Transportation by road has the advantage over other means of transport because of its easy accessibility, flexibility of operations, door-to-door service and reliability. Consequently, passenger and freight movement in India over the years have increasingly shifted towards roads vis-à-vis other means of transport.

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. In this section 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 3500 BC. The earliest authentic record of road was found from Assyrian empire constructed about 1900 BC.

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 corss section is shown in Fig.2.1. 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 ag 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.

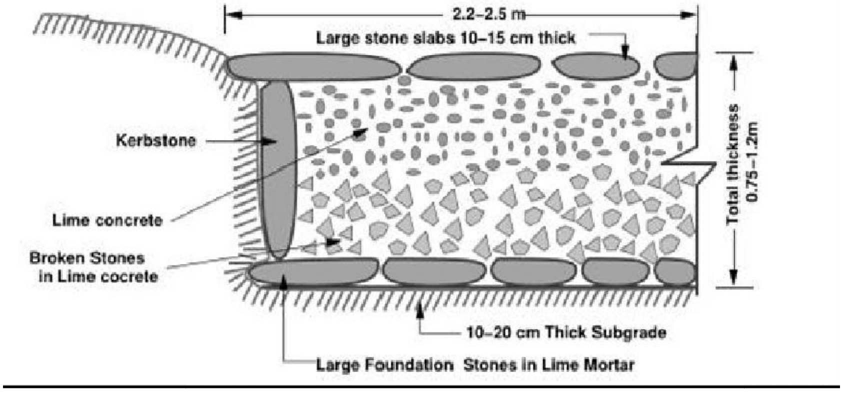

Fig.2.1 Roman roads

French roads

The significant contributions were given by Tresaguet in 1764 and a typical cross section of this road is given in Figure 2.2. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200 mm 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 country side. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

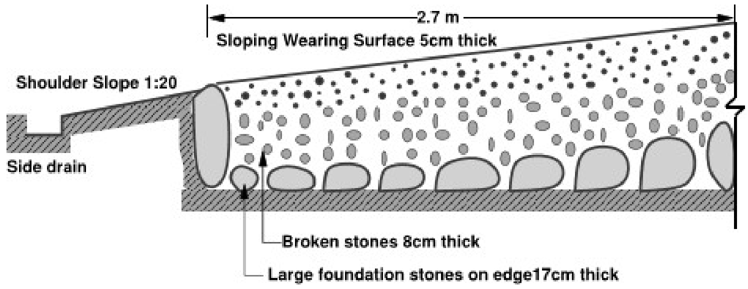

Fig. 2.2. French roads

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 250 mm 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. A typical cross section of British roads is given in Fig. 2.3.

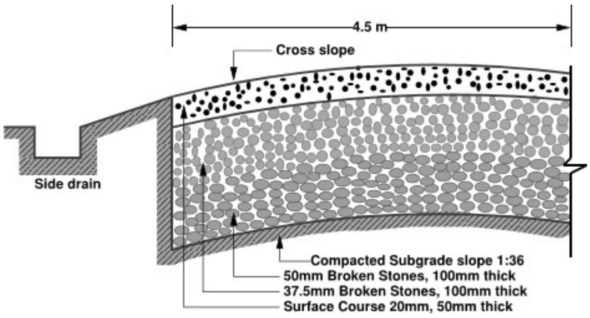

Fig. 2.3. British roads

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 2500-3500 BC. The Mauryan 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 programme, for a period of 20 years (hence called twenty year plan) that is to formulate plans and implement those plans within the next 20 years.
- ✓ 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) in 1934
- ✓ The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation, 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

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 committee planned to construct 2 lakh kms 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 16kms per 100 sq.km

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. 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.
- 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.

Lucknow road congress 1984

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/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.

2.4 Current Scenario

About 60 per cent of freight and 87 per cent passenger traffic is carried by road. Although National Highways constitute only about 2 per cent of the road network, it carries 40 per cent of the total road traffic. Easy availability, adaptability to individual needs and cost savings are some of the factors which go in favour 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 cent per annum. The share of road traffic in total traffic has grown from 13.8 per cent of freight traffic and 15.4 per cent of passenger traffic in 1950-51 to an estimated 62.9 per cent of freight traffic and 90.2 per cent of passenger traffic by the end of 2009-10. The rapid 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.

Lecture 3

HIGHWAY PLANNING

2.1 Overview

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 earlier stages of planning and project development.

The Stages of Highway Development

Although the names may vary by State, the five basic stages in the highway development process are: planning, project development (preliminary design), final design, right of way, and construction. After construction is completed, ongoing operation and maintenance activities continue throughout the life of the facility.

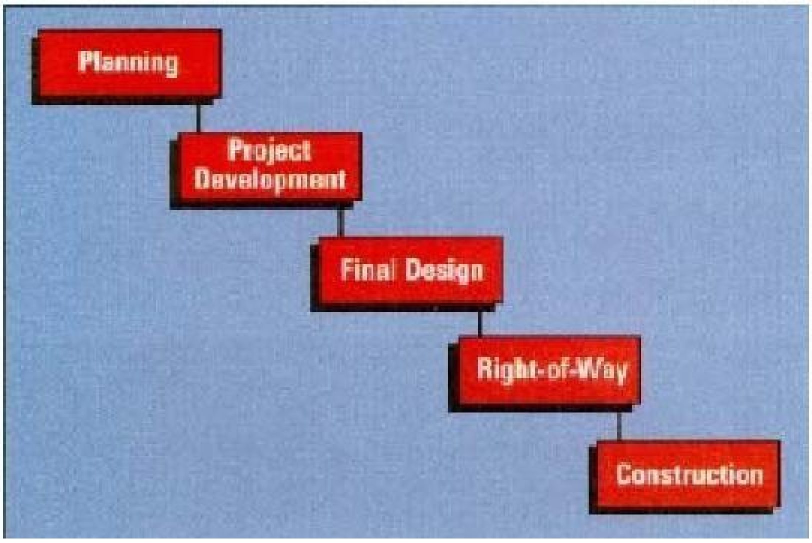


Fig.3.1 Process of Highway Planning

- ✓ **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. The route is experiencing an inordinate number of safety and accident problems that can only be resolved through physical, geometric changes (safety).
4. Developmental pressures along the route make a reexamination of the number, 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.

Fig. 3.2 Factors to consider in planning.

✓ **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.

The following paragraphs discuss some important considerations of design, including:

- Developing a concept
- Considering scale and
- Detailing the design.

➢ Developing a Concept

A design concept gives the project a focus and helps to move it toward a specific direction. There are many elements in a highway, and each involves a number of separate but interrelated design decisions. Integrating all these elements to achieve a common goal or concept helps the designer in making design decisions.

Some of the many elements of highway design are

a. Number and width of travel lanes, median type and width, and shoulders
b. Traffic barriers
c. Overpasses/bridges
d. Horizontal and vertical alignment and affiliated landscape.

➢ Considering Scale

People driving in a car see the world at a much different scale than people walking on the street. This large discrepancy in the design scale for a car versus the design scale for people has changed the overall planning of our communities. For example, it has become common in many suburban commercial areas that a shopper must get in the car and drive from one store to the next.

The design element with the greatest effect on the scale of the roadway is its width, or cross section. The cross section can include a clear zone, shoulder, parking lanes, travel lanes, and/or median. The wider the overall roadway, the larger its scale; however, there are some design techniques that can help to reduce the perceived width and, thus, the perceived scale of the roadway. Limiting the width of pavement or breaking up the pavement is one option.

In some instances, four lane roadways may look less imposing by designing a grass or planted median in the center.

- **Detailing the Design**

Particularly during the final design phase, it is the details associated with the project that are important. Employing a multidisciplinary design team ensures that important design details are considered and those they are compatible with community values. Often it is the details of the project that are most recognizable to the public. A multidisciplinary design team can produce an aesthetic and functional product when the members work together and are flexible in applying guidelines.

- **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 may be 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.

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.

2.3 Highway Route Surveys and Location

To determine the geometric features of road design, the following surveys must be conducted after the necessity of the road is decided.

A variety of survey and investigations have to be carried out by Road engineers and multidiscipline persons.

A. Transport Planning Surveys
    - Traffic Surveys
    - Highway inventories
    - Pavement Deterioration Study
    - Accident study
B. Alignment and Route location surveys
    - Desk study
    - Reconnaissance
    - Preliminary Survey
    - Final location survey
C. Drainage Studies
    - Surface run- off : Hydrologic and hydraulic
    - Subsurface drainage: Ground water & Seepage
    - Cross–drainage: Location and waterway area required for the cross-drainage structures.
D. Soil Survey
    - Desk study
    - Site Reconnaissance
E. Pavement Design investigation Soil property and strength, Material Survey

Lecture 4

INTRODUCTION TO GEOMETRIC DESIGN

4.1. Overview

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 runways and 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. Factors affecting the geometric design,
2. Highway alignment, 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.
8. 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. (See Fig. 4.1). Accordingly, the roads can classified 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(120 km/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.
- **Collectors 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.

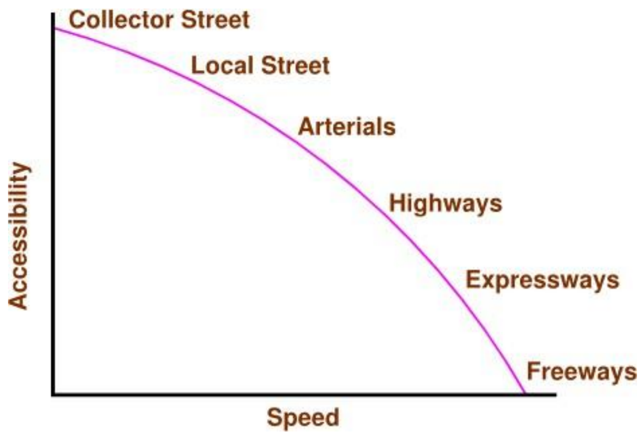


Fig.4.1. Speed vs accessibility

Roads can be classified based on some other criteria. They are given in detail below.

Based on usage

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

- All-weather roads: Those roads which are negotiable during all weathers, except at major river crossings where interruption of tra c 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 carriage way

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 atleast a WBM layer they 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 unsurfaced roads.

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

Other criteria

Roads may also be classified based on the traffic volume in that road, load transported through that road, or location and function of that road.

- Traffic volume: Based on the traffic volume, they are classified as heavy, medium and light tra c roads. These terms are relative and so the limits under each class may be expressed as vehicles per day.
- Load transported: Based on the load carried by these roads, they can be classified as class I, class II, etc. or class A, class B etc. and the limits may be expressed as tonnes per day.

- Location and function: The classification based on location and function should be a more acceptable classification since they may be defined clearly.

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.

Lecture 5

Cross sectional elements

Overview

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 gut-ters. Cross section of various roads are given bellow.

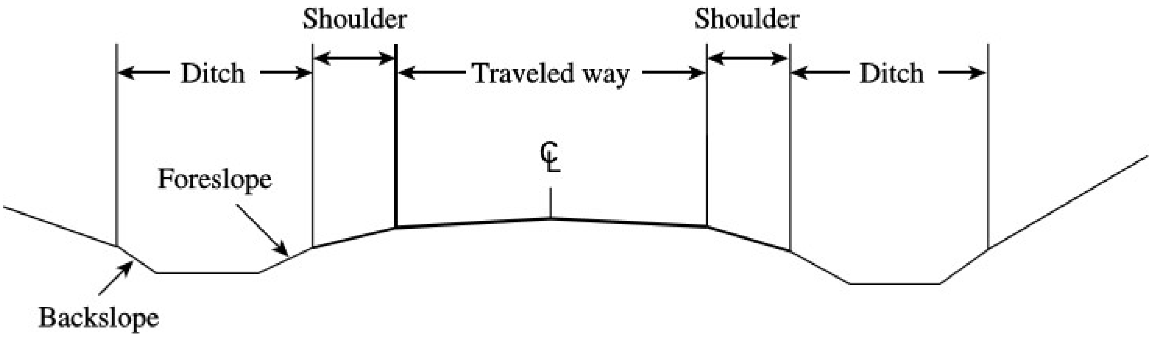


Fig.5.1. Two-lane highway cross section, with ditches.

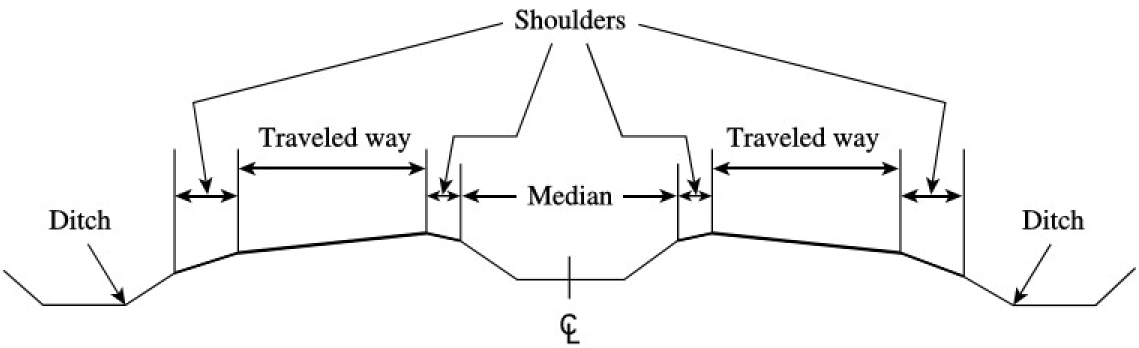


Fig.5.2.Divided highway cross section, depressed median, with ditches.

Pavement surface characteristics

For a safe and comfortable driving four aspects of the pavement surface are important; the friction between the wheels and the pavement surface, smoothness of the road surface, the light reflection characteristics of the top of pavement surface, and drainage to water.

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 a ect 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 a ect friction are:

The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coe cient of friction and denoted as f . The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coe cient of longitudinal friction as 0.35-0.4 depending on

the speed and coe cient of later 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 tyres.

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 Reflection

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 undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface.

Width of carriage way

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

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Di erent types of kerbs are (Figure 12:3):

- 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 given below.

- Shoulders
- Parking lanes
- Bus-bays
- Service roads
- Cycle track
- Footpath
- Guard rails

Lecture 6

Sight distance

Overview

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 a particular, unforeseen roadway hazard or pass a slower 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) is the defined 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.

PIEV 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 a 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:

$$SSD = 0.278\,Vt + \frac{V^2}{254\,(f \pm n)} \qquad \text{(METRIC)}$$

where SSD	=	required stopping sight distance, m or ft.
V	=	speed, kph
t	=	perception-reaction time, sec., typically 2.5 sec. for design
f	=	coefficient of friction, typically for a poor, wet pavement
n	=	grade, decimal.

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 1.2 m 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

Lecture 7

Horizontal alignment I

Overview

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. 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 design speed as noted earlier, is the single most important factor in the design of horizontal alignment. The design speed also depends on the type of the road. For e.g, the design speed expected from a National highway will be much higher than a village road, and hence the curve geometry will vary significantly.

Factors Affecting Alignment

I. Safety
II. Grades
III. Design speed
IV. Cost of resumption of land
V. Construction costs

Operating speed is influenced by all other factors so it is the critical factor to consider.

Horizontal curve

The presence of horizontal curve imparts centrifugal force which is 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.

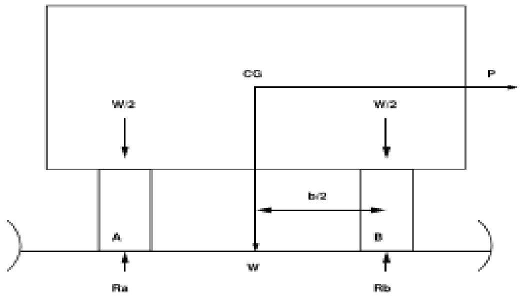


Fig. 7.1. Effect of horizontal curve

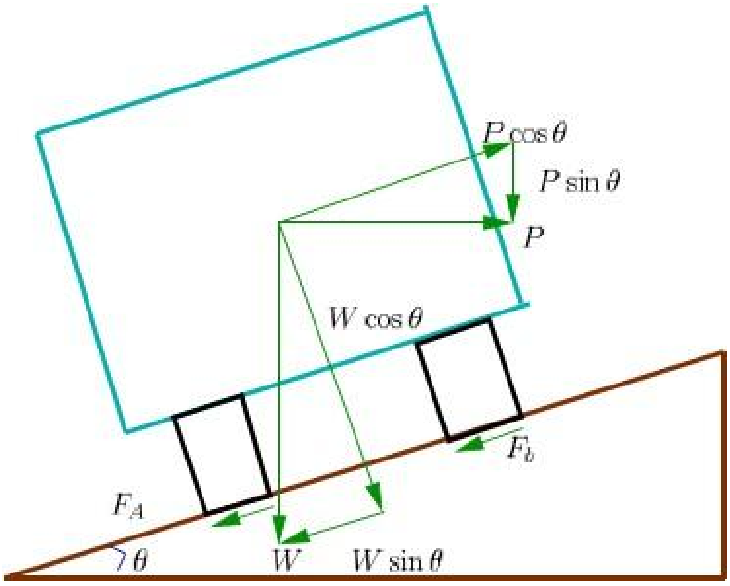


Fig.7.2 Analysis of super elevation

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 mF 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,

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

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

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

By solving the above equation we will get,

$$e + f = \frac{v^2}{gR} = \frac{V^2}{127R}$$

e = superelevation, max. 0.07

f= lateral friction, max. 0.15

v= speed in m/s

V=speed in kmph

R= Radius in m

Lecture 8

Horizontal alignment II

Overview

This section discusses the design of superelevation and how it is attained. A brief discussion about pavement widening at curves is also given.

When being applied to the road need to take into account

- Safety
- Comfort
- Appearance
- Design speed
- Tendency for slow vehicles to track towards centre
- Difference between inner and outer formation levels
- Stability of high laden vehicles
- Length of road to introduce superelevation
- Provision for drainage

Design of super-elevation

For fast moving vehicles, providing higher superelevation without considering coefficient 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 coefficient of friction is safe, i.e.centrifugal force is counteracted by superelevation and coefficient of friction .

Maximum Superelevation

- Max range from flat to mountainous of 0.06 – 0.12 respectively but most authorities limit to0.10
- In urban areas limit max values to 0.04-0.05 Minimum Superelevation
- Should be elevated to at least the cross-fall on straights ie 3% (0.03)

Attainment of super-elevation

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

    rotating the outer edge about the crown

    shifting the position of the crown:

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

    rotation about the center line :

    rotation about 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 coe cient 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 coe cient of friction.

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

Ideally, the radius of the curve should be higher than R_{ruling} . However, very large curves are also not desirable. Setting out large curves in the field becomes difficult. In addition, it also enhances driving strain.

Extra widening

Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons:

Mechanical widening

The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels

Psychological widening

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

Lecture 9

Horizontal alignment III

Overview

In this section we will deal with the design of transition curves and setback distances. Transition curve ensures a smooth change from straight road to circular curves. Setback distance looks in for safety at circular curves taking into consideration the sight distance aspects.

Horizontal Transition Curves

A transition curve differs from a circular curve in that its radius is always changing. As one would expect, such curves involve more complex formulae than the curves with a constant radius and their design is more complex.

The need for Transition Curves

Circular curves are limited in road designs due to the forces which act on a vehicle as they travel around a bend. Transition curves are used to introduce those forces gradually and uniformly thus ensuring the safety of passenger.

Transition curves have much more complex formulae and are more difficult to set out on site than circular curves as a result of the varying radius.

- ✓ 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, and
- ✓ to provide gradual introduction of extra widening.
- ✓ to enhance the aesthetic appearance of the road.

The use of Transition Curves

Transition curves can be used to join to straights in one of two ways:

- Composite curves

- Wholly transitional curves

Types of Transition Curve

There are two types of curved used to form the transitional section of a composite or wholly transitional curve. These are:

-The clothoid

-The cubic parabola.

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 superelevation, and an empirical formula given by IRC.

1. Rate of change of centrifugal acceleration
2. Rate of introduction of super-elevation
3. By empirical formula

Setback Distance

Setback distance m or the clearance distance is the distance required from the centerline of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at a horizontal curve. The setback distance depends on:

1. sight distance (OSD, ISD and OSD),
2. radius of the curve, and
3. length of the curve.

Curve Resistance

When the vehicle negotiates a horizontal curve, the direction of rotation of the front and the r ear wheels are different. The front wheels are turned to move the vehicle along the curve, whereas the rear wheels seldom turn.

Lecture 10

Vertical alignment-I

Overview

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.

Gradient

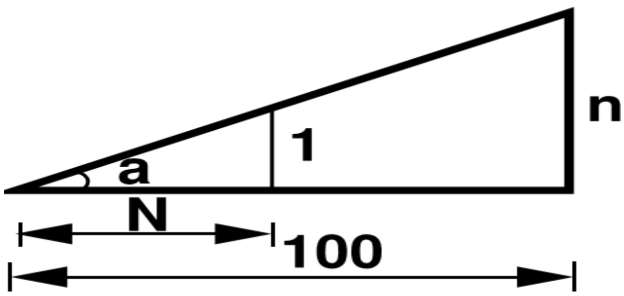
Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. Before nalizing the gradients, the construction cost, vehicular operation cost and the practical problems in the site also 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 = $_1$ + $_2$. Example: 1 in 30 = 3.33% 2^o is a steep gradient, while 1 in 50 = 2% 1^o 10^0 is flatter gradient.



Representation of gradient

IRC Specifications for gradients for different roads

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

Types of gradient

Many studies have shown that gradient upto 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.

Ruling gradient

- Limiting gradient
- Exceptional gradient
- Critical length of the grade
- Minimum gradient
- Summit curve

Summit curves

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet.

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.

Lecture 11

Vertical alignment-II

Overview

Valley curve Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet in any of the following four ways:

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

Design considerations

Thus the most important design factors considered in valley curves are:

(1) impact-free movement of vehicles at design speed and

(2) Availability of stopping sight distance under headlight of vehicles for night driving.

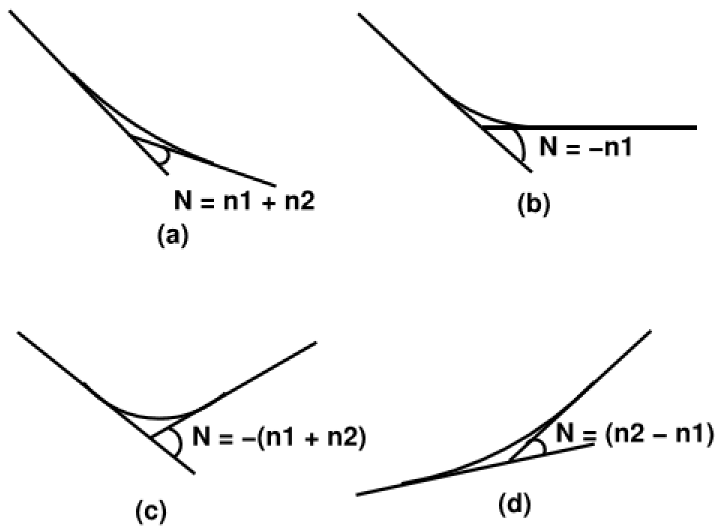


Fig. 11.1 Types of valley curve

Length of the valley curve

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

1. Comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a comfortable 3 level of about 0.6m/sec.

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

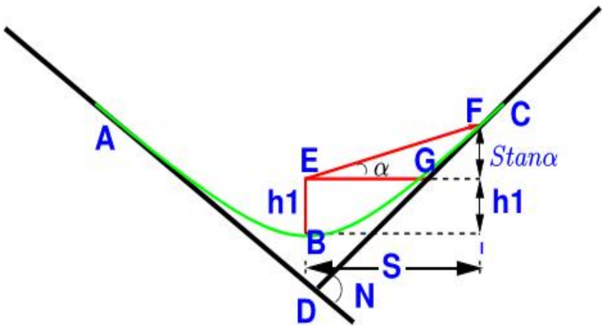


Fig. 11.2 Valley curve, case1, L > S

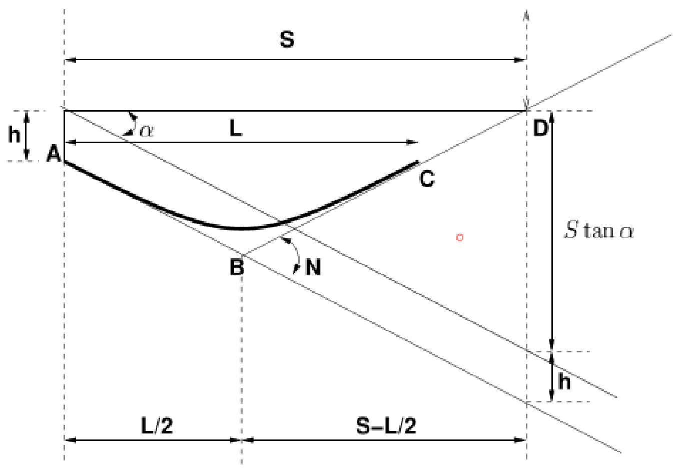


Fig.11.3 Valley curve, case 2, S > L