VISVESVARAYA TECHNOLOGICAL UNIVERSITY
BELGAUM

TRANSPORTATION ENGINEERING

(Subject Code: 21CV56)

LECTURE NOTES

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MODULE 1
PRINCIPLES OF TRANSPORTATION ENGINEERING

Topics to be covered

Principles of Transportation Engineering: Importance of transportation, Different modes of transportation and comparison, Characteristics of road transport Jayakar committee recommendations, and implementation – Central Road Fund, Indian Roads Congress, Central Road **Research Institute Highway Development and Planning**: Road types and classification, roadpatterns, planning surveys, master plan – saturation system of road planning, phasing road Development in India, problems on best alignment among alternate proposals Salient Features of 3rd and 4th twenty year road development plans and Policies, Present scenario of road development in India (NHDP & PMGSY) and in Karnataka (KSHIP & KRDCL) Road development plan - vision 2021.

Importance of Transportation

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

- **Availability of raw materials:** Transportation helps in carrying the raw materials from one place to another place. Initially raw materials are made at one place and are being transported to another place for processing and for manufacturing goods.
- **Availability of goods to the customer:** The goods are being transported from one place to another place. These goods which are produced at one place are transported to other distant places for their usage. It flexibly moves the goods from one place to another place.
- **Enhances the standard of living:** It improves the standard of living. As the transportation of each and every good is being done then the productivity increases which results in the reduced or the effective costs. Because of reduction in the cost they can use differentcommodities for different purposes and can lead a secure life.
- **Helps a lot during the emergencies and even during natural disasters:** Transportation helps during the natural disturbances. It helps in quick moving from one place to another place and supplies the required operations.
- **Helps for the employment:** Transportation provides employment for many people as drivers, captains, conductors, cabin crew and even the people are used for the construction of different types of transportation vehicles. And even by the use of transportation the remote people are being employed with the access to the urban facilities and the opportunities.
- **Helps in mobility of the laborers:** Many people are traveling to other countries on their employment basis. Transportation plays an important role in such cases.

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- **Helps for bringing nations together:** Transportation on the whole is used for globalization i.e. it brings nations together and it creates awareness about the cultural activities and even about the industries and helps a lot for importing and exporting of different goods. These above are some of the necessities which make us to use transportation.

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

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

- Production or supply
- Consumption for human wants or demand.

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

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

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

Concentration of population into urban area: improves transportation facilities bring prosperity to the urban population. The employment opportunities, prosperity and superior facilities for education, medical care etc available in urban area attracts the population from other areas, resulting in enhanced economic activities. Inadequate transportation facilities lead toconcentration of population in cities which often results in growth of slums in urban area, leadingto various associated problems. If efficient transportation facilities area available, the people would prefer to reside at localities away from urban centers and commute to the city for their work. In general the transportation facilities are essential for the well being of the community.

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

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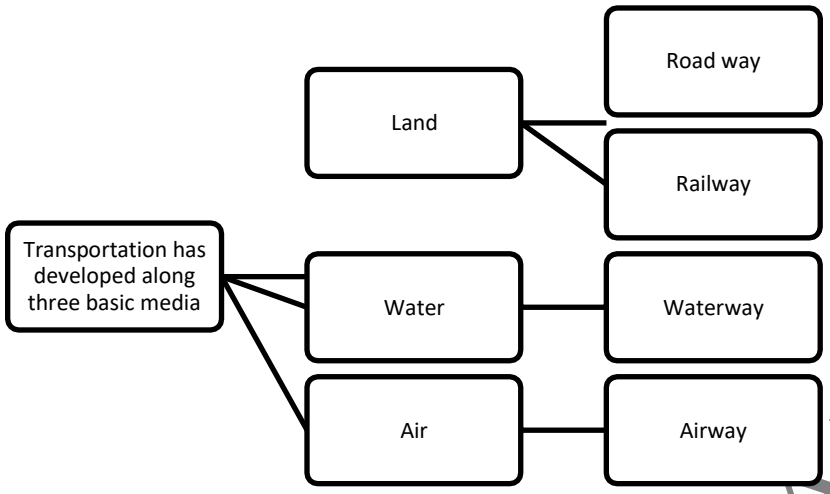
Different Modes of Transportation



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

The four major modes of transportation are:

- Roadways or highways
- Railways
- Airways
- Waterways

Roadway

Advantages	Disadvantages
Lesser Risk of Damage in Transit	Seasonal Nature
Less Capital Outlay	Accidents and Breakdowns
Door to Door Service	Unsuitable for Long Distance and Bulky Traffic
Service in Rural Areas	Slow Speed
Flexible Service	Lack of Organization
Suitable for Short Distance	Large consumer of petroleum energy
Max service to one and all	
Private Owned Vehicles	
Feeder to other Modes of Transport	

Railway

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

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

Airway

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

Waterway

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

Characteristics of Road Transport

- Roads are used by various types of road vehicles like cars, buses, truck, two and three wheeled automobiles, pedal cycles and animal drawn vehicles. But railway tracks are used only by rail locomotives and wagons, waterways are used only by ships and boats.
- Road transport requires a relatively small investment for the government. Motor vehicles are much cheaper than other carriers like rail locomotives and wagons, water and air carriers.
- Construction and maintenance of road is also cheaper than that of railway tracks, docks, harbors and airports.
- Road transport offers a complete freedom to road users to transfer the vehicle from one lane to another and from one road to another according to need and convenience. This flexibility of changes in location, direction, speed, and timing of travel is not available in other modes of transport.
- In particular for short distances travel, road transport saves time.

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- Speed of movement is directly related with the severity of accident. The road safety decreases with increasing dispersion in speed. Road transport is subjected to a high degree of accidents due to flexibility of movements offered to the road users.
- Road transport is the only means of transport that offers itself to the whole community alike.

Highway Development in India

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

Jayakar Committee Recommendations and Implementation of Recommendations

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

- Road development in the country should be considered as a national interest. As the provincial and local government do not have the financial and technical capacity for road development.
- Extra tax to be levied from the road users as fund to develop road.
- A Semi-official technical body has to be formed to collect and pool technical knowhow from various parts of the country and to act as an advisory body on various aspects of the roads.
- A research organization should be instituted at National level to carry out research and development work and should be available for consultation.

Implementations

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

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

Central Research Fund (CRF)

- Central Research Fund (CRF) was formed on 1stMarch 1929.
- The consumers of petrol were charged an extra levy of 2.64 paisa/litre of petrol to buildup this road development fund.
- From the fund collected 20 percent of the annual revenue is to be retained as meeting expenses on the administration of the road fund, road experiments and research on road and bridge projects of special importance.

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

Indian Road Congress (IRC)

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

Central Road Research Institute (CRRI)

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

Highway Research Board (HRB)

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

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

Road Classification

- **Based on weather**
  - **All-weather roads:** These roads are negotiable during all weather, except at major river crossings where interruption of traffic is permissible up to a certain limit extent, the road pavement should be negotiable during all weathers.

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- **Fair-weather roads:** On these roads the traffic may be interrupted during monsoon season at causeways where streams may overflow across the roads.

- **Based on the carriage way**
  - **Paved Roads:** These roads are provided with a hard pavement course which should be at least a water bound macadam (WBM) layer.
  - **Unpaved Roads:** These roads are not provided with a hard pavement course of at least a WBM layer. Thus earth roads and gravel roads may be called as unpavedroads.
- **Based on Surface pavement provided**
  - **Surface Roads**: These roads are provided with a bituminous or cement concrete surfacing. Roads which are provided with bituminous surfacing are called as black toped roads and that of concrete are referred to as concrete roads respectively.
  - **Unsurfaced Roads**: These are not provided with bituminous or cement concrete surfacing.
- **Based on Traffic Volume**
  - Heavy traffic roads
  - Medium traffic roads
  - Light traffic roads
- **Based on Load transported or tonnage**
  - Class-I or Class-A
  - Class-II orClassBetc
- **Based on location and Function**

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

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headquarters or other main roads. These are of lower design specification than MDR. These roads have a single lane and carry mixed traffic.

- ❖ **Village Roads (VR):** These are roads connecting villages or groups of villages with each other to the nearest road of a higher category.

- **Modified Classification of Road system by Third Road Development Plan**
  - ❖ Primary System (Expressways and National Highways)
  - ❖ Secondary System (State Highways and Major District Roads)
  - ❖ Tertiary System (Other District Roads and Village Roads).

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

- **Based on Urban Roads**
  - ❖ Arterial roads
  - ❖ Sub-arterial roads
  - ❖ Collector Streets
  - ❖ Local Streets

  Arterial and Sub-arterial roads are primarily for through traffic on a continuous route, but sub-arterials have a lower level of traffic mobility than the arterials. **Collector streets**provide access to arterial streets and they collect and distribute traffic from and to localstreets which provide access to abutting property.

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Road Patterns

- **Rectangular or block pattern**

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

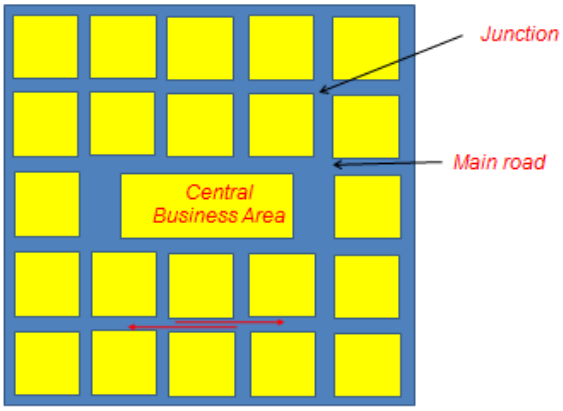
Advantages:

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

Limitations:

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

Example: Chandigarh has rectangular pattern



- **Radial or star and block pattern**

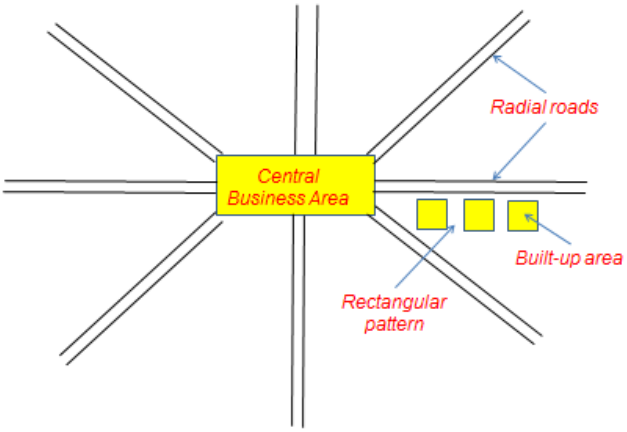
In this pattern, the entire area is divided into a network of roads radiating from the business outwardly. In between radiating main roads, the built-up area may be planned with rectangular block.

Advantage:

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

Limitations:

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



- **Radial or star and circular pattern**

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

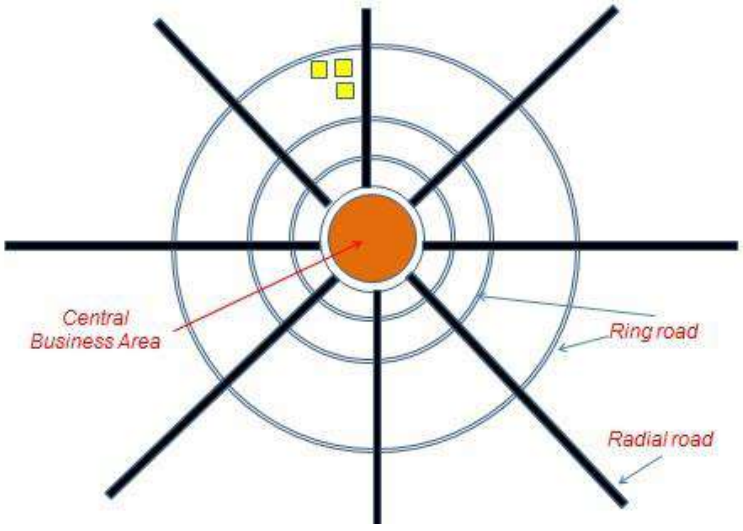
Advantages:

- ❖ At traditional intersections with stop signs or traffic signals, some of the most common types of crashes are right-angle, left-turn, and head-on collisions. These types of collisions can be severe because vehicles may be traveling through the intersection at high speeds. With circular pattern, these types of potentially serious crashes essentially are eliminated because vehicles travel in the same direction.
- ❖ Installing circular pattern in place of traffic signals can also reduce the likelihood of rear-end crashes.
- ❖ Removing the reason for drivers to speed up as they approach green lights and by reducing abrupt stops at red lights.
- ❖ Because round abouts improve the efficiency of traffic flow, they also reduce vehicle emissions and fuel consumption.

Limitations:

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

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



- **Radial or star and grid pattern**

Change in direction, and because street patterns are the most enduring physical element of any layout, it could potentially contribute to systematic site planning and, consequently, deservesa closer look. Though the network is entirely interconnected, north-south movement becomes circuitous, indirect, and inconvenient, making driving an unlikely choice and vividly illustrating that interconnectedness by itself is insufficient to facilitate movement.

Advantages:

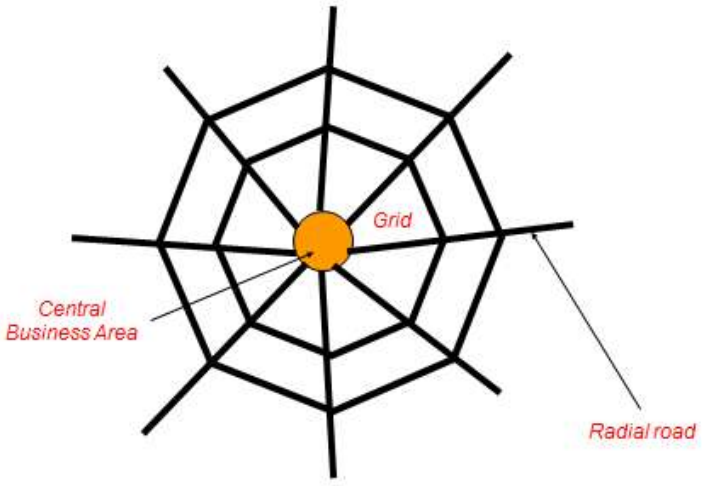
- ❖ Keep vehicular traffic safe with a high proportion of 3-way intersections.
- ❖ Reduce cut-through traffic by similar or other means.
- ❖ Improve traffic flow in both directions using Savannah's cellular structure.
- ❖ Improve land use efficiency and unit density.

Limitations:

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

Examples:

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



- **Hexagonal pattern**

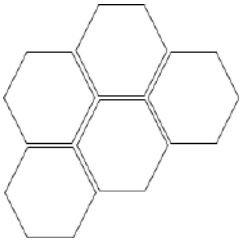
In this pattern, the entire area is provided with a network of roads formatting hexagonal figures. At each corner of the hexagon, three roads meet the built-up area boundary by the sides of the hexagons is further divided in suitable sizes.

Advantages:

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

Limitations:

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



Planning Surveys

The studies for collecting the factual data for highway planning are known as fact finding studies or planning surveys. The planning surveys consist of the following studies

- Economic studies
- Financial studies
- Traffic or road use studies
- Engineering studies

Economic studies

The details to be collected include the following

- ❖ Total population and classified distribution of different population based on occupation, income etc
- ❖ Trend of population growth
- ❖ Agricultural and industrial products
- ❖ Industrial and agricultural development and future trends
- ❖ Existing facilities of communication, education, banks, hospitals, post office etc
- ❖ Per capita income

Financial studies

The details to be collected are

- ❖ Sources of income and estimated revenue
- ❖ Living Standards
- ❖ Resources from local levels, toll taxes, vehicle regestration and fines
- ❖ Future trends in financial aspects

Traffic or road use studies

Traffic surveys should be carried out in the whole area and on selected routes and locations in order to collect the following details

- ❖ Traffic Volume/day, annual or daily traffic peak flow and design hourly volume
- ❖ Origin and destination studies
- ❖ Traffic flow patterns
- ❖ Mass transportation facilities
- ❖ Accidents, their cause and cost analysis
- ❖ Future trend and growth in traffic volume
- ❖ Growth of passenger trips and trend in the choice of modes

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Engineering studies

The required engineering studies are

- ❖ Topographic study
- ❖ Soil details
- ❖ Location and classification of existing roads
- ❖ Road life studies
- ❖ Specific problems in drainage constructions & maintenance.
- Assessment of various other developments in the area that is likely due to the proposed highway development.

Objective of Planning Surveys

- Workout, the financial system and recommended changes in tax arrangements and budget procedures, provide efficient, safe economics, comfortable and speedy movement for goods and people.
- Plan a road network for efficient traffic operation at minimum cost.
- Plan for future requirements and improvements of roads in view of developments and social needs.
- Fix up data wise priorities for development of each road link based on their utilities.

Preparation Of Plans

Before finalizing the alignment and other details of the road development programme, the information collected during the fact finding studies are presented in the form of plans.

Plan-1: This plan should give the topographical details related to existing road network, drainage, structures, towns and villages with population, agricultural, industrial and commercial activities.

Plan-2: Should give the details pertaining to the distribution of population.

Plan-3: Should indicate the location of places with productivity.

Plan-4: Should indicate the existing network of roads and proposals received.

Master Plan

Master plan is the final road development plan for the study area which may be a block, taluk, district, state or the whole country. Based on the above plans, different possible network of new roads and improvement of some of the existing roads are proposed. In each proposal, thepopulation and productivity of each locality, the traffic flow, topography and all other details, both existing and possible changes in future are kept in view. In developing countries like India, the total target road length to be achieved for the country as whole, during a selected plan period may be fixed depending upon the financed that could be made available during the plan period.

Determination of Optimum Road Length

To decide the best road system out of various alternative proposals, it is desirable to make use of concept of saturation system based on U.S system of highway planning.

Saturation System

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In this system optimum road length is calculated for an area based on the concept of attaining maximum utility per unit length of the road. This is also called as maximum utility system. Factors to attain maximum utility per unit length are

- Population served by the road network
- Productivity (industrial and agricultural) served by the road network.

Population factors or units

Since, the area under consideration consists of villages and towns with different population these are grouped into some convenient population range and some reasoning values of utility units to each range of population serve are assigned.

Population less than 500, utility unit = 0.25

501 to 1001, utility unit = 0.50

1001 to 2000, utility unit = 1.00

2001 to 5000, utility unit = 2.00 etc.

Productivity factors or units: The total agricultural and industrial products served by each road system are worked out and the productivity served may be assigned appropriate values of utility units per unit weight.

Utility per unit length of road

The total utility units served by each road system are found by adding the population units and productivity units. The total units scored are divided by the total road length of each system to obtain the utility rate per unit length of road.

Highway Planning In India

The first attempt for proper planning of the highway development programme in India on a long term basis was made at the Nagpur Conference in 1943. After, the completion of the Nagpur Road Plan targets, the Second Twenty year Plan was drawn for the period 1961-1981. The Third Twenty Year Road Development Plan for the period 1981-2001 was approved only by the year 1984.

First Twenty Road Plan (Nagpur Road Plan)

The conference of chief engineer held at Nagpur in 1943 for first twenty road development plan (1943-1953). The roads were classified into five major categories: NH, SH, MDR, ODR and VR. Recommendations were made for the geometric standards of roads, bridges and highway organization. Two formulae were finalized based on star and grid pattern to calculate the road length for the country as a whole.

Salient feature

- The responsibility of construction and maintenance of national highways were assigned to the central government.
- Planned for 20 year (1943-63) aiming to provide 2 lakh km of surfaced roads and remaining unsurfaced roads. Total targeted road length 5,32,700 km . Achieved 7, 09,122km by the end of 1961.
- Road density was 16km/100sqkm.

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- The road length formulated is based on star and grid pattern. But due consideration was given for existing irregular pattern and obligatory points not fitting in the geometric pattern.
- The size of grid is 16km so that max distance from the centre is 8km and average distance from village road to metalled road is 3.2 km.
- The ODR and VR are meant to provide internal road system linking to higher category of road network.
- An allowance of 15 % was given for agricultural and industrial development during next 20 years.
- The length of railway tracks in the area was also considered in deciding the length of the first category of road.

Formulae

- NH+ SH+ MDR (km) = [A/8 + B/32 + 1.6N + 8T] +D – R
- ODR+ VR (km) = [0.32V + 0.8 Q + 1.6 P + 3.2 S] + D

Where, A= agricultural area, km2
B= Non-Agricultural area, km2
N = number of towns and villages with population range 2001-5000.
T= number of towns and villages with population over 5000
D = Development allowance of 15 percent of road length calculated to be provided for agricultural and Industrial during the next 20 years
R= Existing length of railway track in km.
V= Number of villages with population 500 or less
Q= Number of villages with population range 501-1000
P = Number of villages with population range 1001-2000
S= Number of villages with population range 2001-5000

Second Twenty Year Road Plan (1961-1981) Bombay Road Plan

This plan envisaged overall road length of 10,57,330 km by the year 1981 achieved. The cost of the plan has been worked out to Rs. 5,200 crores based on 1958 price level. Five different formulae were framed to calculate the length of NH, SH, MDR, ODR and VR.

Classification of the Roads by Bombay Road Plan:

- **Express way:** are those connecting major capitals and other important centre with in the country where the traffic density is high and the vehicles are allowed to travel with no cross interruption. The express way are constructed with high design standards and design speed.
- National highway
- State highway
- Major district road
- Other district road
- Village road

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Salient feature

- Drawn on more scientifically in view of development needed in under developed areas.
- Targeted road density 32km per 100 sqm, road length of 10,57,330 km, achieved road length = 15,02,697km.
- Maximum distance of any place in a developed or agricultural area would be 6.4 km from a metalled road and 2.4 km from any category of roads.
- Every town with population above 2000 in plains and above 1000 in semi-hill areas and above 500 in hilly areas should be connected by a metalled road.
- While calculating the road length in hilly regions, an allowance up to 100 percent to be made in arriving at the road length.
- Expressways have also been considered in this plan and 1600 km of length has been included in the proposed target of National Highways.
- Length of railway track is considered independent of the road system.
- The development factor of only 5 % is provided for future development and unforeseen factors.

Formulae

- NH = [A/64+ B/80 +C/96 + 32K + 8M] +D
- NH+ SH, (km) = [A/20 + B/24 + C/32] + [48K + 24 M + 11.2 N + 1.6 P] + D
- NH + SH+ MDR (km) = [A/8 + B/16 + C/24] + [48 K + 24 M + 11.2 N + 9.6 P + 6.4 Q+ 2.4 R] + D
- NH+SH+MDR+ODR, (km) = [3A/16+3B/32+C/16] + [48K +24 M + 11.2 N +9.6P + 12.8 Q + 4R + 0.8 S + 0.32 T] + D
- NH+SH+ MDR+ ODR+ VR (km) =[A/4 + B/8 + C/12] + 48K + 24 M + 11.2 N + 9.6 P + 12.8 Q + 5.9 R + 1.6 S + 0.64 T + 0.2 V] +D

Where,

A = Developed and agricultural areas; km2

B= Semi-developed area,

C = Underdeveloped area,

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

M = number of towns with population range 1,00,000 – 50,000

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

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

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

R = number of towns with population range 5,000- 2,000

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

T = number of towns with population range 1,000- 500

V = number of towns with population range below 500

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

Third Twenty Year Road Development Plan (1981-2001) (Lucknow Plan)

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It was finalized and the plan document was published by the year 1984. The major objectives or salientfeatures are

- The future road development should be based on the revised classification of road system consisting of Primary, Secondary and Tertiary road system.
- The road network should be developed so as to preserve the rural oriented economy and to develop small towns with all the essential facilities.
- All the villages with population of 500 should be connected by all weather roads.
- The overall density of road is increased to 82km per 100 sq.km
- The NH network should be expanded to form square grids of 100 km sides so that no part of the country is more than 50 km away from NH.
- Expressway should be constructed along major traffic corridors to provide fast travel.
- Roads should also be built in less industrialized areas that attract the growth of industries.
- Long term master plans for road development should be prepared at various levels.
- All towns and villages with population over 1500 should be connected by Major district Roads and villages with population 1000 to 1500 by ODR.
- There should be improvements in environmental quality and road safety.

Formulae

- ❖ Length of NH (km) = area of the region/ 50
- ❖ Length of SH (km)
  - ➢ By area, SH (km) = area of the region/ 25
  - ➢ Based on no. Of towns, SH (km) = 62.5 x no. Of towns – NH

Adopt length of SH (higher of the two criteria)

- Length of MDR, in the District
  - ➢ Based on area, MDR (km) = area of the region/12.5
  - ➢ Based on number of towns, MDR(km) = 90 x number of towns

Provide length of MDR (higher of the two criteria)

- Total length of all categories of roads may be assumed to provide an overall density of road length equal to 82km per 100 sq.km area by the year 2001.

NH + SH + MDR + ODR + VR (km) = area of the region x (82/100)

Therefore length of ODR + VR (km) = Total Length – (NH + SH + MDR)

<u>Salient Features Of Vision 2021</u>

- The fourth 20-year road development plan of the country has not yet been got approved as an official plan document for development of roads. Instead 'road development plans Vision 2021' has been formulated (2001 – 2021).
- This document covers
  - ❖ Primary road system consisting of expressways and NH
  - ❖ Secondary road system consisting of SH and MDR
- It was observed that target length of third road development plan was not achieved. The total length of NH achieved was 57,700km as against the target of 66,000km and that of SH achieved was 1,24,300km as against the target of 1,45,000km. The total length of

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MDR+ODR+VR was 24,89,000kmwhere as the actual achievement was 29,94,000km. Thus against the overall total target length of 27,00,000km the total achieved was 31,76,000km.

- The total target length to be achieved as per Vision 2021 are
  - ❖ Primary highway system consisting of 15,766km of expressways and 80,000km of NH.
  - ❖ Secondary road system consisting of 1,60,000km of SH and 3,20,000km of MDR.

Pradhan Mantri Gram Sadak Yojana (PMGSY)

- It was launched by the central government in December 2000.
- To provide village connectivity with all-weather road.
- The Ministry of Rural Development was vested with the responsibility to prepare the master plans in consultation with the state governments.
- The objective of this rural development programme is to provide all-weather road connectivity to all villages having population over 1000 by the year 2003 and to villages withpopulation 500 and above by the year 2007.
- This is probably one of the largest rural road development programmes ever taken up in the country.
- The PMGSY became a part of the Bharat Nirmanprogramme.
- According to latest figures made available by the state government, there are about 1.73 lakh km unconnected habitations and about 3.65lakh km new road connectivity are required to be taken up under the PMGSY programme as per the norms.
- The revised cost of this project is estimated to be Rs 1,32,150crores (2003-04 prices).

National Highways Development Projects (NHDP)

- It was observed that target length of third road development plan was not achieved. The total length of NH achieved was 57,700km as against the target of 66,000km and that of SH achieved was 1,24,300km as against the target of 1,45,000km. The total length of MDR+ODR+VR was 24,89,000kmwhere as the actual achievement was 29,94,000km. Thus against the overall total target length of 27,00,000km the total achieved was 31,76,000km.
- Realizing the deficiencies in the NH system of country, the National Highways Authority of India (NHAI) took up the NHDP by the year 2000, in different phases.
- **Phase I:**
  'Golden Quadrilateral' of total length 5846km connecting the four major metropolitan cities. The four sides of quadrilateral are
  - ❖ Delhi – Mumbai
  - ❖ Mumbai – Chennai (via Bangalore)
  - ❖ Chennai – Kolkata
  - ❖ Kolkata – Delhi

  This project was started in December 2000 and was planned to be completed in six years.

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- **Phase II:**consisting of
  - ❖ North – South corridor connecting Srinagar too Kanyakumari
  - ❖ East – West corridor connecting Silchar to Porbandar, of total length 7,300km.
- Further development of selected stretches of NH was planned in **Phases III, IV** and **V**.
- Development of expressways was planned as **Phase VI** and improvement of urban road networks as phase **VII**.

Karnataka State Highways Improvement Project (Kship)

- Karnataka State Highways Improvement Project (KSHIP) is a road upgrading and rehabilitation initiative by Government of Karnataka under the World Bank loan to undertake improvement of 3411 km of roads consisting of State Highways and Major District Roads.
- The broad objective of the Project is improving of existing road network involving rising of formation levels; strengthening of pavements; widening and realignment of roads where necessary.
- The work involved pavement design, highway design, and design of structures and environmental and social impact evaluation of the project.
- The expected contract period for construction work is 36 months.
- The design life (or operation period) of the project is 20 years from the start of operation.

Karnataka Road Development Corporation Limited (Krdcl)

The Government has constituted **"Karnataka Road Development Corporation Ltd"** vide Government order No.PWD 172 CRM 97 dated 01-06-1999 and this was established on 21st July 1999 as a wholly owned Government of Karnataka enterprises.

- The Corporation is established under Companies Act, 1956 (Sl.No.of 196 (56) as a Public Limited Company wholly owned by Government of Karnataka and is under theadministrative control of the Public Works Department.
- The Corporation will take up development programme for Roads, Bridges and other related infrastructure development works connected with surface transport.
- The Corporation has its Registered Office at Bangalore.
- The Corporation has an initial Authorized Share Capital of Rs.200.00 crores. The initial paid up capital of Rs.10.00 crores will be subscribed in cash.
- The Corporation functions under the supervision and control of the Board of Directors.

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Questions

1. Explain Importance of Transportation.
2. What are the social effects of transportation? Explain.
3. Explain Different Modes of Transportation.
4. Differentiate between roadways, airways & waterways.
5. What are Jayakar Committee Recommendations and Implementation Recommendations?
6. What are the objectives of CCRI?
7. What are the objectives of IRC?
8. What are the objectives of HRB?
9. Explain classification of roads with their advantaged & disadvantages.
10. What are the objectives of Pradhan Mantri Gram Sadak Yojana?
11. What are the objectives of planning survey?
12. Explain the process involved in planning survey.

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MODULE - 2

HIGHWAYS ALIGNMENT AND SURVEYS

Highway Alignment and Surveys: Ideal Alignment, Factors affecting the alignment, Engineering surveys-Map study, Reconnaissance, Preliminary and Final location & detailed survey, Reports and drawings for new and re-aligned projects

Highway Geometric Design: Cross sectional elements–width, surface, camber, Sight distances–SSD, OSD, ISD, HSD, Design of horizontal and vertical alignment–curves, super-elevation, widening, gradients, summit and valley curves

Introduction

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

If any improper alignment present, leads to increase in

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

Requirements of an Ideal Alignment

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

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

Factors Controlling Alignment

The various factors which control the highway alignment are

- Obligatory points
- Traffic
- Geometric design
- Economics
- Other considerations

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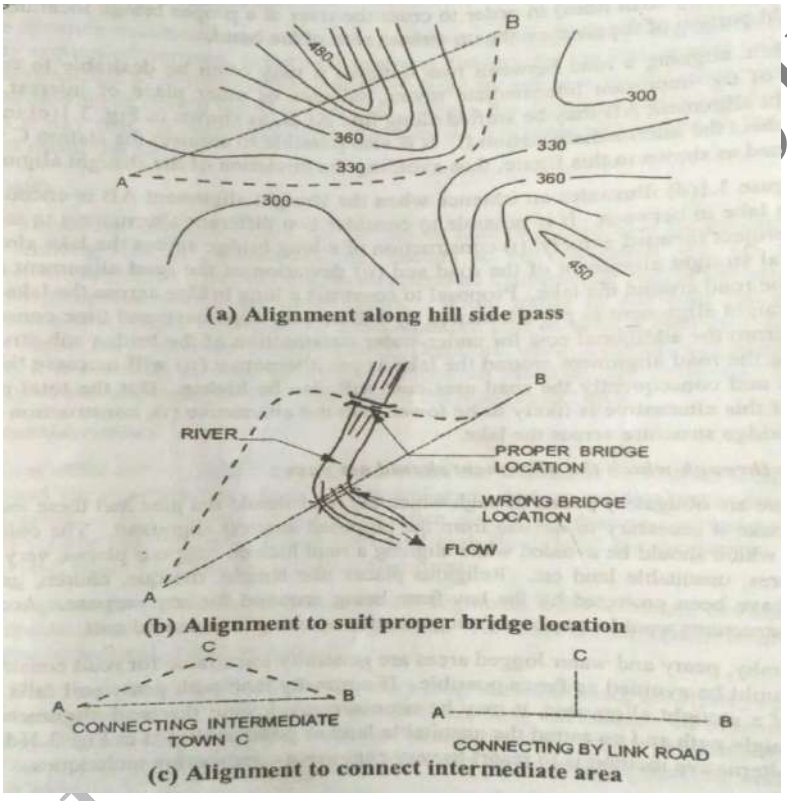
Obligatory Points: there are control points governing the alignment of the highways. These control points may be divided broadly into two categories.

- Points through which the alignment is to pass

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

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



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

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

- Points through which the alignment should not pass

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

Traffic

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

Geometric design

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

Economics

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

Other consideration

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

<u>Special Considerations for Hilly Area Alignment</u>

In hill roads additional care has to be given for

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

Stability

While aligning hill roads, special care should be taken to align the road along the side of the hill which is stable. A common problem in hill roads is that of landslides. The cutting and filling of earth to construct roads on hill side causes steepening of existing slopes and this affect its stability of the hill slopes.

Drainage

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

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Geometric standard of hill roads

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

Resisting length

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

Engineering Surveys for Highway Alignment

The stages of engineering surveys for highway locations are

- Map study
- Reconnaissance survey
- Preliminary surveys
- Final location and detailed surveys

Map study

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

Reconnaissance

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

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

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Preliminary Survey

This survey can be done either by Conventional approach or aerial survey if the area is more. The main objectives of preliminary survey are

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

Final Location and Detailed survey

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

Drawings and Reports

The following drawings are usually prepared in a highway projects

- Key map : Proposed and existing roads, important places
- Index Map : topography, size being 32 x 20 cm
- Preliminary survey plans : alternate alignment, other information
- Detailed plan : alignment, boundaries, counter intervals, A2 size sheet
- Longitudinal section: Datum line, existing ground, vertical profile, scale 1 H: 10 V
- Detailed cross section: level at every 100 m interval
- Land acquisition plans; details of buildings, well, other details
- Drawing of cross drainage and other retaining structures: scale 1:1, structural details
- Drawings of road intersections: Intersection details and traffic flows
- Land plans showing quarries etc.

Project Report

The project report forms an important part of the project document. It should contains information such as

- General details of the project and its importance

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- Feature of the road including selection of the route, alignment, traffic etc.
- Road design and specifications
- Drainage facilities and cross drainage structures
- Materials, labour and equipments
- Rates
- Construction programming
- Other miscellaneous items like diversion of traffic, road side amenities, rest houses etc.

New Highway Project

The new highway project work may be divided into the following stages

- **Route selection**
  The selection of route is made keeping in view the requirements of alignment and the geological, topographical and other features of the locality and also possible upgrading of speed standards in future, without being necessary to realign the road. After the alignment is finalized, the plans and working drawings are prepared.
- **Materials and design**
  The soil samples collected from the selected route during the soil survey are tested in the laboratory in order to design the required pavement thickness and the design of embankment and cut slopes. The possibility of using low cost construction materials should be fully exposed. When high quality pavement materials like bituminous mixed or cement concrete are used in the surface course, the mix design specification and construction control tests should be strictly followed. In India, CBR method has been recommended by IRC fordesigning the thickness of flexible pavement.
- **Construction**
  The construction of the road may be divided into two stages i.e., earthwork and pavement construction. The earth work consists of excavation and construction of embankments. The pavement construction is subsequently taken up starting with the preparation of subgrade and the construction of sub-base, base and surface courses of the pavement.

Steps In New Project Work

- **Map study**
  This is carried out with the help of available topographic maps of the area.
- **Reconnaissance survey**
  During this survey, a general idea of a topography and other features, field identification of soils and survey of construction materials, by an on the spot inspection of the site.
- **Preliminary survey**
  Topographic details and soil survey along alternate alignments, consideration of geometric design and other requirements of alignment, preparation of plans and comparison of alternate routes, economic analysis and selection of final alignment.
- **Location of final alignment**
  Transfer of the alignment from the drawings to the ground by driving pegs along the centre line of finally chosen alignment, setting out geometric design elements by location of tangent

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points, apex, circular and transition curves, elevation of centre line and superelevation details.

- **Detailed survey**
  Survey of the highway construction work for the preparation of longitudinal and crosssections, computations of earth work quantities and other construction material and checking details of geometric design elements
- **Material survey**
  Survey of construction materials, their collection and testing
- **Design**
  Design details of embankment and cut slopes, foundation of embankments and bridges, and pavement layers and cross drainage structures.
- **Earth work**
  Excavations for highway cutting and drainage system construction and embankments
- **Pavement construction**
  Preparation of subgrade, construction of sub base, base and surface courses
- **Construction controls**
  Quality control tests during different stages of construction and check for finished road surface such as unevenness, camber, superelevation and extra widening of pavement atcurves.
- **Construction planning and programming**
  The construction planning and programming to be carried out taking into accounts all the restraints and existing problems. In order to minimize the construction cost and time, it is essential to resort to appropriate approaches such as use of critical path method (CPM) and project evaluation and review technique (PERT).

Necessity of Re- Alignment

- Improvement of horizontal alignment design elements, such as radius, super elevation, transition curve, clearance on inner side of the curve of shifting the curve to provide adequate sight distance, elimination of reverse curve and undesirable zigzag.
- Improvement of vertical alignment design elements like steep gradients, changes in summit curves to increase sight distance, correction of undesirable undulations like humps.
- Raising the level of a portion of a road which is subjected to flooding, sub mergence or water-logging during monsoons.
- Re-construction of weak and narrow bridges and culverts and changes in water way at locations slightly away from the existing site.
- Construction of over bridges or under bridges at suitable locations across a railway line in place of level crossing or across another road to provide grade separated intersection.
- Re-alignment required due to a portion of road being submerged under water at the reservoir area on account of construction of a new dam.
- Construction of a bypass to avoid the road running through a town or city
- Defense requirement.

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Steps In Re Alignment

- Reconnaissance of the stretch of road to be re-aligned, study of the deficiency and possible changes in alignment.
- Survey of existing road recording the topographic features and all other existing features including drainage conditions along a strip of land on either side of the road.
- Observation of spot level along the centre line of the road and cross section levels at suitable intervals.
- Soil survey along the stretches of land through which the re-aligned road may possibly pass.
- Comparison of economics and feasibility of alternate proposal of realignment.
- Finalization of the design features and realigned road stretch
- Preparation of drawings.
- Marking out centre line
- Earthwork and preparation of sub grade
- Checking of geometric design elements
- Design and construction of new pavement

Geometric Design of Highway

Geometric design of highways deals with the following elements

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

Design Control and Criteria

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

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

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Design speed

RC : 73-1980

TABLE 2. DESIGN SPEEDS

S. No.	Road classification	Design speed, km/h							
		Plain terrain		Rolling terrain		Mountainous terrain		Steep terrain	
		Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed	Ruling design speed	Minimum design speed
1.	National and State Highways	100	80	80	65	50	40	40	30
2.	Major District Roads	80	65	65	50	40	30	30	20
3.	Other District Roads	65	50	50	40	30	25	25	20
4.	Village Roads	50	40	40	35	25	20	25	20

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

Topography

The topography or the terrain conditions influence the geometric design of highwaysignificantly. The terrains are classified based on the general slope of the country across the alignment as plain, rolling, mountainous and steep terrain. The design standards specified for different classes of roads are different depending on the terrain classification. For example the design speed oh NH and SH on plain terrain with general cross slope of 10% is 100kmphwhereas on rolling terrain with general slope of 10 to 25% is 80kmph and that on mountainous terrain with cross slope 25 to60% is 50kmph.

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

Traffic factors

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

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which affect traffic behavior include the physical, mental and psychological characteristics of drivers and pedestrians.

Design hourly volume and capacity

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

Environmental and other factors

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

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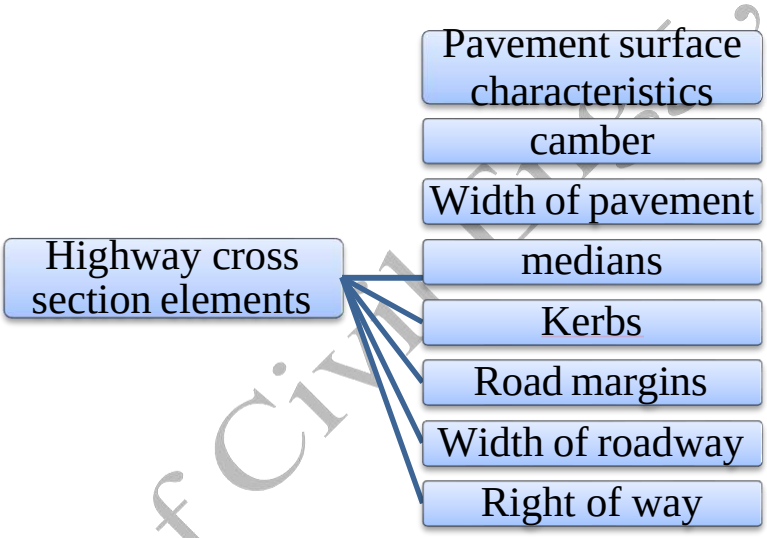
Highway Cross Section Elements



Pavement Surface Charcteristics

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

- Friction
- Unevenness
- Light reflecting characteristics
- Drainage of surface water

Friction

The friction or Skid resistance between vehicle tyre and pavement surface is one of the factors determining the operating speed and minimum distance required for stopping the vehicles. When vehicle negotiates a horizontal curve, the lateral friction developed counteracts the centrifugal

forces and thus governs the safe operating speed. Frictional force is an important factor in the

acceleration and retarding abilities of vehicles. The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f. The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending onthe speed for calculating stopping sight distance and coefficient of lateral friction as 0.15 for horizontal curve design. Lack of adequate friction can cause skidding or slipping of vehicles.

- 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.

Factors affecting friction

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

Below table shows the recommended value of 'f' by IRC

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

Pavement Unevenness

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

- Increase in discomfort and fatigue to road users
- Increase in fuel consumption and tyre wear
- Increase in vehicle maintenance cost
- Reduction in vehicle operating speed increase in accident rate

Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulations of the pavement surface recorded per unit horizontal length of the road. It is measured by an instrument called Bump integrator (BI) in terms of unevenness index. An unevenness index value less than1500 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 isconsidered as uncomfortable even for 55 kmph.

The unevenness may be caused due to the following reasons

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

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- Use of inferior pavement materials
- Improper surface and subsurface drainage
- Unscientific construction practices
- Poor maintenance practices
- Localized failures

Light Reflecting Characteristics

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

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 off rain water from road surface. The objectives of providing camber are

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

The required camber of a pavement depends on

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

Types of camber

There are generally three types of the cambers

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

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

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

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

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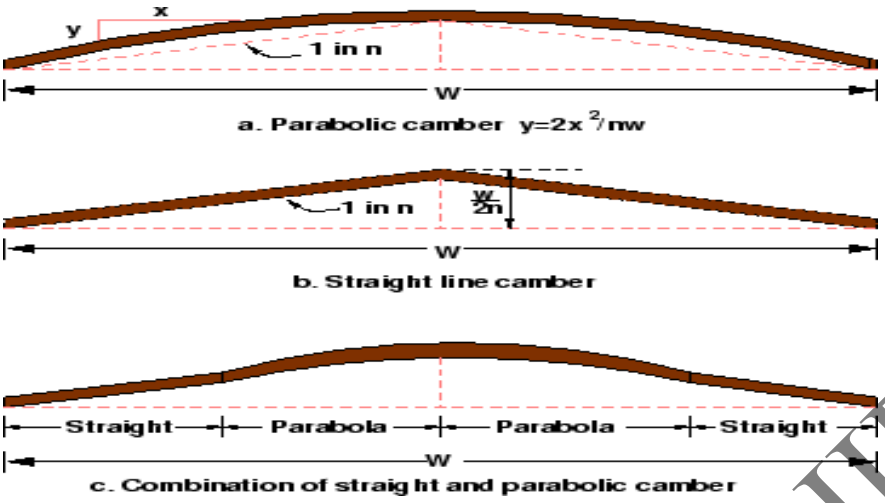
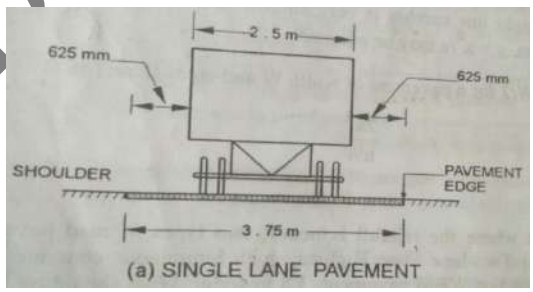


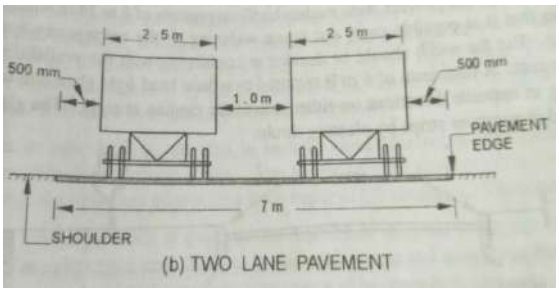
Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (eg. 1 in 50 or2%) and the value depends on the type of pavement surface. The values suggested by IRC for various categories of pavement is given in Table

Sr.No	Type Of Road Surface	Range of camber in areas of	
		Heavy rainfall	Low rainfall
1	Cement concrete and thick bituminous surface	1 in 50 or 2 %	1 in 60 or 1.7 %
2	Thin bituminous surface	1 in 40 or 2.5%	1 in 50 or 2 %
3	Water bound macadam and gravel pavement	1 in 33 or 3%	1 in 40 or 2.5 %
4	Earth road	1 in 25 or 4%	1 in 33 or 3 %

Width Of Pavement Or Carriage Way

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





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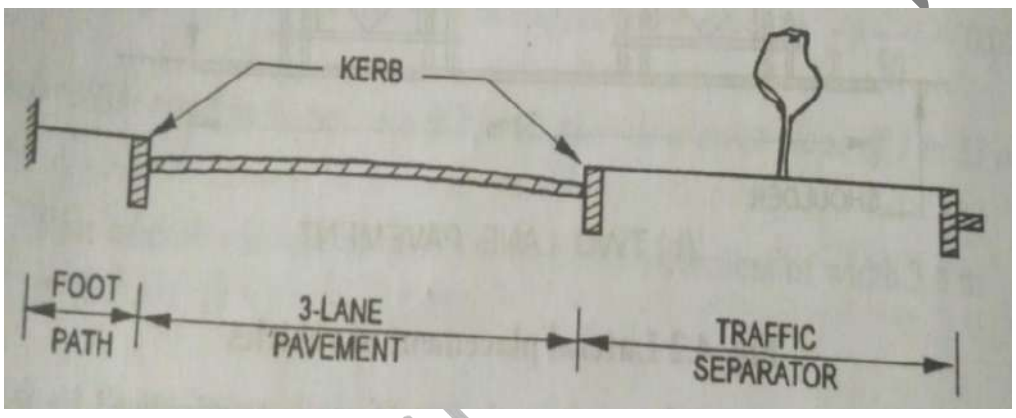
Class Of Road	Width Of Carriageway (m)
Single lane road	3.75
Two lanes, without raised kerbs	7
Two lanes, with raised kerbs	7.5
Intermediate Carriageway	5.5
Multi-lane pavements	3.5 per lane

Medians or traffic separators



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

- To channelize traffic into streams at intersections
- To shadow the crossing and turning traffic
- To segregate slow traffic
- To protect pedestrians

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

Kerbs

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

- **Low or mountable kerbs**

  These types of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows

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the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.

- **Semi-barrier type kerbs**

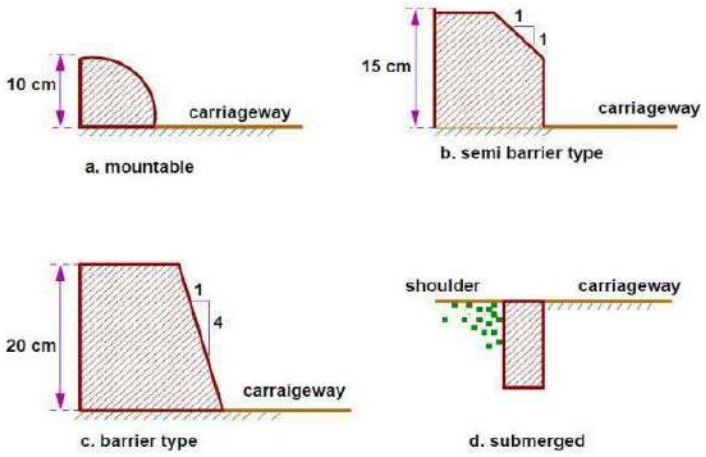
  When the pedestrian traffic is high, these kerbs are provided. Their height is 15cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.

- **Barrier type kerbs**

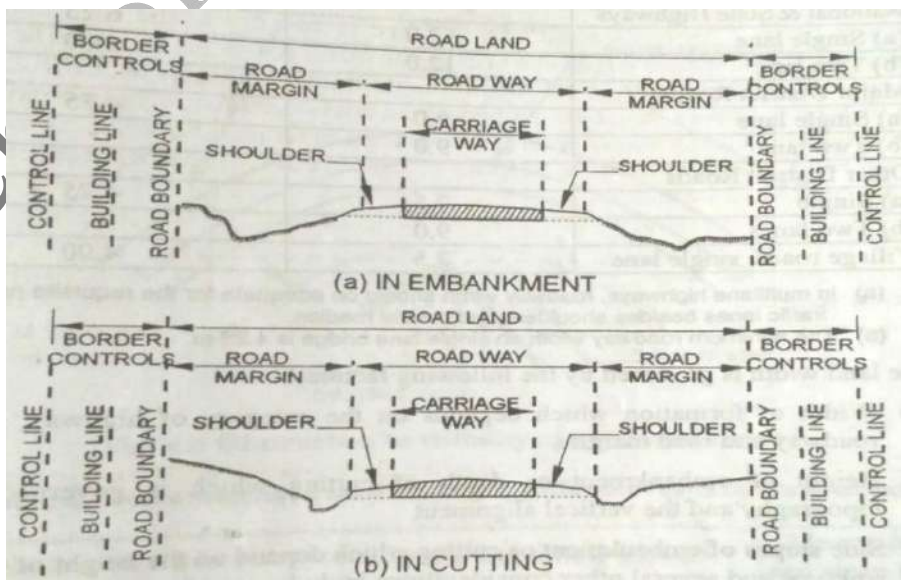
  They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.

- **Submerged kerbs**

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



Road Margins



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❖ **Shoulder**

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

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

❖ **Parking lanes**

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

❖ **Bus-bays**

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

❖ **Cycle track**

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

❖ **Footpath**

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

❖ **Guard rails**

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

❖ **Drive ways**

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

❖ **Lay byes**

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

❖ **Frontage road**

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

❖ **Embankment slope**

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

Width of Formation Or Roadway

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

Table Width of formation for various classed of roads

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

Right of Way and Land Width

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

❖ Width of formation: It depends on the category of the highway and width of roadway and road margins.

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

Typical Cross Section of Roads

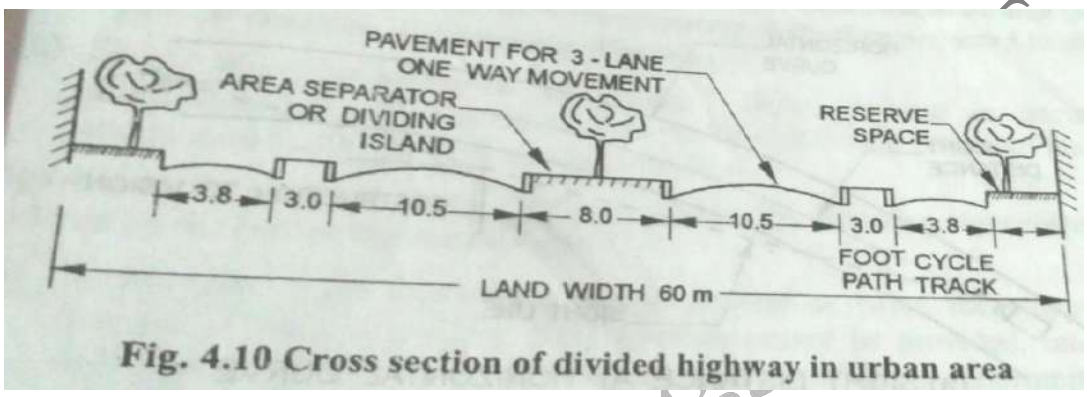


Fig. 4.10 Cross section of divided highway in urban area

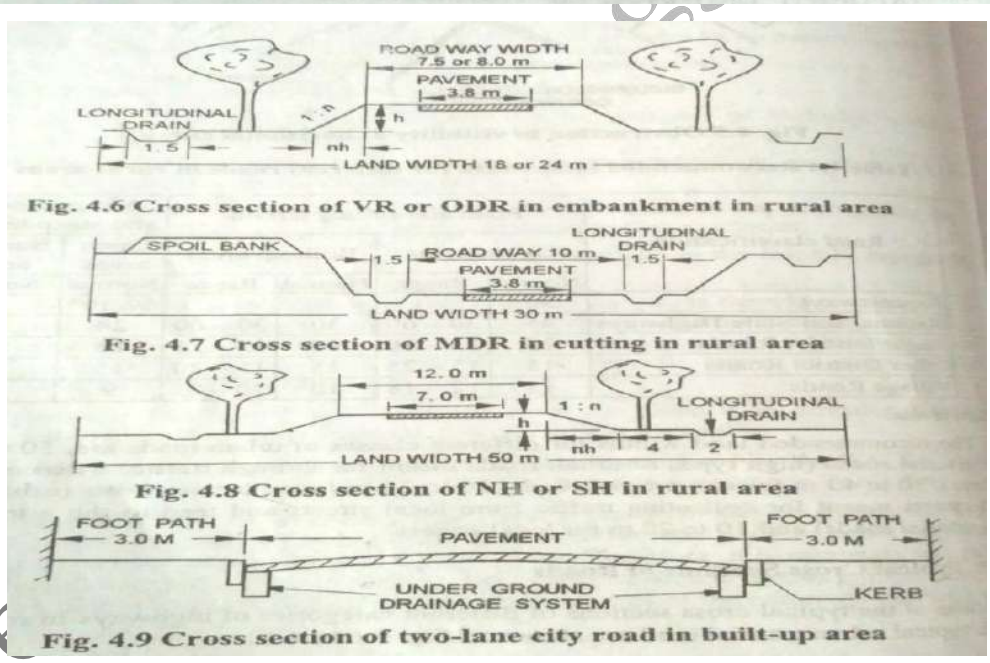
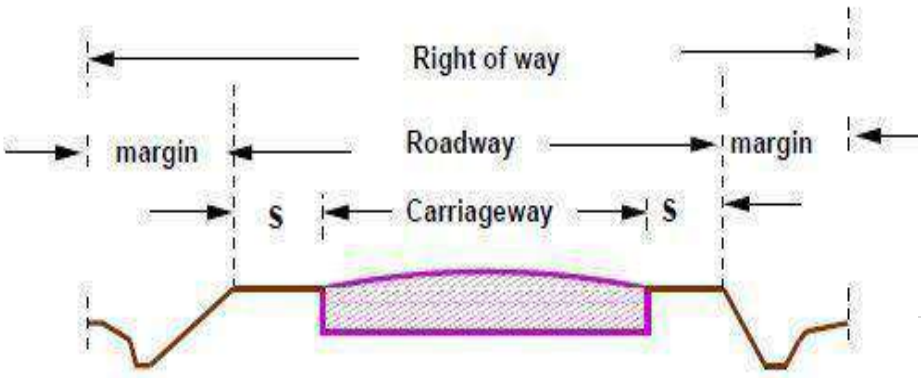


Fig. 4.6 Cross section of VR or ODR in embankment in rural area

Fig. 4.7 Cross section of MDR in cutting in rural area

Fig. 4.8 Cross section of NH or SH in rural area

Fig. 4.9 Cross section of two-lane city road in built-up area



Sight Distance

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

Restrictions To Sight Distance

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

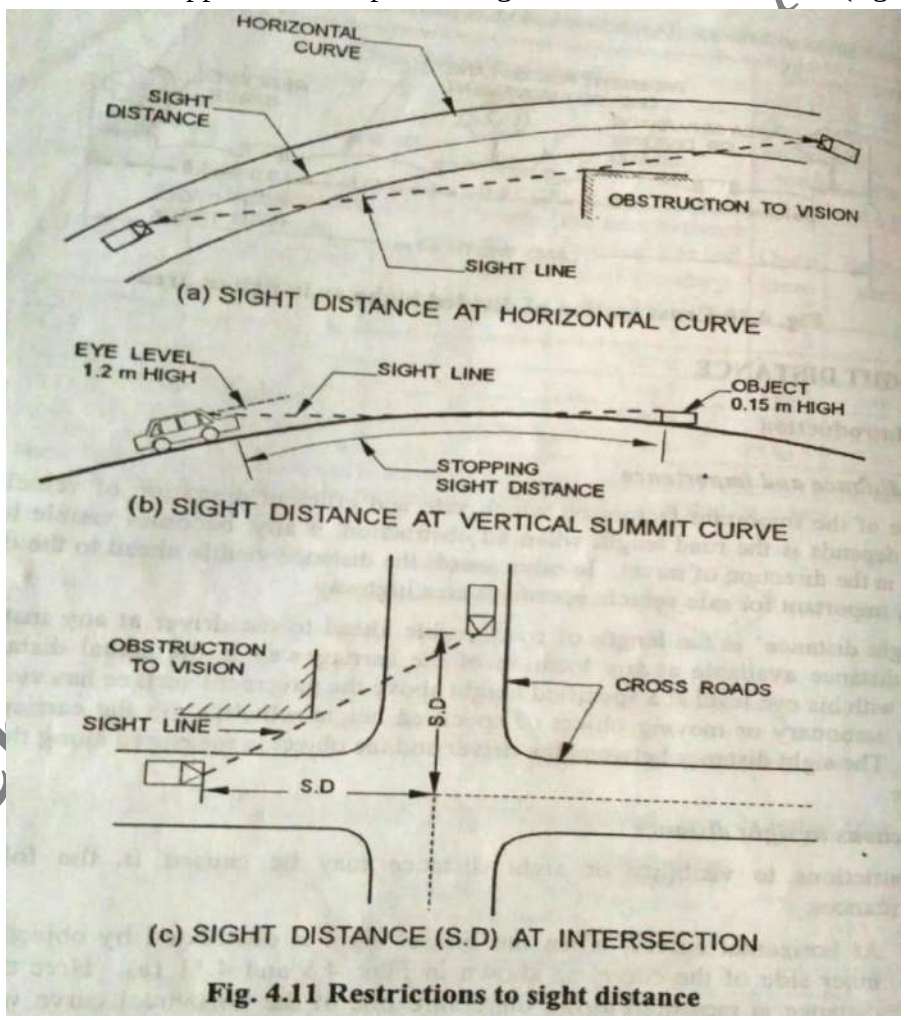


Fig. 4.11 Restrictions to sight distance

Types of Sight Distance

Three types of sight distances situations are considered in the design

- Stopping sight distance (SSD) or Absolute minimum sight distance

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- Safe overtaking sight distance (OSD) or Passing sight distance
- Safe sight distance for entering into uncontrolled intersections

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

❖ Intermediate sight distance

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

❖ Head – light sight distance

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

Stopping Sight Distance (SSD)

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

- Features of the road ahead
- Height of the driver's eye above road surface
- Height of the object above the road surface

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

Factors on Which Stopping Sight Distance Depends

- Total reaction time of the driver
- Speed of vehicle
- Efficiency of brakes
- Frictional resistance between the road and the tyre
- Gradient of the road, if any

Total reaction time

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

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PIEVtheory

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

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

- **Intellection time**
  It is the time required for the driver to understand the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.
- **Emotion time**
  It is the time elapsed during emotional sensations and other mental disturbance such as fear, angry or any other emotional feelings like superstition etc with reference to situation. It varies for different drivers.
- **Volition time**
  It is the time taken by the driver for the final action, such as brake application.

Speed of vehicle

The stopping distance depends very much on the speed of the vehicle. First, during the total reaction time of the driver the distance moved by the vehicle will depend on the speed. Second, the braking distance or the distance moved by the vehicle after applying the brakes, before coming to a stop depends also on the initial speed of the vehicle. Hence it is evident that higher the speed, higher will be the stopping distance. Hence it is evident that higher the speed, higher will be the stopping distance.

Efficiency of brakes

The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes is less.

Frictional resistance between road and tyres

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

Gradient of the road

Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While descending a gradient, gravity

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also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

Analysis of Stopping Sight Distance

The stopping sight distance of a vehicle is the sum of

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

Lag distance

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

Lag distance = vt (m)

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

Braking distance

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

F * I = W * f * I

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

Hence $WfI = Wv^2/2g$

Therefore braking distance, $I = v^2/2gf$

Where l = braking distance, m

V = speed of vehicle, m/s

f = frictional coefficient

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

Stopping distance on level road

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

If speed is V kmph, $SD = 0.278Vt + \frac{V^2}{254f}$

Stopping distance on slope ground

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

If speed is V kmph, $SD = 0.278Vt + \frac{V^2}{254(f \pm n\%)}$

Overtaking Sight Distance (OSD)

The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the minimum overtaking sight distance or the safe passing sight distance. The OSD is the distance measured

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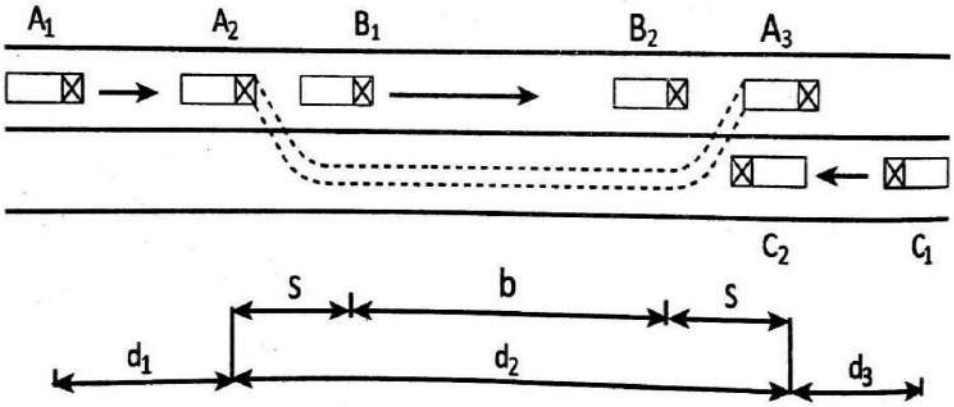
along the centre of the road which a driver with his eye level at 1.2m above the road surface can see the top of an object 1.2m above the road surface.

Factors on which OSD depends

- Speeds of overtaking vehicle, overtaken vehicle and the vehicle coming from opposite direction, if any
- The minimum spacing between vehicles depends on the speeds
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road, if any

Analysis of overtaking sight distance on a two way road



Vehicle A travelling at the design speed v m/s or V kmph desires to overtake another slower vehicle B moving at a speed of v_b m/s or V_b kmph. The vehicle A has accelerate, shift to the adjacent right side lane, complete the overtaking and return to the left lane, before the on-comingvehicle C approaches the overtaking stretch as shown in fig.

The OSD is divided into three components

- d_1 the distance traveled by overtaking vehicle A during the reaction time t
- d_2 the distance traveled by the vehicle during the actual overtaking operation T
- d_3 is the distance traveled by on-coming vehicle C during the overtaking operation (T).

Therefore

$$OSD = d_1 + d_2 + d_3$$

It is assumed that the vehicle A is forced to reduce its speed to v_b, the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d_1 is given by:

$$d1 = v_b t$$

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

$$s = 0.7v_b + 6$$

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

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

The distance traveled by the vehicle C moving at design speed v m=sec during overtaking operation is given by:

$$d_3 = vT$$

The overtaking sight distance is

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

where
v_b is the velocity of the slow moving vehicle in m/sec^2,
t the reaction time of the driver in sec,
s is the spacing between the two vehicles in m
a is the overtaking vehicles acceleration in m/sec^2.
In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph or 4.5m/s slower than the design speed. Therefore v_b = (v – 4.5)m/s or V_b = (V – 16)kmph
The acceleration values of the fast vehicle depends on its speed and given in Table

Speed		Maximum overtaking acceleration	
V, kmph	V, m/s	A, kmph	a, m/sec^2
25	6.93	5.0	1.41
30	8.34	4.80	1.30
40	11.10	4.45	1.24
50	13.86	4.0	1.11
65	18.0	3.28	0.92
80	22.20	2.56	0.72
100	27.80	1.92	0.53

If v is in kmph, than OSD is given by

OSD = $0.28V_bt + 0.28V_bT+2s + VT$

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$T = \sqrt{\frac{14.4\ s}{A}}$

A is in kmph/s

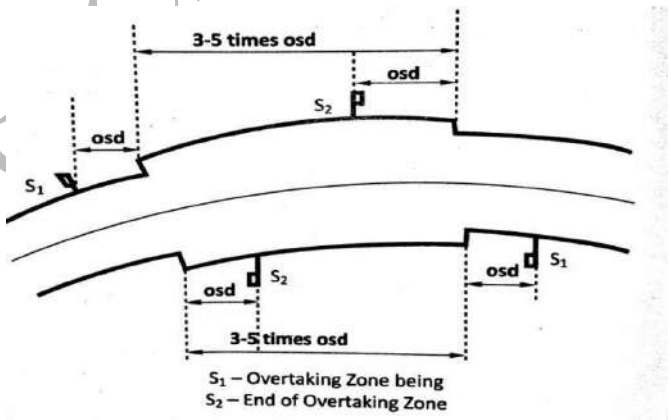
$S = 0.2V_b + 6$

Absolute Minimum Sight Distance

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

Overtaking Zones

It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable and there may be stretches where the safe overtaking distance cannot be provided. In such zones where overtaking or passing is not safe or is not possible, sign posts should be installed indicating "no passing" or "overtaking prohibited" before such restricted zones start. However overtaking opportunity for vehicles moving at design speed should be given at as frequent intervals as possible. These zoneswhich are meant for overtaking are called 'overtaking zones'. Figure shows an overtaking zone with specifications for the position of the sign posts. Sign posts should be installed at sufficient distance in advance to indicate the start and end of overtaking zone. The minimum length of overtaking zone should be three times the safe overtaking sight distance and desirable length should be five times the OSD.



Sight Distance at Uncontrolled Intersections

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

- Enabling the approaching vehicle to change speed

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- Enabling approaching vehicle to stop
- Enabling stopped vehicle to cross main road

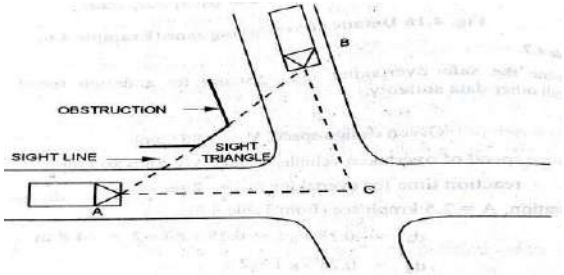

Fig. 4.17 Sight distance at intersection

Enabling the approaching vehicle to change speed

The sight distance should be sufficient to enable either one or both the approaching vehicles to change speed to avoid collision. The vehicle approaching from the minor road should slow down. The total reaction time required approaching from the minor road should be slow down. The total reaction time is assumed as two seconds. Hence the two sides AC and BC of the sight triangle along the intersection approaches up to the conflict point C should be at least equal to the distance covered by a vehicle travelling at design speed in two seconds preferably in three seconds.

Enabling approaching vehicle to stop

In this case, the distance for the approaching vehicle should be sufficient to bring either one or both of the vehicles to a stop before reaching a point of collision. Hence, the two sides AC and BC of the sight available should each be equal to the safe stopping distance. The traffic of the minor road is generally controlled by an appropriate traffic sign. In such a case the sight distance for a minor road should be at least equal to the SSD for the design speed of that road.

Enabling stopped vehicle to cross main road

The sight distance available from the stopped position of the minor road should be sufficient to enable the stopped vehicle to start, accelerate and cross the main road, before another vehicle travelling at its design speed on the main road reaches the intersection. The time, T required for the stopped vehicle to cross the main road would depend upon the reaction time of the driver, width of the main road, acceleration and length of vehicle.

Design of Horizontal Alignment

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

Horizontal Curve

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A horizontal curve is a curve in plan to provide change in direction to the centre line of road. A simple circular curve may be designated by either the radius, R of the curve in m or the degree, D of the curve. The relation between the radius and degree of the circular curve is given by

$$R = \frac{1720}{D}$$

When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle. The centrifugal force developed depends on the radius of the horizontal curve and the speed of the vehicle negotiating the curve. This centrifugal force is counteracted by the transverse frictional resistance developed between the tyres iscounteracted by the transverse frictional resistance developed between the tyres and the pavement which enables the vehicle to change the direction along the curve and to maintain the stability of the vehicle. Centrifugal force P is given by

$$P = \frac{Wv^2}{gR}$$

Where, W = weight of the vehicle, kg

R = radius of the circular curve, m

v = speed of the vehicle, m/s

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

The ratio of the centrifugal force to the weight of the vehicle, P/W is known as the centrifugal ratio or impact ratio. Therefore centrifugal ratio, P/W = $\frac{v^2}{gR}$

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

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

Overturning effect

The centrifugal force that tends the vehicle to overturn about the outer wheels B on horizontal curve without superelevation is illustrated in Fig 4.18. Let h be the height of the centre of gravity of the vehicle above the road surface and b be the width of the wheel base or the wheel track of the vehicle.

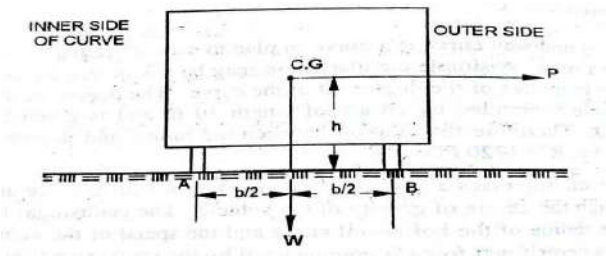

Fig. 4.18 Overturning effect due to centrifugal force

The overturning moment due to centrifugal force, P = Ph

This is restricted by the restoring moment due to weight of the vehicle W and is equal to (W.b/2). The equilibrium condition for overturning will occur when Ph= b/2h. This means that there is

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danger of overturning when the centrifugal ratio P/W or v^2/gR attains a values of b/2h.

Transverse skidding effect

The centrifugal force developed has also the tendency to push the vehicle outwards in the transverse direction. The forces developed under this condition are sown in Fig 4.19. If the centrifugal force developed exceeds the maximum transverse friction force or transverse skid resistance counteracting the centrifugal force, the vehicle will start skidding in the transverse direction.

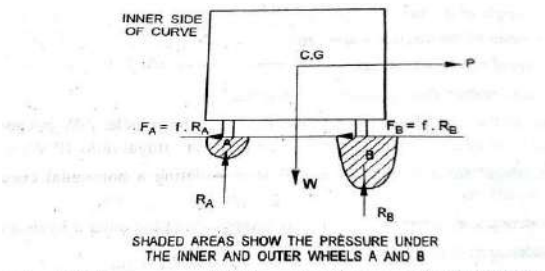

Fig. 4.19 Transverse skidding effect due to centrifugal force

The equilibrium condition for the transverse skid resistance developed is given below

$P = F_A + F_B = f(R_A+R_B) = fW$

Where, f = coefficient of friction

R_A and R_B= normal reactions at wheels A and B

R_A+R_B= W = weight of vehicle

Since P = fW, the centrifugal ratio P/W= f

In other words when the centrifugal ratio attains a value equal to the coefficient of lateral friction, f there is a danger of lateral skidding. Thus to avoid both overturning and lateral skidding on a horizontal curve, centrifugal ratio should always be less than b/2h and alsotransverse friction coefficient, f.

If friction coefficient, f is less than b/2h, the vehicle would skid and not overturn. On the other hand if the value of b/2h is lower than f, the vehicle would overturn on the outer side before skidding. Thus the relative danger of lateral skidding and overturning depends on whether f is lower or higher than b/2h.

Super elevation

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as super elevation or cant or banking. The rate of superelevation. 'e' is expressed as the ratio of the height of outer edge with respect to the horizontal width. From figure

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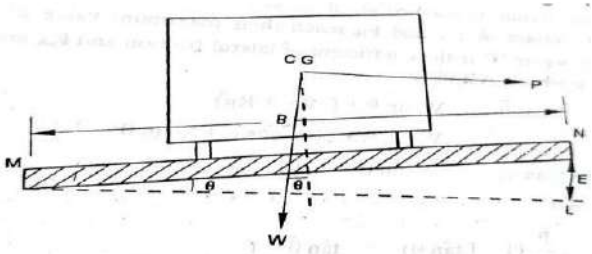

Fig. 4.20 Superelevated pavement section

$e = \frac{NL}{ML} = tan\theta$

In practice the inclination θ with the horizontal is very small and the value of tan θ seldom exceeds 0.07. Therefore the value of tan θ is practically equal to sin θ.

$e = tan\ \theta = sin\ \theta = \frac{E}{B} = \frac{total\ superelvated\ height}{width\ of\ pavement}$

Analysis of Super elevation

The forces acting on the vehicle while moving on a circular curve of radius R (m) at speed of v m/s are shown in figure. These forces are

- The centrifugal force $P = Wv^2/gR$ acting horizontally outwards through the centre of gravity, CG.
- The weight W of the vehicle acting vertically downwards through the CG.
- The frictional force developed between the wheels and the pavement counteracting transversely along the pavement surface towards the centre of the curve.

The centrifugal force developed is thus opposed by corresponding value of

- ❖ The friction developed between the tyres and the pavement surface
- ❖ A component of the force of gravity due to the superelevation provided.

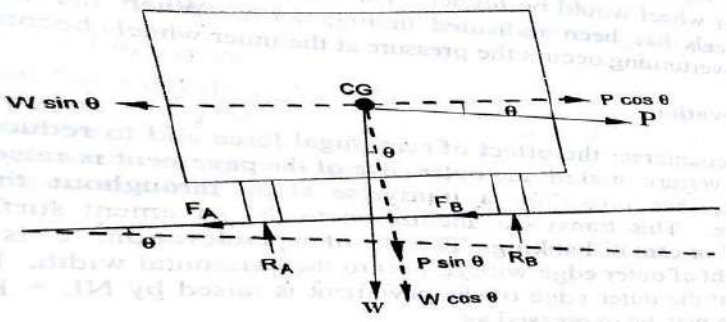

Fig. 4.21 Analysis of superelevation

Figure shows the cross section of pavement with all forces. Considering the equilibrium of the components of forces acting parallel to the plane

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

$P\cos\theta = W\sin\theta + fR_A + fR_B$ .....(1)

f is the coefficient of lateral friction and R_A and R_B are the normal reactions at wheels A and B.

Equilibrium of the components of forces acting perpendicular to the plane

$W\cos\theta + P\sin\theta = R_A + R_B$

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Therefore equation (1) becomes

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

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

$P\cos\theta - fP\sin\theta = W\sin\theta + Wf\cos\theta$

Dividing by $W\cos\theta$,

$\frac{P}{W}(1 - f\tan\theta) = \tan\theta + f$

i.e., centrifugal ratio, $\frac{P}{W} = \frac{\tan\theta + f}{1 - f\tan\theta}$

The value of coefficient of lateral friction, 'f' is taken as 0.15 for the design of horizontal curves. The value of tanθ or transverse slope due to superelevation seldom exceeds 0.07 or about 1/15. Hence the value of (f tanθ) is about 0.01. Thus the value of (1 – f tanθ) = 0.99 and may be approximated to 1.0.

Therefore, $\frac{P}{W} = \tan\theta + f = e + f$

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

Therefore the general equation for design of superelevation is given by

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

where,

e = rate of superelevation = tanθ

f = design value of lateral coefficient = 0.15

v = speed of the vehicle, m/s

R = radius of the horizontal curve, m

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

If V is in kmph, than superelevation is given by

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

Maximim Super elevation

From the practical view point it will be necessary to limit the maximum allowable superelevation to avoid very high values of 'e'. In the case of heavily loaded trucks and bullock carts carrying less dense materials like straw or cotton, the centre of gravity of the loaded vehicle will be relatively high and it will not be safe for such vehicles to move on a road with high rate of superelevation. Hence to avoid the danger of toppling of such loaded slow moving vehicles, it is essential to limit the value of maximum allowable superelevation. The IRC has fixed the maximum limit of superelevation in plain and rolling terrains and in snow bound areas as 7.0%or 0.07. On hill roads not bound by snow a maximum superelevation of 10% and on urban roads 4% is recommended.

Minimum Superevelation

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From drainage considerations it is necessary to have a minimum cross slope to drain off the surface water. If the calculated superelevation is equal to or less than the camber of the road surface, then the minimum superelevation to be provided on horizontal curve may be limited to

the camber of the surface. Thus after the elimination of the crown a uniform cross slope equal to the camber is maintained from outer to inner edge of pavement at the circular curve.

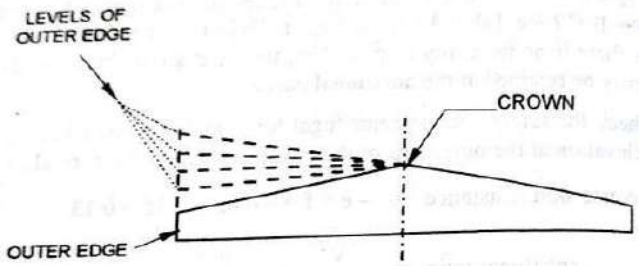
Attainment of Super elevation In The Field

The road cross section at the straight portion is cambered with the crown at the centre of the pavement and sloping down towards both the edges. But the cross section on the portion of circular curve of road is super elevated with a uniform tilt sloping down from the outer edge of the pavement up to inner edge. Thus the crowned camber sections at the straight before the start of the transition curve should be changed to a single cross slope equal to the desired super elevation at the beginning of the circular curve. This change may be conveniently attained at a gradual and uniform rate through the length of horizontal transition curve. The full superelevation is attained by the end of transition curve or at the beginning of the circular curve. The attainment of superelevation may be split up into two parts

- Elimination of crown of the cambered section
- Rotation of pavement to attain full superelevation

Elimination of crown of the cambered section

This may be done by two methods. In the first method, the outer half of the cross slopes is rotated about the crown at a desired rate such that the surface falls on the same plane as the inner half and the elevation of the centre line is not altered as shown in figure below.



(a) OUTER EDGE ROTATED ABOUT THE CROWN

Thus no point on the curve will have a negative super elevation the outer half of the pavement even at the start of the transition curve. This method has a drawback that the surface drainage will not be proper at the outer half, during a short stretch of the road with a cross slope less than the camber between point A and C in fig 4.24.

In the second method of eliminating the crown, known as diagonal crown method, the crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively. This method is not usually adopted as a portion of the outer half of the pavement has increasing values of negative super elevation on a portion of the outer half, before the crown is eliminated as shown in figure.

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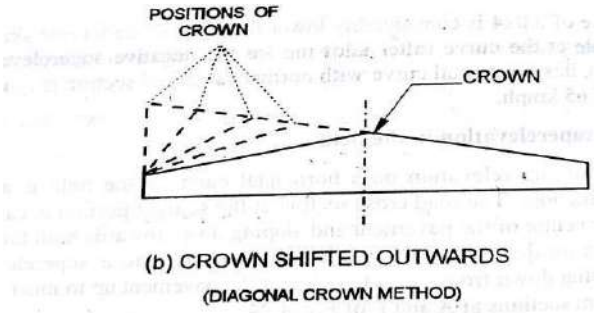

Fig. 4.22 Elimination of crown of cambered section

Rotation of pavement to attain full superelevation

When the crown of the camber is eliminated, the superelevation available at this section is equal that of camber. But the superelevation to be provided at the beginning of circular curve may be greater than the camber in many cases when the design superelevation is more than the minimum value. Hence the pavement section will have to be rotated further till the desired banking is obtained. There are two methods of rotating the pavement cross section to attain the full superelevation after the elimination of the camber (shown in figure below).

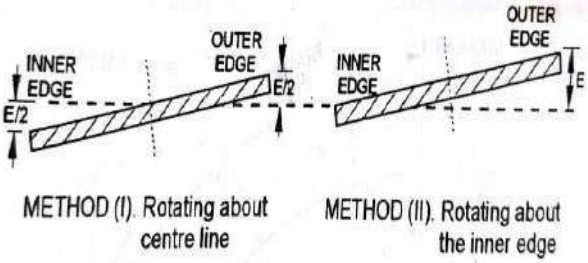

Fig. 4.23 Rotation of pavement section to attain full superelevation

- By rotating the pavement cross section about the centre line, depressing the inner edge and raising the outer edge each by half the total amount of superelevation, i.e., by E/2 with respect to the centre.
- By rotating the pavement cross section about the inner edge of the pavement section raising both the centre as well as the outer edge of the pavement such that the outer edge is raised by the full amount of super elevation, E with respect to the inner edge.

In this method as the pavement section is rotated about the centre line, the vertical profile of the centre line remains unchanged, the outer edge is banked and inner edge is depressed resulting in an advantage in balancing the earth work. The disadvantage of this method is the drainage problem due to depressing the inner edge below the general level.

The second method of rotating about the inner edge is preferable in very flat terrain in high rain fall areas when the road is not taken on embankment, in order to avoid the drainage problem. In this case the centre of the pavement is also raised, which may be considered as a disadvantage of the method as the vertical alignment of the road is altered. The plan of the horizontal curve including the straight, transition and circular curves are shown in figure (a). Elimination of the crown of cambered section, attainment of uniform slope and the two methods of rotating the pavement section to attain full super elevation has been illustrated in figure (b). The vertical

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profiles of the inner edge, centre line and outer edge by the two methods of rotation are shown in figure (c).

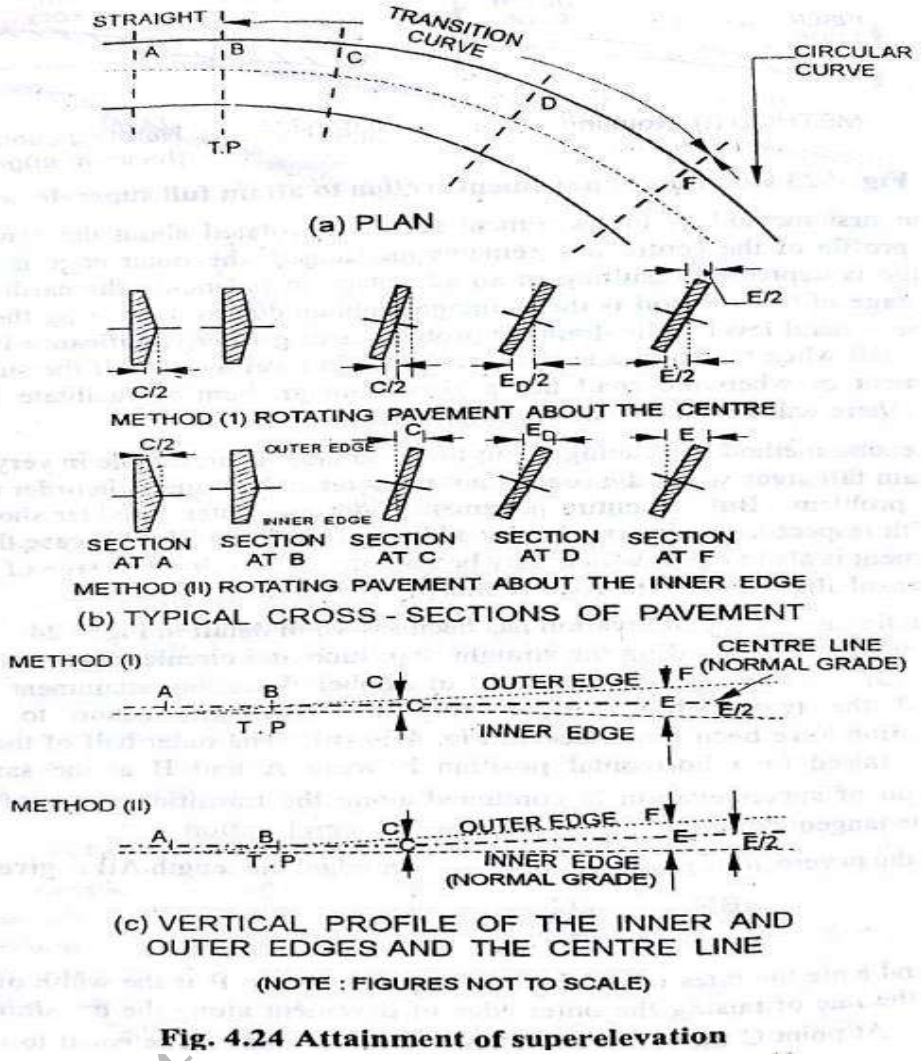

Fig. 4.24 Attainment of superelevation

The super elevation is introduced by raising the outer edge the pavement at a rate not exceeding 1 to 150 in plain and rolling terrain and 1 in 60 on mountainous and steep terrain as per recommendations of the IRC.

Radius of Horizontal Curve

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

$R_{ruling}= \frac{v^2}{g(e+f)}$ or $R_{ruling}= \frac{V^2}{127(e+f)}$

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.

Widening of Pavement on Horizontal Curves

The objects of providing extra widening of pavement on horizontal curve are due to the following reasons

- An automobile such as car, bus or truck has a rigid wheel base and only the front wheels can be turned. When the vehicle takes a turn to negotiate a horizontal curve, the rear wheels do not follow the same path as that of the front wheels. This phenomenon is called 'off tracking'. The off tracking depends on the length of the wheel base of the vehicle and the turning angle or the radius of the horizontal curve negotiated.
- At speeds higher than the design speeds when the superelevation and lateral friction developed are not fully able to counteract the outwards thrust due to the centrifugal force, some transverse skidding may occur and the rear wheels any take paths on the outside of those traced by the front wheels on the horizontal curves. However this occurs only at excessively high speeds.
- The path traced by the wheels of a trailer in the case of trailer units, it also likely to be either side of the central path of towing vehicle, depending on the speed, rigidity of the universal joints and pavement roughness.
- In order to take curved path with larger radius and to have greater visibility at curve, the drivers have tendency not to follow the central path of the lane, but to use the outer side atthe beginning of a curve.
- While two vehicles cross or overtake at horizontal curve there is a psychological tendency to maintain a greater clearance between the vehicles, than on straights for increase safety.

Analysis of Extra Widening On Horizontal Curves

Extra widening of pavement on horizontal curves is divided into two parts

- Mechanical widening
- Psychological widening

Mechanical widening

The expression for extra width can be derived from the simple geometry of a vehicle atahorizontal curve as shown in figure. Let R_1 is the radius of the outer track line of the rear wheel, $R_2$is the radius of the outer track line of the front wheel 'l' is the distance between the front and rear wheel (taken as 6.1 or 6m for commercial vehicles), n is the number of lanes, then the mechanical widening $W_m$is derived below

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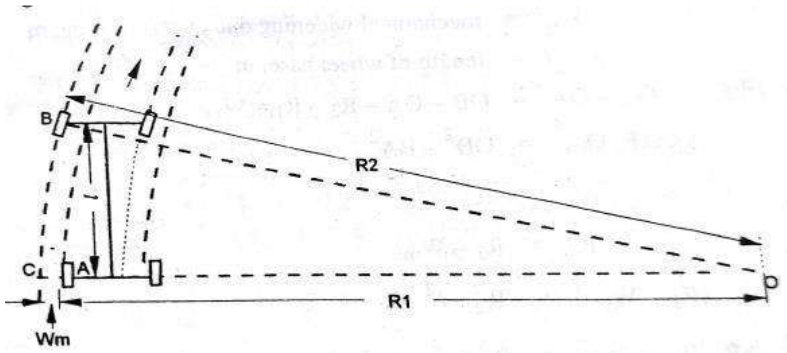

Fig. 4.25 Off-tracking and mechanical widening on horizontal curve

In figure, OC – OA = OB – OA = $R_2 – R_1 = W_m$

$R_1 = R_2 - W_m$

From ΔOAB, $OB^2 = OA^2 + BA^2$

$$\begin{aligned} R_2^2 &= R_1^2 + l^2 \\ &= (R_2 - W_m)^2 + l^2 \\ &= R_2^2 - 2R_2W_m + W_m^2 + l^2 \\ 2R_2W_m - W_m^2 &= l^2 \end{aligned}$$

Therefore the widening needed for a single lane road is

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

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

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

Please note that for large radius, $R_2 \approx R$, which is the mean radius of the curve, then W_m is given by

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

Psychological widening

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At horizontal curves drivers have a tendency to maintain a greater clearance between the vehicles than on straight stretches of road. Therefore an extra width of pavement is provided for psychological reasons for greater maneuverability of steering at higher speeds and to allow for the extra space requirements for the overhangs of vehicles. Psychological widening is therefore important in pavements with more than one lane. An empirical formula has been recommended by the IRC for deciding the additional psychological widening 'W_{ps}' which is dependent on the design speed, V (kmph) of the vehicle and the radius, R (m) of the curve. The psychological widening is given by

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

Hence the total widening W_e required on a horizontal curve is given by

$$W_e = W_m + W_{ps}$$

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

The extra width recommended by the IRC for single and two lane pavements are given in table below

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

Method of Introducing Extra Widening In the Field

The widening is introduced gradually, starting from the beginning of the transition curve or the tangent point (TP) and progressively increased at uniform rate equally on both sides, till the full value of designed widening 'W_e' is reached at the end of transition curve where full values of super elevation is also provided, as shown in figure below. The full value of extra width W_e is continued throughout the length of the circular curve and then decreased gradually along the length of transition curve. Usually the widening is equally distributed i.e., $W_e/2$ each on innerand outer sides of the curve.

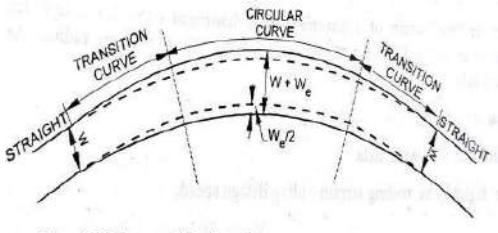

Fig. 4.26 Extra widening of pavement on horizontal curve

On sharp curves of fill roads the extra widening W_e may be provided in full, only on the inside of the curve, as shown in figure below. On horizontal circular curves without transition curves, two-thirds the widening is provided at the end of the straight section, i.e., before the start of the circular curve beyond the tangent point as in the case of super elevation.

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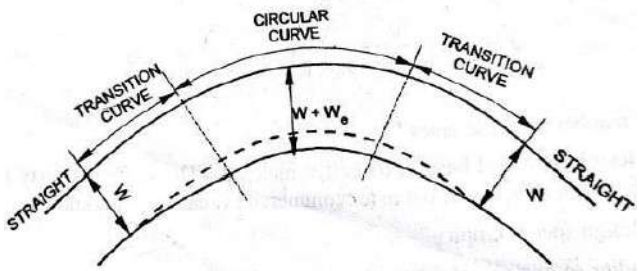

Fig. 4.27 Widening of pavement on sharp curve

Horizontal Transition Curves

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

- 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.

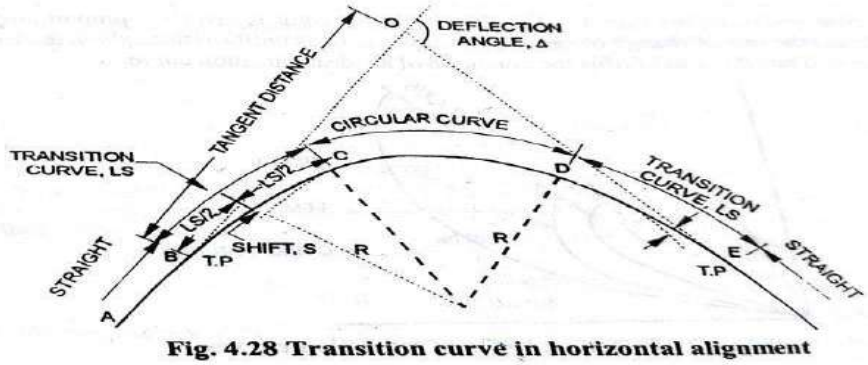

Fig. 4.28 Transition curve in horizontal alignment

Different Types of Transition Curves

The types of transition curves commonly adopted in horizontal alignment of highways are

- Spiral
- Lemniscates
- Cubic parabola

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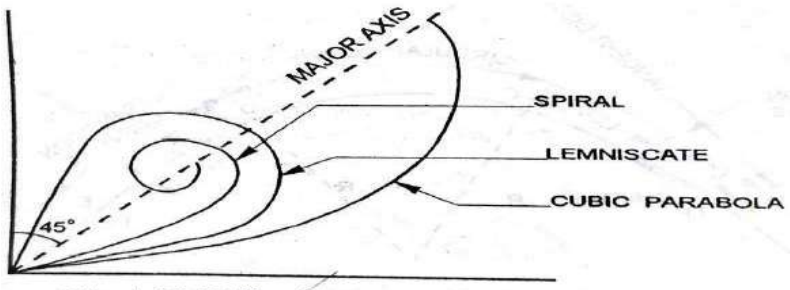

Fig. 4.29 Different types of transition curves

The general shapes of these three curves are shown in figure. All the three curves follow almost the same path up to deflection angle of 4º, and practically there is no significant difference even up to 9º. In all these curves, the radius decreases as the length increases. But the rate of change of radius and hence the rate of change of centrifugal acceleration is not constant in the case of lemniscates and cubic parabola, especially at deflection angles higher than 4º. In spiral curve the radius is inversely proportional to the length. The IRC recommends the use of the spiral as transition curve for the following reasons

- ❖ The spiral curve satisfies the requirements of an ideal transition, as the rate of change of centrifugal acceleration is uniform throughout the length.
- ❖ The geometric property of spiral is such that the calculations and setting out the curve in the field is simple and easy.

The equation of the spiral may be written as

$L_R = L_s R_c$ = constant

Therefore, $L = m\sqrt{\theta}$

m = constant = $\sqrt{2RL_s}$

θ = tangent deflection angle in radius

Factors Affecting Transition Curves Length

- Radius of circular curve, R
- Design speed, V
- Allowable rate of change of centrifugal acceleration, C (0.5 to 0.8, depending on the design speed)
- Maximum amount of super elevation, E which depends on the maximum rate of super elevation, e and the total width of the pavement, B at the horizontal curve.
- Whether the pavement cross section is rotated about the inner edge or the centre line to introduce full amount of super elevation, after the elimination of the camber.
- Allowable rate of introduction of super elevation, which depends on the terrain, location and environmental conditions of site.

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Length of Transition Curve

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

Rate of change of centrifugal acceleration

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

$$C = \frac{v^2}{Rt} = \frac{\frac{v^2}{RL_S}}{v} = \frac{v^3}{L_S R} \text{ (m}^3\text{/s)}$$

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

If the design speed is V kmph

$L_s = \frac{0.0215V^3}{CR}$

By IRC, $C = \frac{80}{(75+V)}$ (m^3/s), (0.5<C<0.8)

Where V is in kmph

i.e., the minimum and maximum values of C are limited to 0.5 and 0.8 respectively.

Rate of introduction of super-elevation

Raise (E) of the outer edge with respect to inner edge is given by E = eB = e(W +We). The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve. Therefore, the length of the transition curve Ls is

$L_s = Ne$ (W +We) = EN (pavement rotated about inner edge)

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

By empirical formula

For plain and rolling terrains

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

For mountainous and steep terrains

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

Where V is in kmph

Setting out Transition Curve

Transition curves are introduced between the tangent points of the straight stretches and the ends

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of the circular curve on both sides as shown in figure. If the length of transition curve is Ls and the radius of the circular curve is R, the shift, S of the transistion curve is given by the formula

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

Set-Back Distance on Horizontal Curves

The 'set back distance' or 'clearance' required from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance depends upon the following factors

- Required sight distance, S
- Radius of horizontal curve, R
- Length of the curve, L_c which may be greater or lesser than S

Let C be the obstruction to vision on the inner side of a horizontal highway curve of radius R, ACB the line of sight and arc AFB be the sight distance S (refer figure below). The length of the curve is denoted by L_c. The two conditions considered are when the length of the curve is greaterthan and less than the sight distance S.

When L_c>S

The sight distance is measured long the centre line of the road and the angle subtended at the centre, α is equal to S/R radians. Therefore half central angle is given by

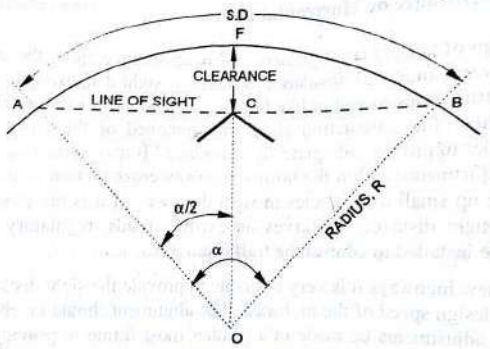

Fig. 4.30 Clearance or set-back distance when length of curve is greater than SD

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

Set back distance or clearance, m = CF = OF – OC

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

In the case of wide roads with two or more lanes, if d is the distance between the centre line of the road and the centre line of the inside lane in m, than

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

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

When L_c<S

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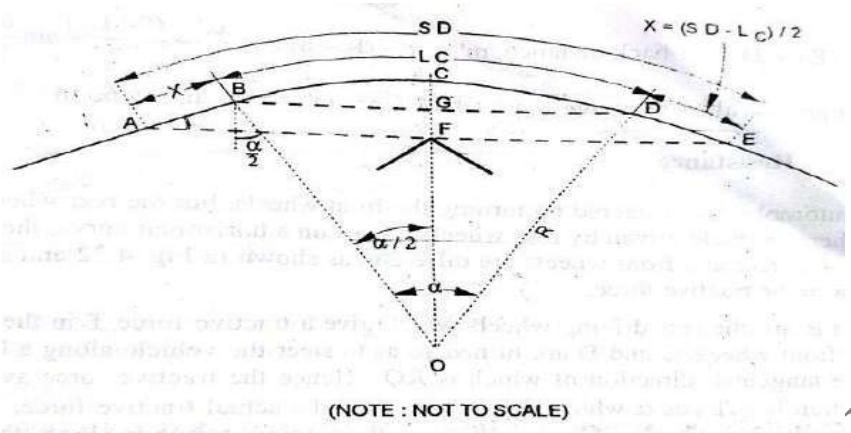

Fig. 4.31 Set-back distance when length of curve is less than SD

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

m' = FG + GC

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

Design of Vertical Alignment

The natural ground or the topography may be level at some places, but may have slopes of varying magnitudes at other locations. In order to have smooth vehicle movements on the roads, the changes in the gradient should be smoothened out by the vertical curves. The verticalalignment is the elevation or profile of the centre line of the road. The vertical alignment consistsof grades and vertical curves. The vertical alignment of a highway influences

- Vehicle speed
- Acceleration and deceleration
- Stopping distance
- Sight distance
- Comfort while travelling at high speeds
- Vehicle operation cost

Gradient

Gradient 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 or n%.

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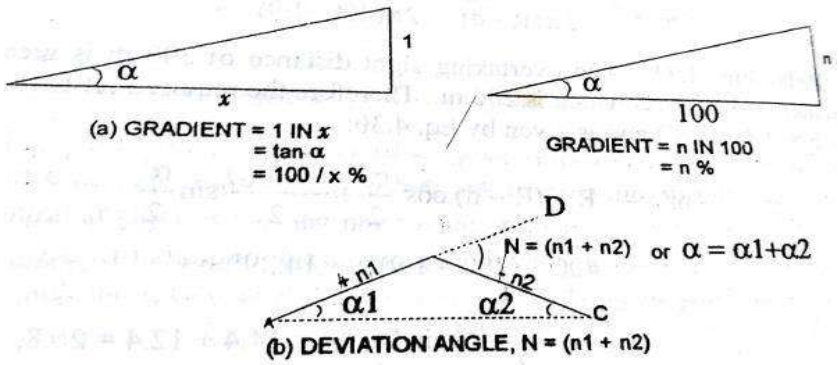

Fig. 4.33 Measure of gradients

Types of Gradient

Many studies have shown that gradient up to 7% 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, flatter gradients are desirable, it isevident that the cost of construction will also be very high.

Therefore, IRC has specified the desirable gradients for each terrain. However, it may not be economically viable to adopt such gradients in certain locations, steeper gradients are permitted for short duration. Gradients are divided into four categories

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

Ruling gradient

Ruling gradient is the maximum gradient within which the designer attempts to design the vertical profile of a road. Gradients up to the ruling gradient are adopted as a normal course in design of vertical alignment and accordingly the quantities of cut and fill are decided. Hence ruling gradients is also known as 'design gradient'. However flatter gradients may be preferred where ever practicable.

The selection of ruling gradient for the purpose of design is a complex job as several factors such as type of terrain, the length of the grade, the speed, pulling power of different types of vehicles and presence of horizontal curves are to be considered. In plain terrain or flat country it may be possible to adopt a flat gradient. But on hill roads it may not be economical or sometimes not even possible to adopt the same gradient because of large difference in levels to be covered in short length of road. Therefore different values of ruling gradient are specified on different terrains. The IRC has recommended ruling gradient values of

- ❖ 1 in 30 on plain and rolling terrain
- ❖ 1 in 20 on mountainous terrain
- ❖ 1 in 16.7 on steep terrain

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Limiting gradient

Where topography of a place compels adopting steeper gradient than the ruling gradient, 'limiting gradient' is used in view of enormous increase in cost in constructing roads with gentlergradients. However the length of continuous grade line steeper than the ruling gradient should belimited. On rolling terrain and on hill roads, it may be frequently necessary to exceed ruling gradient and adopt limiting gradient but care should be taken to separate such stretches of steep gradients by providing either a level road or a road with easier grade.

Exceptional gradient

In some extra ordinary situations it may be unavoidable to provide still steeper gradients than limiting gradient at least for short stretches and in such cases the steeper gradient up to 'exceptional gradient' may be provided. However the exceptional gradient should be strictly limited only for short stretches but exceeding about 100m at a stretch.

Minimum gradient

The road can be level, with little or no gradient. In such cases there will be problems of drainage. Though the surface water can be drained off to the side drains by providing proper camber on the pavement surface and cross slope on the shoulders, a certain longitudinal slope is essential, to drain the water along the side drains depending on the surface of the drains.

A minimum gradient of about 1 in 500 may be sufficient to drain water in concrete drain or gutter, but on inferior surfaces of drains a slope of 1 in 200 or 0.5 percent may be neededwhereas on kutcha open drains or soil drains, steeper slopes up to 1 in 100 or 1.0 percent may be needed depending on the soil type.

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Grade Compensation on Horizontal Curves

When sharp horizontal curve is to be introduced on a road which has already the maximum permissible gradient, then the gradient should be decreased to compensate for the loss of tractive effort due to the curve. This reduction in gradient at the horizontal curve is called grade compensation or compensation in gradient at horizontal curve, which is intended to off-set the extra tractive effort involved at the curve. This is calculated from the empherical relation

Grade compensation, $\% = \frac{30+R}{R}$

The maximum value of grade compensation is limited to 75/R, where R is the radius of the circular curve in m.

According to the IRC the grade compensation is not necessary for gradients flatter than 4% and therefore when applying grade compensation correction, the gradients need not be eased beyond 4%.

Vertical Curves

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

- Summit curves or crest curves with convexity upwards
- Valley curves or sag curves with concavity upwards

Summit curves

Summit curves with convexity upwards are formed in any one of the cases illustrated in figure below. The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them.

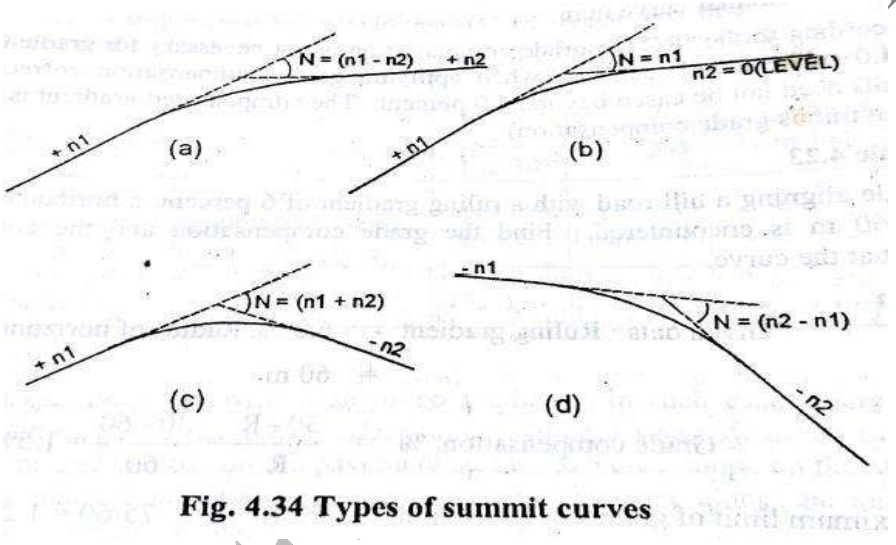

Fig. 4.34 Types of summit curves

Length of the summit curve

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

Distance, Let L is the length

Case a: Length of summit curve greater than sight distance

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

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

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Case b: Length of summit curve less than sight distance

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

When stopping sight distance is considered the height of driver's eye above the road surface (h1) is taken as 1.2 meters, and height of object above the pavement surface (h2) is taken as 0.15 meters. If overtaking sight distance is considered, then the value of driver's eye height (h1) and the height of the obstruction (h2) are taken equal as 1.2 meters.

Valley curve

Valley curves or sag curves with convexity downwards are formed in any one of the cases illustrated in figure below. The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them.

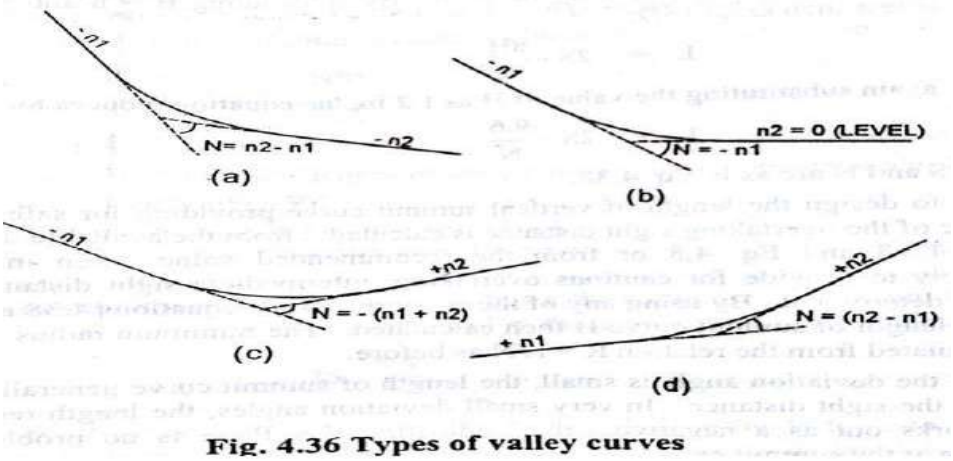

Fig. 4.36 Types of valley curves

Length of the valley curve

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

1. Comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a Comfortable level of about 0:6m/sec^3.
2. A safety criterion; that is the driver should have adequate headlight sight distance at any Part of the country.

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Comfort criteria

The length of the valley curve based on the rate of change of centrifugal acceleration that will ensure comfort: Let c is the rate of change of acceleration, R the minimum radius of the curve, v is the design speed and t is the time, then c is given as: $Ls = v^3/CR$

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

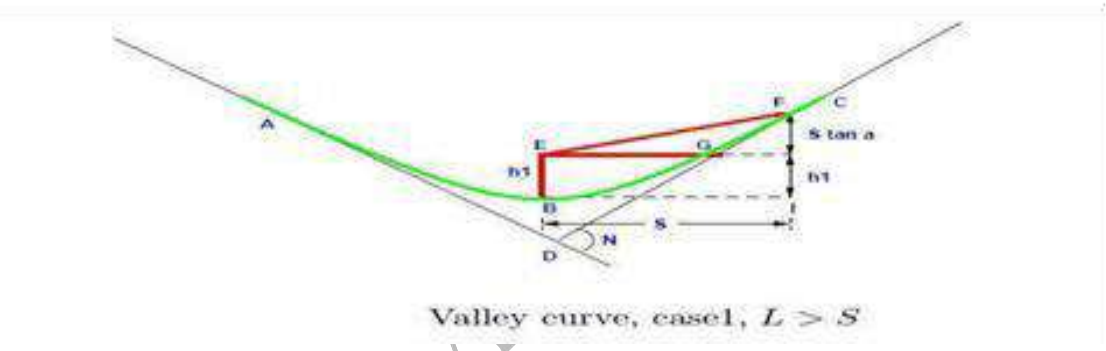
$$R = \frac{Ls}{N}$$

Safety criteria

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

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

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



Valley curve, case1, $L > S$

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

$$h_1 + S\tan\alpha = aS^2$$

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

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

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

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

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve,

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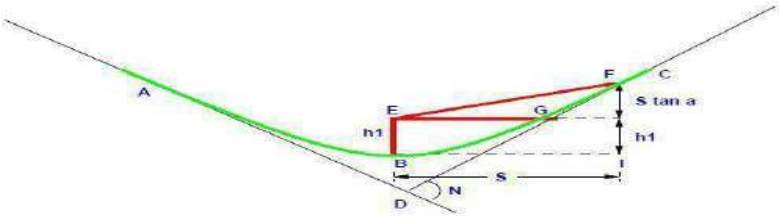
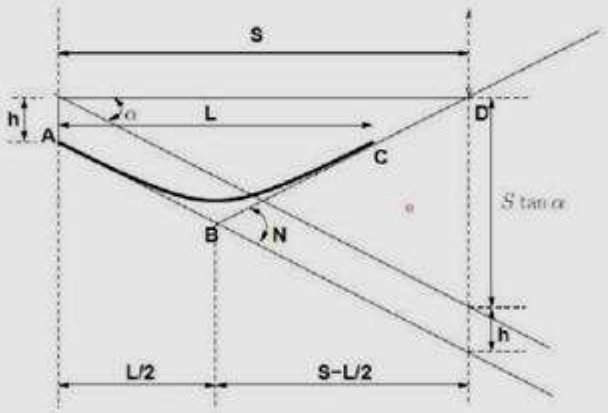
then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve. The case is shown in figure below.



Valley curve, case1, $L > S$



Valley curve, case 2, $S > L$

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

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

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

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Important Question

1. What are the requirements of an ideal alignment? Explain factors controlling alignment.
2. What are the special considerations for hilly area alignment?
3. Explain engineering surveys for highway alignment.
4. Explain the process for new project work
5. Explain the factors controlling geometric design of highways
6. Explain pavement surface characteristics.
7. What is Sight Distance? What is the Restrictions to Sight Distance?
8. What is Stopping Sight Distance? Explain the Factors on Which Stopping Sight Distance Depends.
9. How stopping distance is analyzed?
10. What is Overtaking Zones?
11. What is super elevation? Explain analysis of super elevation.
12. What are objectives of providing extra widening of pavement on horizontal curve?
13. Explain Analysis of Extra Widening On Horizontal Curves.
14. Explain Different Types of Transition Curve.
15. Explain factors influencing the Design of Vertical Alignment.

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MODULE - 3

PAVEMENT MATERIALS

Pavement Materials: Subgrade soil - desirable properties-HRB soil classification determination of CBR and modulus of subgrade reaction with Problems Aggregates-Desirable properties and tests, Bituminous materials-Explanation on Tar, bitumen, cutback and emulsion-tests on bituminous material

Pavement Design: Pavement types, component parts of flexible and rigid pavements and their functions, ESWL and its determination (Graphical method only)-Examples

Sub Grade Soil

Subgrade soil is an integral part of the road pavement structure which directly receives the traffic load from the pavement layers. The subgrade soil and its properties are important in the design of pavement structure. The main function of the subgrade is to give adequate support to thepavement and for this the subgrade should possess sufficient stability under adverse climate and loading conditions. The formation of waves, corrugations, rutting and shoving in black top pavements and the phenomena of pumping, blowing and consequent cracking of cement concretepavements are generally attributed due to the poor subgrade conditions.

Properties of Soil

The desirable properties of soil as a highway material are

- Stability
- Incompressibility
- Permanency of strength
- Minimum changes in volume and stability under adverse conditions of weather and ground water
- Good drainage, and
- Ease of compaction.

The soil should possess adequate stability or resistance to permanent deformation under loads and should possess resistance to weathering, thus retaining the desired subgrade support. Minimum variation in volume with variation in water content will ensure minimum variation in differential expansion and differential strength values of the subgrade. Good drainage is essentialto avoid excessive moisture retention and to reduce the potential frost action. Ease of compaction ensures higher dry density and strength under particular type and amount of compaction.

Index Properties Of Soil

The soil properties on which their identification and classification are based are known as index properties. The index properties which are usually used are grain size distribution, liquid limit and plasticity index.

Grain size distribution is found by mechanical analysis. The components of soils which are coarse grained may be analyzed by sieve analysis and the soil fines by sedimentation analysis. The grain size analysis is hence carried out to determine the percentage of individual grain size present in a soil sample. Dry sieve analysis is carried out only on non-cohesion soil. But if the soil has even a small fraction of slit or clay with some cohesive property, the small lumps formed cannot be separated by dry sieving. Therefore, according to the Bureau of Indian

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standards (BIS) specification, 'wet sieve analysis should be carried out on all such cohesive soils.

Liquid limit is the maximum water content at which the soil will flow under the application of very small shearing force. The liquid limit is usually determined in the laboratory using a mechanical device.

Plastic limit is the minimum moisture content at which the soil remains in a plastic state. Plasticity index is defined as the numerical difference between liquid limit and plastic limit. Plasticity index thus indicates the range of moisture content over which the soil is in plastic condition.

Soil Classification Based On Grain Size

The most accepted grain size classification is the M.I.T. (Massachusetts Institute of Technology) classification system. The Indian Standards Institution (I.S.I) has also adopted the same limits of M.I.T system for the Indian standard classification system of soil grains. The limits of the grains size for each component as per this system are shown below.

Soil classification based on grain size

Gravel	Sand			Silt			Clay		
	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine
	2.0*	0.6*	0.2	0.06	0.02	0.006	0.002	0.0006	0.0002

Fractions of soils	
Larger then 2.00mm size	Gravel
Between 2.00mm – 0.06mm size	Sand
Between 0.06mm – 0.002mm size	Silt
Smaller than 0.002 size	Clay

Soil Classification Systems

The various soil classification systems in use in the field of highway engineering are

- Burmister descriptive classification
- Casagrande soil classification
- Unified soil classification of revised casagrande soil classification and I.S. soil classification systems
- U.S. Public Roads Administration (PRA) classification
- Highway Research Board (HRB) or American Association of State Highway Officials (AASHO) classification or revised PRA classification
- Federal Aviation Agency (FAA) classification
- Civil Aeronautics Administration (CAA) classification
- Compaction classification

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Highway Research Board (HRB) Classification Of Soils

This is also called Revised Public Roads Administration (PRA) soil classification system. Soils are divided into seven groups A-1 to A-7. A-1, A-2 and A-3 soils are granular soils, percentage fines passing 0.074 mm sieve being less than 35 percent. A-4, A-5, A-6 and A-7, soils are fine grained or silt-clay soils, passing 0.074 mm sieve being greater than 35 percent.

A-1 soils are well graded mixture of stone fragments, gravel coarse sand, fine sand and non-plastic or slightly plastic soil binder. The soils of this group are subdivided into two subgroups, A-1-a, consisting predominantly of stone fragments or gravel and A-1-b consisting predominantly of coarse sand.

A-2 group of soils include a wide range of granular soils ranging from A- 1 to A-3 groups, consisting of granular soils and up to 35% fines of A-4, A-5, A-6 or A-7 groups. Based on the fines content, the soils of A-2 groups are subdivided into subgroups A-2-4, A-2-5, A-2-6 and A-2-7.

A-3 soils consist mainly, uniformly graded medium or fine sand similar to beach sand or desert blown sand. Stream-deposited mixtures of poorly graded fine sand with some coarse sand and gravel are also included in this group.

A-4 soils are generally silty soils, non-plastic or moderately plastic in nature with liquid limit and plasticity index values less than 40 and 10 respectively.

A-5 soils are also silty soils with plasticity index less than 10%, but with liquid limit values exceeding 40%. These include highly elastic or compressible, soils, usually of diatomaceous of micaceous character.

A-6 group of soils are plastic clays, having high values of plasticity index exceeding 10% and low values of liquid limit below 40%; they have high volume change properties with variation in moisture content.

A-7 soils are also clayey soils as A-6 soils, but with high values of both liquid limit and plasticity index (LL greater than 40% and plasticity index greater than 10%).

Group Index of Soil

In order to classify the fine grained soils within one group and for judging their suitability as subgrade material, an indexing system has been introduced in HRB classification known as Group Index. Group index is function of percentage material, passing 200 mesh sieve (0.074mm), liquid limit and plasticity index of soil given by equation

$G I = 0.2a + 0.005ac + 0.01bd$

Where,

a = that portion of material passing 0.074mm sieve, greater than 35 and not exceeding 75 percent (0 to 40)

b = that portion of material passing 0.074mm sieve, greater than 15 and not exceeding 35 percent (0 to 40)

c = that value of liquid limit in excess of 40 and less than 60 (0 to 20)

d = that value of plasticity index exceeding 10 and not more than 30 (0 to 20)

The plasticity chart of HRB soil classification system shown in figure below. The soil groups showing the classification limit of various properties is given in table 6.4.

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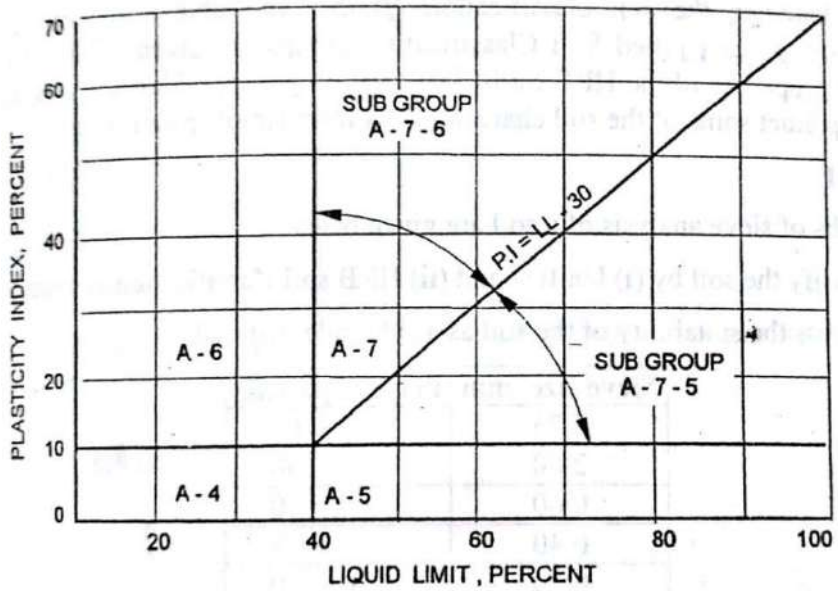

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Table 6.4 Highway research board soil classification system

General classification	Granular soils, less than 35 percent passing No. 200 sieve or 0.074 mm sieve							Fine grained (silt-clay) soils, more than 35% passing No. 200 sieve size				
Classification Group	A-1		A-3	A-2				A-4	A-5	A-6	A-7	
Sub classification	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5	A-7-6
Sieve analysis, % passing												
No. 10 sieve (2 mm size)	50 max.											
No. 40 sieve (0.42 mm size)	30 max.	50 max.	51 max.									
No. 200 sieve (0.074 mm size)	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction												
Passing no. 40 sieve												
Liquid limit	-	-	-	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	41 min
Plasticity index	6 max.	6 max.	Non plastic	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.	11 min.
											PI < (LL–30)	PI > (LL–30)
Group Index	0	0	0	0	0	4 max.	4 max.	8 max.	12 max.	16 max.	20 max.	20 max.

Test on Strength Properties Of Soil

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The sub grade soil and its properties are important in the design of

pavement structure. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climaticand loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests.
The tests used to evaluate the strength properties of soils may be broadly divided into three groups:

- Shear tests
- Bearing tests
- Penetration tests

Shear tests are usually carried out on relatively small soil samples in the laboratory. In order to find out the strength properties of soil, a number of representative samples from differentlocations are tested. Some of the commonly known shear tests are direct shear test, triaxial compression test, and unconfined compression test.
Bearing tests are loading tests carried out on soil sub grade or at formation level in-situ, using a loading plate of relatively large bearing area. The ratio of the deformation or settlement of the plate to the diameter of the loaded area is quite small. The results of the bearing tests are influenced by variations in the soil properties within the stressed soil mass underneath and hencethe overall stability of the part of the soil mass stressed could be studied.
Penetration tests may be considered as small scale bearing tests in which the size of the loaded area is relatively much smaller and ratio of the penetration to the size of the loaded area is much greater than the ratios in bearing tests. The penetration tests are carried out in the field or in the laboratory. The CBR test and cone penetration tests are commonly known penetration tests.

Plate Bearing Test

In plate bearing test, a compressive stress is applied to the soil or pavement layer through rigid plate's relatively large size and the deflections are measured for various stress values. The deflection level is generally limited to a low value, in the order of 1.25 to 5 mm. The plate- bearing test has been devised to evaluate the supporting power of sub grades or any other pavement layer by using plates of larger diameter. The plate-bearing test was originally meant tofind the modulus of sub grade reaction in the Westergard's analysis for wheel load stresses in cement concrete pavements.

Test Procedure

- The test site is prepared and loose material is removed so that the 75 cm diameter plate rests horizontally in full contact with the soil sub-grade. The plate is seated accurately and then a seating load equivalent to a pressure of 0.07 kg/cm^2 (320 kg for 75 cm diameter plate) is applied and released after a few seconds.
- The settlement dial gauge is now set corresponding to zero load.
- A load is applied by means of jack, sufficient to cause an average settlement of about 0.25 mm. When there is no perceptible increase in settlement or when the rate ofsettlement is less than 0.025 mm per minute (in the case of soils with high moisture content or in clayey soils) the load dial reading and the settlement dial readings are noted.
- Deflection of the plate is measured by means of deflection dials, placed usually at one-third points of the plate near its outer edge.
- To minimize bending, a series of stacked plates should be used.

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- Average of three or four settlement dial readings is taken as the settlement of the plate corresponding to the applied load. Load is then increased till the average settlement increase to a further amount of about 0.25 mm, and the load and average settlement readings are noted as before.
- The procedure is repeated till the settlement is about 1.75 mm or more.
- Allowance for worst subgrade moisture and correction for small plate size should be dealt properly.

Modulus of subgrade reaction

Modulus of subgrade reaction K is defined as the pressure sustained per unit deformation of subgrade at specified deformation or pressure level, using specified plate size. A graph is plotted with the mean settlement versus bearing pressure (load per unit area) as shown in Figure. The pressure p corresponding to a settlement is obtained from this graph. The modulus of subgrade reaction is calculated from the relation.

$$K = \frac{p}{0.125}\, kg/cm^3$$

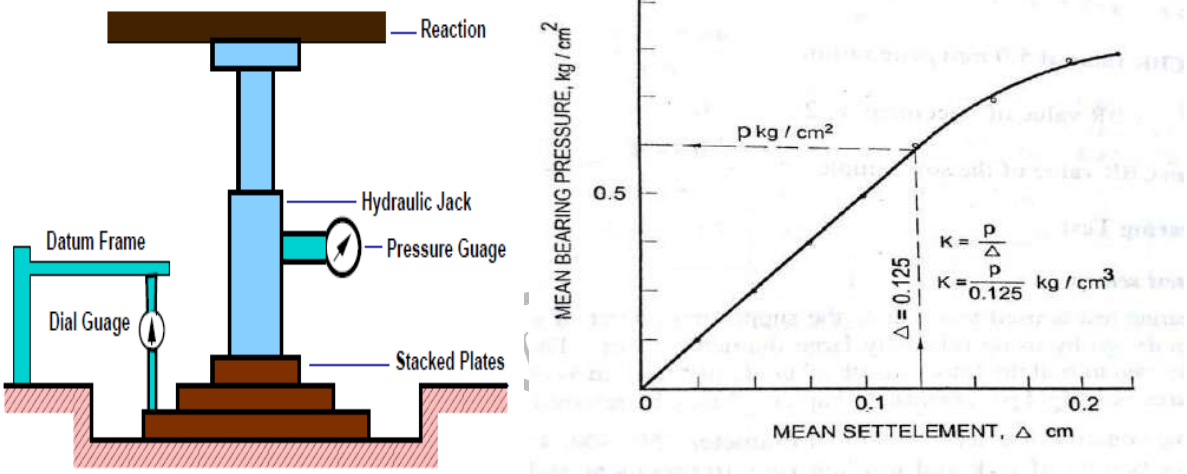

Fig. 6.13 Bearing pressure – settlement curve

Plate Load Test

Correction for small plate size

In some cases the load capacity may not be adequate to cause 75cm dia plate to settle 0.175cm. In such a case a plate of smaller dia (say 30cm) may be used. Then K value should be found by applying a suitable correction for plate size. Assuming the subgrade to be an elastic medium with modulus of elasticity E (kg/cm2), the theoretical relationship of deformation (cm) under a rigid plate of radius a (cm) is given by

$$\Delta = 1.18\,\frac{p_a}{E}$$

But, $K = \frac{p}{\Delta} = \frac{p \times E}{1.18\, p a} = \frac{E}{1.18\, a}$

If the value of E is taken as constant for a soil then K is inversely proportional to aor Ka is constant i.e., $K\, a = K_1\, a_1$ or $K = K_1\, a_1 / a$. Hence if the test is carried out with a smaller plate of radius a and the modulus of subgrade reaction K is found. Then the corrected value of modulusof subgrade reaction K for standard plate of radius a, is given by

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$$K = K_1 \frac{a_1}{a}$$

California Bearing Ratio (CBR) Test

This is a penetration test developed by the California division of highway for evaluating the stability of soil subgrade and other pavement materials. The test results have been correlated with flexible pavement thickness requirement for highway and airfield. CBR test may be conducted in the laboratory on a prepared specimen in a mould or in situ in the field.

The laboratory CBR apparatus consists of

- **Cylindrical mould** of 150mm dia, 175mm height with 50mm collar height, detachable perforated base with spacer disc of 148mm dia and 47.7mm thick is used to obtain aspecimen of exactly 127.3mm height.
- **Loading Machine -** Compression machine operated at a constant rate of 1.25mm/min.Loading frame with cylindrical plunger 50mm dia & dial gauge for measuring the deformation due to application of load.
- **Compaction rammer**

Type of Compaction	No of layers	Wt of hammer (kg)	Fall (cm)	No of blows
Light compaction	3	2.6	31	56
Heavy compaction	5	4.98	45	56

- **Annular weight or surcharge weight** - 2.5 kg of surcharge wt of 147mm dia are placed on specimen both at the soaking and testing of prepared samples.

Procedure

- About 5kgs of soil is taken passing though 20mm IS sieve and retained on 4.75mm IS sieve.
- The soil is mixed with water upto OMC.
- The spacer disc is placed at the bottom of the mould over the base plate & a coarse filter paper is placed over the spacer disc. Then the moist soil sample is to be compacted over this in the mould by adopting either IS light compaction or IS heavy compaction.
- For IS heavy compaction 3 equal layers of compacted thickness about 44mm by applying 56 evenly distributed blows from 2.6 kg rammer.
- For IS heavy compaction 5 equal layers of compacted thickness about 26.5mm byapplying 56 evenly distributed blows from 4.89 kg rammer.
- After compacting last layer, the collar is removed and the excess soil above the top of the mould is evenly trimmed off by means of straight edge (of 5mm thickness).
- Clamps are removed and the mould with compacted soil is lifted leaving below the perforated base plate & the spacer disc which is removed.
- Then the mould with compacted soil is inverted & placed in position over the base plate. Now the clamp of the base is tightened. Another filter paper is placed on the top surface of the sample & the perforated plate with adjustable stem is placed over it.

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- Now surcharge weights of 2.5 or 5kgs are placed over the perforated plate & the whole mould with the weights is placed in a water tank for soaking such that water can enter the specimen both from the top & bottom.
- The test set up is kept undisturbed in the water tank to allow soaking of the soil specimen for full 4 days or 96 hrs.
- The mould is taken out of the water tank & the sample is allowed to drain in a perpendicular position for 15 min surcharge weight, perforated plate with stem, filter paper is removed.
- Then the specimen is clamped over base plate, surcharge weights are placed on specimens centrally such that the penetration test could be conducted.
- The mould with base plate is placed under the penetration plunger of loading machine.
- The penetration plunger is seated at the centre of the specimen & is brought in contact with the top surface of the soil sample by applying a seating load of 4kgs.
- The dial gauge for measuring the penetration values of the plunger is fitted in position. The dial gauge of proving ring & the penetration dial gauge are set to 0.
- Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min. A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively.
- The load readings are recorded at penetration of 0, 0.5, 1.0, 1.5, 2, 2.5, 3, 4, 5, 7.5, 10 & 12.5mm.
- In case the load reading starts decreasing before 12.5mm penetration, the max load & the corresponding penetration values are recorded. After the final reading the load is released & the mould from loading machine.
- The proving ring calibration factor is noted so that load dial gauge value can be converted into the load in kg.
- Two typical types of curves may be obtained as shown in fig. The normal curve is with convexity upwards as for specimen no. 1 and the loads corresponding to 2.5 and 5.0 mm penetration values are noted. Sometimes a curve with initial upward concavity is obtained, indicating the necessity of correction as for specimen no. 2. In this casecorrected origin is established by drawing a tangent from the steepest point on the curve. The load values corresponding to 2.5 and 5.0mm penetration values from the corrected origin are noted.
- CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore,
- $$CBR,\% = \frac{Load\ sustained\ by\ the specimen}{Load\ sustained\ by\ the \text{standard}\ aggregates}$$

  Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimensis reported as the CBR value of the sample.

  Standard load values on crushed stone aggregates for specified penetration values

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Penetration, mm	Standard load, kg	Unit Standard load, kg/cm^2
2.5	1370	70
5.0	2055	105

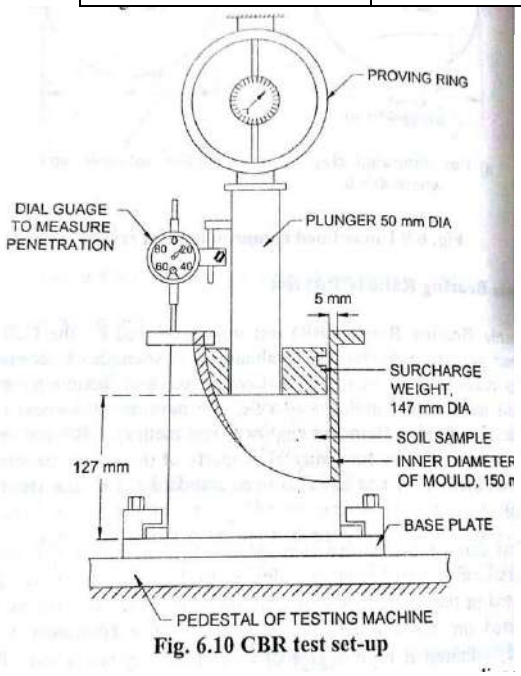

Fig. 6.10 CBR test set-up

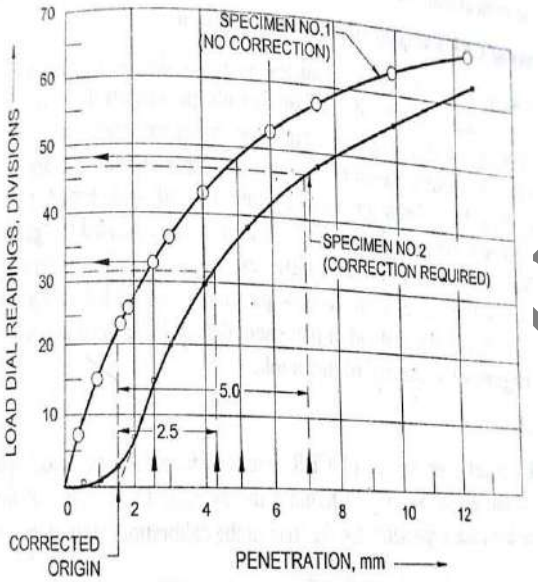

Fig. 6.11 Load – penetration curves of CBR test

Aggregates

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic. Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). Aggregate is used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a by-product ofother manufacturing industries.

Desirable Properties of Road Aggregates

- **Strength:** The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should posse's high resistance to crushing and to withstand the stresses due to traffic wheel load.
- **Hardness:** The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.
- **Toughness:** Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred

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wheels from one particle to another at different levels causes severe impact on the aggregates. Sever impact like hammering is quite move on water bound macadam roads where stones protrude out especially after the monsoons. The magnitude of impact would increase with the roughness of the road surface, speed of vehicle and other vehicular characteristics.

- **Durability:** The stone used in pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may be called as soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that ofatmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.
- **Shape of Aggregate:** Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky andelongated particles will have less strength and durability when compared with cubical,angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.
- **Adhesion with Bitumen:** The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

Tests on Aggregates

In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out

- Crushing test
- Abrasion test
- Impact test
- Soundness test
- Shape test
- Specific gravity and water absorption test
- Bitumen adhesion test

Crushing Test

This test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions (Figure).

Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed (W_1) and placed in the test standard test cylinder of 15.2cm diameter, 14cm height with a base plate in three layers each layer being tampered again. The plunger is placed on the top of the specimen and a compressive load of 40 tones gradually applied at the rate of 4 tones per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material is noted (W_2).

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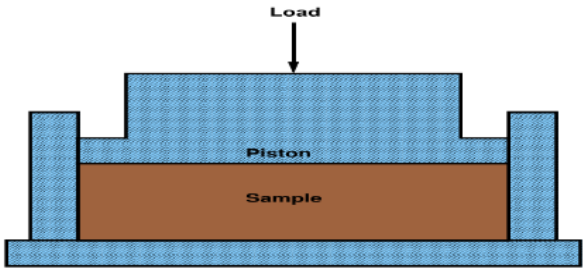
The aggregate crushing value is the percentage of the crushed material passing 2.36mm sieve (W_2) in terms of weight of the total sample (W_1).

$$AggregateCrushingValue = \frac{W_2}{W_1} \times 100$$

Aggregate crushing value for good quality aggregate used in base course shall not exceed 45% and for surface course shall be less than 30%.



Abrasion Test

Due to the movements of traffic on the road stones used in the surface course are subjected to wearing action at the top. Hence road stones should be hard enough to resist the abrasion due to traffic. Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works.

Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS:2386 part-IV). The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated (Figure). An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinderalong with the aggregates. The number of the abrasive spheres varies according to the grading ofthe sample. The quantity of aggregates to be used depends upon the gradation and usually rangesfrom 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates. After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value.

A maximum value of 40 percent is allowed for WBM base course in Indian conditions. For bituminous concrete, cement concrete a maximum value of 30% is specified.

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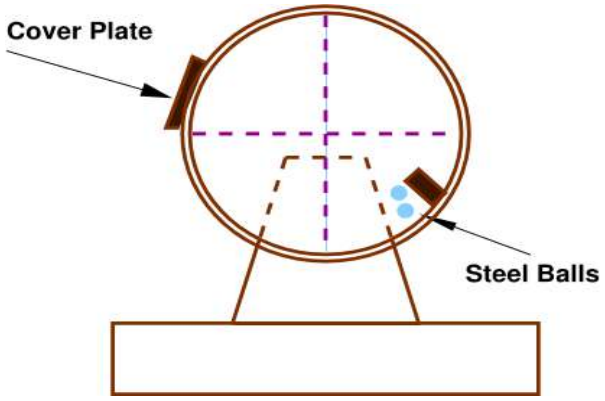
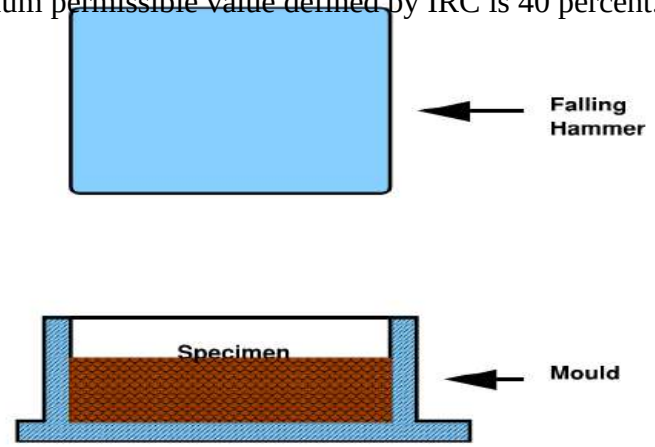


Impact Test

A test designed to evaluate the toughness of stone or the resistance of aggregate to impact, which has a different effect than the resistance to gradually increasing compressive stress. The aggregate impact test is carried out to evaluate the resistance to impact of aggregates.
Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 numbers of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 number of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve and the impact value is measured as percentage of aggregates passing sieve (W_2) to the total weight of the sample (W_1).

$$AggregateImpactValue = \frac{W_2}{W_1} \times 100$$

Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent.



Soundness Test

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing is likely to disintegrate prematurely. To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V. Aggregates of

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specified size are subjected to cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105 to 110°C to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.

Shape Test

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it and by its angularity number. Aggregates which are flaky or elongated aredetrimental to higher workability.

Flakiness index

The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. This test is applicable to aggregates larger than 6.3 mm. Test procedure had been standardized in India IS:2386 part-I. The sample of aggregate to be tested is first sieved through a set of sieves and separated into specified size ranges. Now to separate the flaky material, the aggregates which pass through the appropriate thickness slot of the thickness gauge are found. The flaky material passing the appropriate slot from each size range of aggregates are added up and let this total weight of flaky particles be W_1 g. If the total weight of sample taken from the different size ranges is W g, the flakiness index is given by

$$flakinessindex = \frac{100W_1}{W}\ \%$$

Elongation index

The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm. This test is also specified in (IS:2386 Part-I).The sample of aggregate to be tested is first sieved through a set of sieves and separated into specified size ranges. Now to separate the elongated material, the aggregates which do not pass through the appropriate elongated slot of the elongated gauge are found. The elongated material not passing the appropriate slot from each size range of aggregates are added up and let this total weight of elongated particles be W_1 g. If the total weight of sample taken from the different size ranges is W g, the elongation index is given by

$$elongationindex = \frac{100W_1}{W}\ \%$$

Flakiness index and elongation index values in excess of 15% are generally considered undesirable.

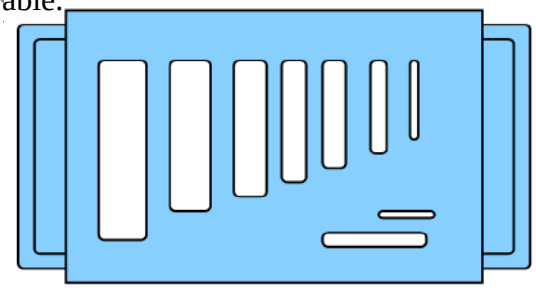

Fig: Flakiness Gauge

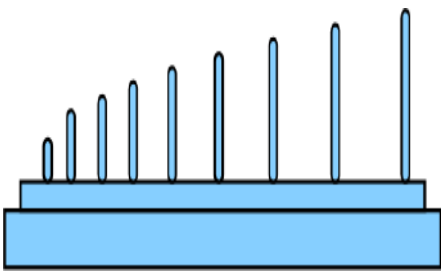

Fig: Elongation Gauge

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Angularity number

Based on the shape of the aggregate particles, they may be classified as rounded, irregular or partly rounded, angular and flaky. Angularity or absence of rounding of the particles of an aggregate is a property which is of importance because it affects the ease of handling a mixtureof aggregate and binder. The degree of packing of particles of single sized aggregates dependson the shape and angularity of the aggregate. Hence the angularity of the aggregate can be estimated from the properties of voids in a sample of aggregate compacted in a particularmanner. The range of angularity number for aggregates used in construction is 0 to 11. The higher the angularity number, more angular is the aggregate.

The apparatus for testing the angularity number consists of a metal cylinder of capacity 3 litre, tamping rod and a metal scoop. The test sample is sieved and a specified size range of the aggregate, such as 16 – 20mm, 12.5 – 16mm, etc are used for the test. Aggregates are filled in three layers and each layer is tamped 100 times. The excess aggregates are struck off to the top level of the cylinder and weight of aggregate with cylinder is taken as W g. then cylinder is emptied and the weight of the cylinder with water is taken as C g. the specific gravity of aggregate is taken as G. Therefore, the angularity number is given by

$$\text{Angularity Number} = 67 - \frac{100W}{CG_a}$$

Specific Gravity and Water Absorption Tests

The specific gravity of an aggregate is considered to a measure of the quality or strength of the material. Stones having low specific gravity values are generally weaker than those having higher values. Water absorption is an indicator for the strength of rock. Stones having higher water absorption values are porous and thus weak. The test is conducted in laboratory by wire basket method.

About 2kg of dry sample of coarse aggregate is placed in wire basket and immersed in water for 24hours. The sample is weighed in water and the buoyant weight is found (W1). Te empty weight of basket in suspension with water is found (W2). The aggregates are then taken out, surface dried well with absorbent cloth is weighed (W3). The aggregates are then dried in an oven at a temperature 110°C for 24 hours and then the oven dry weight is determined (W4). Specific gravity is calculated by dividing the dry weight of aggregate by weight of equal volume of water.

$$specificgravity = \frac{W_4}{(W_3 - (W_1 - W_2))}$$

Water absorption is expressed as the percent water absorbed in terms of oven dried weight of the aggregates.

$$waterabsorption = \frac{(W_3 - W_4)100}{W_4}$$

Bitumen Adhesion Test

Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold. This problem can bedealt with by removing moisture from the aggregate by drying and increasing the mixing temperature. Further, the presence of water cause stripping of binder from the coated aggregates.

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This problem occurs when bitumen mixture is permeable to water. Several laboratory tests are conducted to arbitrarily determine the adhesion of bitumen binder to an aggregate in the presence of water. Static immersion test is one specified by IRC and is quite simple. The principle of the test is by immersing aggregate fully coated with binder in water maintained at 400°C temperature for 24 hours. IRC has specified maximum stripping value of aggregates should not exceed 5%.

Bituminous Materials

Bituminous binders used in pavement construction works include both bitumen and tar. Bitumen is a petroleum product obtained by the distillation of petroleum crude where-as road tar is obtained by the destructive distillation of coal or wood. Both bitumen and tar have similar appearance, black in colour though they have different characteristics. Both these materials can be used for pavement works.

Types of bituminous materials

Bituminous material used in highway construction may be broadly divided as

- Bitumen
- Tar

Bitumen

Crude petroleum obtained from different places is quite different in their composition. The portion of bituminous material present in the petroleum's may widely differ depending on the source. Almost all the crude petroleum's contain considerable amounts of water along with crude oil. Hence the petroleum should be dehydrated first before carrying out the distillation. General types of distillation processes are fractional distillation and destructive distillation. In fractional distillation the various volatile constituents are separated at successively higher temperatures without substantial chemical change and the residue obtained from this is petroleum bitumen.

Desirable Properties of Bitumen

- The viscosity of the bitumen at the time of mixing with aggregates and compaction of the pre-mix should be adequate.
- The bituminous binder should become sufficiently viscous on cooling that the compacted bituminous pavement layer can gain stability and resist deformation under traffic loads.
- In bituminous mix, binder used form ductile thin films around the aggregates to serve as a satisfactory binder in improving the physical interlocking of the aggregates.
- The bituminous binder used should not be highly temperature susceptible. During the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The bitumen binder should have sufficient adhesion with the aggregates in the presence of water.
- There has to be adequate affinity and adhesion between the bitumen and aggregate used in mix.

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Tests on Bitumen

There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

- Penetration test
- Ductility test
- Softening point test
- Specific gravity test
- Viscosity test
- Flash and Fire point test
- Solubility test
- Spot test
- Float test
- Water content test
- Loss on heating test

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Penetration Test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened toa pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25°C. It may be noted that penetration value is largely influenced by any inaccuracy with regardsto pouring temperature, size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred. The Figure shows a schematicPenetration Test setup.

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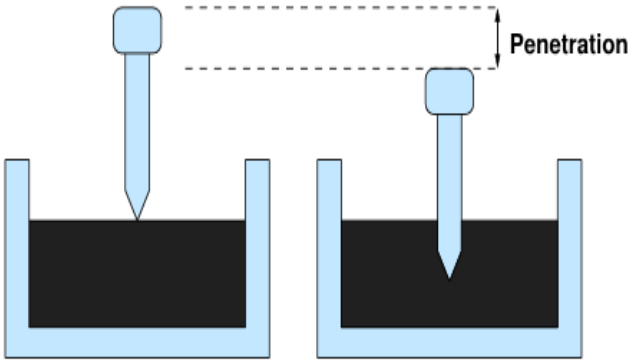
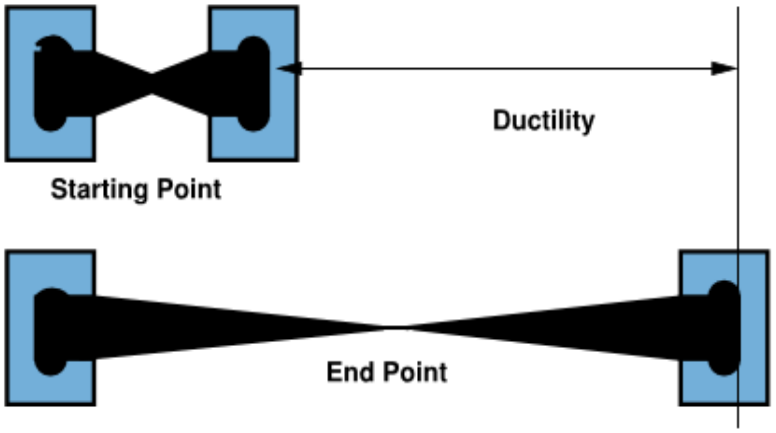


Ductility Test

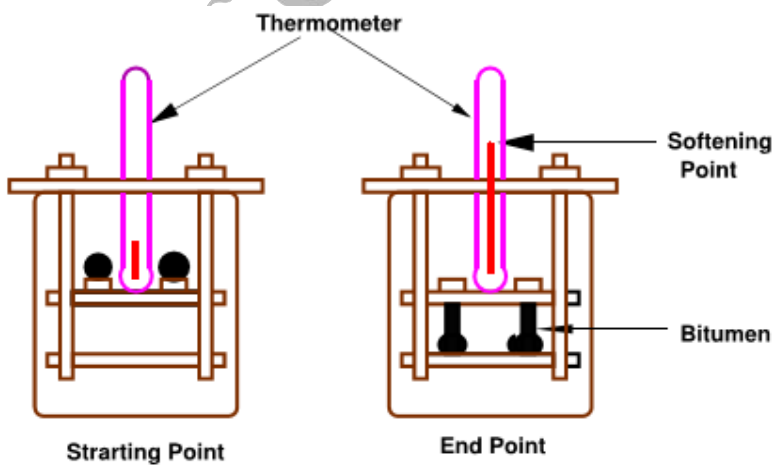
Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate.These samples with moulds are cooled in the air and then in water bath at 27°C temperature. The

excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The rate of pulling is 50mm per minute. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc. A minimum ductility value of 75 cm has been specified by the BIS. Figure shows ductility moulds to be filled with bitumen.



Softening Point Test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5°C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates. Figure shows softening point test setup.



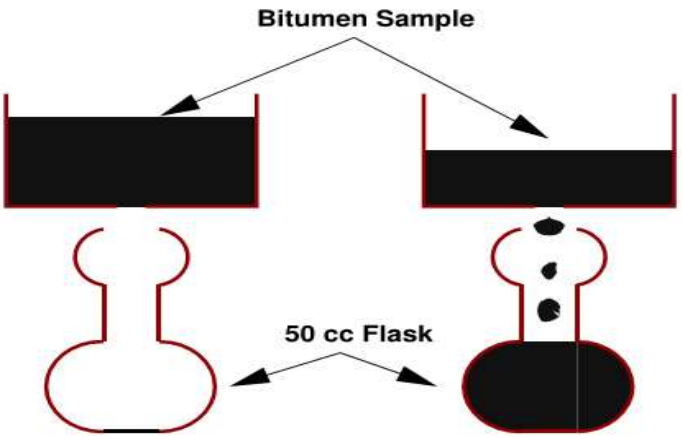
Specific Gravity Test

In paving jobs, to classify a binder, density property is of great use. In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values. The density of bitumen is greatly influenced by its chemical composition. Increase in

aromatic type mineral impurities cause an increase in specific gravity. The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27°C. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi solid or solid state. The specific gravity of bitumen varies from 0.97 to 1.02.

Viscosity Test

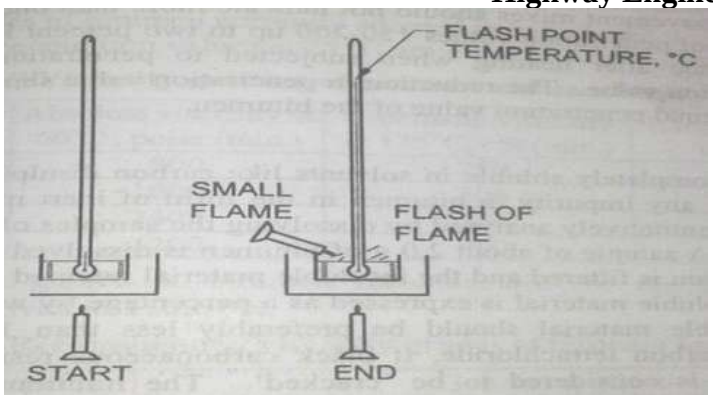
Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observedto result in lower stability values. At high viscosity, it resists the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles. Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in seconds is the time taken by the 50 ml bitumen material topass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25°C or 10 mm orifice at25 or 40°C.



Flash and Fire Point Test

At high temperatures depending upon the grades of bitumen materials leave out volatiles and this volatile catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions. The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

Pensky-Martens closed cup apparatus or open cup are used for conducting the tests. The material to be tested is filled in the cup up to a filling mark. The bitumen sample is then heated at the rate of 5°C to 6°C per minute, stirring the specimen. The test flame is applied at intervals depending upon the expected flash and fire points. The BIS has specified the minimum value of flash point by open cut test as 220°C.



Float Test

Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used. The apparatus consists of an aluminum float and a brass collar filled with bitumen to be tested. The specimen in the mould is cooled to a temperature of 5°C and screwed in to float. The total test assembly is floated in the water bath at 50°C and the time required for water to pass its way through the specimen plug is noted in seconds and is expressed as the float value.

Water Content Test

It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water content in bitumen is determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling of the water. The weight of the water condensed and collected is expressed as percentage by weight of the original sample. The allowable maximum water content should not be more than 0.2% by weight.

Loss on Heating Test

When the bitumen is heated it loses the volatility and gets hardened. About 50gm of the sample is weighed and heated to a temperature of 163°C for 5hours in a specified oven designed for this test. The sample specimen is weighed again after the heating period and loss in weight is expressed as percentage by weight of the original sample. Bitumen used in pavement mixes should not indicate more than 1% loss in weight, but for bitumen having penetration values 150- 200 up to 2% loss in weight is allowed.

Solubility Test

Pure bitumen is completely soluble in solvents like carbon disulphide and carbon tetrachloride and any impurities present is analyzed by dissolving the sample in any two solvents. A sample ofabout 2g of bitumen is dissolved in about 100ml of solvent. The solution is filtered and the insoluble material retained is washed, dried and weighed. It is expressed as a percentage of original samples. The insoluble material should be preferably less than 1%. In solubility test with carbon tetrachloride, if black carbonaceous residue is over 0.5%, the bitumen is considered to be cracked.

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Spot Tests

This is a test for detecting over heated or cracked bitumen. This test is considered to be more sensitive than the solubility test for detection of cracking. About 2g of bitumen is dissolved in 10ml of naphtha. A drop of this solution is taken out and placed on a filter paper, one after one hour and second after 24 hours after the solution is prepared. If the strain of the spot on the paper is uniform in colour, the bitumen is accepted as uncracked. But if the spots from brown or black circle in the centre with an annular ring of lighter colour surrounding it, the bitumen is considered to be over heated or cracked.

Different Forms of Bitumen

- **Cutback Bitumen**

Characteristics

Cutback bitumen is obtained by blending bitumen binder with suitable volatile diluents or solvents in the required proportion to reduce its viscosity to the desired range. The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate. Cutback bitumen is used for cold weather bituminous road construction and maintenance. The distillates used for preparation of cutback bitumen are naphtha, kerosene, diesel oil, and furnace oil. The rate at which the cutback hardens on the road depends upon the characteristics and quantity ofthe volatile oil used as the diluents and also on the atmospheric temperature and humidity at the work site. Cutback bitumen binder of appropriate type and grade is selected for use as track coat without the need to heat. This binder is particularly preferred for use in sites at sub zerotemperatures and in regions of high altitude.

Types

There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC). RC is recommended for surface dressing and patchwork. MC is recommended for premix with less quantity of fine aggregates. SC is used for premix with appreciable quantity of fine aggregates.

Tests

- Kinematic viscosity
- Flash point test
- Distillation test
- Tests on residue from distillation upto 360°C
- Viscosity at 60°C
- Ductility at 27°C
- Matter soluble in Trichloro-ethylene
- Water content

- **Bitumen Emulsion**

Characteristics

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material. An emulsion is a two phase system consisting of two immiscible liquids, the one being dispersed as fine globules in the other. A small proportion of an emulsifier (half to one percent by weight of emulsion) is used to

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facilitate formation of dispersion and to keep the globules of dispersed in suspension. The function of this emulsifier is to form a protective coating around the globules of binder, resisting the coalescence of the globules. Emulsifiers usually adopted are soaps, surface active agents and colloidal powders. Two common methods followed for the preparation of emulsion are the colloid mill method and the high speed mixer method.

Types and uses

- Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC).
- The main advantage of bitumen emulsion are they can be used without heating for sparing or preparing mixes, they are particularly useful for patch repair works and can be used even the surface is wet.
- The RC bitumen emulsions are used in spray applications like tack coat, for surface treatments, surface dressing and penetration macadam.
- The MC bitumen emulsion may be used in cold bituminous mixes in which percentage of coarse aggregates are substantially high, with a desirable gradation of zero percent fines passing 75 microns sieve and they are also used for surface dressing and penetration macadam.
- The SC bitumen emulsion are used for prime coat, slurry seal treatments, recycling works and on soil stabilization

Tests

- Viscosity test – to assess ability to be sprayed through jets
- Water content – to estimate the actual binder quantity
- Settlement test – to evaluate settlement when left standing undisturbed
- Demulsibility test – to find the residue after mixing with calcium chloride as specified
- Miscibility test – to assess coagulation due to addition of distilled water
- Cement mixing test – to assess stability in presence of fines in aggregates
- Coating test – to assess coating of stone aggregates
- Sieving test – to measure sedimentation of emulsion during storage
- Particle charge - to evaluate the type of chargers

- **Bituminous Primers**

In bituminous primer the distillate is absorbed by the road surface on which it is spread. The absorption therefore depends on the porosity of the surface. Bitumen primers are useful on the stabilized surfaces and water bound macadam base courses. Bituminous primers are generally prepared on road sites by mixing penetration bitumen with petroleum distillate.

- **Modified Bitumen**

The viscosity of ordinary paving grade bitumen varies considerably with temperature as a result the bituminous pavement surface course also becomes susceptible to temperature changes.During hot weather the bituminous surface course becomes soft resulting in possibility of permanent deformation and early rutting along the wheel paths of heavy vehicles. During cold weather, the bituminous pavement surface course becomes too stiff and brittle with the possibility of early cracking under repeated application of heavy wheel loads. Certain additives or blend of additives called as bitumen modifiers can improve properties of bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. It

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reduces temperature susceptibility. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The advantages of using modified bitumen are as follows

- ❖ Lower susceptibility to daily and seasonal temperature variations
- ❖ Higher resistance to deformation at high pavement temperature
- ❖ Better age resistance properties
- ❖ Higher fatigue life for mixes
- ❖ Better adhesion between aggregates and binder
- ❖ Prevention of cracking and reflective cracking

TAR

Tar is the viscous liquid obtained when natural organic materials such as wood and coal carbonized or destructively distilled in the absence of air. Based on the material from which taris derived, it is referred to as wood tar or coal tar; the latter is more widely used for road work because it is superior. Three stages for the production of road tar are

- Carbonization of coal to produce crude tar
- Refining or distillation of crude tar and
- Blending of distillation residue with distillate oil fraction to give the desired road tar.

There are five grades of roads tars, viz., RT- I, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties. RT-l has the lowest viscosity and is used for surface painting under exceptionally cold weather as this has very low viscosity. RT-2 is recommended for standard surface painting under normal Indian climatic conditions. RT-3 may be used for surface painting, renewal coats and premixing chips for top course and light carpets. RT-4 is generally used for premixing tar macadam in base course. For grouting purposes RT-5 may be adopted, which has the highest viscosity among the road tars.

The various tests that are carried out on road tars are listed below

- ❖ Specific gravity test
- ❖ Viscosity test on standard tar viscometer
- ❖ Equiviscous temperature (EVT)
- ❖ Softening point
- ❖ Softening point of residue
- ❖ Float test
- ❖ Water content
- ❖ Distillation fraction on distillation upto 200°C, 200°C to 270°C and 270°C to 3 30°C.
- ❖ Phenols, percent by volume
- ❖ Naphthalene, percent by weight
- ❖ Matter insoluble in toluene, percent by weight

The requirements for the five grades of road tars based on the above test results are given by the ISI.

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Comparison Between Bitumen And Tar

Bitumen	Tar
It has black to dark brown color	It also has black to dark brown in color
It is natural petroleum product	Tar is produced by the destructive distillation of coal or wood
It is soluble in carbon disulphide & in carbon tetrachloride	Tar is soluble only in toluene
It has better weather resisting property	It has inferior weather resisting property
Bitumen are less temp susceptible	Tar is more temp susceptible
Free carbon content is less	Free carbon content is more
neither binds the aggregate well nor retains the presence of water	It binds aggregate more easily &retains it better in the presence of water.

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Pavement Design

Requirements of Highway Pavement

The highway pavements have to fulfill two major requirements, namely

- Functional requirements from the point of view of road users
- Structural requirements from the point of view of highway engineer

Functional requirements of road pavement

From the point of view of users of road vehicles, the functional requirements of roadway pavement is generally limited to the roadway surface condition. The surface

- Should be firm and non-yielding under the wheel load
- Should have good riding quality
- Should be less slippery

Structural requirements of road pavements

- The structural design of the pavement is to be carried out considering the various design factors related to the traffic, topography, soil type, drainage, climatic and environmental factors and the desirable design life.
- Each pavement layer is laid evenly and well compacted
- The pavement structure consists of subgrade, sub base, base and surface course

Types Of Pavement

Based on the structural behavior, road pavements are generally classified into two categories

- Flexible pavement
- Rigid pavement

Other types of pavement structures include

- Semi-rigid pavement or composite pavement
- Interlocking cement concrete block pavement

Flexible Pavements

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-graintransfer through the points of contact in the granular structure (Figure). The wheel load acting onthe pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally has manylayers. Hence, the design of flexible pavement uses the concept of layered system. Based on this,flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear.

The lower layers will experience lesser magnitude of stress and low quality material can be used.

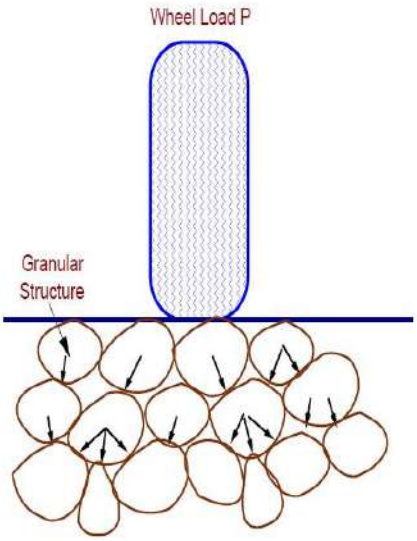

Figure 19:1: Load transfer in granular structure

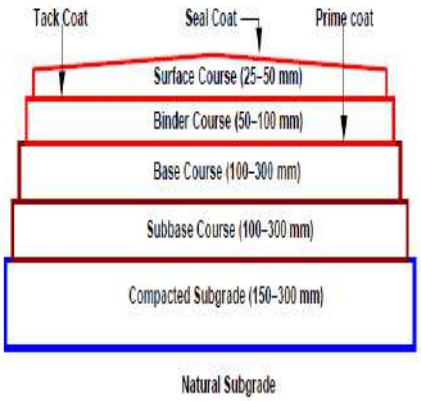

Figure 19:2: Typical cross section of a flexible pavement

Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such asnational highways). Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

Advantages of flexible pavement

- Adaptability to stage construction
- Availability of low-cost types that can be easily built
- Ability to be easily opened and patched
- Easy to repair frost heave and settlement
- Resistance to the formation of ice glaze

Disadvantages of rigid pavement

- Higher maintenance costs
- Shorter life span under heavy use

- Damage by oils and certain chemicals
- Weak edges that may require curbs or edge devices

Rigid Pavements

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

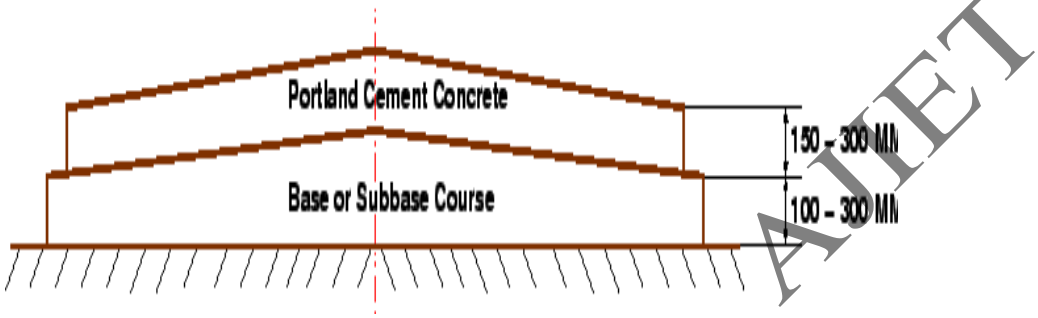

Figure: Typical Cross section of Rigid pavement

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

Advantages of rigid pavement

- Low maintenance costs
- Long life with extreme durability
- High value as a base for future resurfacing with asphalt
- Load distribution over a wide area, decreasing base and sub grade requirements
- Ability to be placed directly on poor soils
- No damage from oils and greases.
- Strong edges

Disadvantages of rigid pavement

- High initial costs
- Joints required for contraction and expansion
- Generally rough riding quality
- High repair costs

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Comparision Between Flexible and Rigid Pavement

Properties	Flexible	Rigid
Design Principle	Empirical method Based on load distribution characteristics of the components	Designed and analyzed by using the elastic theory
Material	Granular material	Made of Cement Concrete either plan, reinforced or prestressed concrete
Flexural Strength	Low or negligible flexible strength	Associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of subgrade soil.
Normal Loading	Elastic deformation	Acts as beam or cantilever
Excessive Loading	Local depression	Causes Cracks
Stress	Transmits vertical and compressive stresses to the lower layers	Tensile Stress and Temperature Increases
Design Practice	Constructed in number of layers.	Laid in slabs with steel reinforcement.
Temperature	No stress is produced	Stress is produced
Force of Friction	Less. Deformation in the sub grade is not transferred to the upper layers.	Friction force is High
Opening to Traffic	Road can be used for traffic within 24 hours	Road cannot be used until 14 days of curing
Surfacing	Rolling of the surfacing is needed	Rolling of the surfacing in not needed.

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Components of Flexible Pavements

The components of a typical flexible pavement structure consists of

- Prepared soil subgrade
- Granular sub base cum drainage layer
- Granular base course
- Bituminous binder and surface course

Functions of soil subgrade

- The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed.
- It should be compacted to the desirable density, near the optimum moisture content
- To provide an adequate support to the road pavement.
- To provide stability to the road pavement.
- To provide good drainage of rain water percolating through the road pavement
- The minimum thickness of compacted subgrade is 500mm on NH and SH and major arterial roads and 300mm for rural roads which carry low volume of traffic.

- The strength test commonly adopted for the evaluation of soil subgrade are CBR, dynamic cone penetrometer test, triaxial compression or direct shear test and plate bearing test

Functions of granular sub base (GSB) and drainage layer

- The sub-base course is the layer of material beneath the base course and the primaryfunctions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure
- The aggregates of lower strength having good permeability may be used in the GSB layer
- Coarse graded aggregates with low percentage of fines (less than 5% finer than 0.075mm size) will serve as a good drainage layer.
- The GSB cum drainage layer is laid above the subgrade covering the full width of the formation between the longitudinal drains.
- The part of the rain water which may enter into the pavement layers through the shoulders or the pavement surface will get drained out quickly into the longitudinal or road side drains. Thus it is possible to retain the subgrade and other pavement layers in relatively dry condition.

Functions of granular base course

- The granular base course is considered as the most important component of flexible pavement layer which sustains the wheel load stresses and disperses through larger area on tothe GSB layer below
- A good base course enhances the load carrying capacity of the flexible pavement structure.
- Good quality coarse aggregates are generally used in the granular base course of flexible pavements.
- As per the specifications laid down by the ministry of road transport and highways, govt. of India (MORTH), the aggregates used in the base course should have low aggregate impact value (less than 30%) and low los Angeles abrasion value(less than 40%)

Functions of thin bituminous surface

- The thin bituminous surface course prevents the entry of surface water into the pavement layers during the rains and thus protects the base course and other pavement layers below
- With a good surfacing and an effective drainage layer, it is possible to keep the soil subgrade in relatively dry condition and retain its stability
- The bituminous surfacing serves as a wearing course for the traffic and provides a dust free pavement surface under dry weather
- Thin bituminous layers such as surface dressing, 20mm thick pre mixed bituminous carpet with seal coat and 20mm thick mixed seal surface are commonly adopted in the wearing course of roads with low traffic volume with less proportion of heavy commercial vehicles.

Functions of thick bituminous binder and surface courses

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,

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- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Marshall Stability test and mix design method has been recommended by the IRC for designing the dense bituminous mixes such as DBM binder course and bituminous concrete surface course in India.

Components of Rigid Pavements

The components of a typical rigid pavement or cement concrete (CC) pavement structure consists of

- Compacted soil subgrade at the bottom or lowest layer
- Granular sub base (GSB) course and drainage layer
- Base course
- CC/pavement quality concrete (PQC) pavement slab

Functions of soil subgrade

- To provide an adequate support to the road pavement.
- To provide stability to the road pavement.
- To provide good drainage of rain water percolating through the road pavement
- The strength test commonly adopted for the evaluation of soil subgrade in rigid pavement is plate bearing test

Functions of GSB and drainage layer

- The sub-base course is the layer of material beneath the base course and the primaryfunctions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure
- Coarse graded aggregates with low percentage of fines (less than 5% finer than 0.075mm size) will serve as a good drainage layer.
- An effective drainage layer under the CC pavements has the following benefits
  - ❖ Increase in service life and improved performance of the CC pavements
  - ❖ Prevention of early failures of the rigid pavement due to pumping and blowing
  - ❖ Protection of the subgrade against frost action in frost susceptible areas

Functions of base course

- The granular base course is generally provided under the CC pavement slab in low volume roads and also in roads with moderate traffic loads.
- For heavy traffic or load, high quality base course materials such as lean cement concrete or dry lean concrete (DLC) are preferred as base course
- The DLC layer provides a uniform support, high K value and an excellent working platform for laying the PQC slab with a sensor paver
- A separation layer consisting of a suitable type of membrane is laid over the DLC base course before laying the PQC slab in order to prevent bonding between the two.

Function of PQC pavement slab

- M40 cement concrete mix with a minimum flexural strength of 45kg/cm2 is recommended by IRC for use in CC pavements of highways with heavy to very heavy traffic loads.

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- The CC pavement slab is expected to withstand the flexural stresses caused by the heavy traffic loads and warping effects in the CC slab due to temperature differences between top and bottom slab caused by daily variation in temperature during the 24 hours cycles.
- The steel reinforcement if any, placed at mid depth of the CC pavement slab is not useful to take up the flexural/tensile stresses caused by the heavy wheel loads or warping in the slabs. Therefore high quality CC mix with heavy wheel strength is used for the construction of the PQC slab of the CC pavements.

Equivalent Single Wheel Load (ESWL)

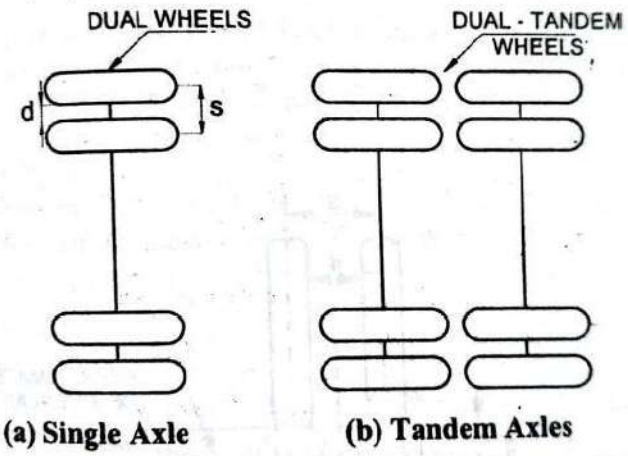

Fig. 7.3 Wheel load configuration of heavy vehicles

Equivalent single is wheel load (ESWL) is the wheel load assembly In order to limit the maximum load on single wheel within the specified limit and to carry greater load it is necessary to provide dual wheel assembly on the rear axles of heavy road vehicles. Equivalent Single Wheel Load (ESWL) of the dual wheel load assembly at a depth, 'z' may be defined as the singlewheel load replacement of the dual wheel load assembly which will cause the same magnitudeof vertical deflection or same value of compressive stress at that depth, a Thus ESWL at any selected depth, z may be determined based on either equivalent deflection or equivalent stress criterion.

Suppose a dual wheel load assembly causes a certain value of maximum deflection A at a particular depth z (say, depth z equal to the thickness T of the pavement). As per deflection criterion the ESWL is that single wheel load having the same contact pressure, p which produces the same value of maximum deflection A at the depth z.

Similarly as per stress criterion, the ESWL is the single wheel load producing the same value of maximum stress at the desired depth z as the dual wheel load assembly.

Fig shows the end view of a dual wheel load assembly. This figure also illustrates the stress overlap on a single layer due to the dual wheels. Let the spacing between the centres of the two wheels be 'S' and the clear gap between the inner sides of the two wheels be as shown in Fig. In order to simplify the analysis, the load dispersion is assumed to be at an angle of 45°. Let 'a' be the radius of the equivalent circular contact area of each wheel. Then S = (d+ 2a).

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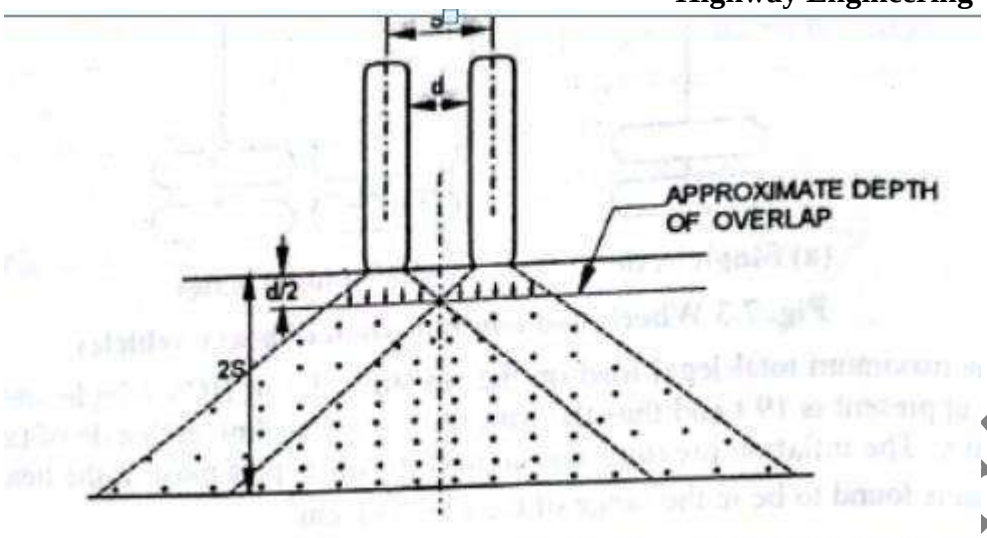
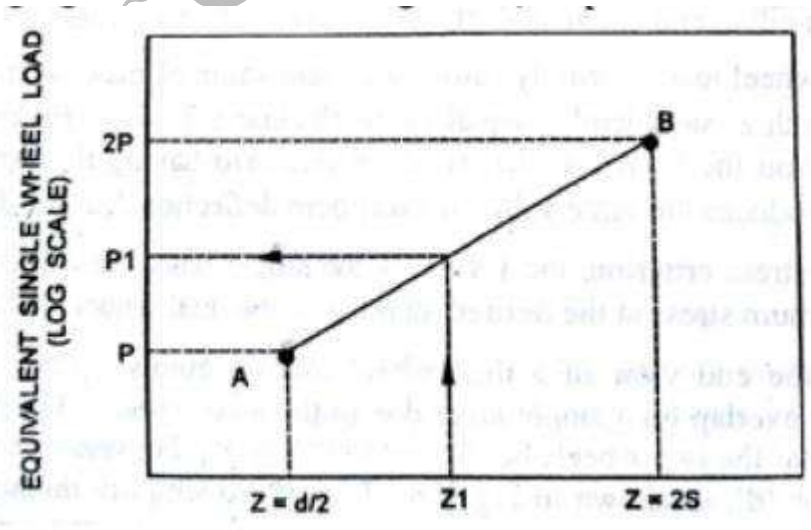


Fig. 7.4 Stress overlap due to dual wheels

Up to the depth z - d/2, each wheel load P acts independently. At depths greater than d!2, the compressive stresses within the pavement due to each load begins to overlap. At depth z = 2S and above, the overlapped area of compressive stress is considerably high when compared to the total area covered due to the dual wheel loads. Therefore the total stress due to the dual wheels atany depth greater than 2S or the ESWL is considered to be equivalent to magnitude 2P.

In order to simplify determination of stresses due to dual wheel load at any desired depth or to carry out pavement design, the ESWL value is often made use of. The ESWL is usually determined by the equivalent stress criterion using a simple graphical method. The value of ESWL varies depending upon the total pavement thickness, which is yet to be designed. Therefore the determination of design value of ESWL requires trial and error method and the simple graphical method is a very useful tool. In the simple graphical method, a straight line relationship is assumed between ESWL and depth on log-log scales. For determining ESWL, theplot is made as shown in Fig. 7.5.



Two points A and B are plotted on the log-log graph with coordinates of A being (p, d/2) and of B being (2P, 2S). The straight line AB is considered to be the locus of pogo where any single wheel load is equivalent to a certain set of dual wheels. In order to design the pavement

thickness due to dual wheel load assembly by the simplified approach, it is necessary to determine the ESWL at the depth z which is equal to the pavement thickness T, which is yet tobe determined. Therefore to calculate the ESWL for a dual assembly, it is necessary to assume or estimate a trial pavement design thickness, say z1. Thus ESWL is obtained at this assumed or trial thickness from this graph.

If the design thickness so obtained is equal to the assumed thickness, then the ESWL calculations could be considered as correct for the design of flexible pavement Otherwiseadditional trials are made by assuming another trial thickness or depth Z2:. The trials are continued until the assumed thickness z for the determination of ESWL is almost equal to the designed thickness of the pavement using this particular value of ESWL and this value is accepted as the design value of ESWL of the dual wheel load assembly.

This ESWL value is made use of for the design of flexible pavement. Any number of trial thickness values can easily be made using this log-log chart. For pavement thickness values exceeding 2S, ESWL, is taken as 2P.

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Questions

1. Explain the properties of soil
2. How soil is classified based on its grain size?
3. Explain classification of Soils by Highway Research Board (HRB)
4. Explain Plate Bearing Test
5. Explain California Bearing Ratio (CBR) Test
6. What are the properties of road aggregates? Explain
7. What are the tests conducted on aggregates? Explain.
8. What are the Desirable Properties of Bitumen?
9. Explain tests on bitumen.
10. What are the good requirements for highway?
11. How pavement is classified? Explain.
12. Explain components of rigid pavement.
13. Explain components of flexible pavements.
14. What is Equivalent Single Wheel Load (ESWL)

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MODULE 4

PAVEMENT CONSTRUCTION

Pavement Construction: Design of soil aggregate mixes by Rothfuch's method. Uses and properties of bituminous mixes and cement concrete in pavement construction. Earthwork; cutting and Filling, Preparation of subgrade, Specification and construction of
i) Granular Sub base, ii) WBM Base, iii) WMM base, iv) Bituminous Macadam, v) Dense Bituminous Macadam vi) Bituminous Concrete, vii) Dry Lean Concrete sub base and PQC viii) concrete roads

Rothfuch's Method

This method is used when a number of materials have to be mixed together for obtaining a desired or design gradation. The desired gradation may be decided either based on recommended grain size distribution charts or tables or using the below Fuller's equation.

P= 100 (d/D) n

Where,
D = diameter of largest particle, mm
P = percent finer than diameter 'd' (mm) in the material
n = gradation index, which have values ranging from 0.5 to 0.3 depending upon the shape.

On a graph paper, with Y-axis representing percent passing and X-axis representing particle size, as shown in figure. A diagonal line is drawn from point corresponding to (100 percent passing, maximum particle size of the material) to a point corresponding to (zero percent passing, smallest particle size of the materials)

The different particle sizes are marked on X-axis corresponding to the mean values of percentage finer taken on the Y-axis.

For different materials say A, B and C, sieve analysis has to be done and percentage finer has to be calculated for each range of particle size for all the materials and grain size distribution curves of these three materials are plotted as shown in fig and the balancing straight lines of A, B and C are obtained, allowing only minimum of the areas on either sides of the balancing lines.

The opposite ends of the balancing straight lines of A and B are joined (i.e., zero percent passing of materials A is joined with 100 percent passing of B). Similarly the opposite ends of balancing lines of B and C are joined.

The points where these lines meet the desired gradation line represent the proportion in which the materials A, B and C are to be mixed. These values may be read from the Y-axis by projecting the points of intersection as shown in fig.

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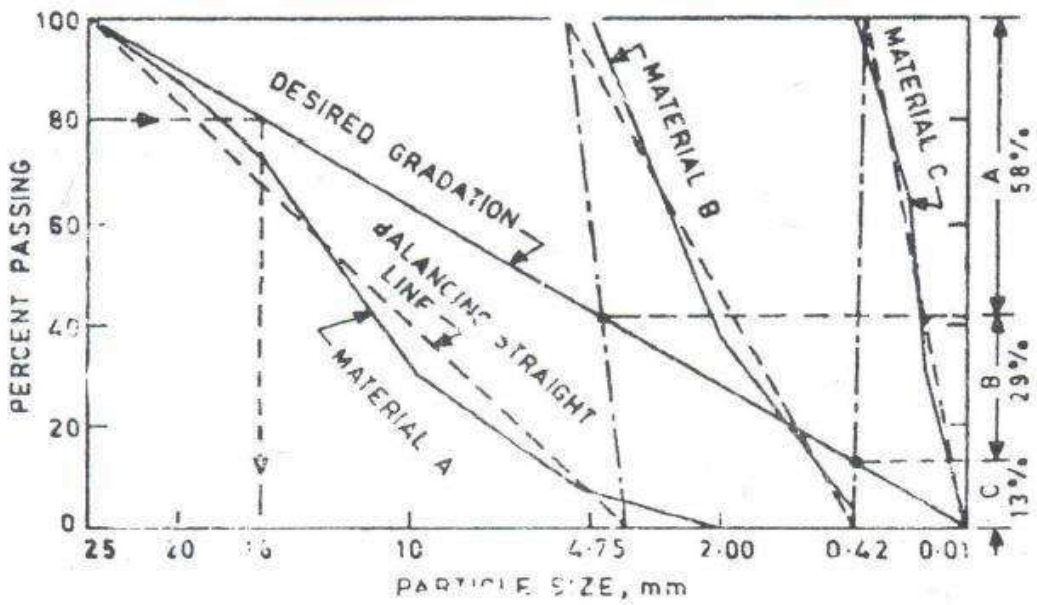

Properties of Bituminous Mix:

Mix design methods and design requirements form an essential part for all asphalt concrete mixtures. The agency or authority responsible for paving construction (Department of Transportation) usually establishes the mix design method and design requirements.

Once these are established, it becomes the responsibility of the Contractor/Producer and his technician to develop the mix within the framework of the specification requirements.

An asphalt concrete mixture must be designed, produced and placed in order to obtain thefollowing desirable mix properties:

1. Stability
2. Durability
3. Flexibility
4. Fatigue Resistance
5. Skid Resistance

1. Stability

Stability of an asphalt pavement is its ability to resist shoving and rutting under loads (traffic). A stable pavement maintains its shape and smoothness under repeated loading; an unstable pavement develops ruts (channels), ripples (wash boarding or corrugation) and other signs of shifting of the mixture.

Because stability specifications for a pavement depend on the traffic expected to use the pavement, the requirements can be established only after a thorough traffic analysis. Stability specifications should be high enough to handle traffic adequately, but not higher than traffic conditions require. Too high a stability value produces a pavement that is too stiff and therefore less durable than desired.

2. Durability

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The durability of an asphalt pavement is its ability to resist factors such as changes in the binder (polymerization and oxidation), disintegration of the aggregate, and stripping of the binder films from the aggregate. These factors can be the result of weather, traffic, or a combination of the two. Generally, durability of a mixture can be enhanced by three methods. They are:

1. Using maximum binder content,
2. Using a dense gradation of stripping-resistant aggregate, and
3. Designing and compacting the mixture for maximum impermeability

3. Impermeability

Impermeability is the resistance of an asphalt pavement to the passage of air and water into or through it. This characteristic is related to the void content of the compacted mixture, and much of the discussion on voids in the mix design sections relates to impermeability.

Even though void content is an indication of the potential for passage of air and water through a pavement, the character of these voids is more important than the number of voids. The size of voids, whether or not the voids are interconnected, and the access of the voids to the surface of the pavement all determine the degree of impermeability.

4. Workability

Workability describes the ease with which a paving mixture can be placed and compacted. Mixtures with good workability are easy to place and compact; those with poor workability are difficult to place and compact. Workability can be improved by changing mix design parameters, aggregate source, and/or gradation.

5. Flexibility

Flexibility is the ability of an asphalt pavement to adjust to gradual settlements and movements in the sub-grade without cracking. Since virtually all sub-grades settle (under loading) or rise (from soil expansion), flexibility is a desirable characteristic for all asphalt pavements. An open-graded mix with high binder content is generally more flexible than a dense-graded, low binder content mix. Sometimes the need for flexibility conflicts with stability requirements, so that trade-offs have to be made.

6. Fatigue resistance

Fatigue resistance is the pavement's resistance to repeated bending under wheel loads (traffic). Research shows that air voids (related to binder content) and binder viscosity have a significant effect on fatigue resistance. As the percentage of air voids in the pavement increases, either by design or lack of compaction, pavement fatigue life (the length of time during which an in-service pavement is adequately fatigue-resistant) is drastically shortened. Likewise, a pavement containing binder that has aged and hardened significantly has reduced resistance to fatigue.

7. Skid resistance

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Skid resistance is the ability of an asphalt surface to minimize skidding or slipping of vehicle tires, particularly when wet. For good skid resistance, tire tread must be able to maintain contact with the aggregate particles instead of riding on a film of water on the pavement surface (hydroplaning). Skid resistance is typically measured in the field at 40 mi/hr with a standard tread tire under controlled wetting of the pavement surface.

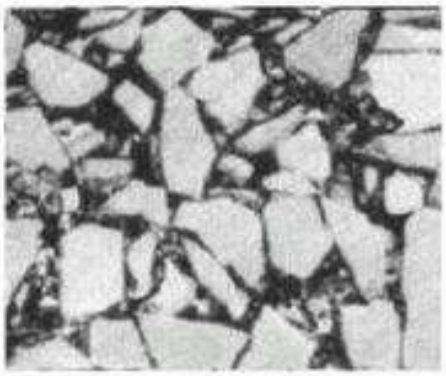
Bituminous Mix:

Based on the nature of gradation selected for the bitumen mixes, they can be classified into:

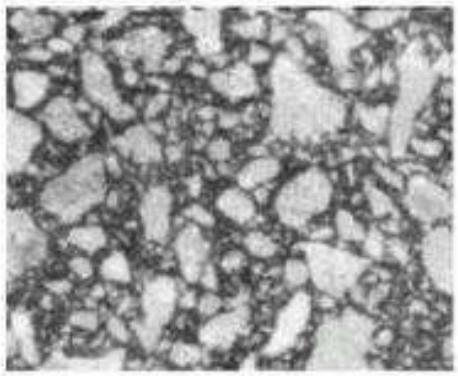
1. Dense Graded Bitumen Mixes
2. Semi-Dense Graded Bitumen Mixes
3. Open Graded Bitumen Mixes
4. Gap Graded Bitumen Mixes

1. Dense Graded Bitumen Mixes:

A dense-graded mix is a well-graded HMA mixture intended for general use. When properly designed and constructed, a dense-graded mix is relatively impermeable. Dense-graded mixes are generally referred to by their nominal maximum aggregate size. They can further be classified as either fine-graded or coarse-graded.



(a) Stone mastic asphalt



(b) Dense graded asphalt

2. Semi-Dense Graded Bitumen Mixes:

The semi-dense bituminous concrete mixes have neither dense nor open graded characteristics.

This will create the separation of aggregate and the bitumen in the BM layer. This will cause stripping and the scaling of SDBC. The scaling later with time will result in the potholes on the road.

3. Open Graded Bitumen Mixes:

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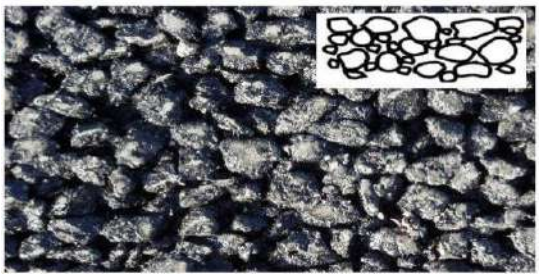
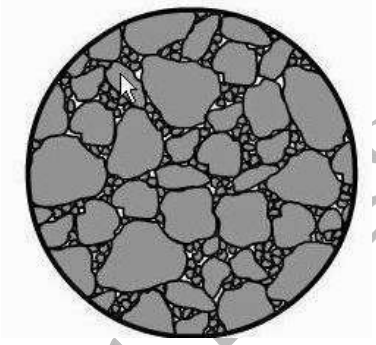
The open graded Bitumen Mixes have fine aggregates in a minimum amount, hence they are very permeable to water. They are employed based on specific functions in the base and for surface mixes.



4. Gap Graded Bitumen Mixes:

The Stone Matrix Asphalt (SMA) is the most commonly used gap graded bituminous mixes. With the increasing traffic and the high pressure of tires of the vehicles will give large stresses to the road pavement. The roads are subjected to overloading conditions in certain cases.



Use of Bitumen in Road Construction

The reasons behind the significant application of bitumen in flexible pavements are explained below:

1. Production of Bitumen is economical

Bitumen is a by-product of crude oil distillation process. Crude oil itself is a composition of hydrocarbons. The primary products that are available are the petrol, diesel, high octane and gasoline. When these fuels are refined from the crude oil, the bitumen is left behind. As the primary product demand is of utmost importance to the society, the bitumen as a by-product has survival for long. This by product is utilized as a new construction material, without going for anyother new resource.

2. Physical and Rheological Properties of Bitumen bring Versatility

The physical and the chemical properties of Bitumen are found to be a function of load level, temperature and the duration of loading. It is a thermoplastic and viscoelastic material. These dependencies make us to truly access the traffic on the road so that a bitumen mix properties can be varied based on the stress levels calculated. This versatility of bitumen results in a large varietyof bitumen mix, based on the road application.

3. The Melting Point of Bitumen is low

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It is highly appreciable about the fact that bitumen has a favorable melting point that helps in both surface dressing and wearing resistance with ease. The melting point of the bitumen should not be too high, that it can be melted easily during laying the pavement. At the same time, bitumen has a melting point, which would not let the already casted road pave to melt and deform under high temperatures. In areas of high temperatures, along with this quality of bitumen, the aggregate composition helps to cover up the effect of large temperature.

4. Bitumen can undergo Recycling

As the melting point of bitumen is favorable, it can be melted back to its original state. This is called as asphalt recycling process. The torn-up asphalt pieces are taken up to the recycling plant, instead of sending them to landfills. This recycled mix can be reused. If necessary, the old bitumen is mixed with new bitumen and new aggregates to make the mix live again.

5. Bitumen gain Adhesive Nature

As explained in the production of bitumen, it is free from hydrocarbon and hence not toxic. The by product is refined to maximum to get rid of organic materials and impurities. The bitumen has a highly adhesive nature, which keeps the materials in the road mix bind together under strong bonds. These become stronger when the mix is set i.e. ready for vehicle movement.

6. Bitumen has Color Variety

The traditional bitumen is black in color. This is because the dense organic material within bitumen is black in color. Now, when certain pigments are added to bitumen, the color of our choice can be obtained. These are colored bitumen. It is costly than the normal colored bitumen. The disadvantage of colored bitumen is that it requires more chemical additives and materials.

Bitumen emulsions:

1. Emulsions are used in bituminous road construction work. They are especially helpful for maintenance and patch repair works.
2. Emulsion can be used in wet weather even when it is raining.
3. Also emulsions have been used in soil stabilization, particularly for stabilization of sands in desert areas.
4. A rapid setting type emulsion is suitable for surface dressing and penetration macadam type of construction.
5. Medium setting type is used for premixing with coarse aggregates.
6. In case of fine aggregates, the surface area of aggregate is more and as a result long duration of time is required to mix the emulsion. Therefore slow setting emulsion is preferred which gives sufficient time for uniform blending of the mix.

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Cement concrete in pavement construction:

The contribution of cement and concrete to transportations and particularly to road construction is considerable. Bridges, tunnels, safety barriers, concrete roads and sound barriers are several examples of successful cement application. A characteristic of the use of cement in the aforementioned applications is the small maintenance cost together with the elongation of the service life of the structure. In road building, cement is also used for the treatment of aggregates and the stabilization of soils. The production of cement binding mixtures, contributes to the upgrade of the bearing capacity of sub grade along with an increase of the bearing capacity of the Pavement layers. This increased bearing capacity provides the ability to construct road surfaces of lesser thickness and thus of a significantly lower cost.

Due to their high bearing capacity and increased stiffness, their specific property not to deform under heavy permanent loads, is the reason why concrete pavements are used for:

- Parking aprons, taxiways and runway takeoff areas in airports
- Parking grounds for vehicles of heavy weight
- Heavy duty Industrial floors (vehicles on tracks and military tanks)
- Floors for handling and storage of containers at ports
- Industrial floors with high requirements in terms of flatness and durability to abrasion and surface exposure to aggressive attacks (use of toxic materials, welding etc)
- Bridge decks
- Road pavements in long tunnels for fire safety reasons, immediate reuse of the road following a fire and better energy consumption during service life (lower intensity lighting required)
- Pavements at toll stations (resistance to braking and acceleration) Concrete floors form an unrivalled type of paving for highways, roads of heavy traffic and simple rural and urban roads. These floors, apart from their ability to withstand permanent deformations and their high bearing capacity, also enjoy additional advantages, which render them attractive in application:
- A greater degree of safety in driving due to improved visibility. The reason is that obstacles are more visible in concrete roads due to the bright color of the surface in comparison to asphalt road paving
- Small to insignificant maintenance cost
- High durability over time
- Reduced total cost of the floor (service life cost analysis) and Lower overall energy consumption.
- Insignificant rolling noise and Low tire wear.

Pavement construction

Preparation of sub-grade:

Sub-grade and the surface of the earth roads are given larger camber of 1in 33 to 1 in 20 because they need faster drainage to be safe from the moisture. A maximum value of camber of 1 in 20 is the limit because higher camber will result in the formation of cross ruts and corrosion ofpavement soils.

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Specifications of Materials:

The earth material used for the construction of earth roads are termed as satisfactory if they possess the following properties:

	Base Course	Wearing Course
1. Clay content	<5%	10 to 18%
2. Silt content	9 to 32%	5 to 15%
3. Sand content	60 to 80%	65 to 80%
4. Liquid limit	<35%	<35%
5. Plasticity Index	<6%	4 to 10%

Construction steps (Procedure)

Material:

Suitable borrow pits are located by doing the survey of the adjacent land which are easy to reach and at economical haulage distance. The various organic materials like trees, shrubs and grass roots are removed before the excavation of the earth.

Location of center line:

The centerline and the road boundaries are marked on the ground by driving the wooden pegs. To follow the desired vertical profile of the road, reference pegs are also driven at a certain spacing which depends upon the estimated length of the road construction per day.

Preparation of the sub-grade:

Following steps are necessary for the preparation of the sub-grade:

(a) Clearing site

(b) Excavation and construction of fills

(c) Shaping of sub-grade.

 The site clearance may be done manually using appliances like spade, pick and hand shovel or using the mechanical equipment like Bulldozer and scraper etc.

 Excavation and construction of fills may also be done manually or using the excavation, hauling and compaction equipment. Dozers are considered very useful for haulage of shortdistance. If the compaction is done manually it will not be sufficient and proper, it should be leftto get consolidated under atmospheric conditions.

 various equipment used by manual labor are shovel, spade, pick-axe, baskets, rammers and hand rollers.

 The sub-grade should be compacted to the desired grade, camber and longitudinal profile.

Pavement construction:

The soil is dumped on the prepared sub-grade and pulverized. The soil may be a mixture of more than one soil to get the desired properties. The moisture content is checked and if extra moisture is

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needed, is added to bring it to OMC. The soil is mixed, spread and rolled in layers such that the compaction thickness of each layer does not exceed 10 cm.

The type of roller for compaction is decided based on soil type, desired amount of compaction and availability of equipment. At Least 95% of dry density of I.S. light compaction is considered desirable. The camber of the finished surface is checked and corrected when necessary.

Opening to traffic:

The compacted earth surface is allowed to dry out for few days and then is opened to traffic.

Specification and construction of Granular Sub base

Scope

This work shall consist of laying and compacting well graded material on prepared subgrade in accordance with the requirements of these specifications.

Materials

 The material to be used for the work shall be natural sand, moorum, gravel, crushed stone or combination thereof depending upon the grading required.

 Materials like crushed slag, crushed concrete, brick metal and kankar may be allowed only with the specific approval of the engineer.

 The maximum size of materials used is 75mm, 53mm and 23.5mm.

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TABLE 400-1. GRADING FOR CLOSE-GRADED GRANULAR SUB-BASE MATERIALS

IS Sieve Designation	Per cent by weight passing the IS sieve		
	Grading I	Grading 11	Grading III
75.0 mm	100	—	—
53.0 mm	80-100	100	—
26.5 mm	55-90	70-100	100-
9.50 mm	35-65	50-80	65-95
4.75 mm	25-55	40-65	50-80
2.36 mm	20-40	30-50	40-65
0.425 mm	10-25	15-25	20-35
0.075 mm	3-10	3-10	3-10
CBR Value (Minimum)	30	25	20

TABLE 400-2. GRADING FOR COARSE GRADED GRANULAR SUB -BASK MATERIALS

IS Sieve Designation	Per cent by weight passing the IS Sieve		
	Grading 1	Grading II	Grading III
75.0 mm	100	—	—
53.0 mm		100	
26.5 mm	55-75	50-80	100
9,50 mm			
4.75 mm	10-30	15-35	25-45
2.36 mm			
0.425 mm			
0.075 mm	<10	<10	<10
CBR Value (Minimum)	30	25	20

Physical requirements

 The water absorption value of the coarse aggregate shall be less than 2 percent

 If it is more than 2%, soundness test shall be carried out.

 The material passing 425 micron sieve shall have LL and PI not more than 25 and 6% respectively.

Strength of sub-base

It shall be ensured prior to actual execution that the material to be used in the sub-base satisfies the requirements of CBR and other physical requirements when compacted and finished.

Construction operations

Preparation of sub-grade

Prior to the laying of sub-base, the sub-grade shall be prepared by removing all vegetation and other extraneous matter, lightly sprinkled with water if necessary and rolled with two passes of smooth wheeled roller.

Spreading and compacting

- The sub-base material of grading specified in the contract shall be spread on the prepared sub-grade with the help of a motor grader of adequate capacity, its blade having hydraulic controls suitable for initial adjustment and for maintaining the required slope and grade during the operation or other means as approved by the engineer.
- When the sub-base material consists of combination of materials, mixing shall be done mechanically by the mix-in-place.
- Manual mixing shall be permitted only where the width of lying is not adequate for mechanical operations.

Surface finish and quality of work

- All works performed shall confirm to the lines, grades, cross sections and dimensions shown on the drawings or as directed by the engineer, subject to the permitted tolerances (as per section 900).
- Control on the quality of materials and works shall be exercised by the engineer in accordance with section 900.

Measurement for payment

GSB shall be measured as finished work in position in cubic metres.

Specification and construction of Water Bound Macadam (WBM) Base

Scope

- This work shall consist of clean, crushed aggregates mechanically interlocked by roiling and bonding together with screening, binding material where necessary and water laid on a properly prepared sub-grade/ sub-base/ base or existing pavement, as the case may be and finished in accordance with the requirements of these Specifications and in close conformity with the lines, grades, cross-sections and thickness as per approved plans or as directed by the Engineer.
- It is, however, not desirable to lay water bound macadam on an existing thin black topped surface without providing adequate drainage facility for water that would get accumulated at the interface of existing bituminous surface and water bound macadam.

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Materials

Coarse aggregates: Coarse aggregates shall be either crushed or broken stone, crushed slag, over burnt (Jhama) brick aggregates or any other naturally occurring aggregates such as kankar and laterite of suitable quality.

Crushed or broken stone: The crushed or broken stone shall be hard, durable and free from excess flat, elongated, soft and disintegrated particles, dirt and other deleterious material.

Crushed slag: Crushed slag shall be made from air cooled blast furnace slag. It shall be of angular shape, reasonably uniform in quality and density and generally free from thin, elongated and soft pieces, dirt or other deleterious materials. It should also comply with the following requirements;

- Sulphur content : Maximum 2 per cent
- Water absorption : Maximum 10 per cent

Test		Test Method	Requirements
1.	* Los Angeles Abrasion value Or	IS:2386 (Pan-4)	40 per cent (Mai)
	* Aggregate Impact value	IS: 2386 (Part -4) or IS:5640**	30 per cent (Max)
2.	Combined Flak mess and Elongation Indices (Total) ***	IS 23 86 (Part-1)	30 per cent (Max)

Over burnt (Jhama) brick aggregates: Jhama brick aggregates shall be made from over burnt bricks or brick bats and be free from dust and other objectionable and deleterious materials.

Screenings: Screenings to fill voids in the coarse aggregate shall generally consist of the same material as the coarse aggregate. However, where permitted, predominantly non-plastic material such as moorum or gravel (other than rounded river borne material) may be used for this purpose provided liquid limit and plasticity index of such material are below 20 and 6 respectively and fraction passing 75 micron sieve does not exceed 10 per cent.

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Binding material: Binding material to be used for water bound macadam as a filler material meant for preventing ravelling, shall comprise of a suitable material approved by the Engineer having a Plasticity Index (PI) value of less than 6.

Construction operations

Preparation of base:

The surface of the sub-grade/ sub-base/ base to receive the water bound macadam course shall be prepared to the specified lines and cross fall (camber) arid made free of dust and other extraneous material.

Spreading coarse aggregates:

The coarse aggregates shall be spread uniformly and evenly upon the prepared sub-grade/sub- base/ base to proper profile. The spreading shall be done from stockpiles along the side of the roadway or directly from vehicles.

Rolling:

Immediately following the spreading of the coarse aggregate, rolling shall be started with three wheeled power rollers of 80 to 100 kN capacity or tandem or vibratory rollers of 80 to 100 kN static weight.

Application of screenings:

After the coarse aggregate has been rolled, screenings to completely fill the interstices shall be applied gradually over the surface. These shall not be damp or wet at the time of application. Dry rolling shall be done while the screenings are being spread. The screenings shall be applied at a slow and uniform rate so as to ensure filling of all voids.

Sprinkling of water and grouting:

After the screenings have been applied, the surface shall be copiously sprinkled with water, swept and rolled.

Application of binding material:

After the application of screenings the binding material where it is required to be used shall be applied successively in two or more thin layers at a slow and uniform rate.

Setting and drying:

After the final compaction of water bound macadam course, the pavement shall be allowed to dry overnight. Next morning hungry spots shall be filled with screenings or binding material as directed.

Surface Finish and Quality Control of Work:

The surface finish of construction shall conform to the requirements of Clause 902. Control on the quality of materials and works shall be exercised by the Engineer in accordance with Section 900.

Arrangement for Traffic:

During the period of construction, the arrangement of traffic shall be done as per Clause 112.

Measurements for payment:

Water bound macadam shall be measured as finished work in position in cubic metres.

Specification and construction of Wet Mix Macadam (WMM)

1. This work shall consist of laying and compacting clean, crushed, graded aggregate and granular material, premixed with water, to a dense mass on a prepared subgrade/sub -base/base or

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existing pavement as the case may be in accordance with the requirements of these Specifications.

2. The material shall be laid in one or more layers as necessary to lines, grades and cross -sections shown on the approved drawings or as directed by the Engineer.
3. The thickness of a single compacted Wet Mix Macadam layer shall not be less than 75 mm.
4. Materials- Coarse aggregates shall be crushed stone. If crushed gravel/shingle is used, not less than 90 per cent by weight of the gravel/shingle pieces retained on 4.75 mm sieve shall have-at least two fractured faces.

Test		Test Method	Requirements
1.	* Los Angeles Abrasion value	IS:2386 (Pan-4)	40 per cent (Mai)
	Or		
	* Aggregate Impact value	IS: 2386 (Part -4) or IS:5640**	30 per cent (Max)
2.	Combined Flak mess and Elongation Indices (Total) ***	IS 23 86 (Part-1)	30 per cent (Max)

5. If the water absorption value of the coarse aggregate is greater than 2 per cent, the soundness test shall be carried out on the material delivered to site.
6. **Grading requirements:**

IS Sieve Designation	Per cent by weight passing the IS sieve
53.00 mm	100
45.00 mm	95-100
26.50 mm	---
22.40 mm	60-80
11.20 mm	40-60
4.75 mm	25-40
2.36 mm	15-30
600.00 micron	8-22
75.00 micron	0-8

7. Materials finer than 425 micron shall have Plasticity Index (PI) not exceeding 6.

Construction operations

Preparation of base:

The surface of the sub-grade/ sub-base/ base to receive the water bound macadam course shall be prepared to the specified lines and cross fall (camber) arid made free of dust and other extraneous material.

Provision of lateral confinement of aggregates:

While constructing wet mix macadam, arrangement shall be made for the lateral confinement of wet mix. This shall be done by laying materials in adjoining shoulders along with that of wet mix macadam layer.

Preparation of mix:

Wet Mix Macadam shall be prepared in an approved mixing plant of suitable capacity having provision for controlled addition of water and forced/positive mixing arrangement like pugmill or pan type mixer of concrete batching plant.

Spreading of mix:

Immediately after mixing, the aggregates shall be spread uniformly and evenly upon the prepared sub-grade/sub- base/base in required quantities. The mix may be spread either by a payer finisher or motor grader. For portions where mechanical means cannot be used, manual means as approved by the Engineer shall be used.

Compaction:

After the mix has been laid to the required thickness, grade and cross fall/camber the same shall be uniformly compacted, to the full depth with suitable roller. If the thickness of single compacted layer does not exceed 100 mm, a smooth wheel roller of 80 to 100 kN weight may be used. For a compacted single layer up to 200 mm, the compaction shall be done with the help of vibratory roller of minimum static weight of 80 to 100 kN or equivalent capacity roller. The speed of the roller shall not exceed 5 km/h.

Setting and drying:

After final compaction of wet mix macadam course, the road shall be allowed to dry for 24 hours.

Opening to Traffic:

Preferably no vehicular traffic of any kind should be allowed on the finished wet mix macadam surface till it has dried and the wearing course laid.

Surface Finish and Quality Control of Work:

The surface finish of construction shall conform to the requirements of Clause 902. Control on the quality of materials and works shall be exercised by the Engineer in accordance with Section 900.

Arrangement for Traffic:

During the period of construction, the arrangement of traffic shall be done as per Clause 112. •

Measurements for payment:

Water bound macadam shall be measured as finished work in position in cubic metres.

Specification and construction of Bituminous Macadam

Scope

This work shall consist of construction in a single course having 50mm to 100mm thickness or in multiple courses of compacted crushed aggregates premixed with a bituminous binder on a previously prepared base to the requirements of these Specifications.

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Materials

Bitumen:

The bitumen shall be paving bitumen of Penetration Grade complying with Indian Standard Specifications.

Coarse aggregates:

The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. They shall be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter, organic or other deleterious matter.

Fine aggregates:

Fine aggregates shall consist of crushed or naturally occurring, material, 01 a combination of the two, passing 2.36 mm sieve and retained on 75 micron sieve. They shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter.

Property	Test	Specification
Cleanliness	Grain size analysis[1]	Max 5 % passing 0.075 mm sieve
Particle shape	Flakiness and Elongation Index (Combined)[2]	Max 30 %
Strength	Los Angeles Abrasion Value[3]	Max 40 %
	Aggregate Impact Value[3]	Max 30 %
Durability	Soundness:[4]	
	Sodium Sulphate	Max *12 %*
	Magnesium Sulphate	Max 18%
Water Absorption	Water absorption[5]	Max 2%
Stripping	Coating and Stripping of Bitumen Aggregate Mixtures[6]	Minimum retained coating 95%
Water Sensitivity[7]	Retained Tensile Strength	Min 80 %

Mix designation Nominal aggregate size Layer thickness IS Sieve (mm)	Grading 1 40mm 80- 100 mm	Grading 2 19mm 50 - 75 mm
	Cumulative % by weight of total aggregate passing	
45	100	
37.5	90-100	
26.5	75-100	100
19	-	90-100
13.2	35-61	56-88
4.75	13-22	16-36
2.36	4-19	4-19
0.3	2-10	2-10
0.075	0-8	0-8
Bitumen content, % by weight of total mixture[1]	3.1 -3.4	3.3-3.5
Bitumen grade	35 to 90	35 to 90

Construction Operations

Weather and seasonal limitations:

Lying shall be suspended while free-standing water is present on the surface to be covered, or during rain, fog and dust storms. After rain, the bituminous surface, prime or tack coat, shall be blown off with a high pressure air jet to remove excess moisture, or the surface left to dry before

laying shall start. Laying of bituminous mixtures shall not be carried out when the air temperature at the surface on which it is to be laid is below 10°C.

Preparation of the base:

The base on which bituminous macadam is to be laid shall be prepared, shaped and compacted to the required profile. A primer coat shall be applied with clause or as directed by the Engineer.

Tack coat:

tack coat in accordance with Clause shall be applied as required by the Contract documents, or as directed by the Engineer.

Preparation and transportation of the mixture:

Pre-mixed bituminous macadam shall be prepared in a hot mix plant of adequate capacity and capable of yielding a mix of proper and uniform quality with thoroughly coated aggregates. In order to ensure uniform quality of the mix and better coating of aggregates, the hot mix plant shallbe calibrated from time to time.

Bituminous materials shall be transported in clean insulated vehicles, and unless otherwise agreed by the Engineer, shall be covered while in transit or waiting tipping. Subject to the approval of the Engineer, a thin coating of diesel or lubricating oil may be applied to the interior of the vehicle to prevent sticking and to facilitate discharge of the material.

Compaction:

Bituminous materials shall be laid and compacted in layers which enable the specified thickness, surface level, regularity requirements and compaction to be achieved.

Compaction of bituminous materials shall commence as soon as possible after laying. Compaction shall be substantially completed before the temperature falls below the minimum rolling temperatures.

Rolling shall commence at the edges and progress towards the centre longitudinally. Rolling shall continue until all roller marks have been removed from the surface.

Rolling shall be continued until the specified density is achieved, or where no density is specified, until there is no further movement under the roller.

Bitumen Penetration	Bitumen Mixing (°C)	Aggregate Mixing (°C)	Mixed Material (°C)	Rolling (°C)	Laying (°C)
35	160-170	160-175	170 Maximum	100 Minimum	130 Minimum
65	150-165	150-170	165 Maximum	90 Minimum	125 Minimum
90	140-160	140-165	155 Maximum	80 Minimum	115 Minimum

Surface Finish and Quality Control of Work:

The surface finish of the completed construction shall conform to the requirements of Clause 902. For control of the quality of materials supplied and the works carried out, the relevant provisions of Section 900 shall apply.

Protection of the Layer:

The bituminous macadam shall be covered with either the next pavement course or wearing course, as the case may be, within a maximum of forty-eight hours. If there is to be any delay, the course shall be covered by a seal coat. The seal coat in such cases shall be considered incidental tothe work and shall not be paid for separately.

Arrangements for Traffic:

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During the period of construction, arrangements for traffic shall be made in accordance with the provisions of Clause 112.

Measurement for Payment:

Bituminous macadam shall be measured as finished work in cubic metres, or by weight in metric tones, where used as regulating course, or square metres at the specified thickness as indicated in the Contract or shown on the drawings, or as otherwise directed by the Engineer.

Specification and construction of Dense Bituminous Macadam

Scope:

This clause specifies the construction of Dense Graded Bituminous Macadam, (DBM), for use mainly, but not exclusively, in base/binder and profile corrective courses. DBM is also intended for use as road base material. This work shall consist of construction in a single or multiple layers of DBM on a previously prepared base or sub-base. The thickness of a single layer shall be 50mm to 100mm.

Materials

Bitumen:

The bitumen shall be paving bitumen of Penetration Grade complying with Indian Standard Specifications for "Paving Bitumen" IS: 73.

Coarse aggregates:

The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. They shall be clean, hard, and durable, of cubical shape, free from dust and soft or friable matter, organic or other deleterious substances.

Fine aggregates:

Fine aggregates shall consist of crushed or naturally occurring mineral material or a combination of the two, passing the 2.36mm sieve and retained on the 75 micron sieve. They shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleterious matter.

Filler:

Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the Engineer. The filler shall be free from organic impurities and have a Plasticity Index not greater than 4. The Plasticity Index requirement shall not apply if filler is cement or lime.

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Property	Text	Specification
Cleanliness (dust)	Grain size analysis [1]	Max 5% passing 0.075mm sieve
Particle shape	Flakiness and Elongation Index (Combined)[2]	Max 30%
Strength*	Los Angeles Abrasion Value[3] Aggregate Impact Value[4]	Max 35% Max 27%
Durability	Soundness:[5] Sodium Sulphate Magnesium Sulphate	 Max 12% Max 18%
Water Absorption	Water absoption[6]	Max 2%
Stripping	Coating and Stripping of Bitumen Aggregate Mixtures[7]	Minimum retained coating 95%
Water Sensitivity	Retained Tensile Strength	Min80%

Filler

IS Sieve (mm)	Cumulative per cent passing by weight of total aggregate
0.6	100
0.3	95- 100
0.075	85-100

Aggregate content

Grading	1	2
Nominal aggregate size	40mm	25 mm
Layer Thickness	80-100 mm	50-75 mm
IS Sieve [1] (mm)	Cumulative % by weight of total aggregate passing	
45	100	
37.5	95-100	100
26.5	63-93	90-100
19	-	71-95
13.2	55-75	56-80
9.5	-	-
4.75	38-54	38-54
2.36	2«^2	28-42
1.18	-	-
0.6	-	-
0.3	7-21	7-21
0.15	-	-
0.075	2-8	2-8
Bitumen content % by mass of total mix [2]	Min4.0	Min4.5
Bitumen grade (pen)	65 or 90	65 or 90

Mixture Design

Requirement for the mixture:

Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table.

Minimum stability (kN at 60°C)	9.0
Minimum flow (mm) Maximum flow	2 4
(mm) Compaction level (Number of blows)	75 blows on each of the two faces of the specimen
Per cent air voids	3-6
Per cent voids in mineral aggregate (VMA)	See Table 500-12 below.
Per cent voids filled with bitumen (VFB)	65-75

Nominal Maximum Practice Size[1] (mm)	Minimum VMA, Per cent Related to Design Air Voids, Per cent[2]		
	3.0	4.0	5.0
9.5	14.0	15.0	16.0
12.5	13.0	14.0	15.0
19.0	12.0	13.0	14.0
25.0'	11.0	12.0	13.0
37:5	10.0	11.0	12.0

Binder content:

The binder content shall be optimised to achieve the requirements of the mixture set out in the table and the traffic volume specified in the contract. The Marshall method for determining the optimum binder be adopted as described in The Asphalt Institute Manual MS-2.

Job mix formula:

The Contractor shall inform the Engineer in writing, at least 20 days before the start of the work, of the job mix formula proposed for use in the works. While establishing the job mix formula, the Contractor shall ensure that it is based on a correct and truly representative sample of thematerials that will actually be used in the work and that the mixture and its different ingredients satisfy the physical and strength requirements of these Specifications.

Plant trials:

permissible variation in job mix formula: Once the laboratory job mix formula is approved, the Contractor shall carry out plant trials at the mixer to establish that the plant can be set up to produce a uniform mix conforming to the approved job mix formula. Once the plant trials have demonstrated the capability of the plant, and the trials are approved, the laying operation may commence

Laying Trials:

Once the plant trials have been successfully completed and approved, the Contractor shall carry out laying trials, to demonstrate that the proposed mix can be successfully laid, and compacted. The laying trial shall be carried out on a suitable area which is not to form part of the works,

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unless specifically approved in writing, by the Engineer. The area of the laying trials shall be a minimum of 100 sq. m. of construction similar to that of the project road, and it shall be in all respects, particularly compaction, the same as the project construction, on which the bituminous material is to be laid.

Weather and seasonal limitations:

Laying shall be suspended while free-standing water is present on the surface to be covered, or during rain, fog and dust storms. After rain, the bituminous surface, prime or tack coat, shall be blown off with a high pressure air jet to remove excess moisture, or the surface left to dry before laying shall start. Laying of bituminous mixtures shall not be carried out when the air temperature at the surface on which it is to be laid is below 10°C.

Preparation of base:

The base on which Dense Graded Bituminous Material is to be laid shall be prepared in accordance with Clauses or as directed by the Engineer. The surface shall be thoroughly swept clean by a mechanical broom, and the dust removed by compressed air. In locations where- mechanical broom cannot access, other approved methods shall be used as directed by the Engineer.

Prime coat:

Where the material on which the dense bituminous macadam is to be laid is other than a bitumen bound layer, a prime coat shall be applied, as specified, in accordance with the provisions of Clause or as directed by the Engineer.

Tack coat:

Where the material on which the dense bituminous macadam is to be placed is a bitumen bound surface, a tack coat shall be applied as specified, in accordance with the provisions of Clause 503, or as directed by the Engineer.

Preparation and transportation of the mixture:

Pre-mixed bituminous macadam shall be prepared in a hot mix plant of adequate capacity and capable of yielding a mix of proper and uniform quality with thoroughly coated aggregates. In order to ensure uniform quality of the mix and better coating of aggregates, the hot mix plant shallbe calibrated from time to time.

Bituminous materials shall be transported in clean insulated vehicles, and unless otherwise agreed by the Engineer, shall be covered while in transit or waiting tipping. Subject to the approval of the Engineer, a thin coating of diesel or lubricating oil may be applied to the interior of the vehicle to prevent sticking and to facilitate discharge of the material.

Compaction:

Bituminous materials shall be laid and compacted in layers which enable the specified thickness, surface level, regularity requirements and compaction to be achieved.

Compaction of bituminous materials shall commence as soon as possible after laying. Compaction shall be substantially completed before the temperature falls below the minimum rolling temperatures.

Rolling shall commence at the edges and progress towards the centre longitudinally. Rolling shall continue until all roller marks have been removed from the surface.

Rolling shall be continued until the specified density is achieved, or where no density is specified, until there is no further movement under the roller.

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Opening to Traffic:

The newly laid surface shall not be open to traffic for at least 24 hrs after laying and completion of compaction, without the express approval of the Engineer in writing.

Surface Finish and Quality Control of Work:

The surface finish of the completed construction shall conform to the requirements of Clause 902. For control of the quality of materials supplied and the works carried out, the relevant provisions of Section 900 shall apply.

Specification and construction of Bituminous Concrete (BC)

Scope:

This clause specifies the construction of Bituminous Concrete, for use in wearing and profile corrective courses. This work shall consist of construction in a single or multiple layers of bituminous concrete on a previously prepared bituminous bound surface. Single layers shall be 25mm to 100mm in thickness.

Materials

Bitumen:

The bitumen shall be paving bitumen of Penetration grade complying with Indian Standard Specification for Paving Bitumen, IS: 73.

Coarse aggregates:

The coarse aggregates shall consist of crushed rock, crushed gravel or other hard material retained on the 2.36 mm sieve. They shall be clean, hard, and durable of cubical shape, free from dust and soft or friable matter, organic or other deleterious substances.

Fine aggregates:

Fine aggregates shall consist of crushed or naturally occurring mineral material or a combination of the two, passing the 2.36mm sieve and retained on the 75 micron sieve. They shall be clean, hard, durable, dry and free from dust, and soft or friable matter, organic or other deleteriousmatter.

Filler:

Filler shall consist of finely divided mineral matter such as rock dust, hydrated lime or cement approved by the Engineer. The filler shall be free from organic impurities and have a Plasticity Index not greater than 4. The Plasticity Index requirement shall not apply if filler is cement or lime.

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Aggregate grading and binder content

Property	Test	Specification
Cleanliness (dust)	Grain size analysis [1]	Max 5% passing 0.075mm sieve
Particle shape	Flakiness and Elongation Index	Max 30% (Combined)[2]
Strength*	Los Angeles Abrasion Value[3]	Max 30%
	Aggregate Impact Value[4]	Max 24%
Polishing	Polished Stone Value[3]	MinS5
Durability	Soundness:[6]	
	Sodium Sulphate	Max 12%
	Magnesium Sulphate	Max 18%
Water Absorption	Water absorption[7]	Max 2%
Stripping	Coating and Stripping of Bitumen Aggregate Mixtures[9]	Minimum retained coating 95%
Water Sensitivity**	Retained Tensile Strength[8]	Min80%

Aggregate content

Grading	1	2
Nominal aggregate size	**13mm**	**10mm**
Layer Thickness	**35-40 mm**	**25-30 mm**
IS Sieve [1] (mm)	**Cumulative % by weight of total aggregate passing**	
45		
37.5		
26.5	100	
19	79-100	100
13.2	59-79	79-100
9.5	52-72	70-88
4.75	35-55	53-71
2.36	28-44	42-58
1.18	20-34	34-48
0.6	15-27	26-38
0.3	10-20	18-28
0.15	5-13	12-20
0.075	2-8	4-10
Bitumen content % by mass of total mix [2]	5.0-6.0	5.0-7.0
Bitumen grade (pen)	65	65*

Mix Design

Requirement for the mixture:

Apart from conformity with the grading and quality requirements for individual ingredients, the mixture shall meet the requirements set out in Table.

Binder content:

The binder content shall be optimised to achieve the requirements of the mixture set out in the table and the traffic volume specified in the contract. The marshall method for determining the optimum binder be adopted as described in The Asphalt Institute Manual MS-2.

Job mix formula:

The Contractor shall inform the Engineer in writing, at least 20 days before the start of the work, of the job mix formula proposed for use in the works. While establishing the job mix formula, the Contractor shall ensure that it is based on a correct and truly representative sample of thematerials that will actually be used in the work and that the mixture and its different ingredients satisfy the physical and strength requirements of these Specifications.

Plant trials

Permissible variation in job mix formula:

Once the laboratory job mix formula is approved, the Contractor shall carry out plant trials at the mixer to establish that the plant can be set up to produce a uniform mix conforming to the approved job mix formula. Once the plant trials have demonstrated the capability of the plant, andthe trials are approved, the laying operation may commence.

Laying Trials:

Once the plant trials have been successfully completed and approved, the Contractor shall carry out laying trials, to demonstrate that the proposed mix can be successfully laid, and compacted. The laying trial shall be carried out on a suitable area which is not to form part of the works,unless specifically approved in writing, by the Engineer. The area of the laying trials shall be a minimum of 100 sq. m. of construction similar to that of the project road, and it shall be in all respects, particularly compaction, the same as the project construction, on which the bituminous material is to be laid.

Construction Operations:

Weather and seasonal limitations:

Laying shall be suspended while free-standing water is present on the surface to be covered, or during rain, fog and dust storms. After rain, the bituminous surface, prime or tack coat shall be blown off with a high pressure air jet to remove excess moisture, or the surface left to dry before laying shall start. Laying of bituminous mixtures shall not be carried out when the air temperature at the surface on which it is to be laid is below 10°C.

Preparation of base:

The base on which Dense Graded Bituminous Material is to be laid shall be prepared in accordance with Clauses or as directed by the Engineer. The surface shall be thoroughly swept clean by a mechanical broom, and the dust removed by compressed air. In locations where- mechanical broom cannot access, other approved methods shall be used as directed by the Engineer.

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Tack coat:

Where the material on which the dense bituminous macadam is to be placed is a bitumen bound surface, a tack coat shall be applied as specified, in accordance with the provisions of Clause 503, or as directed by the Engineer.

Preparation and transportation of the mixture:

Pre-mixed bituminous macadam shall be prepared in a hot mix plant of adequate capacity and capable of yielding a mix of proper and uniform quality with thoroughly coated aggregates. In order to ensure uniform quality of the mix and better coating of aggregates, the hot mix plant shallbe calibrated from time to time.

Bituminous materials shall be transported in clean insulated vehicles, and unless otherwise agreed by the Engineer, shall be covered while in transit or awaiting tipping. Subject to the approval of the Engineer, a thin coating of diesel or lubricating oil may be applied to the interior of the vehicle to prevent sticking and to facilitate discharge of the material.

Compaction:

Bituminous materials shall be laid and compacted in layers which enable the specified thickness, surface level, regularity requirements and compaction to be achieved.

Compaction of bituminous materials shall commence as soon as possible after laying. Compaction shall be substantially completed before the temperature falls below the minimum rolling temperatures.

Rolling shall commence at the edges and progress towards the centre longitudinally. Rolling shall continue until all roller marks have been removed from the surface.

Rolling shall be continued until the specified density is achieved, or where no density is specified, until there is no further movement under the roller.

Opening to Traffic:

The newly laid surface shall not be open to traffic for at least 24 hrs after laying and completion of compaction, without the approval of the Engineer in writing.

Surface Finish and Quality Control of Work:

The surface finish of the completed construction shall conform to the requirements of Clause 902. For control of the quality of materials supplied and the works carried out, the relevant provisions of Section 900 shall apply.

Arrangements for Traffic:

During the period of construction, arrangements for traffic shall be made in accordance with the provisions of Clause 112.

Measurement for Payment:

Dense Graded Bituminous Materials shall be measured as finished work either in cubic metres, tons or by the square metre at a specified thickness as detailed on the Contract drawings, or documents, or as directed by the Engineer.

<u>Specification and construction of Dry Lean Concrete sub base:</u>

DLC or Dry Lean Concrete is cement concrete with low slump value to be laid for rigid pavement over sub-base and rolled & compacted by mechanical means.

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• Ordinary Portland cement, Portland Pozzolana Cement or Portland Slag Cement is used for DLC.

• Coarse aggregate shall consist of Clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel and shall be devoid of pieces of disintegrated stone, soft, flaky, elongated, very angular or splintery pieces. The maximum size of the coarse aggregate shall be 25 mm.

• The fine aggregate shall consist of clean, natural sand or crushed stone sand or a combination of the two and shall conform to IS : 383. Fine aggregate shall be free from soft particles, clay, shale, loam, cemented particles, mica, organic and other foreign matter.

• The coarse and fine aggregates may be obtained in either of the following manner:

• In separate nominal sizes of coarse and fine aggregates and mixed together intimately before use.

• Separately as 25 mm nominal single size, 12.5 mm nominal size graded aggregates - and Fine

• Aggregate of crushed stone dust or sand or a combination of these two.

Aggregate Gradation For Dry Lean Concrete

Sl No	Sieve Sizes	Percentage passing the sieve by weight
1	26.50 mm	100%
2	19.00 mm	80-100%
3	9.50 mm	55-75%
4	4.75 mm	35-60%
5	600.00 micron	10-35%
6	75.00 micron	0-8%

• Water for mixing and curing of concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable matter or other substances harmful to the finished concrete.

• The mix shall be proportioned with a maximum aggregate cement ratio of 15: 1.

• The minimum cement content is 150 kg/cum of concrete.

• The average compressive strength of each consecutive group of 5 cubes made shall not be less than 10 MPa at 7 days. In addition, the minimum compressive strength of any individual cube shall not be less than 7.5 MPa at 7 days.

• The batching plant shall be capable of proportioning the materials by weight, each type of material being weighed separately. The cement from the bulk stock shall be weighed separately

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from the aggregates. The batching and mixing shall be carried out preferably in a forced action central batching and mixing plant having necessary automatic controls to ensure accurate proportioning and mixing. Other types of mixers shall be permitted subject to demonstration of their satisfactory performance during the trial length. The type and capacity of the plant shall be got approved by the Engineer before commencement of the trial length. The (weighing balances shall be calibrated by weighing the aggregates, cement, water and admixtures physically either by weighing with large weighing machine or in a weigh bridge. The accuracy of weighing scales of the batching plant shall be within ± 2 per cent in the case of aggregates and ±1 per cent in the case of cement and water.

• Plant mix lean concrete shall be discharged immediately from the mixer, transported directly to the point where it is to be laid and protected from the weather by covering the tippers / dumpers with tarpaulin during transit. The concrete shall be transported by tipping trucks, sufficient in number to ensure a continuous supply of material to feed the laying equipment to work at a uniform speed and in an uninterrupted manner. The lead of the batching plant to paving site shall be such that the travel time available from mixing to paving.

• Lean concrete shall be laid/placed mechanically /manually. The concrete shall be laid in one layer in an even manner without segregation, so that after compaction the total thickness is as specified. The laying of the two- lane road sub-base may be done either in full width or lane by lane. Preferably the lean concrete shall be placed and compacted across the full width of the road, by constructing it in one go or in two lanes running forward simultaneously.

Rolling & Spreading of DLC

• The compaction shall be carried out immediately after the material is laid and leveled with 8 -10 Tonne Static Roller. In order to ensure thorough compaction which is essential, rolling shall be continued on the full width till there is no further visible movement under the roller and the surface is closed.

• As soon as the lean concrete surface is compacted, curing shall commence. Curing shall be done by covering the surface by gunny bags/hessian, which shall be kept continuously moist for 7 days by sprinkling water.

• The minimum dry density obtained shall be 97% of the dry density achieved during trial length construction and the density achieved at the edges (i.e. upto 0.5m from the edge) shall be not less than 95% of the MDD.

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Specification and construction of PQC:

SCOPE:

The Scope of this Segmental Quality Plan/ Methodology shall covers the construction of pavement quality concrete insertion of dowel bars, tie bars in accordance with the requirement of Technical Specifications and in conformity with the line, grades and cross sections shown in drawings.

Material Required:

Cement:

Any of the following types of cement may be used with prior approval of the Engineer:

(i) Ordinary Portland cement IS: 269

(ii) Portland Slag Cement IS: 455

(iii) Portland Pozzolana Cement IS: 1489

Cement to be used may preferably be obtained in bulk form. It shall be stored in accordance with stipulations contained in Clause 1014 and shall be subjected to acceptance test prior to itsimmediate use.

Coarse Aggregate:

- Aggregates to be used in the construction of PQC will be Crushed aggregates.
- The aggregate complying IS: 383 will be used.
- Max Size of coarse aggregate 25mm as per MoRTH 601.2.3.2 (Fourth Revision: August 2001).

Fine Aggregate:

Clean, natural sand from River Banas form location Triveni 20km form Ladpura will be used. The material conforming IS: 383 is ensured.

Construction:

Concrete production, transportation, Paving, Texturing and Curing:-

- A batching plant of 120cum per Hr. capacity has to use for Production of Concrete
- Dumpers having hydraulic jack system to unload having capacity 35 Mt (Approx. 9 cum) concrete will be deploy for transportation of concrete.
- Paving will be carried out in full carriageway width of 8.5 m length.
- The Paver used will be slip from Paver.
- The slip from-paving machine shall compact the concrete by internal vibration and shape it between the side forms with a conforming plate and oscillating finishing beams.
- The final finish of the surface will be done by super smoother attached to the rear portion of the Paver.
- Manson Trolley will be placed in between Paver and Texturing and Curing Machine (TCM) for rectification of any surface defects.
- The alignment of the Paver shall be controlled automatically from the guide wire by 4 set of level sensors and 2 set of steering sensors attached to the Paver.
- Planning and preparation will be done to pave at least at an average uniform speed of one m / min.
- The surface of concrete slab will Tine-textured in a direction parallel to the longitudinal axis of the carriageway.

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- Texturing / Tining will be done with a specified machine specially designed for the purpose for providing grooves at a uniform spacing of 18 mm to 21mm.

  Depth = 3mm to 4mm

  Width = 3mm
- Curing of PQC using curing compound will be followed by texturing by the same TCM.
- Curing will be taken care at the edges also.
- The curing compound will be resin based aluminized reflective curing compound.
- After providing initial cut entire PQC will be covered with Hessian cloth and water turned for 14 days

Opening to Traffic:

- No vehicular traffic including contractor's vehicles will be allowed on the finished surface until a field flexural strength of minimum 4.50 MPa has been achieved where average flexural strength of minimum 3 specimens should exceed 4.50+1.65 s(s=standard deviation).
- Each series of test specimens for measurement of flexural strength should consists of minimum 3 test specimens.
- Prior to opening to traffic the joints should be sealed and areas adjacent to the pavement should be completed to a degree that will ensure traffic safety.

Quality Assurance and Control Checks

- As part of Quality Assurance this Segment Quality Plan for PQC has been prepared in line with the specification provided in relevant MoRTH clauses, Contract Supplementary Technical Specification and other Codes/ Standard / Specifications etc. elsewhere mentioned in this Plan.
- As a part of Quality Control all the Inspection and Testing requirements for various activities involved in laying of PQC will be carried out as per relevant MoRTH Specifications & Contract Technical Specification atc. As described in Inspection and Test Plans attached to this Segment Quality Plan for PQC.
- These Inspection and Test Plans shall consist of type of Inspection and name of the Test to be conducted for Product Realization, frequency of testing acceptance criteria and category of Inspection.
- Inspection and Test Plans should be revised whenever there any change in methodology and specifications etc.

<u>Construction of Cement Concrete Pavement</u>

Scope:

- The work shall consist of construction of unreinforced, dowel jointed, plain cement concrete pavement in accordance with the requirements of these Specifications and in conformity with the lines, grades and cross sections shown on the drawings. The work shall include furnishing of all plant and equipment, materials and labour and performing all operations in connection with the work, as approved by the Engineer.
- The design parameters, viz,, thickness of pavement slab, grade of concrete, joint details etc. shall be as stipulated in the drawings.

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Materials:

- **Source of materials:** The Contractor shall indicate to the Engineer the source of all materials to be used in the concrete work with relevant test data sufficiently in advance, and the approval of the Engineer for the same shall be obtained at least 45 days before the scheduled commencement of the work. If the Contractor later proposes to obtain materials from a different source, he shall notify the Engineer for his approval, at least 45 days before such materials are to be used with relevant test data.

Cement:

- **Any of the following types of cement capable** of achieving the design strength may be used with prior approval of the Engineer, but the preference should be to use at least the 43 Grade or higher.
  - Ordinary Portland Cement, 33 Grade. IS : 269
  - Ordinary Portland Cement, 43 Grade IS : 8112,
  - Ordinary Portland Cement, 53 Grade, IS: 12269.
- If the soil around has soluble salts like sulphates in excess of 0.5 per cent, the cement used shall be sulphate resistant and shall conform to IS:12330.

Admixtures:

Admixtures conforming to IS:6925 and IS: 9103 shall be permitted to improve workability of the concrete or extension of setting time, on satisfactory evidence that they will not have any adverse effect on the properties of concrete with respect to strength, volume change, durability and have no deleterious effect on steel bars. The particulars of the admixture and the quantity to be used, must be furnished to the Engineer in advance to obtain his approval before use.Satisfactory performance of the admixtures should be proved both on he laboratory concrete trialmixes and in trial paving works.

Aggregates:

Aggregates for pavement concrete sha ll be natural material complying with IS : 383 but with a Los Angeles Abrasion Test result not more than 35 per cent The limits of deleterious materials shall not exceed the requirements set out in IS : 383.

Coarse aggregate:

Coarse aggregate shall consist of clean, hard, strong, dense, non-porous and durable pieces of crushed stone or crushed gravel and shall be devoid of pieces of disintegrated stone, soft, flaky, elongated, very angular or splintery pieces. The maximum size of coarse aggregate shall not exceed 25 mm for pavement concrete. Continuously graded or gap graded aggregates may be used, depending on the grading of the fine aggregate. No aggregate which has water absorption more than 2 per cent shall be used in the concrete mix.

Fine aggregate:

The fine aggregate shall consist of clean natural sand or crushed stone sand or a combination of the two and shall conform to IS : 383. Fine aggregate shall be free from soft particles, clay, shale, loam, cemented particles, mica and organic and other foreign matter. The fine aggregate shall not contain deleterious substances more than the following:

Clay lumps-4.0 per cent, Coal and lignite-10 percent, Material pissing IS Sieve No. 75 micron-4.0 percent

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Water:

Water used for mixing and curing of concrete shall be clean and free from injurious amount of oil, sail, acid, vegetable matter or other substances harmful to the finished concrete.

Joint sealing compound:

The joint sealing compound shall be of hot poured, elastomeric type or cold polysulphide type having flexibility, resistance to age hardening and durability.

Proportioning of Concrete:

After approval by the Engineer of all the materials to be used in the concrete, the Contractor shall submit the mix design based on weighed proportions of all ingredients for the approval of the Engineer. The mix design shall be submitted at least 30 days prior to the paving of trial length and the design shall be based on laboratory trial mixes using the approved materials and methods or on the basis of any other rational method agreed to by the Engineer.

Cement content:

The cement content shall not be less than 350 kg per cum of concrete. If this minimum cement content is not sufficient to produce in the field, concrete of the strength specified in the drawings/design, it shall be increased as necessary without additional compensation under the Contract. The cement content shall, however, not exceed 425 kg per cum of concrete.

Concrete strength:

While designing the mix in the laboratory, correlation between flexural and compressive strengths of concrete shall be established on the basis of at least thirty tests on samples. However, quality control in the field shall be exercised on the basis of flexural strength. It may, however, be ensured that the materials and mix proportions remain substantially unaltered during the daily concrete production. The water content shall be the minimum required to provide the agreed workability for full compaction of the concrete to the required density as determined by the trial mixes or other means approved by the Engineer and the maximum free water cement ratio shall be 0.50.

Workability:

The workability of the concrete at the point of placing shall be adequate for the concrete to be fully compacted and finished without undue flow. The optimum workability for the mix to suit the paving plant being used shall be determined by the Contractor and approved by the Engineer.

Design mix:

The Contractor shall carry out laboratory trials of design mixes with die materials from the approved sources to be used. Trial mixes shall be made in presence of the Engineer or his representative and the design mix shall be subject to the approval of the Engineer.

Sub-base:

The cement concrete pavement shall be laid over the sub-base constructed in accordance with the relevant drawings and Specifications contained in Clause 601. If the sub-base is found damaged at some places or it has cracks wider than 10 mm, it shall be repaired with fine cement concrete or bituminous concrete before laying separation layer.

Separation Membrane:

A separation membrane shall be used between the concrete slab and the sub-base. Separation membrane shall be impermeable plastic sheeting 125 microns thick laid flat without creases.

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Before placing the separation membrane, the sub-base shall be swept clean of all the extraneous materials using air compressor.

Weather and Seasonal Limitations

Concreting during monsoon months:

When concrete is being placed during monsoon months and when it may be expected to rain, sufficient supply of tarpaulin or other water proof cloth shall be provided along the line of the work. Any lime when it rains, all freshly laid concrete which had not been covered for curing purposes shall be adequately protected. Any concrete damaged by rain shall be removed and replaced. If the damage is limited to texture, it shall be retextured in accordance with the directives of the Engineer.

Concreting in hot weather:

No concreting shall be done when the concrete temperature is above 30 degree Centigrade.

Side forms and rails:

All side forms shall be of mild steel of depth equal to the thickness of pavement or slightly less to accommodate the surface regularity of the sub-base.

Batching and mixing:

Batching and mixing of the concrete shall be done at a central batching and mixing plant with automatic controls, located at a suitable place which takes into account sufficient space for stockpiling of cement, aggregates and stationary water tanks. This shall be, however, situated at an approved distance, duly considering the properties of the mix and the transporting arrangements available with the Contractor.

Hauling and placing of concrete:

Freshly mixed concrete from the central batching and mixing plant shall be transported to the paver site by means of trucks/tippers of sufficient capacity and approved design in sufficient numbers to ensure a constant supply of concrete. Covers shall be used for protection of concrete against the weather.

Placing of Concrete:

Concrete mixed in central mixing plant shall be transported to the site without delay and the concrete which, in the opinion of the Engineer, has been mixed too long before laying will be rejected and shall be removed from the site. The total time taken from the addition of the water to the mix, until the completion of the surface finishing and texturing shall not exceed 120 minutes when concrete temperature is less than 25°C and 90 minutes when the concrete temperature is between 25°C to 30°C.

Surface texture:

After the final regulation of the slab and before the application of the curing membrane, the surface of concrete slab shall be brush-textured in a direction at right angles to the longitudinal axis of the carriageway.

Opening to Traffic

No vehicular traffic shall be allowed to run on the finished surface of a concrete pavement within a period of 28 days of its construction and until the joints are permanently sealed.

Measurements for Payment:

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Cement Concrete pavement shall be measured as a finished work in square metres with specified thickness.

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Important Questions

1. Explain rothfuch's method
2. Explain properties of bitumen.
3. Explain different classification of bituminous mix.
4. What is bitumen emulsion?
5. Explain the use of Bitumen in Road Construction
6. What are the requirements of a good bitumen ?
7. What are the tests conducted on bitumen? Explain any 3.
8. Explain the construction of cement concrete pavements.
9. Explain construction steps for cement concrete pavement slab.
10. Explain the procedure for construction of earth road.
11. Explain the procedure for construction of gravel roads.
12. Explain the procedure for construction of water bound macadam roads.
13. Explain specifications of material for cement concrete pavement slabs.

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MODULE – 5
HIGHWAY DRAINAGE & HIGHWAY ECONOMICS

Introduction

Highway Drainage: Significance and requirements, Surface drainage system and design Examples, sub surface drainage system, design of filter materials, Types of cross drainage structures, their choice and location

Highway Economics: Highway user benefits, VOC using charts only-Examples, Economic analysis - annual cost method-Benefit Cost Ratio method-NPV-IRR methods- Examples, Highway financing-BOT-BOOT concepts

Highway drainage is the process of removing and controlling excess surface and sub-soil water within the right of way this includes interception and diversion of water from the road surface and subgrade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction.

Importance of Highway Drainage

Significance of Drainage

An increase in moisture content causes decrease in strength or stability of a soil mass the variation in soil strength with moisture content also depends on the soil type and the mode of stress application. Highway drainage is important because of the following reasons:-

- Excess moisture in soil subgrade causes considerable lowering of its stability the pavement is likely to fail due to subgrade failure as discussed in Article 10.1.
- Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.
- In some clayey soils variation in moisture content causes considerable variation in flume of subgrade. This sometimes contributes to pavement failure.
- One of the most important causes of pavement failure by the formation of waves and corrugations in flexible pavements is due to poor drainage.
- Sustained contact of water with bituminous pavements causes failures due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.
- In places where freezing temperatures are prevalent in winter, the presence of water in the subgrade and a continuous supply of water from the ground water can cause considerable damage to the pavement due in frost action.

Requirements of Highway Drainage System

- The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to subgrade.
- The surface water from the adjoining land should be prevented from entering the roadway. The side drain should have sufficient capacity and longitudinal slope to carry

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away all the surface water collected.

- Flow of surface water across the road and shoulders and along slopes should not cause formation of cross ruts or erosion.

Surface Drainage

The surface water is to be collected and then disposed off. The water is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course. Cross drainage structures like culverts and small bridges may be necessary for the disposal of surface water from the road side drains.

Collection of Surface Water

The water from the pavement surface is removed by providing the camber or cross slope to the pavement. The rate of this cross slope is decided based on type of pavement surface and amount rainfall.

where there is restriction of space, Construction of deep open drains may be undesirable. This is particularly true when the road formation is in cutting. In such cases covered drains or drainage trenches properly filled with layers of coarse sand and gravel may be used. In urban roads because of the limitation of land width and also due to the presence of foot path, dividing islandsand other road facilities, it is necessary to provide underground longitudinal drains. Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb and the pavement for short distances. This water may be collected in catch pits at suitable intervals and lead through underground drainage pipes. Section of a typical catch pit with grating to prevent the entry of rubbish into the drainage system.

Drainage of surface water is all the more important in hill roads. Apart from the drainage of water from the road formation, the efficient diversion and disposal of water flowing down the hill slope across the road and that from numerous cross streams is an important part of hill road construction. If the drainage system in hill road is not adequate and efficient, it will result in complex maintenance problems.

Design of Surface Drainage System

The design of surface drainage system may be divided into two phases:

(i) Hydrologic analysis

(ii) Hydraulic analysis

Once the design runoff Q is determined, the next step is the hydraulic design of drains. The side drains and partially filled culverts are designed based on the principles of flow through open channels.

Data for Drainage Design

The following data are to be collected for the design of road side drain:

1. Total road length and width of land from where water is expected to flow on the stretch of the side drain.

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2. Run-off coefficients of different types of surfaces in the drainage area and their respective areas (such as paved area, road shoulder area, turf surface, etc.)

Designed Steps

Simplified steps for the design of longitudinal drains of a road to drain off the surface water given below:

The frequency of return period such as 10 years, 25 years etc. is decided based on finances available and desired margin of safety, for the design of the drainage system.

The values of coefficients of run-off C_1, C_2, C_3 etc. from drainage areas A_1, A_2, A_3 etc. are found and the weighted value of C is computed.

Inlet time for the flow of storm water from the farthest point in the drainage area to the drain inlet along the steepest path of flow is estimated from the distance, slope of the ground and type of the cover.

Time of flow along the longitudinal drain T_2 is determined for the estimated length of longitudinal drain L upto the nearest cross drainage or a water course and for the allowable velocity of flow V in the drain i.e., $T_2 = L$.

The total time T for inlet flow and flow along the drain is taken as the time of concentration or the design value of rain fall duration, $T = T_1 + T_2$.

The required depth of flow in the drain is calculated for a convenient bottom width and side slop of the drain. The actual depth of the open channel drain may be increased slightly to give a free board. The hydraulic mean radius of flow R is determined.

The required longitudinal slope S of the drain is calculated using Manning‟s formula adopting suitable value of roughness coefficient ‘n’ drain in a sandy clay soil from the inlet point to the cross drainage is 540 m. The velocity of flow in the side drain may be assumed as 0.6 rn/sec so that silting and erosion are prevented. Estimate the design quantity of flow on the side drain for a ten-year period of frequency of occurrence of the storm.

Cross Drainage

Whenever streams have to cross the roadway, facility for cross drainage is to be provided. Also often the water from the side drain is taken across by these cross drain in order to divert the water away from the road, to a water course or valley. The cross drainage structures commonly in use are culverts and small bridges. When a small stream crosses a road with a linear waterway less than about six meter, the cross drainage structure provided is called culvert; for higher values of linear waterway, the structure is called a bridge.

Surface Drainage

Change in moisture content of subgrade are caused by fluctuations in ground water tableseepage flow, percolation of rain water and movement of capillary water and even watervapour. In sub-surface drainage of highways, it is attempted to keep the variation of moisture in subgrade soil to a minimum. However only the gravitational water is drained by the usual drainage systems.

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Lowering of Water Table

The Highest level of water table should be fairly below the level of subgrade, in order that the subgrade and pavement layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept atleast 1.0 to 1.2 m the subgrade. In places where water table is high (almost at ground level at times) the best remedy isto take the road formation on embankment of height not less than 1.0 to 1.2 meter. When the formation is to be at or below the general ground level, it would be necessary to lower the water table.

Highway Economics & Finance

Introduction

Better highway system provides varied benefits to the society. Improvements in highway results in several benefits to the road users such as :Reduction in vehicle operational cost per unit length of road. saving travel time and resultant benefits in terms of time cost of vehicles and the passengers Reduction in accident rates. Improved level of service and ease of driving. Increased comfort to passengers. Therefore he level of service of a road system may be assessed from the benefits to the users The improvement in road network also benefits the land owner by providing better access and consequently enhancing the land value. The cost of improvements in the highway of land, materials, construction work and for the other facilities should be worked out. From the point of view of economic justification for the improvements, the cost reductions to the highway users and other beneficiaries of the improvements during the estimated period should be higher than the investments made for the improvement. In the planning and design of highways there is increasingneed for analysis to indicate justification of the expenditure required and the comparative worth ofproposed improvements, particularly when various alternatives are being compared.

The government or any other agency finances highway developments. The funds for these are generally recovered 1ins the road users in the form of direct and indirect taxations.

Highway User Benefits

General Benefits

Several benefits are brought to highway users and others due to the construction of a new highway or by improving a highway. Road user benefits are the advantages, privileges or savings that accrue to drivers or owners through the use of one highway facility as compared with the use of another. The various benefits due to highway improvement may be classified into two categories: (i) quantifiable or tangible benefits in terms of market values and (ii) non quantifiable or intangible benefits.

Quantifilab1e Benefits

Various benefits which can be quantified include benefits to road user such as reduction in vehicle operation cost, time cost and accident cost. The other benefits include enhancement in land value. These are briefly explained below:

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Saving in vehicle operation cost is due to reduction in fuel and oil consumption and reduction in wear and tear of tyres and other maintenance costs. A road with sharp curves and steep grades require frequent speed changes; presence of intersections require stopping idling andaccelerating; vehicle operation on road stretches with high traffic volume or congestion necessitates speed changes and stopping and increased travel time.

Non-quantable Benefits

The non-quantifiable benefits due to improvements in highway facilities include reduction in fatigue and discomfort during travel, increase in comfort and conveniences and improvement in general amenities, social and educational aspects, development of recreational and medical services, improved mobility of essential services and defence forces, aesthetic values, etc..

Motor Vehicle Operation Cost

The factors to be considered for evaluating motor vehicle operation cost would differ depending on the purpose of the analysis. The vehicle may be classified in different groups such as passenger cars, buses, light commercial vehicles, single unit trucks combination vehicles etc., for the purpose of cost analysis. The motor vehicle operation costs depend on several factors which may be grouped .as given below:

Cost dependent on time expressed as cost per year such as interest on capita depreciation cost, registration fee, insurance charges, garage rent, driver's license salaries etc. as applicable.

Cost depending on distance driven expressed as cost per vehicle-kilometer. The items which may be included here are fuel, oil, tyres, maintenance and repairs etc.

Cost dependent on speed include cost of fuel, oil and tyre per vehicle-km-time-cost of vehicles, travel time value of passengers, etc.

Cost dependent on type of vehicle and its condition. Operation costs of larger vehicles are comparatively higher. The operation cost of old vehicles maintained in poor condition is also higher.

Accident costs.

The costs of vehicle operation and time for unit distance may be taken as:

$$T = a + (b+c)$$

Where

a = running cost per unit distance, independent of journey time

b = a fixed hourly cost, dependent on speeds

c = the portion of the running cost which is dependent on speed

pavement surface and its condition, grades, curves and traffic volumes. Also the time costs and accident costs are taken into consideration.

Example - Calculate the operating cost of a passenger car for 100 km length of a rural highway with no sharp curves for most economical speed of vehicles operation using the following

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Highway Costs

General

The total Highway Cost for road user benefit analysis is the sum of the capital costs expressed on an annual basis and the annual cost of maintenance. The total cost for highway improvement is obtained from the estimate prepared from the preliminary plans. The total cost of each highway engineering improvement proposal is calculated from the following five components

(i) Right of way
(ii) Grading drainage, minor structures
(iii) Major structures like bridges
(iv) Pavement and appurtenances
(v) Annual cost of maintenance and operation

Computation of total annual highway cost based on summation of the annual cost of individual items of improvements and their average useful lives is considered to be a proper and accurate approach. It is difficult to estimate the service lives of highway elements as there are several variables such as soil, climate topography and traffic. Road life studies enable estimation of lives of pavements, bridges and other roadway facilities.

(i) Administration (a portion) Personal service, building, equipment operation, office, insurance etc.
(ii) Highway operation Equipment. building vehicle operation including capital costs of vehicle.
(iii) Highway maintenance
(iv) Highway capital cost : Cost of highway components such as right of way, damage, earthwork, drainage system. pavement bridges and traffic services depreciation cost and interest on investment.
(v) Probable life and salvage value at the end of this period.

The average annual highway cost for a road system may be summed up by the formula.

$$\mathbf{Ca - H + T + M + Cr}$$

where

Ca = average annual cost of ownership and operation
H = average cost for administration and management at head quarters
T = average annual highway operation cost.
M = average annual highway maintenance cost.
Cr = average annual capital cost of depreciation of investment capital or the capital recovery with return on capital

The annual cost is considered in the economic assessment of highway projects. Instead of considering the overall cost of a project the annual repayment of a capital loan plus the interest over a specified period of time of the annual capital cost is considered in the analysis.

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economical proposal among various alternatives, in the analysis for economic justification of the proposed improvement, it is required to use judgment such as quantitative selection of the factors in which annual highway cost depends and the estimation of AADT of each class of vehicle considering the normal increase in traffic and the generated traffic.

Methods of Analysis

The procedure for the economic evaluation of highway projects consists of qualification for cost component and the benefits arising out of the project and to evaluate by one of the methods of analysis.

There are several methods of economic analysis. Some of the common methods are. Annual- cost Method, Rate-of-Return Method and Benefit-Cost Method.

Annual-Cost Method

The annual cost of each element of capital improvement is found by multiplying by the appropriate CRF value calculated for the assume life span. The annual cost Cr may be found using the relation

$$C1 = P.\ i(1+i)n = P(CRF)$$

$$(1+i)^{n-1}$$

Rate-of-Return Method

There are number of variations for the determination of raw of return of a highway improvement. In the rate of return method, die interest rate at which two alternative solutions have equal annual cost is found, If the rate of return of all proposed projects are known, the priority for the improvement could be established.

Benefit Cost ratio Method

Principle of this method is to assess the merit of a particular scheme by comparing the annual benefits with the increase in annual cost

Benefit cost ration = Annual benefits from improvement / Annual cost of the improvement

$$= R - R_1 / H_1 - H$$

Where

R = total annual road user cost for existing highway

R1= total annual road user cost for proposed highway improvement

H= total annual cost of existing road

H_1 = total annual cost of proposed highway improvement

The benefit-cost ratios are determined between alternate proposals and those plans dub are not attractive are discarded. Then the benefit cost ratios for various increments of added investment are computed to arrive at the best proposal. hi order to justify the proposed improvement, the ratio should be greater than 1.0. However, the choice of interest rate would affect the results of the

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benefit-cost solutions.

Total annual road user cost for proposal B =RB = Rs. 2491,125
Total annual highway cost of proposal C = HC = Rs.3,75,100
Total annual highway cost of proposal C= HC = Rs.2377,245

Benefit – cost ratio

C = RA-RB = 3081,330 - 2377.245	=	704,085 = 3.546	
A = HC-HA	375,100 - 176,527	198, 573	

Therefore, alternative C is the best one with higher benefit-cost ratio.

Highway Finance

Basic principle in highway financing is that the funds spent on highways are recovered from the road users. The recovery may be both direct and indirect.

Two general methods of highway financing are:
Pay-as-you-go method
Credit financing method

In pay-as-you-go method, the payment for highway improvements, maintenance and operation is made from the central revenue. In credit financing method, the payment for highway improvement is made from borrowed money and this amount and the interests are re-paid from the future income.

Distribution of highway cost

The question of distributing highway cost among the Government, road-user and other has been a disputed task in several countries. Many economists are of the view that the financial responsibility for roads should be assigned only among the beneficiaries on the basis of the benefit each one receives.

There are several theories suggesting the method of distribution of highway taxes between passenger cars and other commercial vehicles like the trucks. However in India the annual revenue from transport has been much higher than the expenditure on road development and maintenance. Therefore there is no problem of distributing the highway cost among otheragencies. Also the taxation on vehicles is being considered separately by the states and there seems to be no theory followed for the distribution of taxes between various classes of vehicles.

Sources of Revenue

The various sources from which funds necessary for highway development and maintenance may be made available, are listed below:

- Taxes on motor fuel and lubricants.
- Duties and taxes on new vehicles and spare part including tyres

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- Vehicles registration tax.
- Special taxes on commercial vehicles
- Other road user taxes
- Property taxes
- Toll taxes

Other funds set apart for highways

Highway financing in India

The responsibility of financing different roads lies with the Central Government, State Governments and local bodies including Corporations, Municipalities, District Boards and Panchayats.

Taxes levied by Central Government for highway financing are:

- Duties arid taxes on motor fuel
- .Excise duty on vehicles and spare parts, tyre etc.
- Excise duty on oils, grease, etc

Taxes levied by the State Governments include:

- Registration fees for vehicles and road tax
- Permits for transport vehicles
- Passenger tax on buses
- Sales tax on vehicle parts tyre etc.
- Fees on driving licenses

Taxes levied by local bodies are mainly the toll tax.

Ever since the introduction of Central Road Fund (CRF) in the year 1929 by taxing motor fuel, this has been the main source of finance for the State Government to meet the road development needs, without having to go through the time consuming process of special sanctions each time. However of late the CRF is also being merged with the general revenue, in March 1976 the Lok Sabha has passed the resolution Of the Ministry of Transport ensuring the existence of the CRF separately with the specified objectives. An Amount of not less than 3.5 paise per litre out of the duty of customs and excise on motorspirit would be set apart towards the CRF for the road development. While utilizing this fund, greater attention would be given to schemes of all-India importance. Twenty percent of the fund would be retained by the central Government as reserve. The fund will also be used for road research schemes, traffic studies, economics surveys and training arrangements for young engineers. The gross revenue from road transport in India during the sixth plan period 1978-83, 1980-85was about Rupees l2,000 Crores

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Important Questions

1. What is the importance of highway drainage?
2. What are the requirements of highway drainage system
3. Explain the process of collection of surface water from pavement surface.
4. Explain hydrologic analysis.
5. Explain hydraulic analysis.
6. Differentiate between quantifilab1e benefits & non-quantable benefits
7. What is motor vehicle operation cost?
8. How the cost of highway improvement is calculated?
9. What are the methods of economic analysis? Explain any 3.
10. What are the sources of revenue?

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