MODULE-1

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, road patterns, 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-vision2021.

HIGHWAY ALIGNMENT AND SURVEYS: Ideal Alignment, Factors affecting the alignment, Engineering survey-Map Study, Reconnaissance, Preliminary and Final location & detailed survey, Reports and drawings for new and re-aligned projects.

INTRODUCTION

Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption. Transportation fulfills these basic needs of humanity. Transportation plays a major role in the development of the human civilization.

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

Function: The purpose of a transportation system is to coordinate the movement of people, goods and vehicles in order to utilize routes most efficiently. When implemented, transportation systems seek to reduce transport costs and improve delivery times through effective timetabling

and route management. Periodic re-evaluations and the development of alternative routes allow for timely changes to the transportation system in order to maintain efficiency.

Features: A standard transportation system will usually feature multiple timetables designed to inform the user of where each vehicle in the fleet is expected to be at any given point in time. These timetables are developed alongside an array of route plans designed to coordinate vehicle movements in a way that prevents bottlenecks in any one location.

Benefits: The main benefit of implementing a transportation system is delivery of goods and personnel to their destinations in a timely manner. This in turn increases the efficiency of vehicle use, as the same vehicle can be used for "multi-drop" jobs, such as bus services or home delivery networks, far more effectively when their routes are planned in advance rather than being generated "on the fly."

Size: Transportation systems are developed in a wide variety of sizes. Local transport networks spanning the bus network for a city and its suburbs are common, as are wide delivery networks for haulage firms. Airlines use international transportation systems to coordinate their flights. The larger the distance being covered, the more effective the use of vehicles when a transportation system is used.

Scope of transportation: Transportation is a non-separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations.

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

IMPORTANCE OF TRANSPORTATION:

Transportation is a toll to measure the Economic, Industrial, Social and Cultural development of any country. The world that we live in now will most likely be impossible had it not been for innovations in transportation. There would not have been any great infrastructure,

industrialization, or massive production, if transportation was incompetent. Life would not have kept up with the fast changing times if there were no huge trucks, bulldozers, trailers, cargo ships, or large aircrafts to carry them to different places. In other words, the global society would not have experienced comfort and convenience had it not been for advancements in the transportation sector.

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 centres viz; farms and factories to the marketing centres and later to the retailers and the consumers for distribution. The transportation has lots of advantages and even disadvantages. The more focus is on advantages as we cannot think about the life without transportation. The importance of transportation may include:

1. 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.

2. 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.

3. Enhances the Standard Of Living: It improves the standard of living. As the transportation of each and every good is being done then the productivity increases which results in the reduced or the effective costs. Because of reduction in the cost they can use different commodities for different purposes and can lead a secure life.

4. 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.

5. 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.

6. 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.

7. Helps for bringing nations together: Transportation on the whole is used for globalization i.e. it brings nations together and it creates awareness about the cultural activities and even about the industries and helps a lot for importing and exporting of different goods.These above are some of the necessities which make us to use transportation.The importance and adequacy of transportation system of a country indicates its economic and social development.

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

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

Economic activity are 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.

Social Effects: Progress follows the lines of transportation. Population has always settled along the river shores, road side and near railway stations.

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

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

2.Concentration of population into urban area: the prosperity and employment opportunities of urban area attract the population from other areas resulting in enhanced the population from other areas movements to and from factories, officer, schools, hospitals and other social needs.

3. 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 defined the territory of the country against external aggression and to guard the borders with the foreign territories transport facilities are needed.

ROLE OF TRANSPORTATION IN NATIONAL DEVELOPMENT

Transportation is a non-separable part of any society. It exhibits a very close relation to the style of life, the range and location of activities and the goods and services which will be available for consumption. Advances in transportation has made possible changes in the way of living and the way in which societies are organized and therefore have a great influence in the development of civilizations. Transportation is responsible for the development of civilizations from very old times by meeting travel requirement of people and transport requirement of goods. Such movement has changed the way people live and travel. In developed and developing nations, a large fraction of people travel daily for work, shopping and social reasons. But transport also consumes a lot of resources like time, fuel, materials and land.

Economic role of transportation Economics involves production, distribution and consumption of goods and services. People depend upon the natural resources to satisfy the needs of life but due to non-uniform surface of earth and due to difference in local resources, there is a lot of difference in standard of living in different societies. So there is an immense requirement of transport of resources from one particular society to other. These resources can range from material things to knowledge and skills like movement of doctors and technicians to the places where there is need of them.

1. Transport extends the range of sources of supply of goods to be consumed in an area, making it possible for user to get resources at cheap price and high quality.

2. The use of more efficient systems of supply results in an increase in the total amount of goods available for consumption.

3. Since the supply of goods is no longer dependent on the type of mode, items can be supplied by some alternative resources if usual source cannot supply what is needed.

Social role of transportation: Transportation has always played an important role in influencing the formation of urban societies. Although other facilities like availability of food and water played a major role, the contribution of transportation can be seen clearly from the formation, size and pattern, and the development of societies, especially urban centers.

Formation of settlements: From the beginning of civilization, the man is living in settlements which existed near banks of major river junctions, a port, or an intersection of trade routes. Cities like New York, Mumbai and Moscow are good examples.

Size and pattern of settlements: The initial settlements were relatively small developments but with due course of time, they grew in population and developed into big cities and major trade centers. The size of settlements is not only limited by the size of the area by which the settlement can obtain food and other necessities, but also by considerations of personal travels especially the journey to and from work. The increased speed of transport and reduction in the cost of transport has resulted in variety of spatial patterns.

Growth of urban centers: When the cities grow beyond normal walking distance, then transportation technology plays a role in the formation of the city. For example, many cities in the plains developed as a circular city with radial routes, whereas the cities beside a river developed linearly. The development of automobiles and other factors like increase in personal income, and construction of paved road network, the settlements were transformed into urban centers of intense travel activity.

Political role of transportation: The world is divided into numerous political units which are formed for mutual protection, economic advantages and development of common culture. Transportation plays an important role in the functioning of such political units.

Administration of an area: The government of an area must be able to send/get information to/about its people. It may include laws to be followed, security and other needful information needed to generate awareness. An efficient administration of a country largely depends on how effectively government could communicate this information to all the country. However, with the advent of communications, its importance is slightly reduced.

Political choices in transport: These choices may be classified as communication, military movement, and travel of persons and movement of freight. The primary function of transportation is the transfer of messages and information. It is also needed for rapid movement of troops in case of emergency and finally movement of persons and goods. The political decision of construction and main maintenance of roads has resulted in the development of transportation system.

DIFFERENT MODES OF TRANSPORTATION

Three basic modes of transport are by land, water and air. Land has given development of road and rail transport. Water and air have developed waterways and airways respectively. Apart from

these major modes of transportation, other modes include pipelines, elevators, belt conveyors, cable cars, aerial ropeways and monorails. Pipe lines are used for the transportation of water, other fluids and even solid particles.

The four major modes of transportation are:

1. Roadways or highways

2. Railways

3. Airways

4. Waterways

Roadways or highways:

1. The transportation by road is the only mode which could give maximum service to one and all.

2. The road or highways not only include the modern highway system but also the city streets, feeder roads and village roads, catering for a wide-range of road vehicles and the pedestrians.

3. This mode has also maximum flexibility for travel with reference to route, direction, time and speed of travel etc. through any mode of road vehicle. It is possible to provide door to door service by road transport.

4. The other three modes (railways; water ways; airways) has to depend on the roadway for the service.

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

Railways:

1. The transportation along the railway track could be advantageous by railways between the stations both for the passengers and goods, particularly for longer distances.

2. The energy requirement to haul unit load through unit distance by the railway is only a fraction

(one fourth to one sixth) of the required by road.

3. Hence, full advantage of this mode of transportation should be taken for the transportation of bulk goods along land where the railway facilities are available.

Airways:

1. The transportation by air is the fastest among the four modes.

2. Air also provides more comfort apart from saving in transportation time for the passengers and the goods between the airports.

Waterways:

1. Transportation by water is the slowest among the four modes.

2. This mode needs minimum energy to haul load through unit distance

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

COMPARISON OF DIFFERENT MODES

ROAD WAYS	RAILWAYS	WATERWAYS	AIRWAYS
1.Max service to one and all 2.Max flexibility with reference to route, direction, time and speed of travel Provide door to door service 3.Acts as feeder for other modes of transport.	1.Advantage for longer distances for carrying passengers and goods. Direction, route , time are fixed can't 2.The hauling unit is 1/6 of road ways. 3.Advantages in carrying bulk goods over long distance	1.Earliest mode of transport for longer distances 2.Flexibility exist in dir, route etc 3.Slowest mode of transport and haul cost is very low. 4.Only presence of proper inland water bodies helps in transportation	1.Fastest mode of transport 2.Flexibility is possible only for small planes & copter. The direction & other entities are controlled. 3.The haul unit per unit length is costly. 4.Initial investments are high

Roadways

Advantages:

1. Flexibility: It offers complete freedom to the road users.

2. It requires relatively smaller investments and cheaper in construction with respect to other modes.

3.It serves the whole community alike the other modes. 4. For short distance travel it saves time.

4.These are used by various types of vehicles.

Disadvantages:

1.Speed is related to accidents and more accidents results due to higher speed.

2.Not suitable for long distance travel

3.Power required per tonne is more.

Railways

Advantages:

1. Can transport heavy loads of goods at higher speed

2.Power required per tonne is less compared to roadways

3.Chances of accidents are less.

Disadvantages:

1.Entry and exist points are fixed

2.Requires controlling system and no freedom of movement 3.Establishment and maintenance cost is higher.

Airways

Advantages:

1.It has highest speed

2.Intercontinental travel is possible

3.Journey is continuous over land and water

Disadvantages:

1.Highest operating cost (cost/ton is more)

2.Load carrying capacity is lowest

3.Depends on whether condition

4.Should follow the flight rules.

Waterways

Advantages:

1.Cheapest: Cost per tonne is lowest

2.Possess highest load carrying capacity

3.Leads to the development of the industries.

Disadvantages*:*

1.Slow in operation and consumes more time

2.Depends on weather condition

3.Chances of attack by other countries on naval ships are more.

4.Ocean tides affects the loading and unloading operation

5.The route is circuitous.

CHARACTERISTICS OF ROAD TRANSPORT

1. 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.

2. 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.

3. 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.

4. In particular for short distances travel, road transport saves time.

5. 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.

6. Road transport is the only means of transport that offers itself to the whole community alike.

JAYAKAR COMMITTEE RECOMMENDATIONS AND IMPLEMENTATION

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

1. 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.
2. Extra tax to be levied from the road users as fund to develop road.
3. A Semi-official technical body has to be formed to collect and pool technical to Know how from various parts of the country and to act as an advisory body on various aspects of the roads.
4. 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,

1. Central Road Fund (CRF) in 1929
2. Indian Roads Congress (IRC) in 1934
3. Central Road Research Institute (CRRI) in 1950.

CENTRAL ROAD FUND (CRF) :

1. Central Research Fund (CRF) was formed on 1st March 1929

2. The consumers of petrol were charged an extra leavy of 2.64 paisa/litre of petrol to build up this road development fund.

3. 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.

4. 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

5. The accounts of the CRF are maintained by the Accountant General of Central Revenues.

6. The control of the expenditure is exercised by the Roads Wings of Ministry of Transport.

INDIAN ROADS CONGRESS (IRC):

1. It is a semi-official technical body formed in 1934.

2. It was formed to recommend standard specifications.

3. 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.

4. IRC has played an important role in the formulation of the 20-year road development plans in India.

5. Now, it has become an active body of national importance controlling specifications, guidelines and other special publications on various aspects of Highway Engineering.

CENTRAL ROAD RESEARCH INSTITUTE (CRRI):

1. CRRI was formed in the year 1950 at New Delhi

2. It was formed for research in various aspect of highway engineering

3. It is one of the National laboratories of the Council of Scientific and Industrial Research.

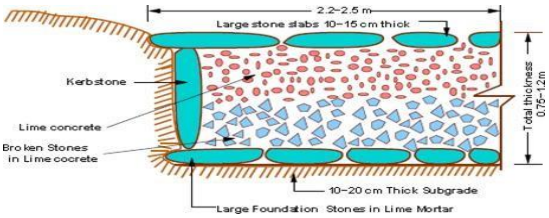
4. This institute is mainly engaged in applied research and offers technical advice to state governments and the industries on various problems concerning roads.

HIGHWAY DEVELOPMENT AND PLANNING

HISTORY:

The invention of wheel brought up the necessity of providing a hard surface to move the vehicles. Such trace of road network is believed to have existed in Mesopotamia in the period of 3500 BC. The first road on which there is some authentic records is that of Assyrian empire constructed by about 1900 BC. Only during Roman empire the roads were built in large scales.

Roman Roads: Many of the early roman roads were of elaborate construction.



The main features of Roman roads are:

1. They were built straight regardless of gradients.

2. They were built after the soft soil was removed and a hard stratum was reached

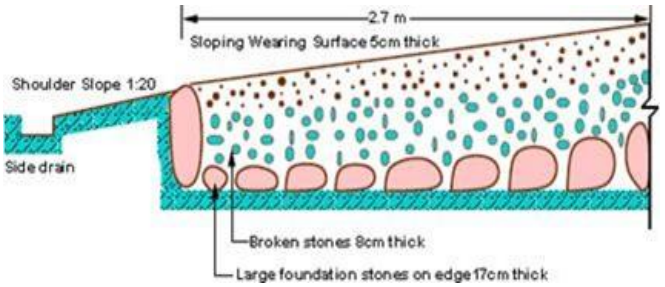
3. The total thickness of the construction was as high as 0.75 to 1.2 mtrs at some places, even though the magnitude of wheel loads of animal drawn vehicles was very low.

4. Large stones were laid in lime mortar at the bottom. Vertical kerbs stones were place along the side of trench.

5. Large size of broken stones missed in lime mortar was laid over the large stones.

FRENCH Roads (Tresaguet Construction):

The main feature of this was that the thickness of construction need be only in the order of 30 cm. Further due consideration was given to sub grade moisture condition and drainage of surface water.



1. The sub grade was prepared by large foundation stones

2.The top wearing course was made of smaller and compacted to a thickness of about 5 stones cm at the edges and gradually increased towards the centre, giving a cross slope.

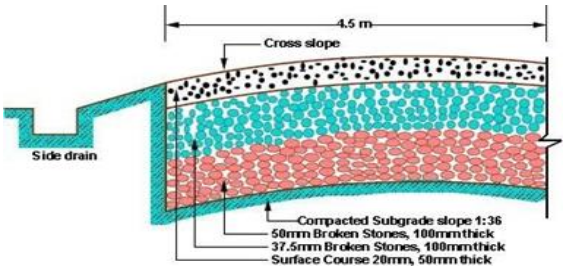
3. The shoulders were also provided cross slope to drain the surface water.

JOHN MECADAM CONSTRUCTION:

1. It is the first method based on scientific thinking.

2. It was realized that the stresses due to wheel load of traffic gets decrease at the lower layers of the pavement and therefore it is not necessary to provide large and strong boulders stones as foundation.

3. Various modern roads are subsequent improvement of this type of constructions



NECESSITY OF HIGHWAY PLANNING:

Planning is the basic requirement for any new project or an expansion programs me. Particularly when funds available are limited and requirement are higher.

The objects of planning are:

1. To plan a road network for efficient and safe traffic operations, but at minimum cost. Here the

costs of construction, maintenance and renewal of pavement layers and the vehicle operation costs are to be given due consideration.

2. To arrive at the road system and the lengths of different categories of roads this could provide maximum utility and could be constructed with in available resources during the plan period.

3. To fix up date wise priorities for development of each link based on utility as the main criterion for phasing the road development programme.

4. To plan for future requirement and improvements of roads in view of anticipated developments.
5. To work out financing system.

CLASSIFICTION OF ROADS

Types of Roads

1. Based on Seasons of the year

a) All weather roads: are those which are negotiable during all weather, expect at major river crossing where interruption to traffic is permissible up to a certain extent.

b)Fair weather roads: are those, the traffic may be interrupted during monsoon season at causeways where streams may overflow across the road.

2. Based on type of carriage way

a)Paved Roads: provided with a hard pavement course at least of WBM layer

b)Unpaved Roads: not provided with hard pavement surface. Earth and gravel roads are unpaved roads.

3. Based on type of pavement surface

a)Surface Roads: provided with a bituminous or cement concrete surfacing.

b)Un Surfaced Roads: not provided with bitumen or cement concrete surfacing.

4. Based on traffic volume

a)Light: Roads on which traffic volume are low. Examples village are ODR roads.

b)Medium: Roads on which the traffic intensity is relatively more to ODR.

c) Heavy: Roads on which the traffic intensity is high.(NH and SH).

5. Based on Load transported or tonnage

a) Class A or Class I: where the vehicles carries less tonnes of load on the roads.

b)Class B or Class II : Roads on which the vehicles carry more loads(LCV, Medium commercial vehicles)

c)Class C or Class III: Roads on which the trucks with heavy tonnes of load are allowed.

6. Based on Location and function

a) National highway

b) State Highway

c) Major district Roads

d) Minor or Other District Roads

e) Village Roads

7. Based on 3rd 20 year road plan

a) Primary System: (Expressway & NH)

b) Secondary System (SH & MDR)

d) Tertiary System or Rural Roads (ODR & VR)

8. Classification of Urban Roads

a) Arterial Roads

b) Sub- arterial Roads

c) Collector streets

d) Local Streets

ROAD PATTERNS

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

Advantages:

1. The rectangular plots may be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front.

2. In this pattern has been adopted for the city roads.

3. The construction and maintenance of roads of this pattern is comparatively easier.

Limitations:

1. This pattern is not very much convenient because at the intersections, the vehicles face each other. **Example**: Chandigarh has rectangular pattern.

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

Advantage:

1. Reduces level of congestion at the primary bottleneck location.

2. Prevents traffic from accessing local flow routes in the direction of the event venue that operate in favor of egress traffic flow.

3. If one is block then other side traffic can move.

4. Vehicles face each other less than block pattern.

Limitations:

1. Proves particularly effective if two-lane ramp traffic does not have to merge at downstream end of ramp.

2. 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

3. Radial or Star and Circular Pattern: In this system, the main radial roads radiating from central business area are connected together with concentric roads. In these areas, boundary By adjacent radial roads and corresponding circular roads, the built-up area is planned with a curved block system.

Advantages:1.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.

2. Installing circular pattern in place of traffic signals can also reduce the likelihood of rear- end crashes.

3. Removing the reason for drivers to speed up as they approach green lights and by reducing abrupt stops at red lights.

4. Because roundabouts improve the efficiency of traffic flow, they also reduce vehicle emissions and fuel consumption.

Limitations:

1. Center lines of roads leading to circular pattern should be properly aligned with the central island.

2. Approach roads should be sufficiently curved, far enough in advance of circular pattern, to reduce vehicle speeds of entering drivers.

3. Islands separating the approach and exit lanes, known as splitter islands, should extend far enough to provide pedestrian refuge and to delineate the roundabout.

4. 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.

5. 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.

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

Advantages:

1. Keep vehicular traffic safe with a high proportion of 3-way intersections.

2. Reduce cut-through traffic by similar or other means.

3. Improve traffic flow in both directions using Savannah's cellular structure.

4. Improve land use efficiency and unit density.

Limitations:

1. Islands separating the approach and exit lanes, known as splitter islands, should extend far enough.

2. 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.

5. 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:

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

Limitation:

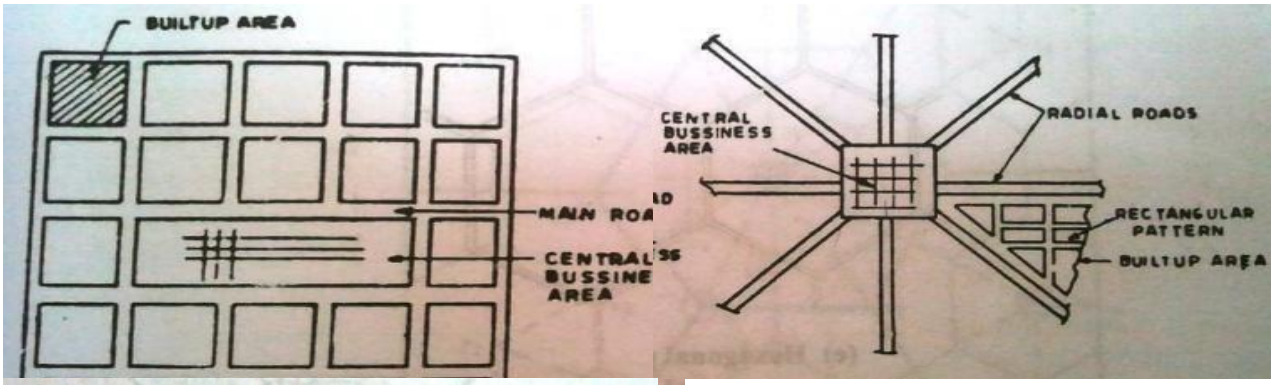
1. Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.

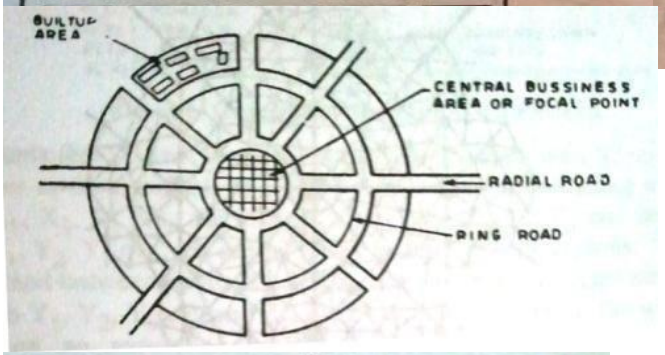
6. Minimum Travel Pattern: In this road pattern, city is contented by sector center, suburban center and neighborhood center by the road which required minimum to connect the city center.

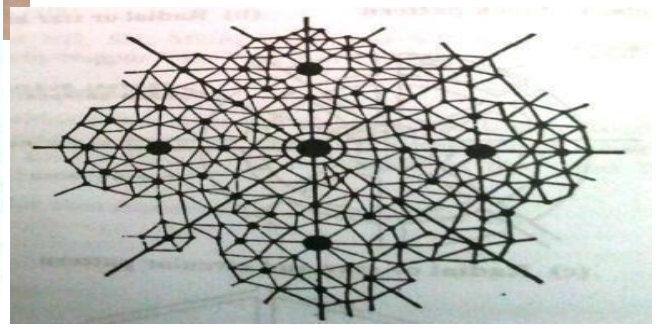
Advantages:

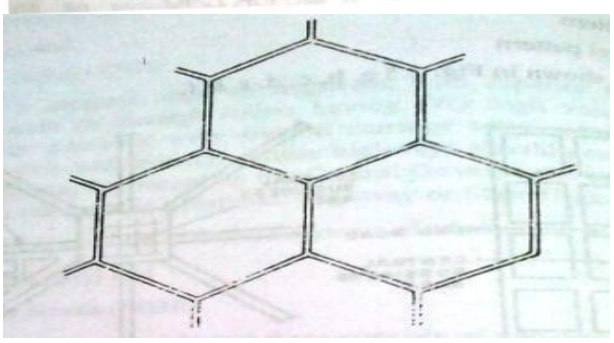
1. These types of potentially serious crashes essentially are eliminated.

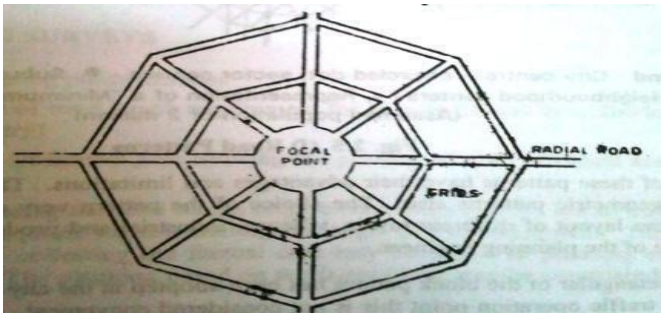
Limitations: 1. Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed. 2. Intersections can be especially challenging for older drivers











PLANNING SURVEYS

The field surveys thus required for collecting the factual data may be called as planning survey or fact finding surveys:

Highway planning phase includes

i) Assessment of road length requirement for an area

ii) Preparation of Master plan showing the phasing of plan in annual and or five year plans.

The planning surveys consists of the following studies

i) Economical Studies

ii) Financial studies

iii) Traffic or road use studies

iv) Engineering studies.

Economic studies	Data collected must confirm to adequacy, accuracy, availability And accessibility	Population, its distribution and classification. Trend of population growth, listing of agricultural and industrial development, their future trends – classification and listing of these details, other activities viz income per capita, banking, post office.
Financial studies		Source of income, Revenue from taxation on road transport, living standard, future trends- details like vehicle registration, court fees and local taxes
Traffic or road user studies		Traffic volume, traffic flow patterns, O & D studies, Mass transportation facilities, Accidents- their costs, trends, Growth of vehicular traffic, passenger trips and good movements.
Engineering studies		Road location and alignment studies, classification, types of roads in use, maintenance problems, soil and topography studies, road life studies.

OBJECTIVE OF PLANNING SURVEYS

1. 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.

2. Plan a road network for efficient traffic operation at minimum cost.

3. Plan for future requirements and improvements of roads in view of developments and social needs.

4. Fix up data wise priorities for development of each road link based on their utilities.

PREPARATION OF PLANS

PLAN 1	General area plan showing almost all existing features viz, topography, exiting road networks, drainage structures, river, villages with population, agricultural area etc..
PLAN 2	The distribution of population groups in accordance with the categories made in the appropriate plan

PLAN 3	Shows the location of places with their respective quantities of productivity .
PLAN 4	Shows existing road network with traffic flows and studies. Proposed new and alternative routes.

INTERPRETATION OF RESULTS OF PLANNING SURVEYS

i) To arrive at the road network with maximum utility among alternative proposals.

ii) to fix up the priority of the construction projects and phase the development plan

iii) To assess the actual road use by studying traffic flow patterns.

iv) Based on the studies, structural and geometric features are constructed.

v) Comparisons of the areas may be obtained on the basis of their economic activities.

vi) On statistical basic, the data obtained in fact finding surveys may be analyzed for the future trends in development of an area.

MASTER PLAN

Master plan is referred to as final road development plan for the study area which may be a city; district or a street or for whole country. It is an ideal plan showing full development of the area at some future date. It serves as the guide for the plan to improve some of the existing roads and to plan the network of new roads. It helps in controlling the industrial, commercial and agricultural and habitat growth in a systematic way of that area. It gives a perceptive picture of a fully developed area in a plan and scientific way.

STAGES IN THE PREPARATION OF MASTER PLAN

1. Data Collection: It includes data regarding existing land use, industrial and agricultural growth, population, traffic flow, topography, future trends.

2. Preparation of draft plan and invite suggestions and comments from public and experts.

3. Revision of draft plan in view of the discussions and comments from experts and public.

4. Comparison of various alternate proposals of road system and finding out the sequence in which the master plan will be implemented.

In India targeted road lengths were fixed in various road plans, based on population, area and agricultural and industrial products. The same way it may be taken as a guide to decide the total

length of road system in each alternate proposal while preparing a master plan for a town or locality.

SATURATION SYSTEM

It is one of the methods to determine the best alternative based on maximum utility of road network. In this system the optimum road length is calculated for area based on the concept of obtaining maximum utility per unit length of road. Hence this system is called saturation system or maximum utility system.

The factors which are taken for obtaining the utility per unit length of road are:

i) Population served by the road network

ii) Productivity served by the net work

A.Agricultural products

B.Industrial products

Since the area under consideration may consist of villages and towns with different populations, it grouped into some ranges and assigned utility units.

Population less than 500, utility unit = 0.25

501-1000, utility unit = 0.50

1001- 2000, utility unit = 1.00

2001 – 5000, utility unit = 2.00 etc..

Similarly the agriculture products for tonnes productivity, utility units = 1 Industrial products for tonnes productivity, utility units =10 etc.

The various steps to be taken to obtain maximum utility per unit length are:

1. 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.

2. 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.

3. Optimum Road length: Based on the master plan the targeted road length is fixed for the country on the basis of area or population and production or both. And the same may be taken as a guide to decide the total length of the road system in each proposal.

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. Recommendations were made for the geometric standards of roads, bridges and highway organization. Two formulae were finalised based on star and grid pattern to calculate the road length for the country as a whole.

CLASSIFICATION OF ROADS

i) National Highway (NH): are main Highways running through the length and breadth of India, connecting major ports, foreign highways, capitals of large states and large industrial and tourist centres including roads required for strategic movement for the defence of India. Examples: NH-1: Delhi-Ambala- Amritsar. NH-1-A: Bifurcation of NH-1 beyond Jalandar to Srinagar and Uri.

ii)State Highway (SH): are arterial roads of a state, connecting up with the national highways of adjacent state, district head quarters and important cities within the state and serving as the main arteries for traffic to and from district roads. Examples: SH17 – Bangalore- Mysore.

iii)Major District Roads (MDR) : are those roads with in a district serving area of production and markets and connecting those with each other or with the main highways of a district.

iv)Other District Roads: are roads serving rural areas of production and providing them with outlet to market centres, taluk head quarters, block development head quarters or other main roads.

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

SALIENT FEATURE

i) The responsibility of construction and maintenance of national highways were assigned to the central government.

ii) Planned for 20 year (1943-63) aiming to provide 2 lakh km of surfaced roads and remaining un surfaced roads. Total targeted road length 5,32,700 km . Achieved 7, 09,122km by the end of

1961.(road density 16km/100sqkm). 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.

iii) 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.

iv) The ODR and VR are meant to provide internal road system linking to Higher category of road network.

v)An allowance of 15 % was given for agricultural and industrial development during next 20 years.

vi)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.

NH, SH, MDR, ODR & VR. SALIENT FEATURE

1. 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.

2. 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.

3. 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.

4. While calculating the road length in hilly regions, an allowance upto 100 percent to be made in arriving at the road length.

5. Expressways have also been considered in this plan and 1600 km of length has been included in the proposed target of National Highways.

6. Length of railway track is considered independent of the road system.

7. 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,

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 1,0

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)

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

i)The future road development should be based on the revised classification of road system consisting of Primary, Secondary and Tertiary road system.

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

iii)All the villages with population of 500 should be connected by all-weather roads.

iv)The overall density of road is increased to 82km per 100 sq.km

v)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.

vi)Expressway should be constructed along major traffic corridors to provide fast travel.

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

viii)Long term master plans for road development should be prepared at various levels.

ix)All towns and villages with population over 1500 should be connected by Major district Roads and villages with population 1000 to 1500 by ODR.

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

FORMULAE

i)Length of NH (km) = area of the region/ 50

ii)Length of SH (km)

a.By area, SH (km) = area of the region/ 25

b.Based on no. Of towns, SH (km) = 62.5 x no. Of towns – NH Adopt length of SH (higher of the two criteria)

iii)Length of MDR, in the District

a.Based on area, MDR (km) = area of the region/12.500- 500 V = number of towns with population range below 500

b.Based on number of towns, MDR(km) = 90 x number of towns Provide length of MDR (higher of the two criteria)

iv)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)

FOURTH TWENTY YEAR ROAD DEVELOPMENT PLAN (2001-2021) VISION: 2021

It is to be recognized that even after the habitations eligible under PMGSY are fully covered. There is still left with a large number (about 1.68 lakh) unconnected habitations of lower size population. To serve the last person and the remotest village. IRC and Ministry of Rural Development have decided to formulate a 20 year vision (May 2007) covering various aspects related to rural areas and it's dovetailing with the higher categories of roads and the urban landscape.

OBJECTIVES

i) The road network as on May 2007 stands at 3.3 million km. Of this, rural roads comprise around 2.7 million km, i.e. about 85 percent. Overall village accessibility stood at 54 percent in the year 2000.

ii) Emphasis is continuing in social development sectors so as to improve the quality of life and alleviate poverty

iii) The objective has to be to provide full connectivity to all habitations including provision of bridges and culverts. Accordingly, the following vision for new connectivity has been recommended.

a)Habitations with population above 1000 (500 in case of hill, NE states, deserts and tribal areas) by the year 2009-10

b) Habitations with population above 500 (250 in case of hill, NE states, deserts and tribal areas) by year 2014-15

c) Habitations with population above 250 by the year 2021-22

iv) The Central Government has also introduced the concept of a Core Network, which is defined as the network that is essential to provide one basic access to each habitation.

v) Proper drainage and design standards were made for rural roads .Many management rule, powers to different authorities and other standard data book was set and prepared by NRRDA (National Rural Road Development Authority).

vi) Importance was given to the use of advanced and latest equipments in road constructions to facilitate the economics.

vii) The Government also needs to develop independent think-tanks and academicians on various aspects of rural roads like engineering, safety, environmental issues, socio-economic impact, etc

viii) Action should be taken by each state to formulate a 5-year Action Plan in the light of recommendations of the Vision document.

SALIENT FEATURES OF VISION 2021

i)The Road Development Plan Vision: 2021 was prepared with the full involvement of the highway profession both within the government and the private sector and represents an expression of the intent for highway development in the two decades from 2001.

ii)This Vision addressed concerns such as the need for mobilization of financial resources including augmentation of road fund, toll financing, private sector participation, capacity augmentation of main highways, strengthening of pavement to cope with movement of heavy commercial vehicles, undertaking massive program me of construction of village roads and preservation of existing road assets.

iii) Aspects such as road safety, social and environment concerns and energy efficiency have also been highlighted.

iv) The vision document laid down targets for main roads but did not specify the length of the rural road network. Instead, stress was laid on preparation of proper district level master plans to optimize the network.

V) Target Roads Lengths by the year 2021:

a. Expressways 10,000 km

b. National Highways 80,000 km

c. State Highways 160,000 km

d. Major District Roads 320,000 km

PRADHAN MANTRI GRAM SADAK YOJANA (PMGSY)

i)The Government of India launched in December 2000, the programme of village connectivity known as Pradhan Mantri Gram Sadak Yojana (PMGSY) with the objective of connecting all unconnected habitations having a population of 500 and above with all- weather roads.

ii)The population threshold is relaxed to 250 in case of hill, tribal and desert areas. In departure from the earlier programmes of rural road development, the PMGSY is a hundred percent funded programme of the central government.

ii) The Ministry of Rural Development (MoRD) has been entrusted with the task of implementing this programme. The National Rural Development Agency (NRRDA) – an arm of the Ministry provides management and technical support to this programme.

iv)The Ministry of Rural Development has already brought out dedicated specifications for rural roads and Standard Data Book with the support of the Indian Roads Congress. This has helped in setting national standards and specifications for rural roads at national level for uniform implementation at local level duly taking into account different terrain, soil and traffic conditions in the country.

v) As per the current guidelines, the PMGSY covers all habitations above 500 population to be provided with all-weather rural roads. In case of hills, deserts and tribal areas, the threshold is relaxed and over all habitations above 250 population.

vi) It is estimated that about 1.79 lakh unconnected habitations need to be taken up under the PMGSY programme. This would involve new construction in a length of about 375,000 km at an estimated cost of Rs. 78,000 crore and improvements of 372,000 km at an estimated cost of Rs. 59,000 crore.

vi) Up to the end of December, 2006, a total of about 83,000 habitations have been covered and rural road works for an amount of Rs.38,387 crore have been sanctioned.

NHAI:

"The National Highways Authority of India was constituted by an act of Parliament, the National Highways Authority of India Act, 1988. It is responsible for the development, maintenance and management of National Highways entrusted to it and for matters connected or incidental thereto. The Authority was operationalized in February, 1995 with the appointment of full time Chairman and other Members. "

National Highways Authority of India (NHAI) is mandated to implement National Highways Development Project (NHDP) which is

1.India 's Largest ever highways project

2.World class roads with uninterrupted traffic flow

The National Highways have a total length of 71,772 km to serve as the arterial network of the country. The development of National Highways is the responsibility of the Government of India. The Government of India has launched major initiatives to upgrade and strengthen National Highways through various phases of National Highways Development project (NHDP), which are briefly as under:

NHDP Phase I : NHDP Phase I was approved by Cabinet Committee on Economic Affairs (CCEA) in December 2000 at an estimated cost of Rs.30,000 crore comprises mostly of GQ (5,846 km) and NS-EW Corridor (981km), port connectivity (356 km) and others (315 km).

NHDP Phase II : NHDP Phase II was approved by CCEA in December 2003 at an estimated cost of Rs.34,339 crore (2002 prices) comprises mostly NS-EW Corridor (6,161 km) and other National Highways of 486 km length, the total length being 6,647 km. The total length of Phase II is 6,647 km.

NHDP Phase-III: Government approved on 5.3.2005 up gradation and 4 laning of 4,035 km of National Highways on BOT basis at an estimated cost of Rs. 22,207 crores (2004 prices). Government approved in April 2007 up gradation and 4 laning at 8074 km at an estimated cost of Rs. 54,339 crore.

NHDP Phase V: CCEA has approved on 5.10.2006 six laning of 6,500 km of existing 4 lane highways under NHDP Phase V (on DBFO basis). Six laning of 6,500 km includes 5,700 km of GQ and other stretches.

NHDP Phase VI: CCEA has approved on November 2006 for 1000 km of expressways at an estimated cost of Rs. 16680 crs . NHDP Phase VII: CCEA has approved on December 2007 for 700 km of Ring Roads, Bypasses and flyovers and selected stretches at an estimated cost of Rs. 16680 crs

MORTH

An apex organization under the Central Government is entrusted with the task of formulating and administering, in consultation with other Central Ministries/Departments, State Governments/UT Administrations, organizations and individuals, policies for Road Transport, National Highways and Transport Research with a view to increasing the mobility and efficiency of the road transport system in the country. The Ministry has two wings: Roads wing and Transport wing.

ROADS WING

Deals with development and maintenance of National Highway in the country Main Responsibilities:

1. Planning, development and maintenance of National Highways in the country.

2. Extends technical and financial support to State Governments for the development of state roads and the roads of inter-state connectivity and economic importance

3. Evolves standard specifications for roads and bridges in the country. 4.Serves as a repository of technical knowledge on roads and bridges.

TRANSPORT WING

Deals with matter relating to Road Transport

Main Responsibilities:

1.Motor Vehicle legislation.

2.Administration of the Motor Vehicles Act, 1988.

3.Taxation of motor vehicles.

4.Compulsory insurance of motor vehicles.

5.Administration of the Road Transport Corporations Act, 1950.

6. promotion of Transport co-operatives in the field of motor transport.

7.Evolves road safety standards in the form of a National Policy on Road Safety and by preparing and implementing the Annual Road Safety Plan.

8.Collects, compiles and analyses road accident statistics and takes steps for developing a Road Safety Culture in the country by involving the members of public and organising various awareness campaigns.

9.Provides grants-in-aid to Non-Governmental Organisations in accordance with the laid down guidelines

THE KARNATAKA STATE HIGHWAYS IMPROVEMENT PROJECT (KSHIP):

It is an initiative of the Public Works Department of the Government of Karnataka for improvement of road network of the state with World Bank assistance.

The Public Works Department carried out Strategic Option Study (SOS) during 1996 on a road network of 13,362 kms comprising State Highways and Major District Roads and the study identified 2888 kms of roads for prioritized improvements.

The World Bank have extended Technical Assistance (T.A.) Loan of US $ 3.2 million for project preparation through the Department of Economic Affairs of Ministry of Finance, Government of India for taking up the Project Coordinating Consultancy (PCC) Services to investigate and prepare detailed project report on the 2888 kms and Institutional Development Strategy (IDS) Study.

The works relating to upgrading and widening of 992 Km will be implemented in eight contract packages under International Competitive Bidding (ICB), where the contract values range from Rs.35 crores to Rs.205 crores. The work relating to rehabilitation and upgradation contracts of smaller value ranging from Rs.3 Crores to Rs.38 Crores will be procured under National Competitive Bidding (NCB).

KARNATAKA ROAD DEVELOPMENT CORPORATION (KRDCL)

i) It was incorporated on 21st of July 1999 as a wholly owned Government of Karnataka Company as per the Provisions of the Company's Act, 1956.

ii) KRDCL is a company under the Public Works, Ports & Inland Water Transport Department.

iii)This Company was established to promote surface infrastructure by taking up Road Works, Bridges etc., and to improve road network by taking up construction widening and strengthening of roads, construction of bridges, maintenance of roads etc., and to take up projects on BOT, BOOT, BOLT.

iv) Since inception Karnataka Road Development Corporation Limited has strived to improve the road network and to establish connectivity to all the nook & corner of the State.

HIGHWAY ALIGNMENT AND SURVEYS

Alignment

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

- Due to improper alignment , the disadvantages are,

  a) Increase in construction

  b) Increase in maintenance cost

  c) Increase in vehicle operation cost

  d) Increase in accident cost

- Once the road is aligned and constructed, it is not easy to change the alignment due to increase in cost of adjoining land and construction of costly structures by the road side.

Requirements

The requirements of an ideal alignment are

- Short
- Easy
- Safe
- Economical

- The alignment between two terminal stations should be short and as far as possible be straight, but due to some practical considerations deviations may be needed.
- The alignment should be easy to construct and maintain. It should be easy for the operation of vehicles. So to the maximum extend easy gradients and curves should be provided.
- It should be safe both from the construction and operating point of view especially at slopes, embankments, and cutting. It should have safegeometric features.
- The alignment should be economical and it can be considered so only when the initial cost, maintenance cost, and operating cost are minimum.

The alignment should be such that it would offer maximum utility by serving maximum populationand products. The utility of a road should be decided from its utility value per unit length of road.

Factors controlling alignment

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

The various factors that control the alignment are as follows:

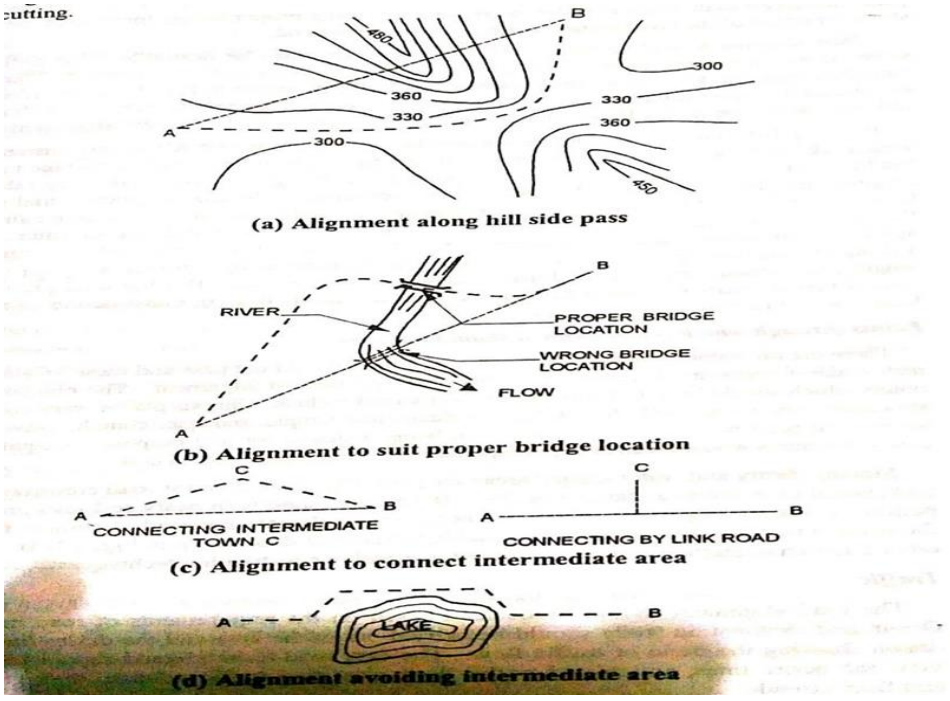
- Obligatory points
- Traffic
- Geometric design
- Economics and Other considerations

Obligatory points: These are the control points governing the highway alignment. These points are classified into two categories. Points through which the alignment should pass and points through which the alignment should not pass. Some of the examples are:

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

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

3.Intermediate town: The alignment may be slightly deviated to connect an intermediate town or village nearby.



(a) Alignment along hill side pass

(b) Alignment to suit proper bridge location

(c) Alignment to connect intermediate area

(d) Alignment avoiding intermediate area

These were some of the obligatory points through which the alignment should pass.

Coming to the second category, that is the points through which the alignment should not pass are:

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

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

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

4.Traffic: The alignment should suit the traffic requirements. Based on the origin- destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.

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

6.Economy: The alignment finalized should be economical. All the three costs i.e. construction, maintenance, and operating cost should be minimum. The construction cost can be decreased much if it is possible to maintain a balance between cutting and filling. Also try to avoid very high embankments and very deep cuttings as the construction cost will be very higher in these cases.

7.Other consideration includes: Drainage consideration, political consideration Surface water level, high flood level Environmental consideration

ENGINEERING SURVEYS FOR HIGHWAY LOCATIONS

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

- Map study (Provisional alignment Identification)
- Reconnaissance survey
- Preliminary survey
- Final location and detailed surveys

MAP STUDY (PROVISIONAL ALIGNMENT IDENTIFICATION)

From the map alternative routes can be suggested in the office, if the topographic map of that area is available.

The probable alignment can be located on the map from the fallowing details available on the map.

- Avoiding valleys, ponds or lake
- Avoiding bend of river

- If road has to cross a row of hills, possibility of crossing through mountain pass.

Map study gives a rough guidance of the routes to be further surveyed in the field

RECONNAISSANCE SURVEY

- To confirm features indicated on map.
- To examine the general character of the area in field for deciding the most feasible routes for detailed studies.
- A survey party may inspect along the proposed alternative routes of the map in the field with very simple instrument like abney level, tangent clinometer, barometer etc.
- To collect additional details.
- Details to be collected from alternative routes during this survey are,
    - Valleys, ponds, lakes, marshy land, hill, permanent structure and other obstruction.
    - Value of gradient, length of gradient and radius of curve.
    - Number and type of cross drainage structures.
    - High Flood Level (HFL).
    - Soil Characteristics.
    - Geological features.
    - Source of construction materials- stone quarries, water sources.
- Prepare a report on merits and demerits of different alternative routs
- As a result a few alternate alignments may be chosen for further study based on practical considerations observed at the site.

PRELIMINARY SURVEY

Objective of preliminary survey are:

- To survey the various alternative alignments proposed after the reconnaissance and to collect all the necessary physical information and detail of topography, drainage and soil.
- To compare the different proposals in view of the requirements of the good alignment.
- To estimate quantity of earthwork materials and other construction aspect and to work out the cost of the alternate proposals.

METHODS OF PRELIMINARY SURVEY:

a)Conventional approach-survey party carries out surveys using the required field equipment, taking measurement, collecting topographical and other data and carrying out soil survey.

Procedure of conventional method of preliminary survey

- Primary traverse
- Topographical features
- Leveling work
- Drainage studies and hydrological data
- Soil survey
- Material survey
- Traffic studies
- Longitudinal and cross sectional profile.
    - Plain Terrain` 100 – 200m
    - Rolling Terrain: 50m
    - Hilly Terrain: 30m

Drainage, Hydrological survey, soil survey, Traffic and Material survey.

b) Modern rapid approach-

By Aerial survey taking the required aerial photographs forobtaining the necessary topographic and other maps including details of soil and geology.

- Finalize the best alignment from all considerations by comparative analysis of alternative routes.

FINAL LOCATION AND DETAILED SURVEY

- The alignment finalised at the design office after the preliminary survey is to be first located on the field by establishing the centre line.

Location survey:

- Transferring the alignment on to ground.
- This is done by transit theodolite.
- Major and minor control points are established on the ground and center pegs are driven, checking the geometric design requirements.
- Centre line stacks are driven at suitable intervals, say 50m interval in plane and rolling terrains and 20m in hilly terrain.

Detailed survey:

- Temporary bench marks are fixed at intervals of about 250m and at all drainage and under pass structure.
- Earthwork calculations and drainage details are to be workout from the level books.
- Cross sectional levels are taken at intervals of 50-100m in Plane terrain, 50-75m in Rolling terrain, 50m in built-up area, 20m in Hill terrain.
- Detail soil survey is to be carried out.
- CBR value of the soils along the alignment may be determined for design of pavement.

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

DRAWING AND REPORT

- Key map
- Index map
- Preliminary survey plans
- Detailed plan and longitudinal section
- Detailed cross section
- Land acquisition plans
- Drawings of cross drainage and other retaining structures
- Drawings of road intersections
- Land plans showing quarries etc

Key map should show the proposed and existing roads, and important places to be connected. The size of the plan generally should not exceed 22 x 20 cm. The scale for the map is chosen suitably depending upon the length of road.

Index map should show the general topography of the area. The details are symbolically represented. The index map should also be of suitable scale, the size being 32 x 20 cm

Preliminary survey plans showing details of the various alternate alignments and a information collected should be normally drawn to scale of 10 cm =1 km to 25 cm =1 km.

Detailed plans show the ground plan with alignment and the boundaries, contours at intervals of 1 to 2 m in plain terrain and 3 to 6 m in hills, showing all details including existing structures. A scale of 1/2400 in close country and a scale of 1/1200 may be adopted for detailed plans. The size of the drawing may be A-2 size or 60 x 42 cm approximately.

Longitudinal sections should be drawn to the same horizontal scale of the ground as in detailed plan. Vertical scale may be enlarged 10 times of the longitudinal scale. The longitudinal section should show the details such as datum line, existing ground surface, and vertical profile of the proposed road and position of drainage crossings.

Detailed cross sections are generally drawn to natural scale of 1 cm 2.0 to 2.5 m. Cross section should be drawn every 100 m or where there are abrupt changes in level. In hill roads the cross sections should be drawn at closer intervals. The cross section drawings should extend at least up to the proposed right of way. The cross section number, the reduced distances and the area of filling and/or cutting should be shown on cross section drawings.

Land acquisition plans and schedules are usually prepared from the drawings for land acquisition details. These plans show all general details such as buildings, wells, nature of gradients and other details required for assessing the values.

The scale adopted may be 1 cm =40 m or less.

Detailed design for cross drainage and masonry structures are usually drawn to scale of 1 cm =1 m. For details of any complicated portion of the structure enlarged scales up to 8 cm= 1 m or up to half full size may be employed. However the size of drawing should not exceed the standard size. Cross sections of streams should be to a scale of not less than 1 cm=10 m.

Drawings of road intersections should be prepared showing all details of pavement, shoulders, islands etc. to scale.

Land plans for quarries: Where quarries for construction materials are to be acquired for new projects, separate land plans should be prepared. The size of these maps and scales may be similar to those suggested under land acquisition

Estimates

The project estimates should consist of general abstract of cost and detailed estimates for each major head. If the project work is proposed to be executed in stages, the estimate should be prepared for each stage separately,

PROJECT REPORT

The first phase of project report soon after completing the preliminary surveys, feasibility and EIA studies is to prepare a "Feasibility Report'.

The Detailed Project Report (DPR) should be prepared after completing all the detailed studies including final location survey, preparation of longitudinal and cross sections, soil and material surveys, drainage studies, etc. The design details of the pavements and all CD structures including major bridges should be carried out and the relevant drawings prepared as specified in the terms of reference for the project preparation.

NEW HIGHWAY PROJECT

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

1. Selection of route, finalization of highway alignment and geometric design Details.

2. Collection of materials and testing of subgrade soil and other construction materials, mix design of pavement materials and design details of pavement layers.

3. Construction stages including quality control

STEPS IN A NEW PROJECT WORK

The various steps in a new highway project may be summarised as given below:

i. Map Study: This is carried out with the help of available topographic maps of the area.

ii.Reconnaissance Survey: During reconnaissance 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.

iii.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. Typical plan, longitudinal section and cross section drawing for the new alignment are shown in Fig. below.

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

v.Detailed Survey: Survey of the highway construction work for the preparation of longitudinal and cross sections, computations of earth work quantities other construction material and checking details of geometric design elements.

vi.Materials Survey of construction materials, their collection and testing.

vii.Design details of embankment and cut slopes, foundation embankments and bridges, and pavement layers and cross drainage structures.

viii.Earth Work: Excavation for highway cutting and drainage system construction of embankments.

ix.Pavement Construction: Preparation of subgrade, construction of sub-base base and surface courses.

x.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 pavements at curves.

xi.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).

STEPS IN THE RE-ALIGNMENT PROJECT

i. Reconnaissance of the stretch of road to be realigned, study of the deficiencies and the possible changes in alignment.

ii.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. The width of the land to be surveyed depends on the amount of shifting anticipated when the road is realigned. The field work may be carried out using plane table and level or by tacheometry or by any of the modern methods.

iii.Observations of spot levels along the centre line of the road and cross section levels at suitable intervals to note the gradient, cross slope, super elevation etc. The cross section levels should be taken at closer intervals at horizontal and vertical curves and near cross drainage works .

iv.Soil survey along the stretches of land through which the realigned road may possibly pass; preparation of typical soil profiles after testing the soil samples in the laboratory.

v.Comparison of economics and considerations of feasibility of alternate proposals of re- alignment and special study of stretches which are difficult for the re-alignment.

vi.Finalisation of the design features of realigned road stretches.

vii.Preparation of drawings (Typical drawings showing plan, longitudinal section and cross section for a re-alignment project shown.

viii.Marking out the centre line of realigned road while trying to utilise the existing road to the maximum extent possible.

ix.Earth-work and preparation of subgrade of the re-alignment road stretches, setting out and construction of new bridges and culverts.

x.Checking the geometric design elements of the newly aligned stretches of the road.

xi.Design and construction of the new highway pavements

MODULE-2

Highway Geometric Design of horizontal alignment elements: Cross sectional elements-width, surface, camber, Sight distances-SSD,OSD,ISD,HSD, Radius of curve, Transistion curve, Design of Horizontal and Vertical alignment-curves, Super-elevation, widening, gradients,Summit and Valley Curves.

INTRODUCTION

Highway Geometric: This is the branch of the highway engineering which deals with the geometrical elements of the roads like, land of width, formation width, carriage way, side slopes, shoulders, kerbs, sigh distance, super elevation and highway curves.

Importance of geometric design

- The geometric design of a highway deals with the dimensions and layout of visible features of the highway such as alignment, sight distance and intersection.
- The main objective of highway design is to provide optimum efficiency in traffic operation with maximum safety at reasonable cost

Geometric design of highways deals with following elements:

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

Design Controls and criteria

The geometric design of Highways depends on several design factors. The important of these factors which control the geometric elements are;

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

1. Design speed

- In India different speed standards have been assigned for different class of road
- Design speed may be modified depending upon the terrain conditions

2. Topography

Classified based on the general slope of the country.

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

3. Traffic factor

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

4. Design hourly volume and capacity

- Traffic flow fluctuating with time
- Low value during off-peak hours to the highest value during the peak hour.
- It is uneconomical to design the roadway for peak traffic flow.

5. Environmental factor

- Aesthetics
- Landscaping
- Air pollution
- Noise pollution

Highway Cross Section Elements

Overview

The features of the cross-section of the pavement influence the life of the pavement as well as the riding comfort and safety. Of these, pavement surface characteristics affect both of these. Camber, kerbs, and geometry of various cross-sectional elements are important aspects to be considered in this regard. They are explained briefly in this chapter.

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:

1. Surface protection especially for gravel and bituminous roads

2. Sub-grade protection by proper drainage

3. Quick drying of pavement which in turn increases safety

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface. The values suggested by IRC for various categories of pavement is given in Table 1. The common types of camber are parabolic, straight, or combination of them (Figure 1)

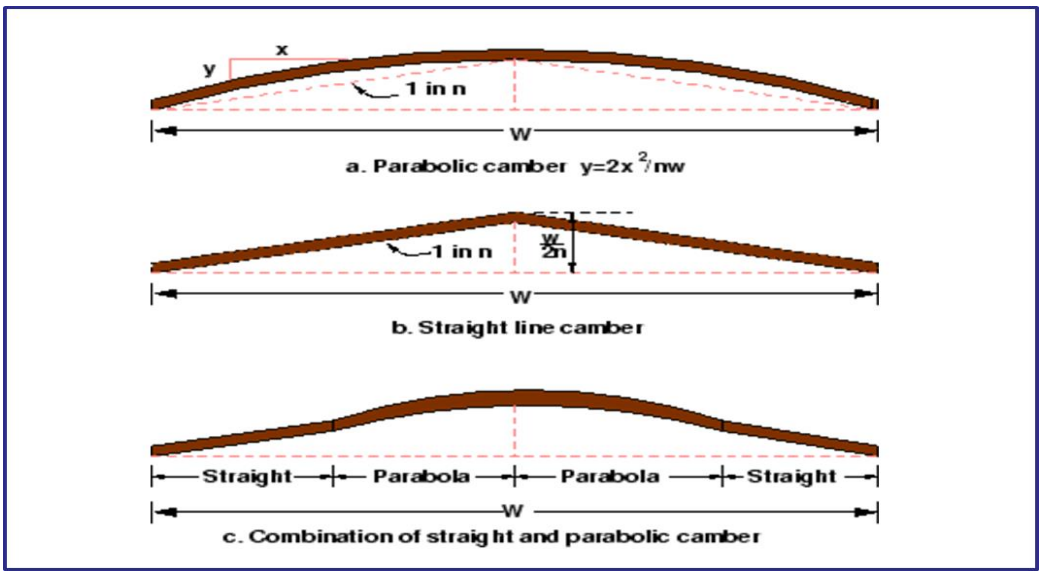


Figure 1: Different types of camber

Recommended Values Of Camber For Different Types Of Road Surface

Sl No.	Type Of Road Surface	Range Of Camber In Areas Of	
		Light	Heavy
1	Cement Concrete And High Type Bituminous Pavement	1.7 %	2%
2	Thin Bituminous Surface	2 %	2.5%
3	Water Bound Macadam(wbm) And Gravel Pavement	2.5 %	3%
4	Earth	3 %	4%

Width of carriage way

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes.

Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This require minimum of lane width

of 3.75 m for a single lane road (Figure 1a). However, the side clearance required is about 0.53 m, on either side or 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane (Figure 1b). The desirable carriage way width recommended by IRC is given in Table 2

	WIDTH OF CARRIAGEWAY RECOMMENDED BY IRC	
SL. NO.	**Class of road**	**Width of carriageway in 'm'**
1	Single lane road	3.75
2	Two lane without raised kerbs	7.0
3	Two lane with raised kerbs	7.5
4	Intermediate lane	5.5
5	Multilane pavement	3.5/lane

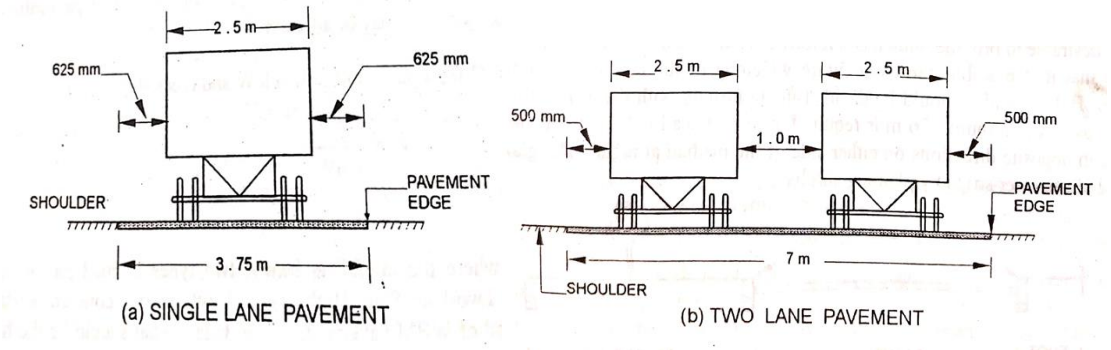


Figure 1: Lane width for single and two lane roads

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are (Figure 1):

Low or mountable kerbs: This type of kerbs is provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.

Semi-barrier type kerbs: When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm 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

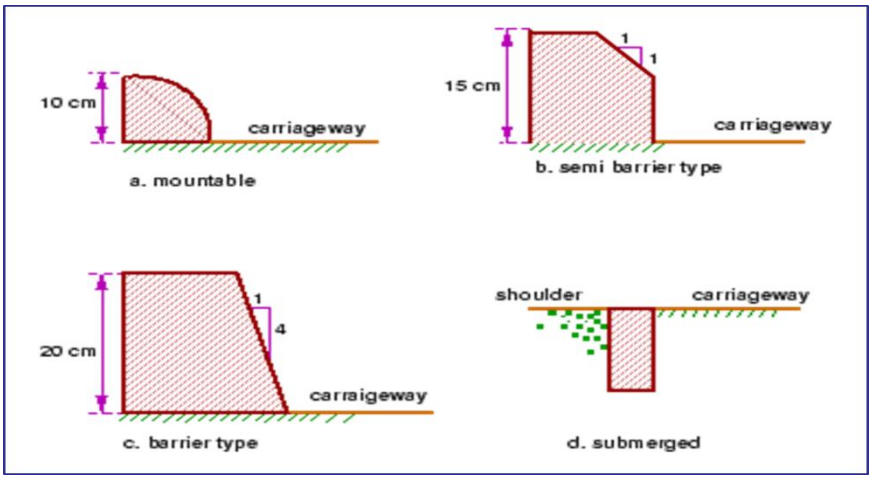


Figure 1: Different types of kerbs

Shoulders

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. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane rural highways in India.

Parking lanes

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

Bus-bays

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

Service roads

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

access to the highway will be provided only at selected points. These roads are provided to avoid congestion in the expressways and also the speed of the traffic in those lanes is not reduced.

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.

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 more smoother than that to induce the pedestrian to use the footpath.

Right of way

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

Width of formation:

It depends on the category of the highway and width of roadway and road margins.

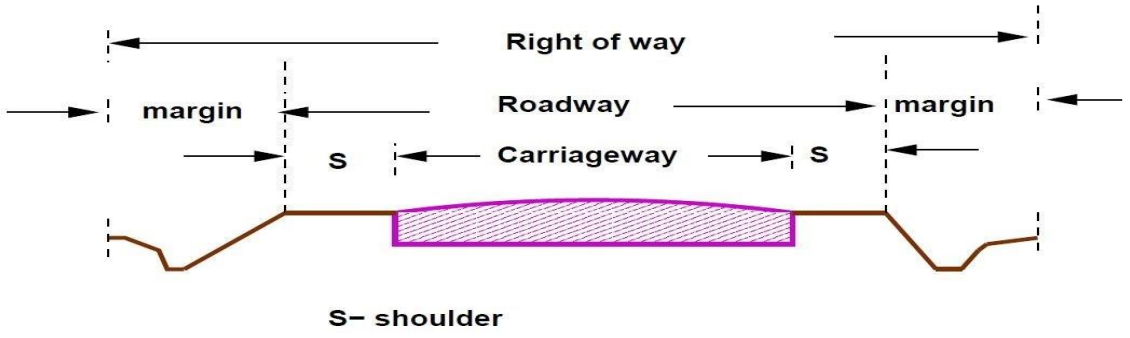
• Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.

• 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: Some land has to be acquired in advance anticipating future developments like widening of the road.



A typical Right of way (ROW)

The importance of reserved land is emphasized by the following. Extra width of land is available for the construction of roadside facilities. Land acquisition is not possible later, because the land may be occupied for various other purposes (buildings, business etc.) The normal ROW requirements for built up and open areas as specified by IRC is given in Table 1 A typical cross section of a ROW is given in Figure 1.

SIGHT DISTANCE

• Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway has visibility of stationary or moving objects.

• It is the length of road visible ahead to the driver at any instance

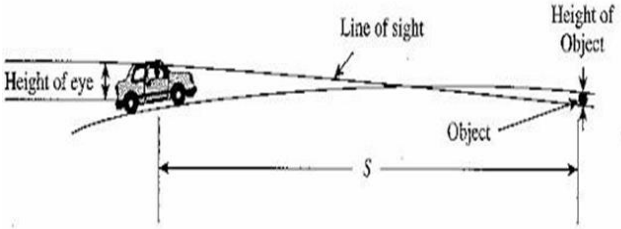
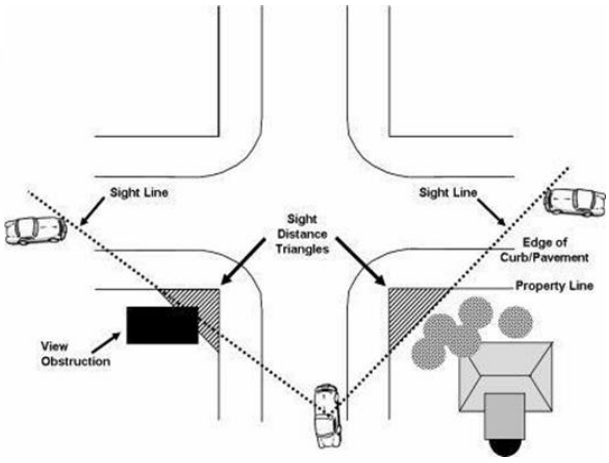


FIGURE 4.8
Stopping sight distance diagram for crest vertical curve.



Types of sight distance:

1. Stopping or absolute minimum sight distance (SSD)

2. Safe overtaking or passing sight distance (OSD)

3. Intermediate sight distance (ISD)

4. Head light sight distance (HSD)

1. Stopping sight distance

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

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

3. Intermediate sight distance

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

4. Head light sight distance:

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

STOPPING SIGHT DISTANCE

SSD is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction.

It depends on:

• Feature of road ahead

• Height of driver's eye above the road surface(1.2m)

• Height of the object above the road surface(0.15m)

Criteria for measurement

• Height of driver's eye above road surface (H)

• Height of object above road surface (h)

Factors affecting the SSD

• Total reaction time of driver

• Speed of vehicle

• Efficiency of brakes

• Frictional resistance between road and tyre

• Gradient of road

Total reaction time of driver:

• It is the time taken from the instant the object is visible to the driver to the instant the brake is effectively applied, it divide into types

1. Perception time

2. Brake reaction time

Perception time:

• 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.

Break reaction time:

• The brake reaction also depends on several factor including the skill of the driver, the type of the problems and various other environment factor.

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

Analysis of SSD

• The stopping sight distance is the sum of lag distance and the braking distance.

Lag distance:

• It is the distance, the vehicle traveled during the reaction time

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

lag distance = v.t metres. Where "v" in m/sec t=2. 5 sec

Lag distance= 0.278 V.t meters Where "v" in Kmph,

T= time in sec=2.5 sec

Braking distance:

• It is the distance traveled by the vehicle after the application of brake. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.

• Work done against friction force in stopping the vehicle is F x l = f W l, where W is the total weight of the vehicle.

The kinetic energy at the design speed of v m/sec will be ½ m. v^2

Braking distance= $v^2/2gf$

SSD= lag distance + braking distance

SSD=0.278V.t + $v^2/254f$

Table 2.6: Coefficient of longitudinal friction

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

- Two-way traffic single lane road: SSD=2*SSD
- In one-way traffic with single or more lane or two- way traffic with more than single lane: Minimum SSD= SSD

Example-1

• Calculate the safe stopping sight distance for design speed of 50kmph for(a) two-way traffic on two lane road (b)two-way traffic on single lane road

Example-2

• Calculate the minimum sight distance required to avoid a head on collision of two cars approaching from opposite direction at 90 and 60kmph.coefficient friction of 0.7 and a brake efficiency of 50%, in either case

Example-3

• Calculate the stopping sight distance on a highway at a descending gradient of 2% for design speed of 80 kmph, assume other data as per IRC specification.

OVERTAKING SIGHT DISTANCE

- The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as overtaking sight distance (OSD)
- The overtaking sight distance or OSD is the distance measured along the centre of the road which a driver with his eye level 1.2 m above the road surface can see the top of an object 1.2 m above the road surface.

Factors affecting the OSD

- speeds of
  - overtaking vehicle
  - overtaken vehicle
  - the vehicle coming from opposite direction, if any.
- Distance between the overtaking and overtaken vehicles.
- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

Analysis of OSD

- d1 is the distance traveled by overtaking vehicle "A" during the reaction time t sec of the driver from position A1 to A2.
- d2 is the distance traveled by the vehicle A from A2 to A3 during the actual overtaking operation, in time T sec.
- d3 is the distance traveled by on-coming vehicle C from C1 to C2 during the over taking operation of A, i.e. T sec.
- B is the overtaken or slow moving vehicle.
- B is the overtaken or slow moving vehicle moving with uniform speed Vb m/sec or Vb Kmph;
- C is a vehicle coming from opposite direction at the design speed V m/sec or V kmph
- The distance traveled by the vehicle A during this reaction time is d1 and is between the positions A1 and A2. this distance will be equal to Vb.t meter
- Where t is the reaction time of the driver in second= 2 sec.

OSD = d1+ d2+ d3

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

S = SPACING OF VEHICLES = (0.2 V b+ 6)

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

If the speed of the overtaken vehicle is not given

Vb= (V-16) kmph, where V= speed of overtaking vehicle in kmph

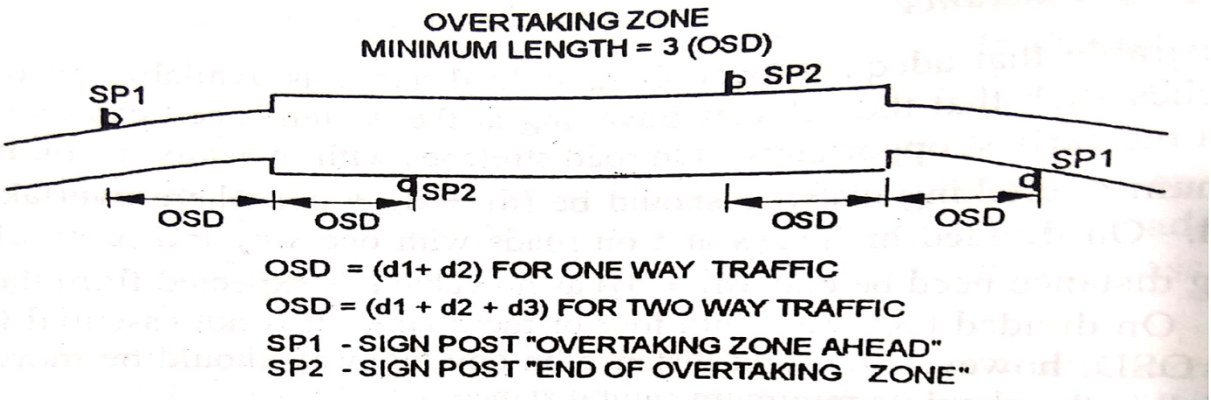
Note: The minimum overtaking sight distance = d1+d2+d3 for two-way traffic.

On divide highways and on roads with one way traffic regulation, the overtaking distance = d1+d2 as no vehicle is expected from the opposite direction

Overtaking Zones

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

- The minimum length of overtaking zone should be three time the safe overtaking distance i.e., 3 (d1+d2) for one- way roads and 3(d1+d2+d3) for two-way roads.
- Desirable length of overtaking zones is kept five times the overtaking sight distance. i.e., 5(d1+d2) for one-way roads and 5(d1+d2+d3) for two-way roads.



Example 1

The speed of the overtaking and overtaken vehicle are 70 and 40 kmph, respectively on a two way traffic road. If the acceleration of overtaking vehicle is 0.99 m/sec^2,

a) Calculate safe overtaking sight distance

b) Calculate the minimum and desirable length of overtaking zone

c) Draw the neat-sketch of the overtaking zone and show the position of the sign post.

DESIGN OF HORIZONTAL ALIGNMENT

Overview

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. These will be discussed in this chapter and the following two chapters.

Design Speed

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

The design speed also depends on the type of terrain. A plain terrain can afford to have any geometry, but for the same standard in a hilly terrain requires substantial cutting and filling implying exorbitant costs as well as safety concern due to unstable slopes.Therefore, the design speed is normally reduced for terrains with steep slopes.

For instance, Indian Road Congress (IRC) has classified the terrains into four categories, namely plain, rolling, mountainous, and steep based on the cross slope as given in table 1. Based on the type of road and type of terrain the design speed varies. The IRC has suggested desirable or ruling speed as well as minimum suggested design speed and is tabulated in table 2.

Table:1 Terrain Classification	
Terrain classification	Cross slope (%)
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	>60

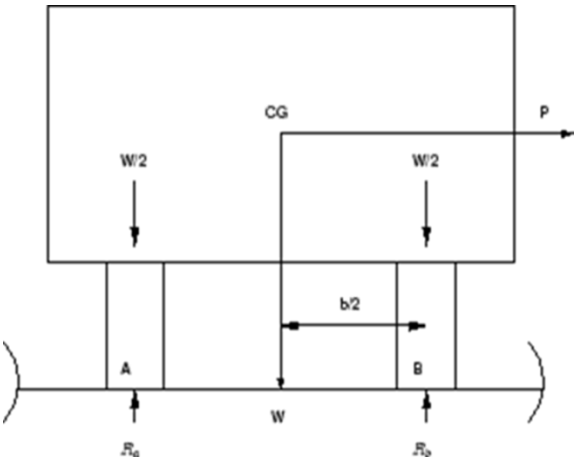
Recommended design speed is given in Table 2

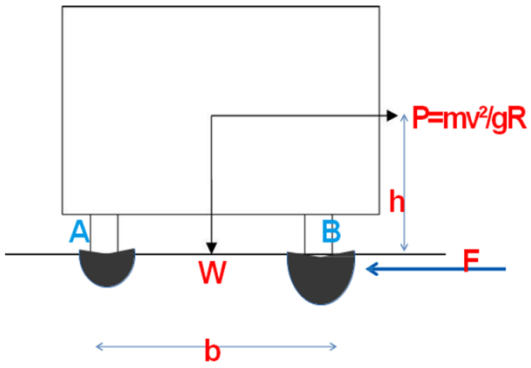
Table 2: Design speed in Kmph as per IRC (ruling and minimum				
Type	Plain	Rolling	Hilly	Steep
NS&SH	100-80	80-65	50-40	40-30
MDR	80-65	65-50	40-30	30-20
ODR	65-50	50-40	30-25	25-20
VR	50-40	40-35	25-20	25-20

Horizontal curve

A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road. The presence of horizontal curve imparts centrifugal force which is reactive force acting outward on a vehicle negotiating it. Centrifugal force depends on speed and radius of the horizontal curve and is counteracted to a certain extent by transverse friction between the tyre and pavement surface. On a curved road, this force tends to cause the vehicle to overtrun or to

slide outward from the centre of road curvature. For proper design of the curve, an understanding of the forces acting on a vehicle taking a horizontal curve is necessary. Various forces acting on the vehicle are illustrated in the figure below.





Various forces acting on the vehicle

• Centrifugal force (P) acting outward,

• Weight of the vehicle (W) acting downward,

• and the reaction of the ground on the wheels (RA and RB).

• The centrifugal force and the weight is assumed to be from the centre of gravity which is at h units above the ground. Let the wheel base be assumed as b units.

• The centrifugal force P in Kg/m^2 is given by

$$P=Wv^2/gR$$

Where,

P = centrifuge force, kg

W = weight of the vehicle, kg

R = radius of the circular curve, m

v = speed of vehicle, m/sec

g = acceleration due to gravity = 9.8 m/sec

- P/W is known as the centrifugal ratio or the impact factor. The centrifugal ratio is thus equal to v^2/gR i.e., $P/W = v^2/gR$----------eq 1
- The centrifugal force acting on a vehicle negotiating a horizontal curve has two effects

    1. Tendency to overturn the vehicle outwards about the outer wheels

    2. Tendency to skid the vehicle laterally, outwards

Analysis of stability of horizontal curves (without super elevation) against overturning and skidding

Overturning effect

Let h- height of COG of veh above road surface , b- width of wheel base of veh.

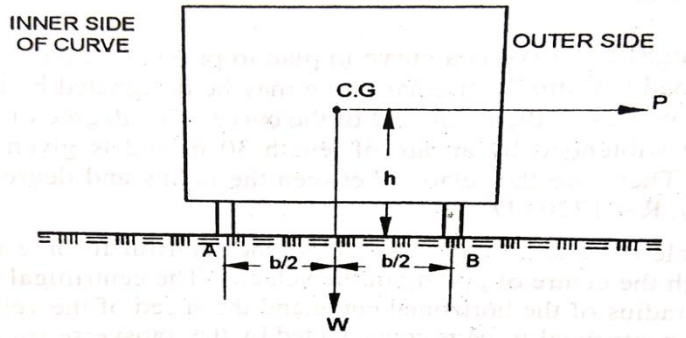
Taking moments of the forces with respect to the outer wheel when the vehicle is just about to ride,

Ph=$\boldsymbol{Wb/2}$ or $\boldsymbol{PW=b/2h}$

p.h= overturning moment

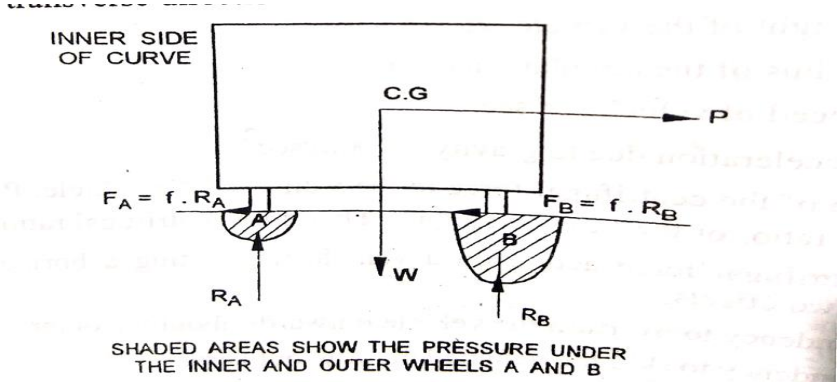
Wb/2 = restoring moment due to weight of vehicle.

The equilibrium condition for overturning will occur when Ph = Wb/2, or when P/W = b/2h. This means that there is danger of overturning when the centrifugal ratio P/W or v^2/gR attains a value of b/2h.



and for safety the following condition must satisfy: $\boldsymbol{b/2h > v^2/gR}$

Transverse skidding effect



This occurs when the centrifugal force P is greater than the maximum possible transverse skid resistance due to friction between the pavement surface and tyre. The transverse skid resistance (F) is given by:

$$F = FA + FB$$

$$= f(RA + RB)$$

$$= fW$$

Where FA and FB is the fractional force at tyre A and B ,

RA and RB is the reaction at tyre A and B ,

f is the lateral coefficient of friction and

W is the weight of the vehicle.

This is counteracted by the centrifugal force (P), and equating**:** $\mathbf{P = fW}$ or $\boldsymbol{PW = f}$

At equilibrium, when skidding takes place (from equation1) $\boldsymbol{PW = f = v^2/gR}$

and for safety the following condition must satisfy:

$\boldsymbol{f > v^2/gR}$ --------Eq 3

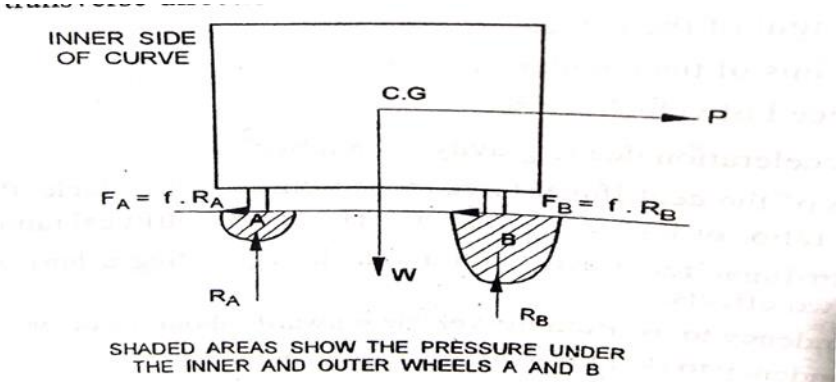
Equation 2 and 3 give the stable condition for design. If equation 2 is violated, the vehicle will overturn at the horizontal curve and if equation 3 is violated, the vehicle will skid at the horizontal curve.

- Thus, to avoid both overturning and lateral skidding on a horizontal curve, the centrifugal ratio (P/W) should be less than (b/2h) and also transverse friction coefficient f.
- If f < (b/2h) , then skidding occur first not overturn .

- If f > (b/2h) , then over turning occur first before skidding.

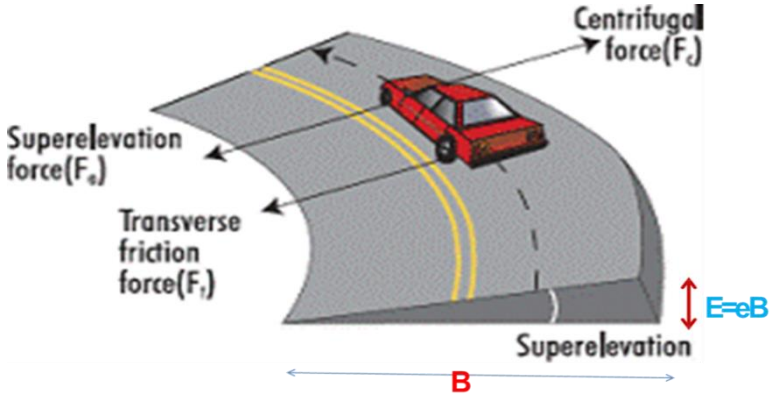
Thus lateral skidding and overturning depends on whether f is lower or higher than(b/2h) .

- At the horizontal curve, if the pavement is kept horizontal across the alignment, the pressure on the outer wheels will be higher due to the centrifugal force acting outwards and hence the reaction *RB* at the outer wheel would be higher.
- The difference in pressure distribution at inner and outer wheel would be as shown in fig.
- When the limiting equilibrium condition for overturning occurs the pressure at the inner wheels becomes equal to zero.



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.
- When the outer edge is raised, a component of the curve weight will be complimented in counteracting the effect of centrifugal force. In order to find out how much this raising should be, the following analysis may be done.
- The forces acting on a vehicle while taking a horizontal curve with super elevation is shown in figure below;



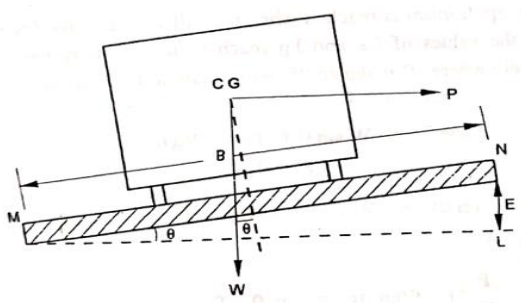


Fig. 4.20 Superelevated pavement section

- The rate of super elevation, 'e' is expressed as the ratio of the height of outer edge with respect to the horizontal width, e=NL/ML= tanθ, θ is very small and value of tanθ seldom exceeds 0.07.
- Therefore, tanθ = sinθ. Hence, e= tanθ ≈ sinθ = , ratio of elevation of outer edge E to the width of pavement B.
- If e is the super elevation rate and E is the total super elevated height of outer edge, the total rise in outer edge of the pavement with respect to the inner edge= NL =E = e B.

Analysis of Super Elevation

The Forces acting on a vehicle on horizontal curve of radius 'R' m at a speed of 'V' $msec/$ are:

1. 'P' the centrifugal force acting horizontally out-wards through the center of gravity,

2. 'W' the weight of the vehicle acting down-wards through the center of gravity, and

3. 'F' the friction force between the wheels and the pavement, along the surface inward.

The centrifugal force developed is opposed by;

1. Friction developed b/w tyres and pavement surface

2. A component of the force of gravity due to the super elevation produced.

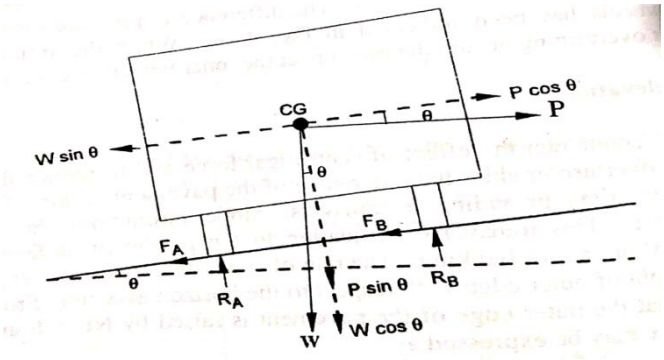


Fig. 4.21 Analysis of superelevation

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

Pcosθ = W sinθ + FA +FB

= W sinθ +f(RA + RB)

= W sinθ +f(W cosθ + P sinθ)

i.e., P(cosθ - f sinθ) = W sinθ +fW cosθ

Dividing by Wcosθ, we get:
$Pcos\theta/Wcos\theta=Wsin\theta/Wcos\theta+fWcos\theta/Wcos\theta+fPsin\theta/Wcos\theta$

$P/W=tan\theta+f+fPW/tan\theta$

$P/$w (1$-tan\theta$)=$tan\theta+f$

$\boldsymbol{P/W=tan\theta+f/1-ftan\theta}$

$\boldsymbol{v^2/gR=tan\theta+f/1-ftan\theta}$

- But normally, f=0.15 and θ<4° , 1-tanθ ≈ 1 and for small θ, therefore ftan θ will be very small and can be neglected , tanθ ≈ sinθ =e= EB then equation 2 becomes,

$v^2/gR=e+f$ -----here v is in m/s.---------(3)

Or $V^2/127R=e+f$---- here V is in kmph

(Counteracting centrifugal force by providing both e and f)

Where

W is the weight of the vehicle,

P is the centrifugal force,

f is the coefficient of friction,

θ is the transverse slope due to super elevation.

'e' is the rate of super elevation= tanθ

f the coefficient of lateral friction =0.15 ,

v the speed of the vehicle in m/s and

R the radius of the curve in m and g= 9.8 m/sec^2

The max value of 'e' is 7% or 1 in 15 for plain and rolling terrain

- The max value of 'e' is 10% or I in 10 for hilly and steeper terrain.
- In urban roads with frequent intersections, 4% of super elevation is provided.

Three specific cases that can arise from equation 3 are as follows:

1. If there is no friction due to some practical reasons, then f=0 and equation (3) becomes $\mathbf{v^2/gR=e}$

This result in the situation where the pressure on the outer and inner wheels are same; requiring very high super-elevation 'e'.

2. If there is no super-elevation provided due to some practical reasons, then e=0 , and equation 3 becomes , $\mathbf{v^2/gR=f}$. This results in a very high coefficient of friction.

3. If e=0 and f= 0.15 then for safe traveling speed from equation 3 is given by $\boldsymbol{vb=\sqrt{fgR}}$

Where $\boldsymbol{vb}$ is the restricted speed.

Equilibrium Super elevation

If f=0 , then the super elevation is known as equilibrium super elevation

e=$V2gR$ or e=$V2127R$ (counteracting of centrifugal force only by ' e') . When we provide equilibrium super elevation the outer and inner wheels of vehicle will be under equal pressure so it is called equilibrium super elevation.

Super elevation for mixed traffic

Only 75% of the design speed is considered in the equilibrium super elevation

e=$\boldsymbol{V^2/127R}$ = $\boldsymbol{(0.75V)^2/127R}$ = $\mathbf{V^2/225\ R}$

From practical consideration, Super elevation should be provided to fully counteract the centrifugal force due to 75% of the design speed. Hence in the design of 'e' value, use this formula (a) always.

Maximum Super elevation

- In the case of heavily loaded bullock carts and trucks 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 a high rate of Super elevation. Because of the slow speed, the centrifugal force will be negligibly small in the case of bullock carts. Hence to avoid the danger of toppling of such loaded slow moving vehicles, it is essential to limit the value of maximum allowable Super elevation.
- Indian Roads Congress had fixed the maximum limit of Super elevation in plan and rolling terrains and in snow bound areas as 7.0 % or 1 in 15.
- On hilly and steeper terrains not bound by snow a maximum Superelevation upto 10% or 1 in 10 .
- On urban road stretches with frequent intersections, it may be necessary to limit the maximum Super elevation to 4.0 %.

Minimum Super elevation

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

Design of super-elevation

- For fast moving vehicles, providing higher super elevation without considering coefficient of friction is safe, i.e. centrifugal force is fully counteracted by the weight of the vehicle or super elevation.
- For slow moving vehicles, providing lower super elevation considering coefficient of friction is safe, i.e. centrifugal force is counteracted by super elevation and coefficient of friction.

IRC suggests following design procedure:

1. Calculate e = $\mathbf{V^2/2}$, if e< e_{max} . Obtained value is provided.

2. If e > e_{max} , calculate the co efficient of lateral friction as follows;

f=$V^2/127R-$. i.e., f=$V^2/127R-0.07$

3. If f≤ 0.15 then ok.

4. If f >0.15 reduce/ restrict the speed as follows;

5. Find the allowable speed va for the maximum e=0.07 and f=0.15, then

0.07+0.15= Va^2/gR

0.07+0.15 = $V/127R$

va=$\sqrt{0.22gR}$

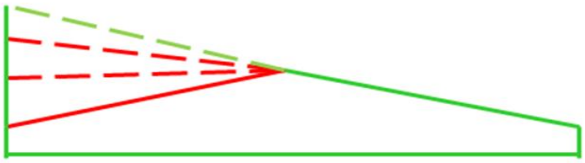
6. If allowable speed > design speed, then design is adequate.

7. If allowable speed < design speed , then speed is limited to allowable speed Va kmph as calculated above.

Attainment of super-elevation:

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

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



Disadvantages

• Small length of road – cross slope less than camber

• Drainage problem in outer half

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

Disadvantages

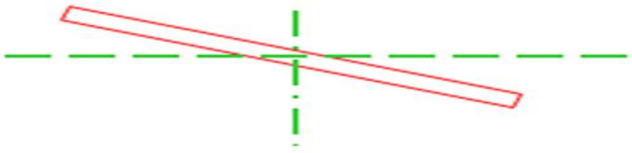
• Large negative super elevation on outer half

• Drivers have the tendency to run the vehicle along shifted crown

2. By Rotation of the pavement cross section to attain full super elevation:

There are two methods of attaining super elevation by rotating the pavement

Rotation about the center line: The pavement is rotated such that the inner edge is depressed and the outer edge is raised both by half the total amount $e/2$ of super elevation, i.e., by with respect to the centre.



Advantages

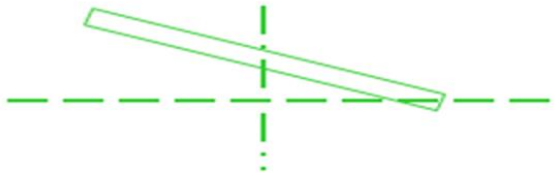
• Earthwork is balanced

• Vertical profile of the C/L remains unchanged

Disadvantages

• Drainage problem: depressing the inner edge below the general level

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



Advantages

• No drainage problem

Disadvantages

• Additional earth filling

• C/L of the pavement is also raised (vertical alignment of the road is changed)

Example 1:

The radius of horizontal circular curve is 100m. The design speed is 50kmph and the design coefficient of lateral friction is 0.15.

a. Calculate the super elevation required if full lateral friction is assumed to develop

b. Calculate the coefficient of friction needed if no super elevation is provided.

c. Calculate the equilibrium super elevation if the pressure on inner and outer wheels should be equal.

Example 2:

A two lane road with design speed 80kmph has horizontal curve of radius 480m. Design the rate of super elevation for mixed traffic. By how much should the outer edges of the pavement be raised with respect to the center line, if the pavement is rotated with respect to the center line?

Example 3:

Design the super elevation for a horizontal highway curve of radius 500m and speed 100kmph.

Example 4:

The design speed of highway is 80kmph. There is horizontal curve of radius 200m on a certain locality. Calculate the super elevation needed to maintain this speed.

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 $Rruling$can be derived by assuming maximum super elevation and coefficient of friction.

$$R_{ruling}=V^2/127(e+f)$$

- Ideally, the radius of the curve should be higher than $Rruling$. However, very large curves are also not desirable. Setting out large curves in the field becomes difficult. In addition, it also enhances driving strain.
- According to the earlier specifications of the IRC, the ruling minimum radius of the horizontal curve was calculated from a speed value, 16 kmph higher than the design speed i,e., (V+16) kmph.

Example 1:

- Calculate the values of ruling minimum and absolute minimum radius of horizontal curve of a national highway in plane terrain. Assume ruling design speed and minimum design speed values as 100 and 80 kmph respectively.

Extra widening

- Extra widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment.
- On horizontal corves, especially when they are not of very large radii, it is common to widen the pavement slightly more than the normal width,

Widening is needed for the following reasons:

1. The driver experience difficulties in steering around the curve.

2. The vehicle occupies a greater width as the rear wheel don't track the front wheel. known as 'Off tracking'

3. For greater visibility at curve, the driver have tendency not to follow the central path of the lane, but to use the outer side at the beginning of the curve.

4. While two vehicle cross or overtake at horizontal curve there is psychological tendency to maintain a greater clearance between the vehicle for safety.

This widening is made mainly for these two reasons:

- the first and most important is the additional width required for a vehicle taking a horizontal curve and
- the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.
- The first is referred as the mechanical widening and the second is called the psychological widening. These are discussed in detail below.

Off tracking

- An automobile has a rigid wheel base and only the front wheels can be turned, when this vehicle takes a turn to negotiate a horizontal curve, the rear wheel do not follow the same path as that of the front wheels. This phenomenon is called off tracking.

- The required extra widening of the pavement at the horizontal curves depends on the length of the wheel base of the vehicle 'l', radius of the curve 'R' and the psychological factors.

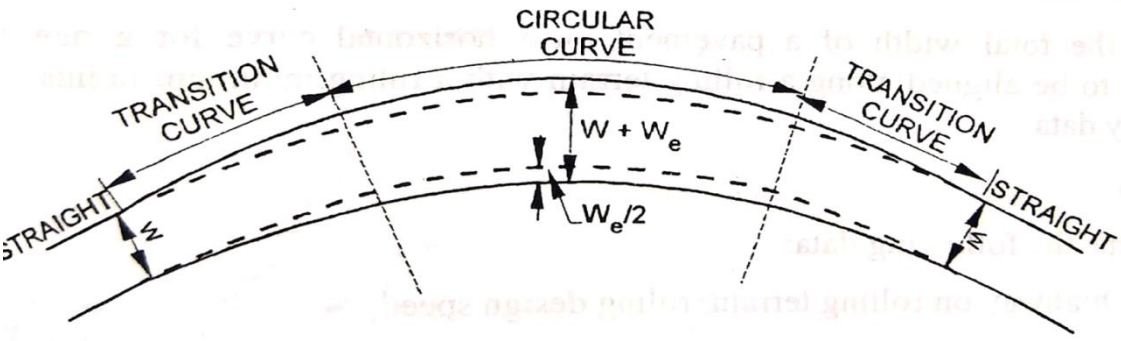


Fig. 4.26 Extra widening of pavement on horizontal curve

Analysis of extra widening on curves

It is divided into two parts;

- **Mechanical widening (Wm):** the widening required to account for the off tracking due to the rigidity of wheel base is called mechanical widening
- **Psychological widening (Wps):** extra width of the pavement is also provided for psychological reasons such as , to provide for greater maneuverability of steering at high speed, to allow for the extra space for overhangs of vehicles and to provide greater clearance for crossing and overturning vehicles on curve. Total widening $\boldsymbol{We=Wm+Wps}$

Total extra widening = Mechanical widening +Psychological Widening

$Wm = nl^2/2R$

$l^2/2R$= off tracking distance

n=no. of traffic lanes

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

R = Mean radius of the curve in m,

Wps = driver tendency= $\mathbf{V/9.5\sqrt{R}}$

V= speed in kmph

R= radius of curve in m.

Total extra widening = Mechanical widening +Psychological Widening $\mathbf{We=nl^2/2R+ V/9.5\sqrt{R}}$

- Extra widening is recommended only when the radius of the curve is small(<300m) .
- For curves of radius < 50m (sharp curves) total extra widening is provided at the inner side of the curve.
- For other curves, both on outer and inner side of the curve provided equally of We/2.
- For curves with R > 300m , no need to provide extra widening.

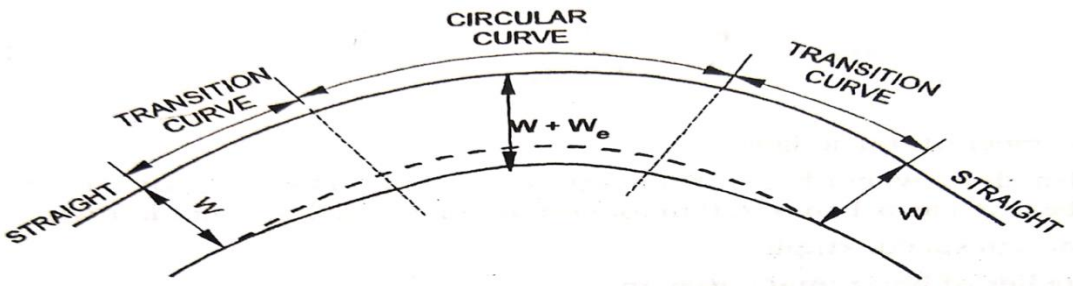


Fig. 4.27 Widening of pavement on sharp curve

Set-back distance on horizontal curves

In design of Horizontal alignment, the SD along the inner side of the horizontal curves should be considered. Presence of obstructions limits this SD on the inner side of curve. It is necessary to provide sufficient clearance or 'Set back distance' on the inner side.Prohibit any structure in future which obstruct the sight line and decrease the SD .

Defn- it is the distance required from the centerline of the horizontal curve to an obstruction on the inner side of the curve to provide an adequate sight distance at the horizontal curve.

The 'Set back Distance ' or 'clearance' reqd from the centre line of a horizontal curve to an obstruction on the inner side of the curve to provide adequate SD depends upon the following factors:

1. required sight distance, S

2. radius of horizontal curve, R

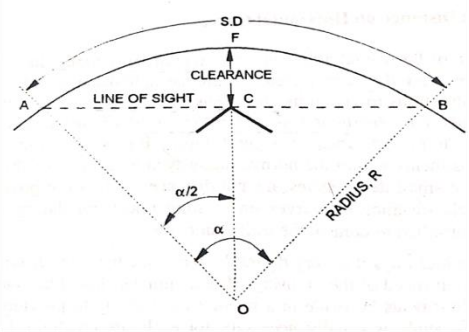
3. length of the curve, L_c which may be greater or lesser than S.

Let C be the obstruction to vision on the inner side of a horizontal curve of radius R, length of the curve is denoted by L_c.

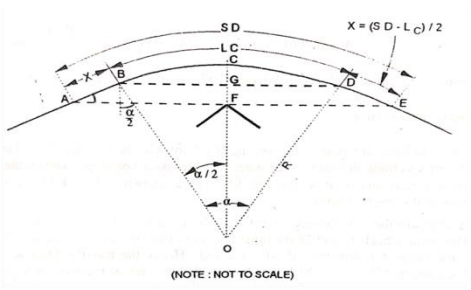
The two conditions considered are,

1. When length of the curve is greater than SD (L_c>S)(S may be SSD or OSD)

2. When length of the curve is lesser than SD (L_c <S) (S may be SSD or OSD)



Clearance or setback distance when length of curve is greater than SD



Clearance or setback distance when length of curve is less than SD

Set back distance can be computed by using

1. Approximate formulas

2. Rational formulas

1.By using approximate formulas(for Single lane roads)

case(i) when (L_c>S)(S may be SSD or OSD)

$$\mathbf{m= \frac{S^2}{8R}}$$

Case(ii) when (L_c <S) (S may be SSD or OSD)

$$\mathbf{m= \frac{L_c(2S-L_c)}{8R}}$$

2.By using rational formulas (for Single lane roads)

case(i) when (L_c>S)(S may be SSD or OSD)

$$\mathbf{m= R\ -Rcos(\frac{\propto}{2})}\text{----------where } \frac{\propto}{2}= \frac{180S}{2\pi R}$$

Case(ii) when (L_c <S) (S may be SSD or OSD)

$$\mathbf{m= R - Rcos(\frac{\propto}{2}) + \frac{S-L_c}{2} sin(\frac{\propto}{2})} \text{ ----------where } \mathbf{\frac{\propto}{2}= \frac{180L_c}{2\pi R}}$$

For multilane roads

1. Approximate formula is not possible

2. By using rational formulas

case(i) when (L_c>S)(S may be SSD or OSD)

$m= R - (R - d)\cos(\frac{\propto}{2})$----------where $\frac{\propto}{2}= \frac{180S}{2\pi(R-d)}$

Case(ii) when (L_c <S) (S may be SSD or OSD)

$m= R - (R - d)cos(\frac{\propto}{2}) + (\frac{S-L_c}{2}) \sin(\frac{\propto}{2})$---------- where $\frac{\propto}{2}= \frac{180L_c}{2\pi(R-d)}$

d= distance required from the centre line of the curve/ road to the centreline of the inner lane .

- In problems if length of curve is not given then assume as case(i) always.
- If number of lane is mentioned then go for rational formula method , if not go for approximate formula method

Curve resistance:

It is defined as the loss of tractive force(engine force) due to turning of a vehicle on a horizontal curve .

CR= T -Tcos∝

Where T= tractive force

∝= turning angle.

VERTICAL ALIGNMENT

Natural ground may not be level at some places have slopes of diff magnitudes. The vertical alignment is the elevation or profile of the centre line of the road

The vertical alignment of a road consists of gradients(straight lines in a vertical plane) and vertical curves.

- The vertical alignment influences
- Vehicle speed
- Acceleration and deceleration
- Stopping distance and sight distance
- Comfort while travelling at high speeds

Vertical curves connect two different gradients or slopes.

Vertical curves are the curves used in a vertical plane to provide a smooth transition between the grade lines of highways and railroads.

Just as a circular curve is used to connect horizontal straight stretches of road, vertical curves connect two gradients.

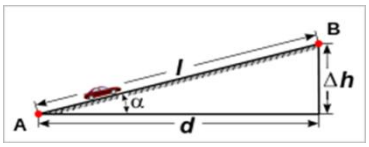
Basic components of vertical alignment

The two basic elements of vertical alignment are Grades and Vertical Curves.

- Grade
- Vertical Curves

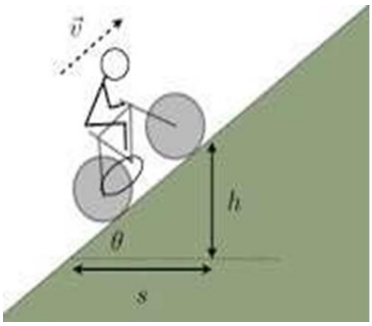
GRADE

The grade of a highway is a measure of its incline or slope. The amount of grade indicates how much the highway is inclined from the horizontal. For example, if a section of road is perfectly flat and level, then its grade along that section is zero. However, if the section is very steep, then the grade along that section will be expressed as a number, usually a percentage, such as 10 percent.



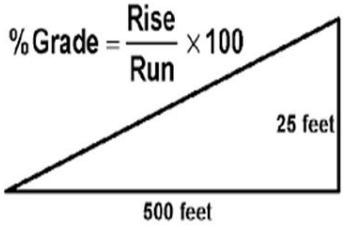
The illustration below shows a highway in profile (from the side). Notice that a right triangle has been constructed in the diagram.

The elevation, or height, of the highway increases in the sketch when moving from left to right. The bottom of the triangle is the horizontal distance this section of highway covers. This horizontal distance, sometimes called the "run" of the highway, indicates how far a vehicle would travel on the road if it were level. However, it is apparent that the road is not level but rises from left to right. This "rise" is a measure of how much higher a vehicle is after driving from left to right along the road.



$$\text{Grade} = \frac{\text{Rise}}{\text{Run}}$$

$$\%\,\text{Grade} = \frac{\text{Rise}}{\text{Run}} \times 100$$



To calculate the grade of a section of highway, divide the rise (height increase) by the run (horizontal distance). This equation, used to calculate the ratio of rise-to-run for highway grades, is the same ratio as the slope "y /x " encountered in a Cartesian coordinate system .

For example ,if the rise of the highway section is 100 feet, while the run is 1,000 feet. The resulting grade is thus 100 feet divided by 1,000 feet, or 0.1.

Highway grades are usually expressed as a percentage. Any number represented in decimal form can be converted to a percentage by multiplying that number by 100. Consequently, a highway grade of 0.1 is referred to as a "10 percent grade" because 0.1 times 100 equals 10 percent. The highway grade for a section of highway that has a rise of 1 kilometer and a run of 8 kilometers is ⅛, or 0.125. To convert the highway grade into a percentage, multiply 0.125 by 100, which results in a grade of 12.5 percent.

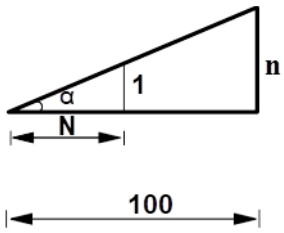
Gradient

- Longitudinal gradient or slopes on roads
- Gradient is the rate of rise or fall along the length of the road with respect to the horizontal

Representation of gradient

- The positive gradient or the ascending gradient is denoted as +n and the negative gradient as −n.
- The deviation angle N is: when two grades meet, the angle which measures the change of direction and is given by the algebraic difference between the two grades i.e., (n1 − (−n2)) = n1 + n2 = α1 + α2.

Example: 1 in 30 = 3.33% ≈ 2° is a steep gradient, while 1 in 50 = 2% ≈ 1 °10’ is a flatter gradient. The gradient representation is illustrated in the figure below



Types of gradient

Ruling gradient

- The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road.
- This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve.

- In flatter terrain, it may be possible to provide flat gradients, but in hilly terrain it is not economical and sometimes not possible also. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions.
- But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for the country as a whole. Hence IRC has recommended some values for ruling gradient for different types of terrain.

Limiting gradient

- This gradient is adopted when the ruling gradient results in enormous increase in cost of construction.
- On rolling terrain and hilly terrain it may be frequently necessary to adopt limiting gradient.
- But the length of the limiting gradient stretches should be limited and must be sandwiched by either straight roads or easier grades.

Exceptional gradient

- Exceptional gradient are very steeper gradients given at unavoidable situations.
- They should be limited for short stretches not exceeding about 100 metres at a stretch.
- In mountainous and steep terrain, successive exceptional gradients must be separated by a minimum 100 metre length gentler gradient. At hairpin bends, the gradient is restricted to 2.5%.

Critical length of the grade

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

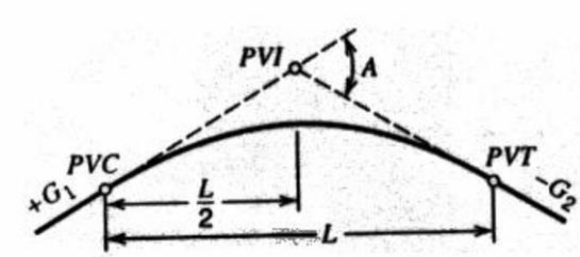
Minimum gradient

- This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage.
- But the longitudinal drainage along the side drains require some slope for smooth flow of water.
- Therefore minimum gradient is provided for drainage purpose and it depends on the rain fall, type of soil and other site conditions.
- A minimum of 1 in 500 may be sufficient for concrete drain and 1 in 200 for open soil drains are found to give satisfactory performance..

Vertical curves

- These are provided along the length of the road wherever there is a change of gradient.

- To smoothen out at the intersections of 2 diff grades and thus to ease off the changes in gradients for the fast moving vehicles.
- To provide a safe and comfort ride for vehicles on a roadway.



VPC: Vertical Point of Curvature

VPI: Vertical Point of Intersection

VPT: Vertical Point of Tangency

G1, G2: Tangent grades in percent

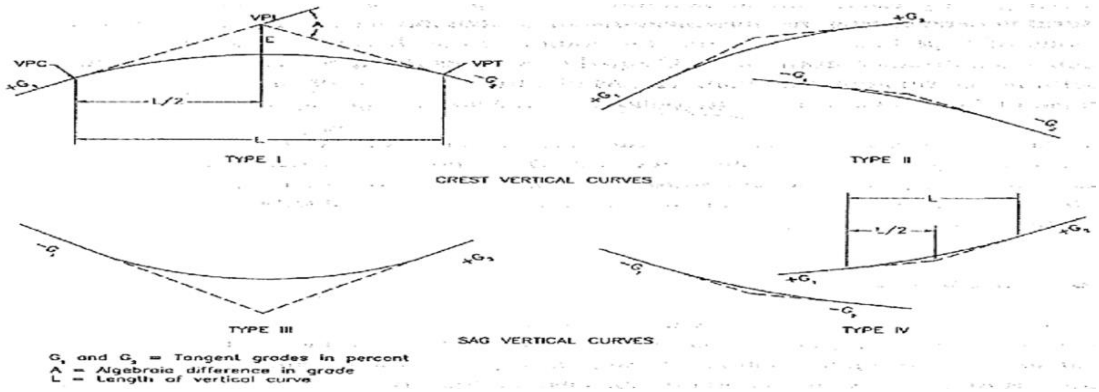
A or N: Algebraic difference in gradient

L: Length of vertical curve

Types of vertical curves

1.Summit curves or crest curves with convexity upwards: crest curves are used when the change in grade is negative, such as hills

2.Valley curves or sag curves with concavity upwards: Sag curves are used where the change in grade is positive, such as valleys.



Summit Curves: they are provided when

a. When a positive gradient meets another milder positive gradient.

b. When positive gradient meet leveled or flat gradient

c. Positive grade meets negative grade (or) when rising grade meets falling grade (or) when ascending grade meets descending grade.

d. When a negative gradient meets another steeper negative gradient (Or) when a descending gradient meets another descending gradient.

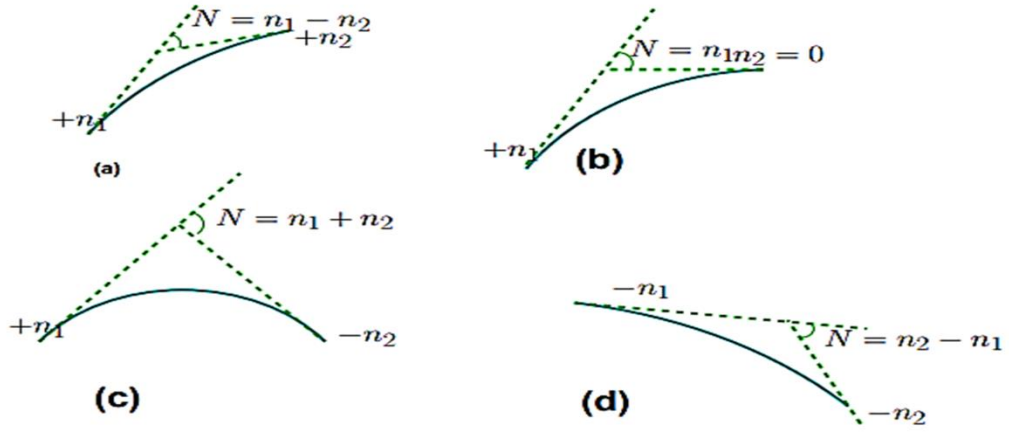
Sight distance is the design criteria for summit curves.

Square parabola is the ideal shape of summit curve.

While designing assume length of curve and length

of chord both are equal.

$y = \frac{Nx^2}{2L}$ L= length of curve



Design of summit curves

Case(i) Assume length of curve 'L' > SSD or OSD or ISD (S)

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

H= height of the drivers eye level above the road surface

h = height of the object above the road surface

For SSD	**For OSD/ISD**
H=1.2m	H= 1.2m
h = 0.15m	h = 1.2m

For L> SSD, **L**= $\frac{NS^2}{4.4}$

For L> OSD/ISD , **L** = $\frac{NS^2}{8H}$= $\frac{NS^2}{9.6}$

If the assumption is wrong then , Case(ii)

Case(ii) length of curve, L < SSD or OSD (S)

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

For L< SSD, H=1.2 and h = 0.15 , L= 2S - $\frac{4.4}{N}$

For L< OSD,ISD ,H =h=1.2 m , L = 2S - $\frac{8H}{N}$=2S - $\frac{9.6}{N}$

The minimum radius of the parabolic summit curve may be calculated from the relation R= L/N.

The highest point on the summit curve is at a distance (L n_1 /N) from the tangent point on the first grade n_1 .

Valley curves

- Valley curves or sag curves with convexity downwards are formed in any of the following cases:

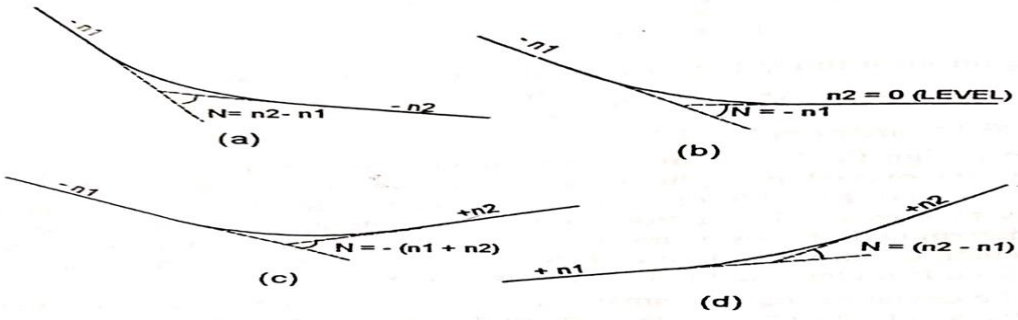


Fig. 4.36 Types of valley curves

Factors considered in the design of valley curve:

1. impact-free movement of the vehicles at design speed or the comfort to the passengers

2. Providing adequate sight distance under head lights of vehicles for night driving

3. Locating lowest point of the valley curve for providing suitable cross drainage facilities so as to prevent stagnation of water during rains.

Module 3

PAVEMENT MATERIALS: Subgrade soil – Desirable properties-HRB soil classification-determination of CBR and modulus of subgrade reaction-Examples on CBR and Modulus of subgrade reaction, Aggregates- Desirable properties and list of tests, Bituminous materials-Explanation on Tar, bitumen, cutback and emulsion-List of tests on bituminous materials.

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

OVERVIEW Pavements are a conglomeration of materials. These materials, their associated properties, and their interactions determine the properties of the resultant pavement. Thus, a good understanding of these materials, how they are characterized, and how they perform is fundamental to understand the pavement structure. The materials which are used in the construction of highway are of intense interest to the highway engineer. This requires not only a thorough understanding of the soil and aggregate properties which affect pavement stability and durability, but also the binding materials which may be added to improve these pavement features.

Highway materials include:

a. Sub-grade soil

b. Stone Aggregates

c. Bituminous materials

d. Cement and cement concrete

SUBGRADE SOIL

The soil that lies below ground level and extends to such depth as may affect the support of the pavement.

Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory. The supporting soil beneath pavement and its special under courses is called sub grade. Undisturbed soil beneath the pavement is called natural sub grade. Compacted sub grade is the soil compacted by controlled movement of heavy compactors.

Subgrade soil

1. Subgrade soil is considered as the integral part of the road structure.

2. It provides support to the pavement from beneath.

3. The properties of subgrade soil are important to the design of pavement structure.

4. Its main function is to give adequate support to the pavement.

5. It should possess sufficient stability under adverse climate and loading conditions.

CLASSIFICATION: Gravel, Sand, Silt, clay

DESIRABLE PROPERTIES

The desirable properties of sub grade soil as a highway material are

1. Stability

2. Incompressibility

3. Permanency of strength

4. Minimum changes in volume and stability under adverse conditions of weather and ground water

5. Good drainage

6. Ease of compaction

1. Stability: the soil with high stability provides excellent subgrade. It should have the property of resilience and should be able to regain its original position after the movement of a wheel load. The main function of a subgrade is to give adequate support to the pavement. This is possible only if the subgrade soil possesses sufficient stability under adverse climate and loading condition.

2. Incompressibility: Incompressibility is an important property to avoid differential settlement of soil. This property is particularly essential and is indispensable in embankment construction. Otherwise, a subgrade may fail due to differential settlement.

3. Permanency of strength: the subgrade soil should possess resistance to weathering. It should be able to retain its characteristic under adverse rain, temperature and frost action.

4. Minimum change in volume: This is a very important property bluging and shrinking under adverse weather conditions should be minimum . This property will help the soil to retain its property.

5. Good Drainage: Good drainage is essential to avoid excessive moisture retention and reduce potential frost action. It also improves stability of the soil.

6. Ease of compaction: This 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. Grain size distribution, Liquid limit, Plastic limit, Plasticity index, Shrinkage limit, Field moisture & compacted dry density.

1. Grain size analysis: It is found by mechanical analysis for Coarse grained soil by sieve analysis and fine grained soil by sedimentation analysis or Hydrometer method. The grain size analysis is carried out to determine the percentage of individual grain size present in a soil sample.

Sieve Analysis:

1) Write down the weight of each sieve as well as the bottom pan to be used in the analysis.

2) Record the weight of the given dry soil sample.

3) Make sure that all the sieves are clean, and assemble them in the ascending order of sieve numbers (#4 sieve at top and #200 sieve at bottom). Place the pan below #200 sieve. Carefully pour the soil sample into the top sieve and place the cap over it.

4) Place the sieve stack in the mechanical shaker and shake for 10 minutes.

5) Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

6) According to size of grains soil is classified as gravel, sand, silt and clay. As per Indian standard classification the limits of grain size are as follows.

Fraction of soils Larger than 2.00mm size- Gravel

Between 2.00mm – 0.06 mm size Sand

Between 0.06mm – 0.002 mm size Silt

Smaller than 0.002 size Clay

Hydrometer Analysis:

(1) Take the fine soil from the bottom pan of the sieve set, place it into a beaker, and add 125 mL of the dispersing agent (sodium hexametaphosphate (40 g/L)) solution. Stir the mixture until the soil is thoroughly wet. Let the soil soak for at least ten minutes.

(2) While the soil is soaking, add 125mL of dispersing agent into the control cylinder and fill it with distilled water to the mark. Take the reading at the top of the meniscus formed by the hydrometer stem and the control solution. A reading less than zero is recorded as a negative (-) correction and a reading between zero and sixty is recorded as a positive (+) correction. This reading is called the zero correction. The meniscus correction is the difference between the top of

the meniscus and the level of the solution in the control jar (Usually about +1). Shake the control cylinder in such a way that the contents are mixed thoroughly. Insert the hydrometer and thermometer into the control cylinder and note the zero correction and temperature respectively.

(3) Transfer the soil slurry into a mixer by adding more distilled water, if necessary, until mixing cup is at least half full. Then mix the solution for a period of two minutes.

(4) Immediately transfer the soil slurry into the empty sedimentation cylinder. Add distilled water up to the mark.

(5) Cover the open end of the cylinder with a stopper and secure it with the palm of your hand.

Then turn the cylinder upside down and back upright for a period of one minute. (The cylinder should be inverted approximately 30 times during the minute.)

(6) Set the cylinder down and record the time. Remove the stopper from the cylinder. After an elapsed time of one minute and forty seconds, very slowly and carefully insert the hydrometer for the first reading. (Note: It should take about ten seconds to insert or remove the hydrometer to minimize any disturbance, and the release of the hydrometer should be made as close to the reading depth as possible to avoid excessive bobbing).

(7) The reading is taken by observing the top of the meniscus formed by the suspension and the hydrometer stem. The hydrometer is removed slowly and placed back in to the control cylinder. Very gently spin it in control cylinder to remove any particles that may have adhered.

(8) Take hydrometer readings after elapsed time of 2 and 5, 8, 15, 30, 6 minutes and 24 hours.

Highway Research Board (HRB) classification of soils

This is also called American Association of State Highway Officials (AASHO) classification of Revised Public Roads Administration (PRA) soil classification system. Soils are divided into seven groups A-I to A-7. A-I, A-2 and A-3 soils are granular soils, percentage fines passing 0.074 mm sieve being less than 35. 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.

The classification of soils by three simple laboratory tests namely, sieve analysis, liquid limit and plastic limit.

A-1soils 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-I-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 PI greater than 10%). These soils have low permeability and high volume change properties with changes in moisture content. This is further classified in to A-7-5 & A-7-6.

HRB Classification Table

HRB-CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

General Description	*Granular materials (35% or less passing 75 micron IS sieve)*							*Silt clay materials (more than 35% passing 75 micron IS sieve)*			
Group Classification	A–1		A–3	A–2				A–4	A–5	A–6	A–7
	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, percent passing 2.0 mm IS sieve	50 max										
425 micron sieve	30 max	50 max	51 min								
75 micron sieve	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 425 micron sieve Liquid Limit				40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		NP	10 max	10 max	11 min	11 max	10 max	10 max	11 min	11 min
Group Index	Zero					4 max		8 max	12 max	16 max	20 max
Usual type of significant constituent materials	Stone fragments gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good					Fair to poor					

For A-7-5, $I_P <= w_L - 30$ For A-7-6, $I_P > w_L - 30$

Group index of soil

In order to classify the fine grained soils with one group and for judging their suitability as subgrade material an Index system has been introduced in HRB classification which is termed as Group Index. Soils are thus assigned arbitrary numerical number known as group index (GI).

Group index is a function of % material passing 75microns (0.075mm) sieve, Liquid limit & Plasticity index of soil and is given by

GI=0.2a+0.005ac+0.01bd.

a=that portion of material passing 75micron sieve, greater than 35 & not exceeding 75% (expressed as a whole no. 0-40).

b=that portion of material passing 75micron sieve greater than15 & not exceeding 35% (expressed as a whole no. from 0-40).

c=that value of LL in excess of 40 and less than 60(expressed as a whole no. from 0-20) d=that value of plasticity index exceeding 10 & not more than 30 (expressed as a whole no. from 0-20).

GI value is varying from 0-20. Higher the value poorer the soil as subgrade.

2. Atterberg Limits

Soils containing clay exhibit a property called plasticity. Plasticity is the ability of a material to be moulded (irreversibly deformed) with out fracturing. This behavior is unique to clays and arises due to the electrochemical behavior of clay minerals. The stiffness or consistency of fine grained soils depends on their moisture content, and varies with variations in the amount of moisture present. Depending on its moisture content, a soil can exist in one of the following states: viscous liquid,

plastic solid, semi solid and solid. Atterberg in 1911 proposed a series of tests, mostly empirical, for the determination of the consistency properties/states of fine grained soils. Atterberg limits define the moisture contents at which the soil changes from one state to another. These include the liquid limit (LL), the plastic limit (PL), shrinkage limit (SL). They are determined by tests carried out on the fine soil fraction passing the 425μm (No. 40) sieve. Liquid limit(AASHTO T89) may be defined as the minimum water content at which the soil will start to flow under the application of a standard shearing force (dynamic loading). Plastic limit(AASHTO T90) – measure of toughness – the moisture content at which the soil begins to fracture when rolled into a 3mm diameter thread. Shrinkage limit (AASHTO T92) is the maximum moisture content after which further reduction in water content does not cause reduction in volume. It is the lowest water content at which a clayey soil can occur in a saturated state. Plasticity index (PI=LL-PL) is the numerical difference between the liquid and plastic limits. Thus, it indicates the range of moisture content over which the soil remains deformable (in plastic state).Consistency limits and the plasticity index are used in the identification and classification of soils.

Generally, soils having high values of liquid limit and plasticity index are poor as subgrades/engineering materials. Both the liquid limit and plastic limit depend on the type and

amount of clay in the soils. In soils having same values of liquid limit, but with different values of plasticity index; it is generally found that rate of volume change and dry strength increases and permeability decreases with increase in plasticity index. On the other hand, in soils having same values of plasticity index but different values of liquid limit, it is seen that compressibility and permeability increase, and dry strength decreases with increase in liquid limit. Soils that cannot be rolled to a thread at any water content are termed as Non-Plastic (NP).

Finally, Liquid limit: Minimum water content at which the soil will flow under the application of very small shearing force.

Plastic limit: Minimum moisture content at which the soil remains in a plastic state. Plasticity index: It is numerical difference between the Liquid limit and Plastic limit. Shrinkage limit: Maximum moisture content at which further reduction in water content does not cause reduction in volume.

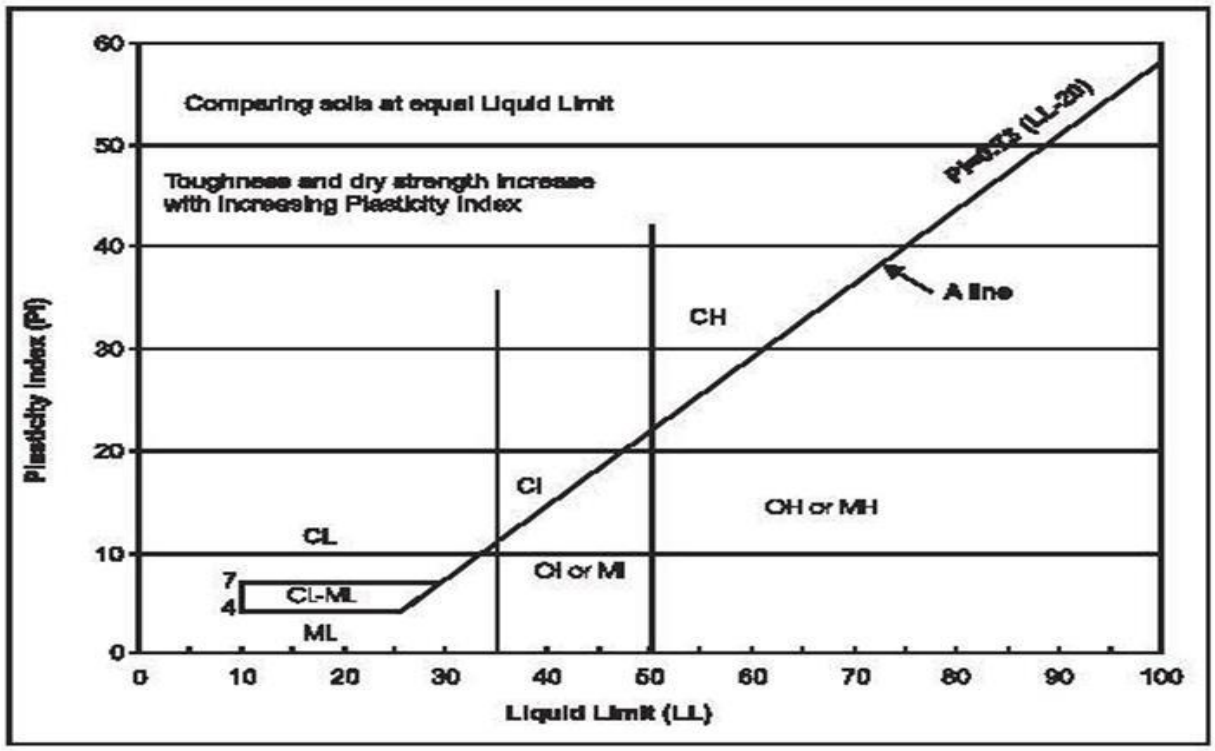
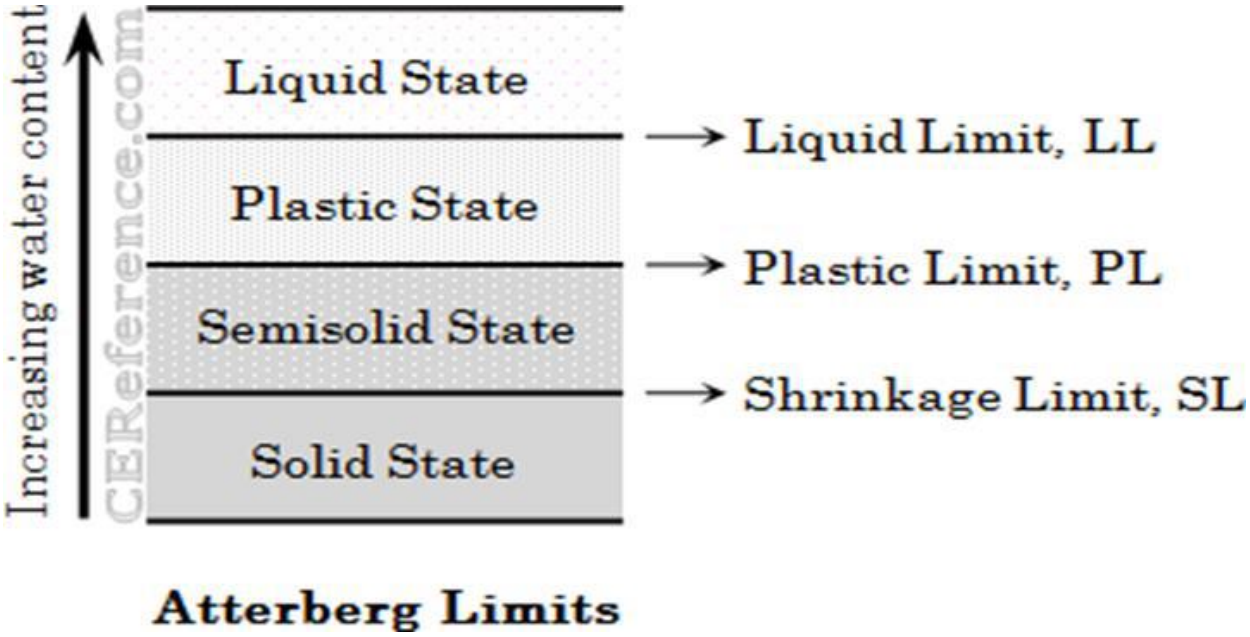


FIG. 5: PLASTICITY CHART FOR LABORATORY CLASSIFICATION OF FINE-GRAINED SOILS.



Atterberg Limits

SUBGRADE SOIL STRENGTH

The factor on which the strength characteristics of soil depend on

Soil type, moisture content, dry density, internal structural of the soil, type and mode of stress application.

Evaluation of soil strength

1. Shear test

2. Bearing test (Plate load test)

3. Penetration test. (CBR)

DETERMINATION OF CBR:

The CBR test is conducted to determine the pavement thickness required on a given soil as there is a correlation between the CBR of soil and pavement thickness.

Lab Procedure

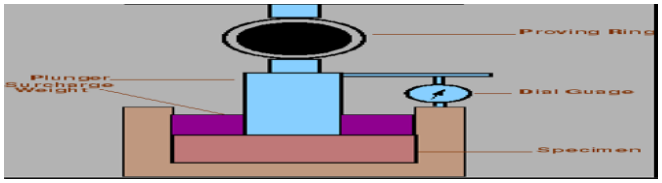


Fig: CBR Test Set up

Specifications

1. Loading machine is a compression machine which operates at the rate of 1.25mm/minute. If such a machine is not available then a calibrated hydraulic pressure with proving ring to measure load can be used. The capacity of the proving ring is 1000kg. Its plunger has a diameter of 50mm.

2. The cylindrical mould has 150mm diameter and 175 mm height and a detachable perforated base.

3. Compaction rammer has 2.6kg weight and fall of 310mm.

4. Spacer disc has 14mm diameter and 47.7mm thickness.

5. Annular weight has 5kg weight and slotted weight has 2.5kg weight.

Procedure

1. Take 5kg of clean and dry soil and add the water equal to given moisture content. Mix it thoroughly either with hands or a towel and separate the sample into three parts.

2. Grease all the internal parts of the dase, cylindrical mould, collar and spacer disc. Keep the spacer disc on base so that its hole is at bottom. Then fix the cylindrical mould and collar to the stand.

3. Put the soil sample into the cylindrical mould in 3 layers compacting each layer 56 times with the light compaction hammer.

4. Remove the collar , cut off excess soil above the level of cylindrical mould with a sharp cutting edge.

5. Reverse the mould, take out the spacer disc. To simulate the field condition of the over lying pavement, keep the annular weight of 5kg as surcharge weight at the top of the sample.

6. Soak the specimen in water for 4 days.

7. After the soaking period, keep the mould with sample and weights on the machine.

8. Bring the plunger to be in contact with the surface of soil and apply a seating load of 4kg.

9. Set the proving ring to zero. Fix a dial gauge to measure the penetration and set it to zero. Now allow the plunger to penetrate the specimen, record the proving ring readings for 0.5, 1.0, 1.5, ……..12.5mm penetration in the dial gauge. Convert the proving ring reading into unit pressure from the given CBR chart (or) multiply the proving ring division by the P.R. Constant to get the load in kg. Divide this load by the area of the plunger in Sq.cm to get the unit pressure in kg/Sq.cm

CBR (in %) = Load carried by soil sample at defined penetration level

Load carried by standard crushed stones at the same penetration level

Determination of Modulus of Subgrade reaction of soil/Plate Load Test

In this test, the strength of soil is determined in the form of modulus of subgrade reaction (K), which is extensively used in the design of rigid pavement. It is a field test

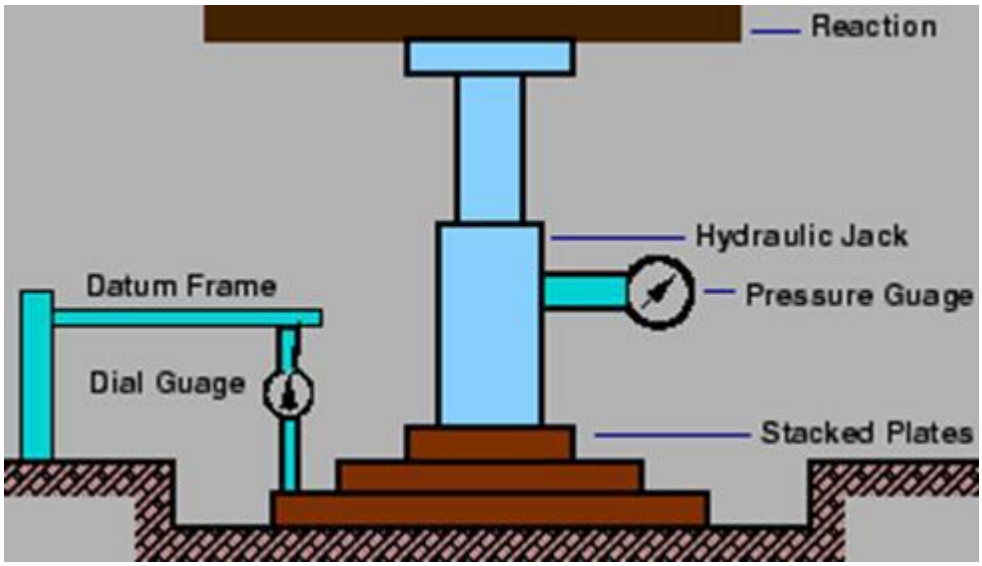


Figure: Plate load test

Procedure

1. Clean the ground surface at which the test is to be done.
2. Keep the standard test plate of 750mm size on the ground.
3. Above this keep some stacking plates on which keep the hydraulic jack.
4. At the top keep the reaction beam.
5. Apply a seating load of 0.75N/mm2 for a few minutes and release.
6. Now apply a load increment sufficient to cause a settlement of 0.75mm. Keep the load until the rate of settlement becomes less than 0.025mm/min.
7. Record the average settlement using a set of dial gauges placed on the stacking plates.
8. Now increase the load to cause a further settlement of 0.75mm and repeat the procedure.
9. Repeat the test for a few more loads.
10. Now plot the settlement values along X-axis and corresponding Bearing pressure values along Y-axis.
11. From this plot find the Bearing pressure corresponding to an average settlement of Δ=0.025cm (0.25mm).

K = P / 0.125(kg/cm2)

Summary:

The quality of any pavement is affected by the materials used for construction. Coming to the subgrade, soil is the most important material. Here we have seen various tests used for finding the strength of soil, the prominent ones being CBR and plate load test. CBR test assesses the strength of soil, whereas plate load test is used to evaluate its support capability.

ROAD AGGREGATES

Overview

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). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured.

Desirable properties of road aggregates

1. Strength

2. Hardness

3. Toughness

4. Durability

5. Shape of aggregates

6. Adhesion with bitumen

1. Strength

The aggregates used in top layers are subjected to

(i) Stress action due to traffic wheel load,

(ii) Wear and tear,

(iii) crushing.

Aggregates should be strong enough to withstand stresses due to wheel load. Particularly aggregates used in wearing course must bear wear and tear and resist crushing.

2. Hardness

The aggregates used in the surface course are continuously subjected to constant rubbing or abrasion and attrition due to moving traffic. Abrasion is rubbing of wheels with aggregates. Attrition is rubbing between aggregates. Both cause wear in aggregates. However, wearing due to attrition is negligible. Wheels of moving vehicles rub the surface course. This may result in wearing away of the top surface, exposing aggregates for direct rubbing by wheels. Abrasive action may be increased due to presence, of abrasive materials like sand. Attrition is caused by relative movement of aggregates. Thus, 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.

3. Toughness

Toughness is the resistance to hammering action by moving wheel loads. Aggregates in water bound macadam pavements protrude out particularly after monsoons. Jumping of moving wheels from one stone aggregate to another at different levels, cause severe impact on aggregates. Therefore, resistance to such impacts is a desirable property of aggregates. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes' severe impact on the aggregates.

4. Shape of aggregates

Aggregates are generally selected by size and not by shape. However , the shape has certain relevance in the selection of aggregates for road construction. 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 and elongated 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.

5. Adhesion with bitumen

The adhesion affinity of aggregates should be more towards bituminous materials than to water. if it is otherwise, the bituminous coating over aggregates would be stripped off in the presence of water.

6. Durability

Durability is a property of resistance to distintegration due to action of weather. This property of aggregates is termed as soundness. Weathering agencies such as rain, wind and sun may lead to physical and chemical distintegration of aggregates. Therefore stone used in road construction should be sound enough to withstand the weathering action.

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

1.Crushing test

2.Abrasion test

3.Impact test 4.Soundness test

5.Shape test

6. Specific gravity and water absorption test

7.Bitumen adhesion test

1. Aggregate Crushing Value

Aim: To determine the crushing value of the given sample of aggregate.

Apparatus

a) Steel cylinder with open ends and a square plate

b) Plunger with piston

c) Cylindrical measure

d) Weighing balance

e) IS sieves (12.5 mm, 10.0mm & 2.36 mm)

f) Compression testing machine

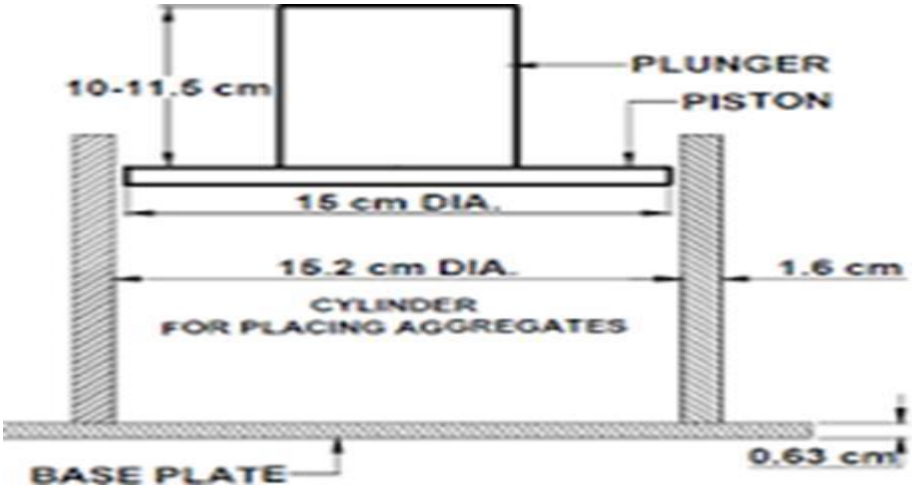
g) Steel Tamping Rod.

Theory

The Principal mechanical properties required in road stones are (i) Satisfactory resistance to crushing under the roller during construction and (ii) adequate resistance to surface abrasion under traffic. Also stresses under rigid tyre rims of heavily loaded animal drawn vehicles are high enough to consider the crushing strength of road aggregate as an essential requirement in India.

Crushing strength of road aggregate may be determined either on aggregate or on cylindrical specimens cut out of rocks. These two tests are quite different is not only the approach but also is the expression of the results.

Aggregate used in road construction, should be strong enough to resist crushing under traffic wheel loads. If the aggregate are weak, the stability of the pavement stretches is likely to be adversely affected, the strength of coarse aggregate is assessed by aggregate crushing test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement, aggregate possessing low aggregate value should be preferred.



Procedure

1. Select clean and dry aggregate passing through IS 12.5 mm and retained on IS 10.0 mm sieve.

2. Weight the empty cylindrical measure. Let the weight be „a g

3. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod. Weigh the cylindrical measure with aggregate. Let the weight be 'b" grams. Thus the weight of aggregate = W1 g

4. Transfer the aggregate into the steel cylinder again in three layers tamping each layer 25 times

5. Place the plunger in the steel cylinder such that the piston rests horizontally over the aggregate surface.

6. Keep the assembly of steel cylinder with plunger in the compression testing machine.

7. Set the pointer to read zero and apply the compressive load of 40 tonnes.

8. Stop the machine. Take out the assembly.

9. Sieve the crushed material on IS 2.36 mm sieve and find the weight of material passing this sieve. Let the weight be W2 g.

10. Then Aggregate crushing value=W2 / W1*100 %

Tabular Column

Weight of empty cylindrical measure = „a" g	
Weight of cylindrical measure with aggregate = „b" g	
Weight of aggregate taken in the cylinder before test =(b-a) = W1 g	
Weight of crushed material Passing IS 2.36 mm sieve = W2 g	
Aggregate crushing value = W2 / W1* 100 %	

Result

The aggregate crushing value of the given aggregate Sample is…….

Desirable value

Strong aggregates give low aggregate crushing value. IRC and ISI have specified that the aggregate crushing value of the coarse aggregate used for cement concrete pavement at surface should not exceed 30 percent. For aggregates used for concrete other than for wearing surfaces, the aggregates

crushing value shall not exceed 45 percent, according to the ISI. However aggregate crushing values have not been specified by the IRC for coarse aggregates to be used in bituminous pavement construction methods.

2. Los Angeles Abrasion Test

Aim: To determine the abrasion of the given aggregate sample.

Apparatus:

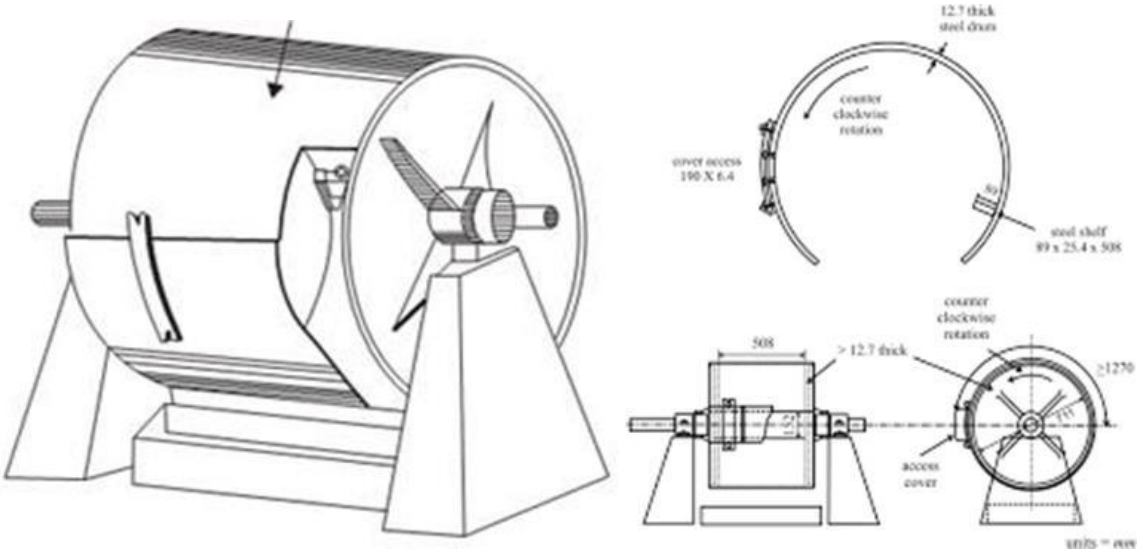
a) Los Angles Abrasion Machine Steel balls-11no.

b) Weighing balance

c) IS Sieves: 20, 12.5, 10, 1.7mm.

Theory

Due to the movement of traffic, the road stones used in the surfacing course are subjected to wearing action at the top. Resistance to wear or hardness is hence an essential property for road aggregates especially when used in wearing course. Thus road stones should be hard enough to resist the abrasion due to the traffic.



Procedure

1) Take the clean and dried aggregates in an oven at 105-110° C.

2) Sieve the given aggregates in sieve size 20-12.5mm and weigh that aggregate in 2.5kg.

3) Again sieve the aggregate in sieve size is 12.5-10mm and take that aggregates in 2.5 k. i.e., W1 gm (2.5+2.5=5kg)

4) Pour the given taking aggregates into the los angles abrasion machine.

5) Put the steel balls into the abrasion machine after pouring the aggregates.

6) Start the machine and rotating the drum for 100 revolutions and stop the machine.

7) After stopping the machine, take out the aggregates and sieve the aggregates in 1.7mm sieve size and take the retained aggregates and note down its weight i.e, W2 gm.

8) Then, Los Angles Abrasion value= (W1-W2/W1)X100 %

Tabular Column

Original weight of aggregate = W1 g	
Weight of aggregates retained on 1.7 mm IS sieve = W2 g	
Loss in weight due to wear= (W1-W2) g	
Los Angles Abrasion value= (W1-W2/W1)*100 %	

Result

The Los Angles Abrasion Value of given aggregates is % at revolution.

Desirable value

The maximum allowable Los Angeles abrasion values of aggregates as specified by IRC for different methods of construction are given in below table.

Sl. No	Types of pavement layer	Los Angeles abrasion value, Maximum %
1	Water bound macadam (WBM), sub-base course	60
2	(i) WBM base course with bituminous surfacing50 (ii) Bituminous Macadam base course (iii) Built-up spray grout base course	50
3	(i) WBM surfacing course40 (ii) Bituminous Macadam binder course (iii) Bituminous penetration Macadam (iv) Built-up spray grout binder course	40
4	(i) Bituminous carpet surface course35 (ii) Bituminous surface dressing, single or two coats (iii) Bituminous surface dressing, using precoated aggregates (iv) Cement concrete surface course (as per IRC)	35
5	(i) Bituminous/Asphaltic concrete surface course30 (ii)Cement concrete pavement surface course (as per ISI)	30

The Los Angeles abrasion value of good aggregates acceptable for cement concrete, bituminous concrete and other high quality pavement materials should be less than 30%. Values up to 50% are allowed in base courses like water bound and bituminous macadam.

Shape Test

Aim: To determine the Flakiness Index, Elongation Index and Angularity Number of the given sample of aggregate.

Theory

The particle shape of aggregate is determined by percentages of flaky and elongated particles contained in it. In case of gravel it is determined by its angularity number. For base course and construction of bituminous and cement concrete types, the presence of flaky and elongated particles are considered undesirable as they may cause inherent weakness with possibilities of breaking down under heavy loads. Rounded aggregate are preferred in cement concrete road construction as the workability of concrete improves. Angular shape of particles is desirable for granular base course due to increased stability derived from the better interlocking. Thus evaluation of shape of the particles, particularly with reference to flakiness, elongation and angularity is necessary.

1. Flakiness Index

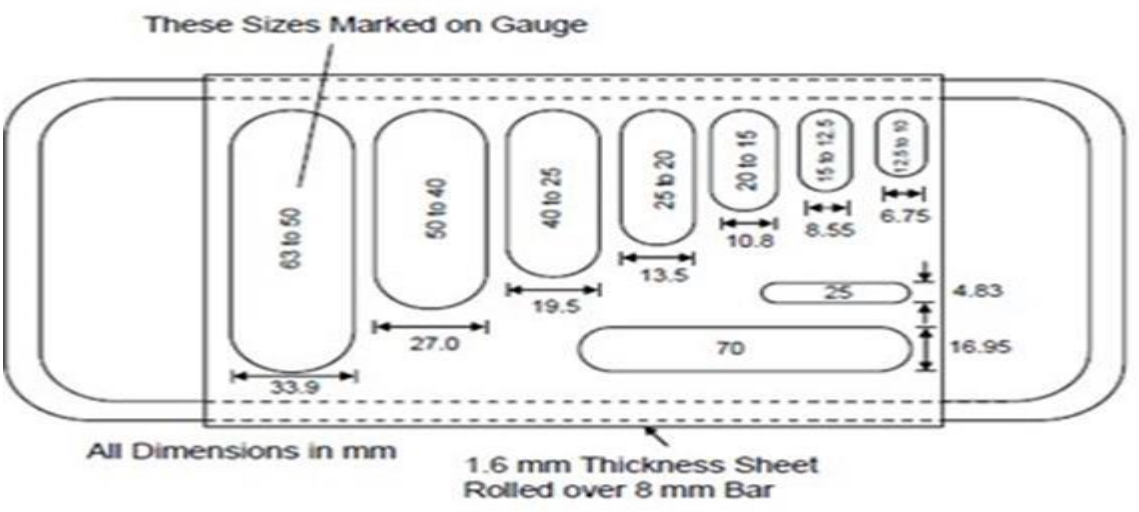
The Flakiness index of aggregate is the percentage by weight of particles whose least dimension [thickness] is less than three- fifths [0.6] times of their mean dimension. The test is not applicable to aggregate size smaller than 6.3 mm

Apparatus

a) Thickness gauge

b) Weighing balance

c) IS Sieves of sizes : 63 mm, 50 mm, 40 mm, 31.5 mm,25 mm,20 mm, 16 mm, 12.5 mm, 10 mm and 6.3 mm



Procedure

1. The sieves are arranged such that the largest size sieve (63 mm) is at the top and the smallest size sieve (6.3 mm) is at the bottom.

2. The given aggregate are sieved. A minimum of 200 pieces of each fraction to be tested are taken and weighed = W1 g.

3. In order to separate flaky aggregate, each fraction is then gauged for thickness through the respective opening on the thickness gauge.

4. The width of the appropriate slot would be 0.6 of the average size range.

5. If the selected size range of aggregate in a group 20-16 mm (i.e., passing 20mm and retained on 16mm) , the width of the slot to be selected in the thickness gauge would be {(20+16)/2= 18} 18 *0.6 = 10.8 mm.

6. The flaky aggregate passing the respective openings are collected and accurately weighed= w1 g.

7. The procedure is repeated for other fractions having weights W2, W3, etc. and the flaky aggregate in them having weights w2, w3 respectively are weighed.

8. Then

$$\text{Flakiness Index} = \frac{(w1+w2+w3+\text{------})}{(W1+W2+W3+\text{-------})} \times 100$$

= …….. %

Result: The flakiness Index of the given sample of aggregate is

2. Elongation Index

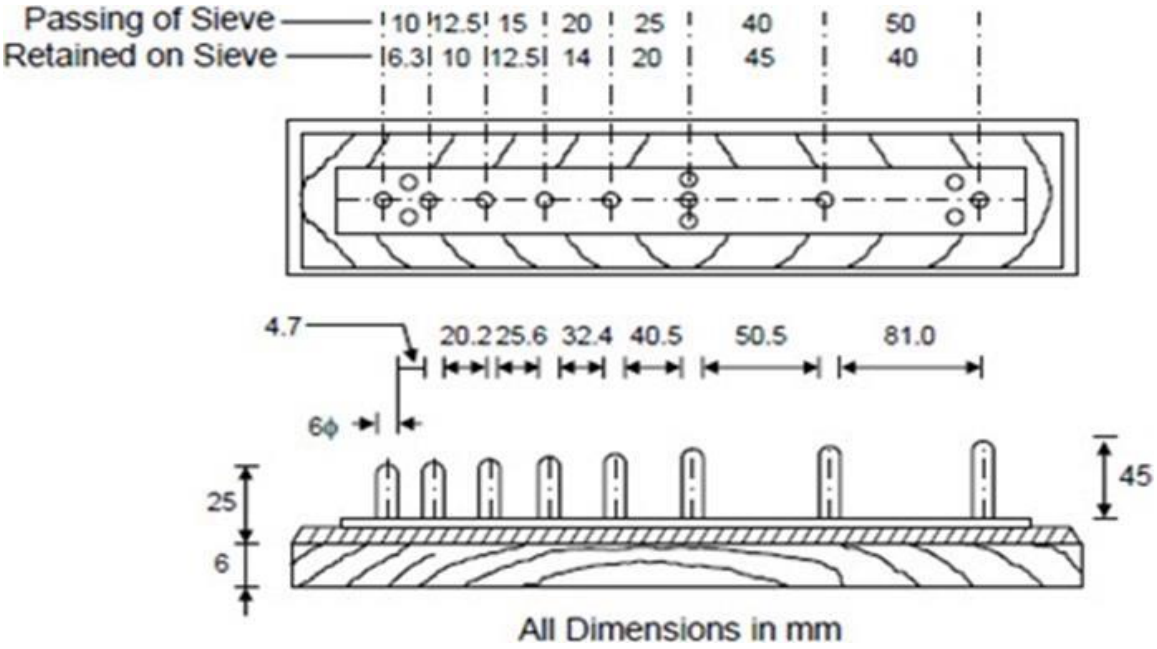
The elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four fifth times [1. 8] times their mean dimension. The elongation test is not applicable to size smaller than 6.3 mm.

Apparatus

a) Length gauge

b) Weighing balance

c) IS Sieve of size as in flakiness Index test.



Procedure

1. The sample is sieved through a set of IS sieves and separated into specified size ranges.

2. A minimum of 200 pieces of each fraction are taken and weighed = W1 g.

3. In order to separate elongated aggregate , each fraction is then gauged individually for length through the respective opening on the length gauge

4. In each fraction, the aggregate retained on the respective opening on the length gauge is collected and weighed =X1 g.

5. The procedure is repeated for other fractions having weights W2, W3, etc, and the weights of elongated aggregate in them X2, X 3 etc, are found.

6. Then

(X1+X2+X3 +----------)

Elongation Index = x 100 %

(W1+W2+W3+----------) $XW*100$=⋯…….%

Result

The elongation Index of the given sample of aggregate = %

Flakiness Index and Elongation Index Observations

Sl. No	Size of aggregate		Weight of the fraction consisting of atleast 200 pieces, gm [3]	Thickness gauge size mm [4]	Weight of aggregate in each fraction passing thickness gauge gm [5]	Length gauge size mm [6]	Weight of aggregate in each fraction retained on length g [7]
	Passing through IS sieve mm [1]	Retained on IS sieve mm [2]					
1	**63**	**50**	**W1=**	**33.90**	**w1=**	**----**	**----**
2	**50**	**40**	**W2=**	**27.00**	**w2=**	**81.0**	**X1=**
3	**40**	**31.5**	**W3=**	**19.50**	**w3=**	**58.0**	**X2=**
4	**31.5**	**25**	**W4=**	**16.95**	**w4=**	**----**	**----**
5	**25**	**20**	**W5=**	**13.50**	**w5=**	**40.5**	**X3=**
6	**20**	**16**	**W6=**	**10.80**	**w6=**	**32.4**	**X4=**
7	**16**	**12.5**	**W7=**	**8.55**	**w7=**	**25.6**	**X5=**
8	**12.5**	**10**	**W8=**	**6.75**	**w8=**	**20.25**	**X6=**
9	**10**	**6.3**	**W9=**	**4.89**	**w9=**	**14.7**	**X7=**
	Total	**----**	**W =**	**----**	**w =**	**----**	**X =**

(w1+w2+w3+---------)

Flakiness Index = x100 percent

(W1+W2+W3+---------)

[X1+X2+X3 --------]

Elongation Index = x 100 percent

(W1+W2+W3+---------)

Desirable value: IRC has recommended the maximum allowable limits of flakiness index values for various types of construction are given below:

Sl. No.	Type of pavement construction	Maximum limit of Flakiness Index, %
1	Bituminous carpet	30
2	(i) Bituminous/Asphaltic concrete25 (ii) Bituminous surface dressing (single coat, two coats and pre-coated) (iii) Bituminous penetration macadam (iv) Built-up spray grout	25
3	i) Bituminous macadam15 (ii) Water bound macadam, base and surfacing courses	15

Though elongated shape of the aggregates also affects the compaction and the construction of pavements, there are no specified limits of elongation index values as in the case of flakiness index for different methods of pavement construction.

The angularity number measures the percent voids in excess of 33 percent which is obtained in the case of the most rounded gravel particles. The angularity number of aggregates generally ranges from zero for highly rounded gravel to about 11 for freshly crushed angular aggregates. Slightly higher values of angularity number also may be obtained in the case of highly angular and flaky aggregates. Thus higher the angularity number, more angular and less workable is the aggregate mix.

It is desirable that the flakiness index of aggregates used in road construction is less than 15% and normally does not exceed 25%.

Elongation index value in excess of 15% percent is considered undesirable; however no recognized limits have been laid down for elongation index.

3. Angularity Number

The angularity number of an aggregate is the amount by which the percentage voids exceeds 33, after being compacted in a prescribed manner. The angularity number is found from the expression (67 - 100 * W / CG, percent). Here the value 67 represents the percentage volume of solids of most rounded gravel, which would have 33 percent voids

Apparatus

a) A metal cylinder closed at one end having 3 litre capacity, diameter and height approximately equal

b) A metal tamping rod, 16 mm in diameter and 600 mm long.

c) Weighing balanced

d) IS sieves 25, 20, 16,12.5, 10, 6.3 and 4.75 mm

Procedure

1) The sieves for each fraction (as specified) are arranged such as 25 - 20 mm, etc.

2) The given sample of aggregate is sieved so that sufficient pieces are obtained in each fraction.

3) The empty cylinder is accurately weighed = „ a‟ g

4) Each aggregate fraction is separately filled in the cylinder in 3 (three) layers tamping each layer 100 (hundred) times with the rounded end of tamping rod. The excess aggregate are removed.

5) The cylinder along with aggregate is weights = „b‟ g

6) The aggregate are removed from the cylinder. The cylinder is completely filled with water and after wiping its outer sides it is weighed with water = „d" g

7) Then Angularity number may be calculated from the expression, Angularity number = 67 - 100 W / CG

Where, W= Mean weight of aggregate in the cylinder

C = Weight of water required to fill the cylinder

G= Average Specific gravity of aggregate.

Result

The angularity number of the given sample of aggregate = ……. %

Observations

Weight of empty cylinder = a g	
Weight of cylinder +aggregate = b g	
Weight of aggregate in the cylinder = (b-a) = W g	
Weight of cylinder + water = d g	
Weight of water in the cylinder = (d-a) = C g	

Angularity Number = 67 – 100 W/ CG

Tabular Column

Weight of aggregate in the cylinder = W g	
Weight of water in the cylinder = C g	
Angularity Number = 67 – 100 W/ CG [Take G=2.68]	

Specific Gravity and Water Absorption Test on Aggregates

Aim : To determine the specific gravity and water absorption of given sample of aggregates.

Apparatus

a) Density basket

b) Weighing balance

c) Water tank

d) Tray

e) IS sieves- 10mm and 20mm.

Theory: The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values. The specific gravity test helps in the identification of stone. Water absorption gives an idea of strength of rock stones having more water absorption are more porous in nature and are generally considered unsuitable unless they are found to be acceptable based on strength, impact and hardness.

Procedure

1. Take about 2kg of given aggregates passing IS 20mm sieve and retained on 10mm sieve.

Keep the aggregate in density basket and then keep the basket in water.

2. Allow the aggregate and basket to be in water for 24 hours.

3. After 24 hours find the suspended weight of basket with aggregate.

4. Remove the basket out of water and remove the aggregate.

5. Keep the empty basket back in water and find the suspended weight.

6. Wipe the surface of aggregate using a cotton cloth to make them surface dry.

7. Find the weight of surface dry aggregate in air.

8. Keep the aggregate in oven at 110° C for 24 hours.

9. Now find the weight of dried aggregate in air.

10. Then specific gravity and Water absorption is calculated from the relation:

$$\text{Specific gravity} = \frac{W4}{W3-(W1-W2)}$$

$$\text{Water absorption} = W3-W4 / W4 * 100\ \%$$

Observation

Weight of aggregate taken = 2000gm

I.S. sieve used 20mm and 10mm

Weight of saturated aggregate suspended in water + basket 'W1'gm	
Weight of empty basket in water 'W2' gm	
Weight of saturated aggregate in water 'Ws' = (W1-W2) gm	
Weight of surface dry aggregate 'W3' gm	

Weight of equal volume of water to the aggregate = W3-Ws gm	
Weight of oven dry aggregate 'W4' gm	
Specific gravity = W4 /W3-(W1-W2)	
Water absorption = W3-W4 * 100 % W4	

Result

The specific gravity of given aggregate sample = …….

The water absorption of given aggregate sample = ……...%

Desirable value

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 3.0 with an average value of about 2.68. though high specific gravity of an aggregate is considered as an indication of high strength, it is not possible to judge the suitability of a sample of road aggregate without finding the mechanical properties such as aggregate crushing, impact and abrasion values.

Water absorption of an aggregate is accepted as measure of its porosity. Sometimes this value is even considered as a measure of its resistance to frost action. Water absorption value ranges from 0.1 to about 2.0 percent for aggregate normally used in road surfacing. Stones with water absorption upto 4.0 percent have been used in base courses. Generally a value of less than 0.6 percent is considered desirable for surface course, though slightly higher values are allowed in bituminous constructions. IRC has specified the maximum water absorption value as 1.0 percent for aggregates used in bituminous surface dressing and built-up spray grout.

Soundness Test

Aim: To study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycle

Apparatus

a) Sodium sulphate or magnesium sulphate

b) Oven

c) Weighing balance

d) IS sieves

Procedure

1) In order, to quicken the effects of weathering due to alternate wet-dry or freeze-thaw cycles in the laboratory, the resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.

2) Clean, dry aggregates of specified size is weighed and counted. Then immersed in the saturated solution of sodium sulphate or magnesium sulphate for 16 to 18 hours.

3) Then the aggregates are dried in an oven at 105-110°C to a constant weight, thus making one cycle of immersion and drying.

4) The number of such cycles is decided by prior agreement and then the specimens are tested. After completing the final cycle, the sample is dried and each fraction of aggregate is examined visually to see if there is any evidence of excessive splitting, crumbling or disintegration of the grains.

5) Sieve analysis is carried out to note the variation in gradation from original. The coarse aggregate fraction of each size range is sieved on specified sieve sizes.

Desirable value

IRC has specified 12percent as the maximum permissible loss in soundness test after 5 cycles with sodium sulphate, for the aggregate to be used in bituminous surface dressing, penetration macadam and bituminous macadam constructions.

Bitumen Adhesion/Stripping Test

Several laboratory tests have been developed to determine the adhesion of bituminous binder to an aggregate in presence of water. These tests may be classified into six types:

a) Static immersion test

b) Dynamic immersion test

c) Chemical immersion test

d) Immersion mechanical test

e) Immersion trafficking test and

f) Coating test

The static immersion test is very commonly used as it is quite easy and simple. The principle of this type of test is by immersing aggregate fully coated with the binder in water maintained at specified temperature and by estimating the degree of stripping. The result is reported as the percentage of stone surface that is stripped off after the specified time periods.

Desirable value: IRC has specified the maximum stripping value as 25 percent for aggregate to be used in bituminous construction like surface dressing, penetration macadam, bituminous macadam and carpet.

IRC has specified that stripping value of aggregates should not exceed 25percent for use in bituminous surface dressing, penetration macadam, bituminous macadam and carpet constructions, when aggregate coated with bitumen is immersed in water bath at 40°C for 24 hours.

Aggregate Impact Test

Aim: To determine the impact value of the given aggregate

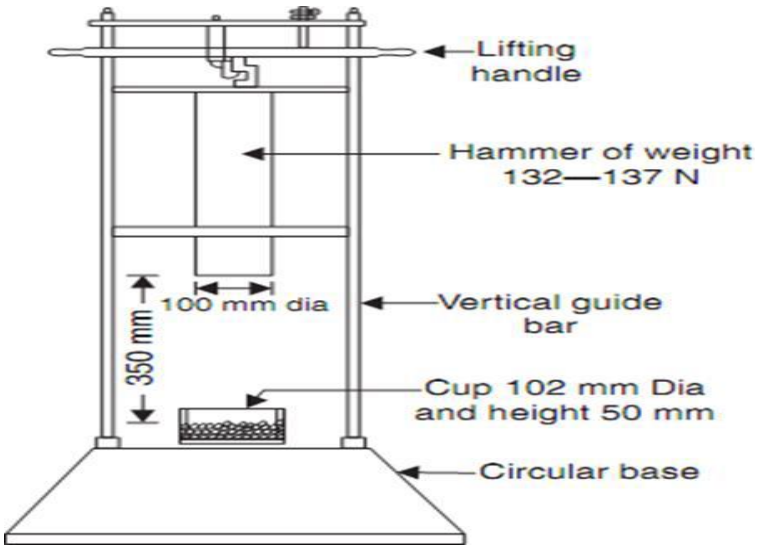
Apparatus: Aggregate impact apparatus

IS sieves (12.5 mm, 10.0 mm and 2.36 mm) Cylindrical measure and cylindrical cup Weighing balance, Tamping rod.

Theory:

Toughness is the property of a material to resist impact. Due to traffic loads the road stones are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact. A test designed to evaluate the toughness of stones i.e. the resistance of the stones to fracture under repeated impacts may be an impact test for road aggregate.

The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregate differs from its resistance to a slow compressive load. The method of tests specifies the procedure for determining the aggregate impact value of coarse aggregate



Procedure

1. Take clean and dry aggregate and sieve on IS 12.5 mm and 10.00 mm sieve.

2. Collect the aggregate passing IS 12.5mm sieve and retained on IS 10.0 mm Sieve.

3. Find the weight of empty cylindrical measure. Let the weight be „a" g.

4. Fill the aggregate in the cylindrical measure in three layers, tamping each layer 25 times with the rounded end of the tamping rod.

5. Roll the tamping rod over aggregate surface and remove excess aggregate, if any.

6. Find the weight of the cylindrical measure with aggregate. Let the weight be „b" g. Thus the weight of aggregate = W1 = (b-a)

7. Transfer all the aggregate from the cylindrical measure to the test cylinder in one layer and tamp the layer 25 times with the rounded end of the tamping rod.

8. Fix the test cylinder firmly to the base of the impact tester.

9. Adjust the height of fall of the plunger to 380+ 5mm and set the blow counter to zero.

10. Lift the plunger gently and allow it to drop. This is one blow. Give 15 such blows.

11. Take out the test cylinder and sieve the crushed material on IS 2.36 mm sieve. Find the weight of material passing the sieve. Let weight be W2 g.

12. Find the weight of aggregate retained on this sieve. Let the weight be W3 g. Then, Aggregate impact value = W2 / W1 * 100 %

And percentage of dust = W3 / W1* 100 %

Tabular Column

Weight of empty cylindrical measure = „a" g.	
Weight of cylindrical measure + Aggregate = „b" g	
Initial weight of aggregate = (b-a)= W1 g	
Weight of aggregate passing IS 2.3 mm sieve after test = W2 g	
Weight of aggregate retained on IS 2.36 mm sieve after test = W3 g	
Aggregate impact value = W2 / W1 * 100 %	
Percentage of dust = W3 / W1* 100 %	

Result

The Impact value of given aggregate sample is = …….. %

Desirable value

Various agencies have specified the maximum permissible aggregate impact values for the different types of pavements, those recommended by the Indian Roads Congress are given below:

Serial No.	Types of pavement material/layer	Aggregate impact value, maximum, %
1	Water bound macadam (WBM), sub-base course	50
2	Cement concrete, base course (as per ISI)	45
3	(i) WBM base course with bitumen surfacing (ii)Built-up spray grout, base course	40
4	Bituminous macadam, base course	35
5	i) WBM, surfacing course	30
	(ii) Built-up spray grout, surfacing course	
	(iii) Bituminous penetration macadam	
	(iv) Bituminous macadam, binder course	
	(v) Bituminous surface dressing	
	(vi) Bituminous carpet	
	(vii) Bituminous/Asphalt concrete	
	(viii) Cement concrete, surface course	

For deciding the suitability of soft aggregates in base course construction, this test has been commonly used. A modified impact test is also often carried out in the case of soft aggregates to find the wet impact value after soaking the test samples. The recommendations is given in the below table

Condition of sample	Maximum aggregate impact value, percent	
	Sub-base and base	Surface course
Dry	50	32

wet	60	39

Aggregate impact value is used to classify the stones in respect of their toughness property as indicated below:

<10% Exceptionally strong

10-20% Strong

20-30% Satisfactory for road surfacing

>35% Weak for road surfacing

The aggregate impact value should not normally exceed 30% for aggregate to be used in wearing course of pavements. The maximum permissible value is 35% for bituminous macadam and 40% for water bound macadam base courses.

SL No.	Type of test	Required property
1	Aggregate impact test	Toughness or resistance to impact
2	Los Angeles Abrasion Test	Hardness or resistance to abrasion
3	Aggregate Crushing Test	Strength or resistance to crushing
4	Soundness/Durability/ Accelerated weathering test	Durability or resistance to weathering
5	Shape test: Flakiness Index, Elongation Index and Angularity Number	Assessment of suitable shape or shape factors of coarse aggregates
6	Specific gravity Test	To measure the quality or strength of material
7	Water absorption Test	To measure the porosity
8	Bitumen adhesion/Stripping Test	Adhesion of bitumen
9	Polished stone value test or accelerated polishing test	Resistance to getting smooth or polished

BITUMINOUS MATERIALS

Introduction

Bituminous binders used in pavement construction works include both bitumen and tar. Both bitumen and tar have similar appearance, black in colour though they have different characteristics.

Origin

Naturally occurring deposits of bitumen are formed from the remains of ancient, microscopic algae and other once-living things. When these organisms died, their remains were deposited in

the mud on the bottom of the ocean or lake where they lived. Under the heat and pressure of burial deep in the earth, the remains were transformed into materials such as bitumen, kerogen, or petroleum. Deposits at the La Brea Tar Pitsare an example. There are structural similarities between bitumens

and the organic matter in carbonaceous meteorites. However, detailed studies have shown these materials to be distinct.

Asphalt or bitumen can sometimes be confused with "tar", which is a similar black, thermoplastic material produced by the destructive distillation of coal. During the early and mid20th century when town gas was produced, tar was a readily available product and extensively used as the binder for road aggregates. The addition of tar to macadam roads led to the word tarmac, which is now used in common parlance to refer to road-making materials. However, since the 1970s, when natural gas succeeded town gas, asphalt (bitumen) has completely overtaken the use of tar in these applications.

1. Asphalt: it is a mechanical mixture of inert mineral matter. Two categories of asphalt are (a) natural asphalt and (b) Residual asphalt. The natural asphalt is obtained from nature. The residual asphalt is obtained by fractional distillation of crude petroleum oil with an asphalt base .

2. BITUMEN: It is a complex organic material and it occurs either naturally , or may be obtained artificially during distillation of petroleum.

3. Straight run bitumen is one distilled to a definite viscosity or penetration without further treatment. The desirable properties of bitumen are:

a) Durability

b) Non-susceptibility to temperature

c) Adequate affinity and adhesion with aggregates

d) Adequacy of viscosity at mixing and compaction

The grade of bitumen used for pavement construction work of roads and airfields are called paving grades and used for water proofing of structures and industrial floors etc. are called industrial grades. The paving bitumen available in India is classified into two categories

1. Paving bitumen from Assam petroleum denoted as A-type and designated as grades A35, A 90.etc.

2. Paving bitumen from other sources denoted as S-type and designated as grades S35, S90 etc.

Cutback Bitumen: The viscosity of bitumen is reduced sometimes by mixing it with a volatile solvent is known as cutback bitumen. This enables its application considerably at lower temperature. Based on the quantity and character of the bitumen and the volatile solvent the cutback bitumen is divided into 3 types.

a) Rapid curing (RC) cutback bitumen

b) Medium curing(MC) cutback bitumen

c) Slow curing(SC) cutback bitumen

Bitumen Emulsion: The bitumen is suspended in a finely divided condition in an aqueous medium and stabilized with an emulsifier; the material is known as Emulsion.

Or

Bitumen Emulsion: it is a liquid product formed by mixing together molten bitumen with hot water in the presence of an emulsifying agent. The emulsifying agent consists of soaps or resinous bodies. On application, the water evaporates, the emulsion breaks up and the bitumen is left in the place. Changing of the colour from chocolate brown to black indicates the breaking of the emulsion. Depending upon the type of emulsifying used, the emulsions are classified as:

a) Rapid setting(RS)

b) Medium setting(MS)

c) Slow setting(SS)

The main advantage of emulsion is , it can be used in wet weather and also even when it rains. These materials are primarily used for maintenance and repair works.

TAR: This is a thermoplastic material obtained by destructive distillation of coal, petroleum, oil, wood or other organic materials. It is brown or black bituminous material with high viscosity. It has great variation in viscosity.

Difference between Bitumen and Tar

Sl. No	**Bitumen**	**Tar**
1	Bitumen is found in black to brown in colour	Tar is usually found in brown colour
2	Bitumen is obtained from fractional distillation of crude oil	Tar is obtained by destructive distillation of coal or wood
3	Bitumen is soluble in carbon disulphide and carbon tetra chloride	Tar is soluble in toluene
4	Molecular weight range for road bitumen is 400 to 5000	Molecular weight range for road tar is 150 to 3000
5	Bitumen consists of large amount of aromatic hydrocarbon	Tar consist of large amount of oily matter with lower molecular weight
6	Bitumen show resistance to coating road aggregate and also does not retain in presence of water	Tar coats more easily and retain it better in presence of water

7	Free carbon content is less	Free carbon content is more
8	It shows more resistance to weathering action	It shows less resistance to weathering action
9	Less temperature susceptibility	More temperature susceptibility
10	Has Good water resistance property	Less water resistance property
11	More durable	Less durable
12	Do not get crystallised	Get crystallised
13	Less phenolic content	More phenolic content(gets oxidized easily

Desirable Properties of Bitumen

1. Viscosity

The viscosity of the bitumen at the time of mixing and compaction should be adequate. This is achieved by heating the bitumen and aggregate prior to mixing or by use of cutbacks or emulsions of suitable grade.

2. Temperature Susceptibility

The bituminous material should not be highly temperature susceptible. During the hottest weather of the region the bituminous mix should not become too soft or unstable. During cold weather the mix should not become too hard and brittle, causing cracking. The material should be durable.

3. Adhesion Property

In presence of water the bitumen should not strip off from the aggregate. There has to be adequate affinity and adhesion between the bitumen and aggregate used in the mix.

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.

1. Penetration test

2. Softening point test

3. Ductility test

4. Viscosity test

5. Specific gravity test

6. Heat stability test

a.Flash point test

b.Fire point test

c.Loss on heating test

7. Solubility test

8. Thin film oven test

9. Float test

10. Water content test

1. Penetration test:

An indirect method of measuring viscosity is the measure of penetration of a standard needle under standard conditions of load, time & temperature. The test measures the hardness or softness of bitumen in terms of penetration expressed in mm/10th of std needle.

Temperature= 250C [test to be performed after sample is kept for 1hr in H2O bath at this temperature]

Load on needle = 100 g

Time in which penetration is recorded = 5 s

The penetration is measured by a graduated dial.

Bitumen is softens to a poring consistency a depth more than 15mm in the container is poured. The expected penetration sample is cooled in 60 min in air and 60 min in water before testing. The standard needle is positioned to get a penetration value for 5sec and is noted.

The penetration value obtained is represented in 80-100 or 80/100 grade bitumen at standard consistence and it range from 20-225mm.

In cold region bitumen with High penetration value is used. In warm region low penetration value is used ex. 30/40 grade.

The factors which affect the Penetration test is test temperature, needle size and weight and period of cooling.

2. Softening point:

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. A viscosity material like bitumen or tar doesn‟t have a well defined

softening point. However a std test determines the temperature at which a std ball will pass through a disc of bitumen contained in ring. The test is known as ring & ball test.

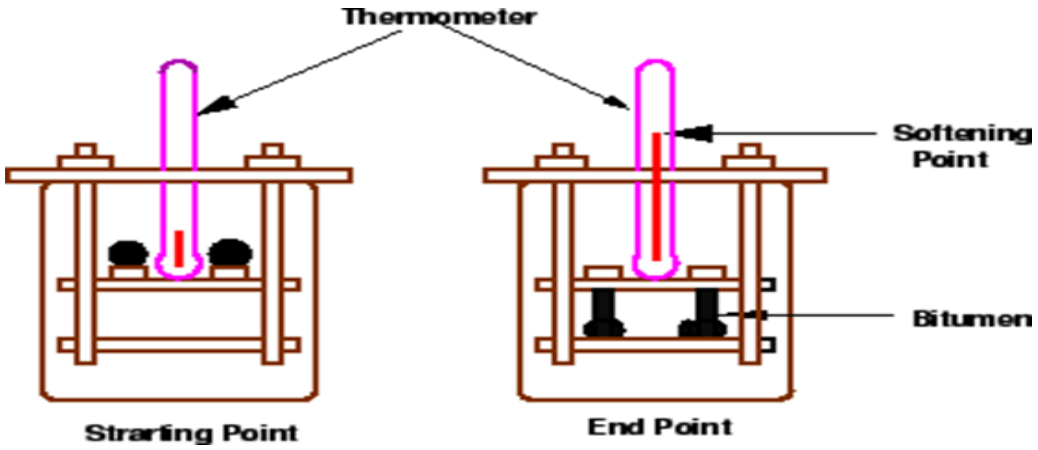
A brass ring of internal dia 17.5 mm at top and 15.9 mm at bottom and of depth 6.4mm.The steel ball of 9.5mm dia and 2.5g. Support distance is 25mm between the bottom of the ring and top surface of the bottom plate of support is provided. Glass container of 85mm dia and 120mm depth is used. The bitumen is heated to poring consistency and poured into ring and cooled for half an hour before testing. A brass ring containing the bitumen sample is suspended in H2O or glycerin at given temperature a steel ball is placed on the disc of bitumen. The liquid medium is then heated at a rate of 50C increase per minute. Metal plate placed at a specified bituminous material touches the bottom at the softening point. With increase in temperature bitumen melts and come down with the weight of ball at particular temperature it touches the bottom plate that point temperature is noted.

The softening point is range between 35 to 750C.

The liquid water is used for bitumen having softening point less than 800C and Glycerine is for softening point more than 800C.

Higher softening point indicates lower temp. susceptibility and in warm climet.

The factors which affect the softening points are quality and type of liquid used, weight of ball, distance between bottom of the ring and bottom base plate and rate of temperature.



3. Ductility test:

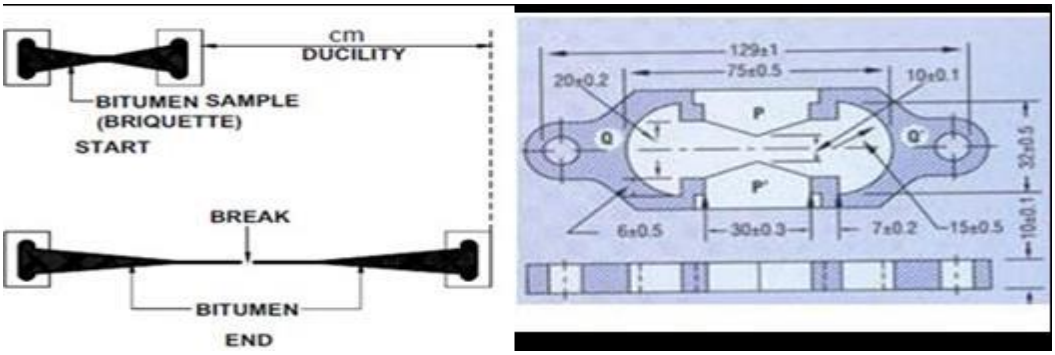
In flexible pavement construction it is important that the binders form ductile thin film around the aggregate. This serves as a satisfactory binder in improving the physical interlocking of the aggregate bitumen mixes. Under traffic loads the bitumen layer is subjected to repeated deformation and recoveries. The binder material which does not possess sufficient ductility would crack and thus provide pervious pavement surface. The test is believed to measure the adhesive property of bitumen and its ability to stretch. The ductility of a binder is an indication of its elasticity & ability to deform under load & return to original condition upon removal of the load. A material which doesn‟t possess adequate ductility would crack under a load.

This is unsatisfactory since water can penetrate into the surfacing through there cracks. The property is determined by measuring the distance that a std briquette of bitumen, necked to a

cross section of 1 sq-cm will stretch without breaking when elongated at a rate of 5 cm/min at 270C. The ductility values should be a minimum of 50 as per IS.

The briquette mould is filled with bitumen and cool for 30 min in air and 30 min in water before testing. Then it is fixed to expanding machine assembly which stretches the bitumen at a rate of 5cm/min and expands till to break and the point is noted by scale.

The factors which affect the ductility is pouring and test temperature, dimension of briquette mould, rate of pulling and period of cooling.



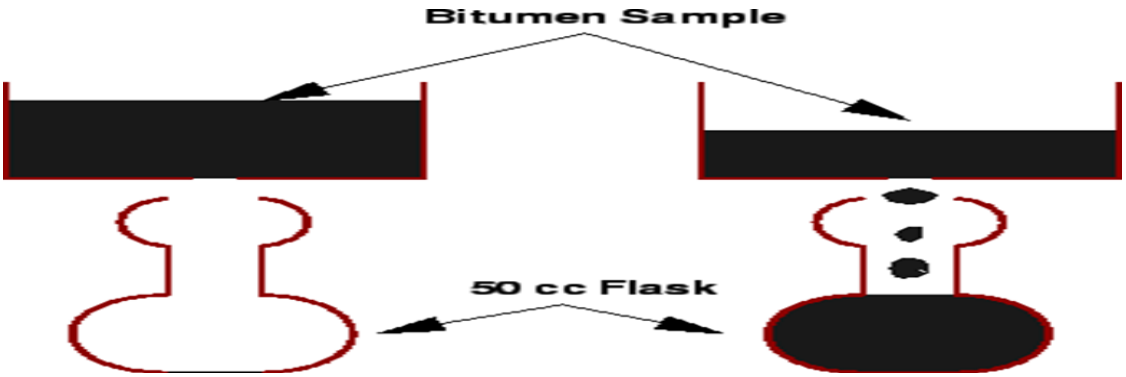
4. Viscosity Test:

Viscosity is the property of a fluid that determines the resistance offered by the fluid to a shearing force under laminar flow conditions, it is thus the opposite of fluidity.

The determination of viscosity is generally done by efflux viscometers. They work on common principles, though they differ in detail. The liquid under test is poured to a specified level into a container surround by water or oil bath providing temperature control at the base of the container is a small orifice with a simple valve control on opening valve, the time in seconds is recorded for a stated quantity of liquid to discharge into a measuring liquid below.

The different type of viscosity testing operator is there they are Efflux viscometer, Standard tar viscometer (10mm dia orifice and 50ml fluid to discharge), Saybolt furol viscometer (3mm dia orifice and 60ml fluid to discharge).

The bitumen is placed in to a standard tar viscometer or efflux viscometer and its temperature is raised to test temperature specified (35, 40, 45, 55& 600C). When the temperature reaches respective test temperature orifice valve is open time elapse is noted to collect the bitumen of 50ml. The time required to collect a bottom container of 50ml is five indirectly the viscosity of bitumen. Then is specified in VG 10, VG20, VG 30 and VG 40.



5. Specific gravity test:

In most applications bitumen is weighed, but finally in use with aggregate the bitumen content is converted on volume basis. Hence determine of specific gravity value is required for conversion of weight to volume. Specific gravity of a binder doesn‟t influence its behavior but all the same, its value is needed for mix design.

Specific gravity of bitumen varies from 0.97 to 1.02. Specific gravity of tar varies from 1.16 to 1.28.

There are two methods to test the specific gravity of bitumen

A.Pycnometer method

B. Balance method

Generally balance method is used in that a cup of 50ml capacity is used and it is oiled before using. The bitumen is poured in to cup and cooled and its weight e is noted and weight of cup with bitumen when immersed in distilled water is weighed f. Specific gravity of bitumen is the ratio of e to the difference between (e and f).

It is used to convert the weight in to volume. Determines Purity of bitumen if the impurity present in the bitumen by showing high value of specific gravity.

6. Heat stability test:

When a bituminous binder is heated continuously it starts emitting volatile vapors above a certain temperature and these volatile vapors can momentarily catch fire in form of flash and continued heating get fired.

A.Flash point:

The flash point of bitumen is that temperature at which it gives off vapors, which ignites in the pressure of a flame, but don‟t continue to burn. The flame point is an induction of critical temperature at & above which suitable precautions should be taken to eliminate fire hazards. The ISI test describes the Penske-Martin method. The method involves a cup into which the bitumen is filled. The bitumen sample is then heated at a rate of 5-60C/min stirring the material continuously.

The test flame is applied at intervals. The flash point is taken at the temperature read on the thermometer when flame causes a bright flash in the interior of cup in a closed system & at the surface of material in open system. It is 2200c.

B.Fire point test:

If heating is continued beyond the flash point, the vapors ignite in the pressure of a flame & continue to burn indicating the fire point temperature. There is no standard method to determine the spontaneous ignition temperature, which can only broadly indicate.

C.Loss on heating test:

The effect of heat on a bituminous binder is the loss of volatile constituents. This loss causes the binder to harden. Thus one method of testing the desirable property of a binder is to find out the loss on heating. This is achieved by an accelerated heating test a 50gm sample is weight is taken and maintained at a temperature of 1600c for 5hours. Then it expressed as a percentage of loss in original weight is determined.

7. Solubility test:

It has already been indicated that all bitumen are substantially soluble in CS2. This is one of the points that define bitumen. Hence any impurity in bitumen in the form of inert minerals, carbon, salts etc. could be quantitatively analyzed by dissolving the samples of bitumen in any of the two solvents.

A sample of 2g of bitumen is dissolved in 100ml of solvent and filtered in soluble material is washed, dried and weighed then it is expressed in percent of original sample. The Indian specifications require 99% solubility.

8. Thin film oven test:

In this test, a sample of bitumen is subjected to hardening conditions as would be expected during hot mixing operations. A 50ml sample of bitumen is placed in a flat bottomed sample pan 140mm inside diameter & 10mm deep, the weighed sample & container are placed in a shelf which rotates at 5 to 6 rpm for 5 hrs in a ventilated oven maintained at 1630C. The loss in weight of the sample is expressed as % of the original weight. This method is then used for identify short term aging or hardening of bitumen.

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 materials from which tar is derived, it is referred to as wood tar or coal tar. It is more widely used for road work because it is superior.

There are five grades of roads tar: RT-1, RT-2, RT-3, RT-4 and RT-5, based on their viscosity and other properties.

RT-1 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.

RT-5 is adopted for grouting purposes, which has highest viscosity among the road tars.

The various tests carried out on road tars are:

a) Specific gravity test

b) Viscosity test on standard tar viscometer

c) Equiviscous temperature (EVT)

d) Softening point

e) Softening point of residue

f) Float test

g) Water content

h) Phenols, percent by volume

i) Naphthalene, percent by weight

j) Matter insoluble in toluene, percent by weight

k) Distillation fraction on distillation up to 200°C, 200°C to 270°C and 270°C to 330°C

Bitumen Emulsion

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. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions

can be measured as per IS:8887- 1995.Threetypes of bituminous emulsions are available, which are Rapid setting(RS),Medium setting (MS),And Slow setting (SC).Bitumen Emulsions are ideal binders for hill road construction. Where Heating of bitumen or aggregates are difficult. Rapid Setting emulsions are used for surface dressing work. Medium Setting emulsions are preferred for premix jobs and patch repairs work. Slow setting Emulsions are preferred in rainy season.

Cutback bitumen

Normal practice is to heat Bitumen to reduce its viscosity. In some situations preference is given to use liquid binders such as cutback bitumen. In cutback bitumen Suitable solvent is used to lower the viscosity of the bitumen. From the environmental point of view also cutback bitumen is preferred. 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. 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.

PAVEMENT DESIGN:

OVERVIEW

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to pro Vide a surface of acceptable riding quality, adequate skid resistance, favorable light reacting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed Bearing capacity of the sub-grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements.

One of the main purposes of pavement design is to produce a soil structure system that will carry traffic smoothly and safely with minimum cost. The increase in axle load and phenomenal growth of traffic warrant as much importance in design, construction and maintenance of roads.

Pavement: A multi-layer system that distributes the vehicular loads over a larger area

Highway pavement is a structure consisting of superimposed layers of selected and processed materials whose primary function is to distribute the applied vehicle load to the sub grade. Pavement is the upper part of roadway, airport or parking area structure

REQUIREMENTS OF A PAVEMENT

The pavement should meet the following requirements:

• Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil

• Structurally strong to withstand all types of stresses imposed upon it

• Adequate coefficient of friction to prevent skidding of vehicles

• Smooth surface to provide comfort to road users even at high speed

• Produce least noise from moving vehicles

Dust proof surface so that traffic safety is not impaired by reducing visibility.

• Impervious surface, so that sub-grade soil is well protected

• Long design life with low maintenance cost.

Objectives of highway pavement

• To provide a stable, non-yielding surface to allow heavy wheel loads to move with least possible rolling resistance

• Provide even surface along the longitudinal profile to enable fast vehicles to move safely and comfortably at design speed

• Reduce and distribute the traffic loading so as not to damage the subgrade

• Provide vehicle access between two points under all-weather conditions

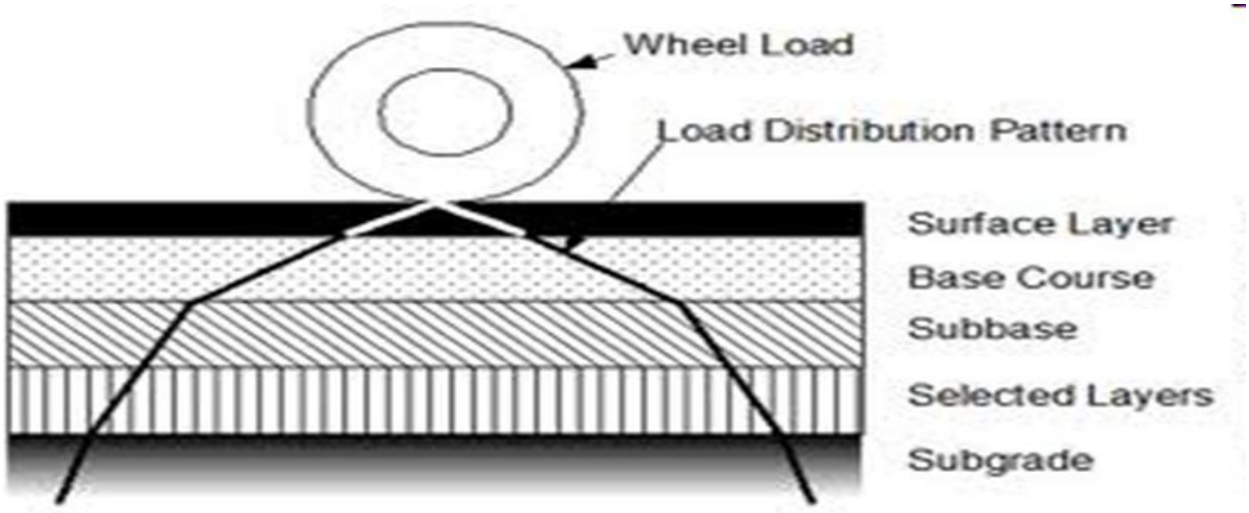
• Provide safe, smooth and comfortable ride to road users without undue delays and excessive wear & tear

• Meet environmental and aesthetics requirement

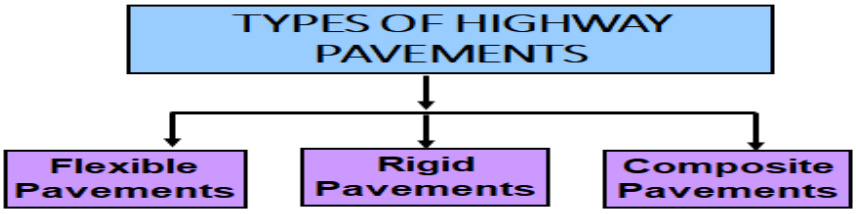
• To transfer the load stresses through wider area on the soil subgrade below

• Magnitude of stresses transferred to the subgrade soil through pavement layers is considerably lower than contact pressure under wheel load on pavement surface

• This depends on thickness and characteristics of materials used in different pavement layers



Classification of Pavement



FLEXIBLE PAVEMENTS

Flexible pavements are those which have Low or negligible flexural strength and are rather flexible in their structural action under the loads.

The flexible pavements layers may Reflects recoverable and non-recoverable deformations of the lower layers including the subgrade on to the upper layers and also to the pavement surface. Thus if the lower layer of the pavement or soil subgrade gets deformed or undulated due to permanent deformation, the flexible pavement layers and also the pavement surface may get undulated to somewhat similar pattern.

The vertical compressive stress is maximum on the pavement surface directly under the wheel load and is equal to the contact pressure under the wheel. Due to the ability Of the flexible pavement layers to distribute the compressive stresses to a larger area in the shape of a truncated cone, the compressive stresses get decreased at the lower layers. Therefore by taking advantage of the stress distribution characteristics of the flexible pavement layers, the "pavement layer system concept' was developed. According to this, the flexible pavement may be constructed consisting of a number of layers and the top layer has to be the strongest as the highest compressive stresses are to be sustained by this layer, in addition to the wear and tear due to the moving traffic and the varying factors due to the weather.

The lower layers of the pavement have to take up only lesser magnitudes of stresses and there is no direct wearing action due to traffic loads and weathering action due to environmental factors and therefore inferior materials with lower cost can be used in lower layers. The lowest layer consists of selected soil which is compacted to the required thickness and density and is called the subgrade' which is laid over prepared/compacted local soil or fill.

Typical layers of conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade. In order to take maximum advantage of this property, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) at the bottom.

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).

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,

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

Binder course

This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage and frost resistance. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

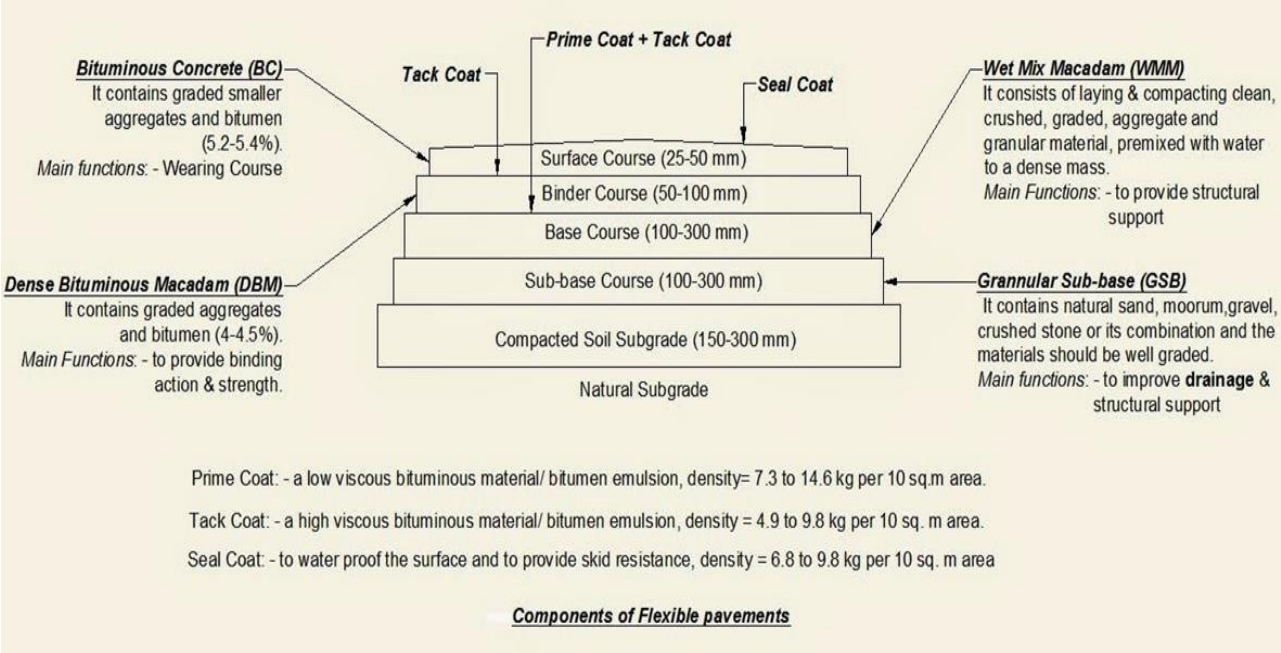
Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, minimize frost action damage and reduce the intrusion of fines from the sub-grade in the pavement structure.

If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course. A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided. It also provides a working platform for construction.

Sub-grade

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.



FACTORS AFFECTING DESIGN AND PERFORMANCE OF FLEXIBLE PAVEMENTS

Factors to be considered in Design of Flexible Pavements Design of Flexible Pavement consists of two parts:

(i) mix design of materials to be used in each pavement component layer (ii) thickness design of the pavement and the component layers The materials used in the pavement layers have to withstand the expected stresses and deterioration caused by the traffic loads and various other climatic and environmental factors. The pavement layers are constructed with appropriately designed mixes using aggregates and binders. Bituminous mixes are designed and laid on surface course of flexible pavements as this layer has to withstand the stresses, wear and tear and deterioration caused by the moving traffic and effects of climate and other factors. The design factors and methods for the structural design of flexible and rigid pavements are presented in this chapter. The various factors to be considered for the dessign of flexible pavements are given below: (a) Wheel loads of heavy vehicles or the traffic loads (b) Subgrade soil (c) Climatic factors (d) Pavement component materials in different layers (e) Drainage and Environmental factors

Equivalent single wheel load

To carry maximum load with in the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load

having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth. The procedure of finding the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

equalancy concept is based on equal stress;

• Contact area is circular;

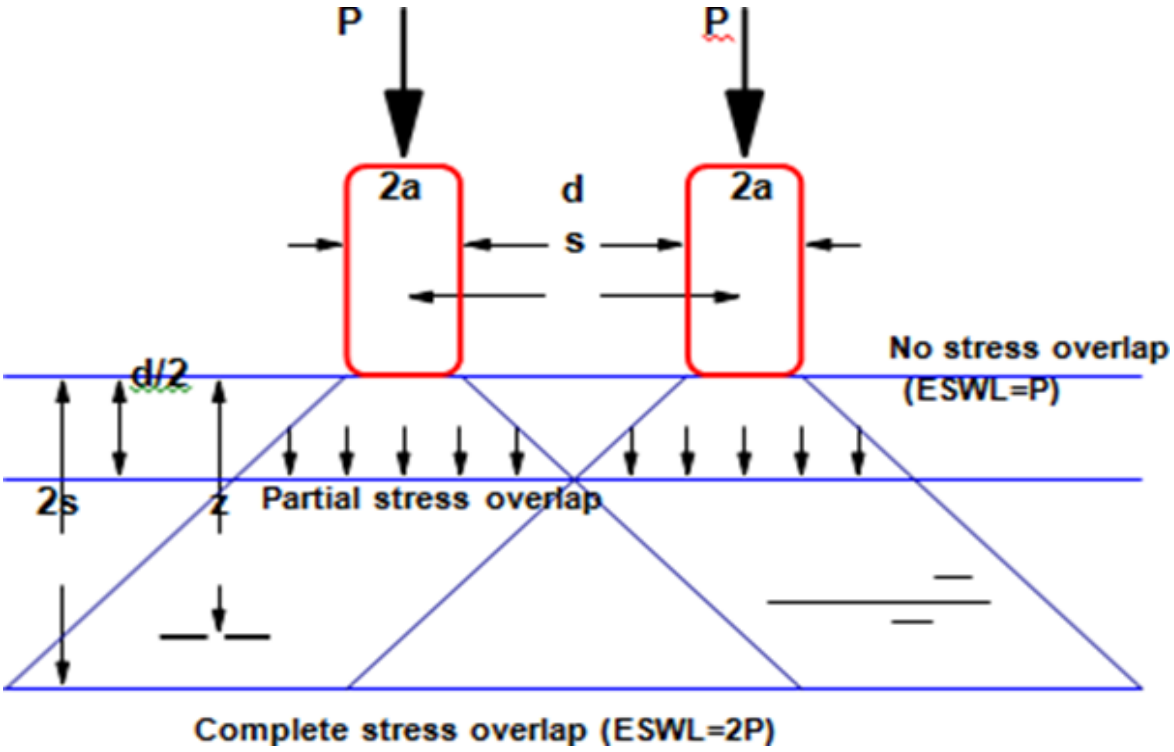
• Influence angle is 45o; and

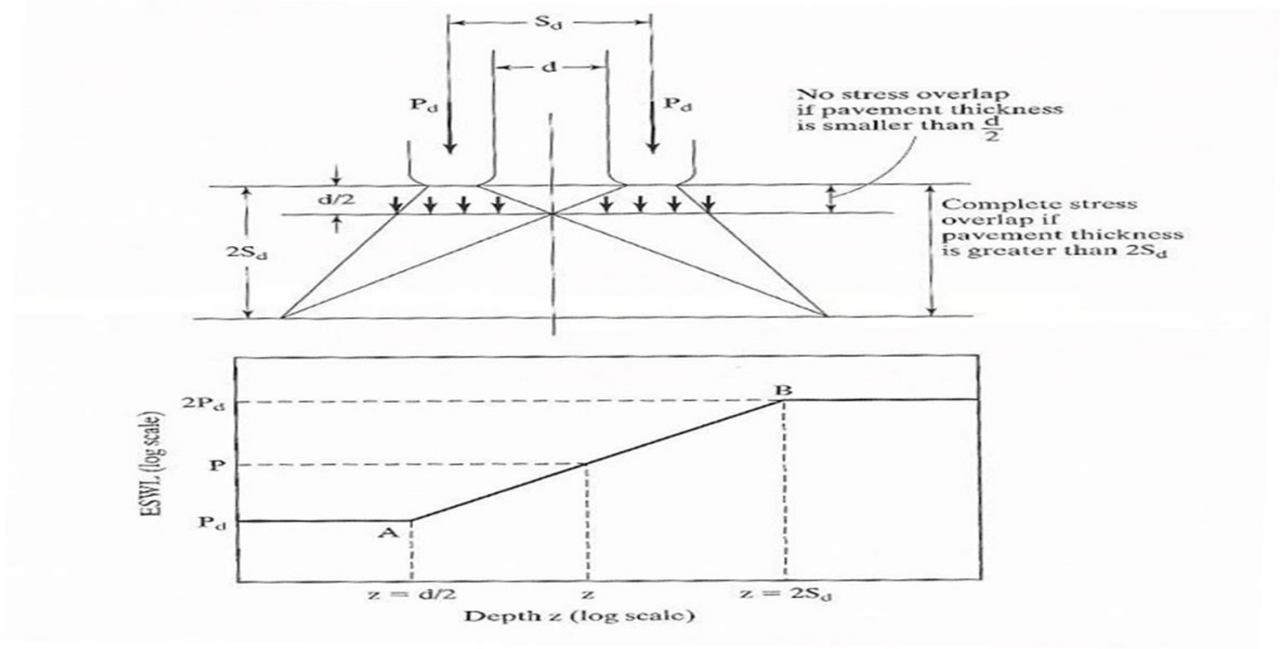
• Soil medium is elastic, homogeneous, and isotropic half

The ESWL is given by

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}(\frac{z}{d/2})}{\log_{10}(\frac{2S}{d/2})}$$

Where P is the wheel load, S is the Center to center distance between the two wheels d is the clear distance between two wheels, and z is the desired depth.

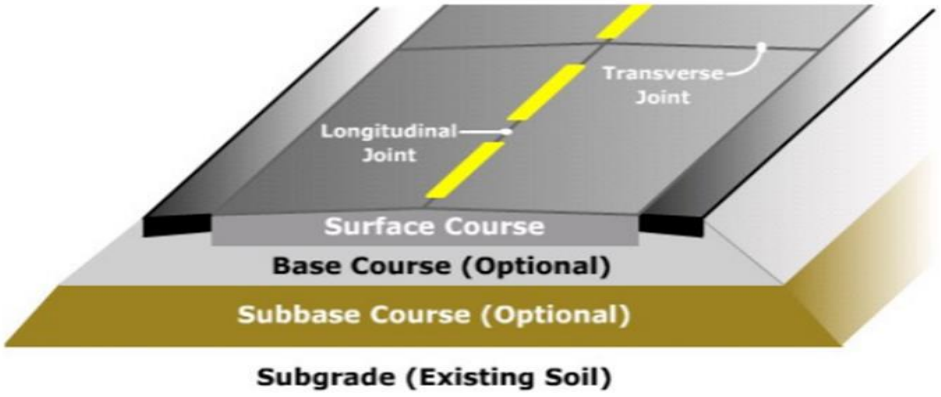




Rigid pavements :Rigid pavements are those which possess noteworthy flexural strength or flexural rigidity The rigid pavements are generally made of Portland cement concrete (CC) Therefore called "CC pavements Plain cement concrete pavement slabs made of specified strength characteristics are laid, with or without steel reinforcement at the joints Most common material used for the design and construction of rigid pavements is high quality plain cement concrete meant for the pavement, generally called Pavement Quality Concrete' (PQC) The CC pavement slabs made of POC are generally expected to sustain up to 45 kg/cm of flexural stresses. In rigid pavements the stresses are not transferred from grain to grain to the lower layers as in the case of flexible pavement layers. The rigid pavement has the 'slab action and is capable of transmitting the wheel load stress through a much wider area below the pavement slab The rigid pavement does not get deformed to the shape of the supporting layer below, as the pavement slab can bridge the gap or minor variations of the surface of the supporting layer below. The main point of difference in the structural behaviour of rigid pavement as compared to the flexible pavement is that the critical condition of stresses in the rigid pavement is the maximum flexural stress occurring at certain critical locations of the CC slab due to the combined action of wheel load and the temperature changes. Flexural stresses are developed at different locations of the CC pavement slab depending on the relative location of the wheel load with respect to its of position on the CC slab and the also the effect of temperature changes at the location at that point of time of the day or night. The stresses in rigid pavements are analysed using the elastic theory, assuming the pavement as an elastic plate resting over an elastic or a viscous foundation Tensile stresses are developed at the bottom or top of the CC slab, depending on the location due to the bending of the slab under wheel load and the temperature variations at the specific location and time of observation. Thus, the types of stresses developed and their distribution within the cement concrete pavement c are quite different when compared to the stresses that are developed in the flexible pavement layers. The cement concrete pavement slab made of POC can very well serve as a good wearing surface as well an effective base course.

The cement concrete pavement slab is not laid directly over the soil subgrade, considering the desirable long life of CC pavements.

A good base or sub-base course laid under the CC pavement slab along with a good drainage layer underneath increases the life of the pavement considerably and therefore works out more economical in the long run. Therefore, the rigid pavement structure of major roads catering for heavy traffic loads consists of (from bottom towards the top): (a) soil subgrade (b) drainage layer (C) lean cement concrete dry lean concrete (DLC) base course or a good granular sub-base course and Pavement slab. The CC pavements are usually designed and constructed for a design life of 30 years or even higher period. Generally a well designed and constructed CC pavement struucture will not require major maintenance work except maintenance of the drairnage system and the joints of the CC pavement.



Typical layers of conventional Rigid pavement includes Concrete slab or surface course, Granular base or stabilized base course, Granular subbase or stabilized subbase course, Frost protection layer and Subgrade soil

Concrete Slab

The concrete slab is the top most layer of rigid pavement which is in direct contact with the vehicular loads. This is also called as surface course. It is water resistant and prevents the water infiltration into the base course. It offers friction to the vehicles to provide skid resistance. The thickness of concrete slab is kept between 150 mm to 300 mm.

Granular Base or Stabilized Base Course

The base course or granular base or stabilized base is the second layer from the top and is constructed using crushed aggregates. This course helps the surface course to take additional loads. It provides stable platform to construct rigid pavement

It is also useful to provide sub surface drainage system. In frost areas, the frost action can be controlled by the stabilized base course. It helps to control swelling of subgrade soil. The base course thickness should be minimum 100mm.

Granular Subbase or Stabilized Subbase Course

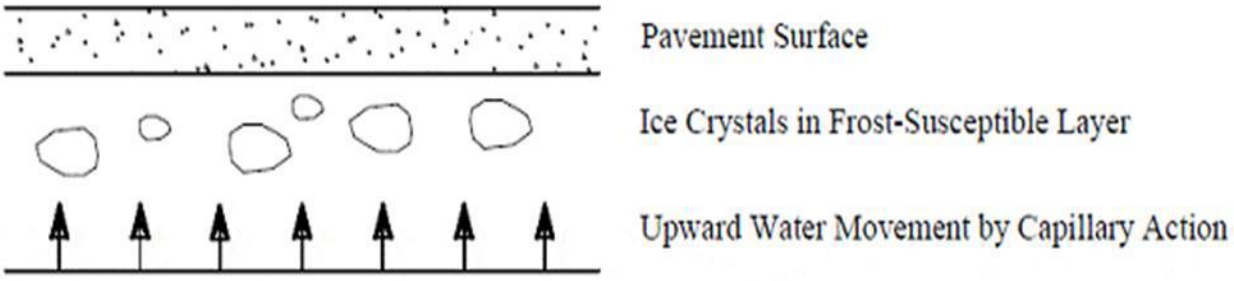
It is the third layer from the top and is in contact with the subgrade soil and base course. It is constructed by using low quality aggregates than the base course but they should be better quality than subgrade.

Generally sub base course is not required when the traffic loading is light. When the loading exceeds 100000 pounds it should be constructed.

Its primary function is to provide support for the top layers and it also serves as frost action controller and prevents the intrusion of fines from subgrade to top layers. The drainage facility will also improve when there is a subbase course. Frost Protection Layer

In low temperature regions there is a problem of frost action on the pavements. If the soil contains high ground water table, during low temperatures the water will freeze and frost heave will formed under the subgrade which will cause the pavement to rise because of non-uniform formation of ice crystals.

Similarly, when the ice melts the pavement will penetrate into the subgrade when load comes on it. To overcome this frost protection layer should be provided. Generally a good base course and subbase course themselves acts as frost protection layers.



Formation of Ice Crystals in Frost-Susceptible Soil

Subgrade Soil

The subgrade is nothing but the existing soil layer which is compacted using equipment to provide stable platform for rigid pavement. The subgrade soils are subjected to lower stresses than the top layers since the stresses will reduce with depth.

Subgrade soils may vary considerably. The stresses coming from the top layers are received by different soils in different manners. Some soils may resist them and some may not. It is depends upon the interrelationship of texture, density, moisture content and strength of subgrade. So, proper examination should be done on subgrade before construction.

At the same time the pavement layers above the subgrade should be capable of reducing stresses imposed on the subgrade soil to prevent the displacement of subgrade soil layers.

Difference between Flexible Pavements and Rigid Pavements:

	Flexible Pavement	Rigid Pavement
1.	It consists of a series of layers with the highest quality materials at or near the surface of pavement.	It consists of one layer Portland cement concrete slab or relatively high flexural strength.
2.	It reflects the deformations of subgrade and subsequent layers on the surface.	It is able to bridge over localized failures and area of inadequate support.
3.	Its stability depends upon the aggregate interlock, particle friction and cohesion.	Its structural strength is provided by the pavement slab itself by its beam action.
4.	Pavement design is greatly influenced by the subgrade strength.	Flexural strength of concrete is a major factor for design.
5.	It functions by a way of load distribution through the component layers	It distributes load over a wide area of subgrade because of its rigidity and high modulus of elasticity.
6.	Temperature variations due to change in atmospheric conditions do not produce stresses in flexible pavements.	Temperature changes induce heavy stresses in rigid pavements.
7.	Flexible pavements have self healing properties due to heavier wheel loads are recoverable due to some extent.	Any excessive deformations occurring due to heavier wheel loads are not recoverable, i.e. settlements are permanent

MODULE-4

Pavement Construction

Pavement Construction: Design of soil aggregate mixes by Routhfuch'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 subbase, 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.

Layers in a Bituminous Pavement

The different layers that are involved in a bituminous pavement are:

1. Base Course
2. Binder Course
3. Concrete layer of bitumen or asphalt

- The layer of mineral aggregates like gravel, stones, and sand together form the bituminous base course layer. This layer is treated as the foundation for the laying the binder and the surface course.
- The bituminous binder course is the second layer above the base course which acts as the first layer of bitumen. This is done in a two-layer resurfacing. This is also called as a leveling course.
- The third layer is the concrete form of bitumen or asphalt. The bituminous concrete is a combination of aggregates that is continuously graded from the maximum size which is mainly less than 25mm to the fine filler of size smaller than 0.075mm to make the mix sufficiently impervious. This provides a layer will have acceptable levels of dissipative and elastic properties.

Main Constituents of Bitumen Mix and their characteristics

The main constituents of a bitumen mix for pavement construction are:

1. Coarse and Fine Aggregates
2. Filler

3. Binder

- The coarse aggregates are known for their abrasion resistance and toughness. These aggregates offer compressive and shear strength to the mix. The fine aggregates fill the voids in the mix created by the coarse aggregates and provide stiffening to the binder. Examples: sand and rock dust. Fillers play the role of filling the voids; they help in stiffening the binder and offer higher permeability. Examples: cement, lime and rock dust. Binders also play the role of filling the voids. These help to undergo particle adhesion and for gluing purpose. This hence increases the impermeability property of the pavement. Examples for this type of the binder are bitumen, tar, and asphalt.
- The gradation of the selected coarse aggregates should be such that the combined aggregates can fulfill the specified or desired gradation of the mixed aggregates. Selection of maximum size of coarse aggregate in the mix should be based on the compacted thickness the layer in which the mix is to be laid. Fine aggregates may be either manufactured or natural sand or a mix of both. The filler material consists of finely powdered mineral matter (85 to 100 percent passing 0.075 mm sieve) such as hydrated lime,

- Portland cement or rock dust or a mix of these, based on the requirements. Appropriate type and grade of bituminous binder is selected depending on the climate conditions, with particular reference to the actual temperature range at the site.
- The stability of the compacted bituminous mix mainly depends on the gradation of the aggregate mix used; the type, grade and percentage of bituminous binder in the mix also contributes towards the stability of the mix. The flexibility of the compacted bituminous mix depends mainly on the binder content and the filler-binder system in the mix.

Types of Bitumen Mixes

There are different types of mix that can be prepared. They Involve:

1. Open-graded bituminous mix
2. Well graded bituminous mix
3. Gap-graded bituminous mix
4. Unbounded bituminous mix

- In case of **Open-Graded bituminous Mix**, the filler and the finer aggregates are absent. These mixes are porous in nature and offer good frictional properties. This lowers the strength if the pavement is constructed for a high-speed pavement construction.
- **Gap-Graded Bituminous Mix**: As the name implies, large coarse aggregates are missing in these types of mix. This has good fatigue property as well as tensile strength.
- **Well – Graded Mix**: A well-graded mix is a dense mix. These have all ranges of aggregates and are sufficiently packed. This facilitates the proper filling of voids in a systematic manner. These types of mix offer good compressive strength and tensile strength**.**

Desirable properties of bituminous mix

The important requirements of well-designed bituminous mixes for use in flexible pavement layers are given below:

a) Adequate stability of the mix to withstand the stresses and deformations due to the repeated application of wheel loads; this may be achieved by selecting suitable type and gradation of aggregates, appropriate binder and its proportion.

b) Adequate flexibility of the mix to withstand fatigue effects and development of cracks during service life of the pavement; to be achieved by selection of proper mix of aggregates and binder

c) Adequate resistance to permanent deformation such as rutting due to movement of heavy wheel loads during hot weather; this may be achieved selection of good quality of aggregates, ensuring its appropriate gradation densification of the mix during compaction.

d) Possess adequate resistance to low-temperature cracking under traffic movements this may be achieved by selection of suitable type and grade of bituminous binder.

e) Durability to sustain the combined effect of adverse weather and repeated traffic loads; this may be achieved by arriving at correct bitumen binder content during mix design to ensure adequate thickness of binder-film around the aggregate particles.

f) Possess sufficient air voids to prevent 'bleeding' of the binder as a consequence of further densification of the bituminous mix under traffic movements and also reduction of skid resistance under wet conditions; this may be achieved by selecting appropriate shape and gradation of aggregates and binder content and ensuring adequate air voids in the compacted mix at the stage of mix design.

g) Possess adequate resistance due to moisture induced damage; this may be achieved by minimizing permeability of the compacted bituminous mix and selection of appropriate binder quality or aggregates in the mix and adequate binder content.

h) The bituminous surface should ensure adequate skid resistance even after continued traffic movements; this requirement may be met by selecting aggregates with suitable texture, shape, gradation and ensuring good resistance to polishing or high polished stone value of the coarse aggregates in the mix.

i) The hot mix should have adequate workability of the mix at the mixing, laying and compacting temperatures

Design of Bituminous Mixes/ Steps in Mix Design Method

There are mainly two stages of mix design in bringing a bituminous pavement:

1. Dry Mix Design
2. Wet Mix Design

In the bitumen mix design, we will determine the:

1. Proportion of bitumen
2. The fine aggregates required for the pavement design and construction
3. The coarse aggregates for the construction
4. The filler materials required

Objective of Bituminous Mix Design

The main objective of the bituminous mix design is to proportion various components for pavement construction to achieve the following objectives:

1. To obtain a durable pavement, sufficient amount of bitumen is required

2. Adequate strength must be provided to obtain resistance against the shear deformation under higher temperatures.

3. Additional voids have to be incorporated to facilitate the compaction performed by the traffic

4. The placement must be performed with ease which will demand sufficient workability

5. The premature cracking in the bitumen pavement can be avoided by providing sufficient flexibility for the bitumen.

6. The flexibility must be attained at smaller temperatures so that the shrinkage cracks can be avoided.

The following steps may be followed for a rational design of a bituminous mix.

a) Selection of Aggregate- Aggregates having sufficient strength, hardness, toughness, soundness are selected. Crushed aggregates and sharp sands produce a mix of higher stability compare to natural gravel and rounded sands.

b) Selection of Aggregate Grading

The density and stability of the mix depend on the gradation or grain size distribution of aggregate. Gradation has a profound effect on mix performance. It might be reasonable to believe that the best gradation is one that produces maximum density. This would involve a particle arrangement where smaller particles are packed between larger particles, thus reducing the void space between particles. This creates more particle-to-particle contact, which in bituminous pavements would increase stability and reduce water infiltration. However, some minimum amount of void space is necessary to:

- provide adequate volume for the binder to occupy,
- promote rapid drainage, and
- Provide resistance to frost action for base and sub base courses.

A dense mixture may be obtained when this particle size distribution follows Fuller law which is expressed as:

P=100(dD)

where,

p is the percent by weight of the total mixture passing any given sieve sized,

D is the size of the largest particle in that mixture, and

n is the parameter depending on the shape of the aggregate (0.5 for perfectly rounded particles).

Based on this law Fuller-Thompson gradation charts were developed by adjusting the parameter n for fineness or coarseness of aggregates. Practical considerations like construction, layer

thickness, workability, etc, are also considered. For example Table below provides a typical gradation for bituminous concrete for a thickness of 40 mm

For a proposed 40 mm thick bituminous concrete layer or bituminous concrete course. The specified gradation of aggregate mix is shown in following table:

Sieve size, mm	Percent passing, by weight	
	Grade 1	Grade 2
20	-	100
12.5	100	80-100
10.0	80-100	70-90
4.75	55-75	50-70
2.36	35-50	35-50
0.6	18-29	18-29
0.3	13-23	13-23
0.15	8-16	8-16
0.075	4-10	4-10
Binder content, percent by weight of mix	5-7.5	5-7.5

If the available gradation is not satisfying the specification or specified gradation proper blending of different grades is to be adopted for this purpose, either by the method of trials and error or Rothfuch's method. Generally densely textured aggregate (well graded) is specified instead of open texture (poorly graded or gap graded). To attain higher stability, higher maximum size aggregate is selected. However the max size of aggregate used depends on compacted thickness of particular layer. Therefore gradation or max size is specified by the designer or user such as IRC.

c) Determination of Specific Gravity

The specific gravity of aggregate mix is represented as bulk specific gravity or apparent specific gravity or effective specific gravity of mix. If the overall volume of the aggregate mix is considered, the bulk specific gravity is obtained in the apparent or effective specific gravity. The volume of capillary which are filled by the water on 21 hours of soaking or immersion is excluded. When the different aggregate are mixed to obtain required gradation, the specific gravity of combined mixture is denoted as 'Ga' is determined using equation.

$$Ga = \frac{100}{W1/G1 + W2/G2 + W3/G3 + W4/G4 + ...}$$

Where,

W1, W2, W3, W4, ... = percent by weight of aggregates

G1, G2, G3, G4, ... = specific gravity of each material used in mix

In the above equation, the total weight of aggregate mix is considered which will be in the numerator then this equation gets modified.

$$Ga = \frac{W1 + W2 + W3 + ...}{W1/a1 + W2/a2 + W3/a3 + ...}$$

Where,

W1, W2, W3, ... = actual weight of component used in the mix.

d) Proportioning of Aggregates

As a first step the design grading is selected based on the type of construction, thickness of the layer and its specification if any. After selecting the aggregates and their gradation, proportioning of aggregates has to be done and following are the common methods of proportioning of aggregates:

• **Trial and error procedure:** Vary the proportion of materials until the required aggregate gradation is achieved.

• **Graphical Methods:** Two graphical methods in common use for proportioning of aggregates are, Triangular chart method and Roch's method. The former is used when only three materials are to be

mixed. Using the graphical method suggested by Rothfuch's . The required method of each component is to be determined to satisfy the design gradation.

• **Analytical Method:** In this method a system of equations are developed based on the gradation of each aggregates, required gradation, and solved by numerical methods. With the advent of computer, this method is becoming popular and is discussed below. The resulting solution gives the proportion of each type of material required for the given aggregate gradation.

Rothfuch's method for proportioning of aggregates

The proportions of aggregate directly affect the performance of mix depending on their shape, texture, and strongly on the gradation. The determination of aggregate proportions depends strongly on the number of aggregate types to be blended, and the limits of the desired gradation.

Aggregates in HMA can be divided into three types according to their size: coarse aggregates (retained on sieve 4.75 mm), fine aggregates (passing sieve 4.75 mm retained on sieve 0.075 mm), and filler (passing sieve 0.075 mm) . Accordingly, in order to find the gradation which gives the desired properties of HMA, it is necessary to understand aggregate blending. The blending of aggregates is a process in which two, three, or more of aggregates, which have different types of sources and sizes, are mixed together to give a blend with a specified gradation.

The blending of aggregates is done because:

- There are no individual sources, sizes, and types of aggregates (natural or artificial) that individually can supply aggregate of gradation to meet a specific or desired gradation.
- It is more economical to use some natural sands or rounded aggregates in addition to crushed or manufactured aggregates, and this process (mixing natural and crushed) cannot be held without using a blending operation. There are different methods and techniques which can be employed to find percentage values. None of these should give a blend outside the specified grading. Obviously, there may be several acceptable combinations. An optimal combination is achieved when the blended or composite percentages match the original desired percentages.

- The determination of aggregate proportions depends strongly on; firstly, the number of aggregate types to be blended; if the number increased, then the determination becomes more complex. Secondly, the range and limits of the target gradation specification. Regardless of which method will be used, there are two important pieces of information that must be known before finding the proportion values. These are the sieve analysis of each material, and the limits of desired specifications.

Procedure:

1. First, sieve analysis of the different selected soils is to be carried out in the laboratory. The results of the grain size distribution are tabulated giving the different sieve sizes and the cumulative percentages passing each sieve, ranging from zero to 100%.

2. The desired gradation is to be decided either based on recommended grain size distribution tables or by using a theoretical equation like Fullers equation assuming an appropriate value of gradation index, n.

3.On a plain graph paper, the cumulative percentages passing various sieves ranging from 0 to 100% are plotted to natural scale on the Y-axis. The X-axis is to represent different particle sizes, but not to any specified scale to be plotted later.

4. The point representing 100 % passing located on the Y-axis represents maximum size of the set of sieves used in the sieve analysis, through which 100% of all the selected materials will pass.

5. A sloping straight line of convenient slope is drawn from this 100% passing point on the Y-axis, to a point corresponding to zero percent passing, lying on the X-axis. The smallest sieve size that will be made use of, will be near this point on the X-axis, before the 0.0% passing. This sloping line represents the 'balancing straight line' of the desired gradation of the mixed aggregates.

6. Using the grain size distribution Table, the cumulative percentage passing any particular sieve size is selected and a line is drawn parallel to the X-axis so that the line intersect the sloping line at a point and from that point of intersection, a line parallel to the Y-axis is drawn to intersect the X-axis. This point on the X-axis marked as the grain size representing the selected sieve size.

7. As an example, in Figure below, let the percentage passing 10 mm sieve be 62%. Then corresponding to 62 % on Y-axis, a dotted line is drawn parallel to X-axis to intersect the sloping line at a particular point from which another dotted line is drawn parallel to Y-axis to intersect the X-axis at a particular point; this point is marked as 10, to represent 10 mm grain size on the X-axis. Similarly each of the other points on the X-axis is plotted from the grain size distribution table to represent various sieve sizes that were used in the sieve analysis test, making use of the respective values of percentage passing each sieve size.

8. It may be noted that the particle sizes plotted on the X-axis are not to a particular scale. The scale of grain sizes plotted on the X-axis varies such that the 'desired grain size distribution' curve on this graph represented by the sloping line is a straight line. In other words, the particle size scale on X-axis is such that the desired gradation is straight line which was drawn first.

9. Now on this chart, the grain size distribution curves of the selected materials to be mixed are plotted. For example, three materials A. B and C available locally are to be mixed. The grain size distribution curves of these three materials are plotted as shown in Fig. below. The balancing straight lines of A, B and C are obtained, allowing only minimum of the areas equally on either side of the balancing lines. The opposite ends of the balancing straight lines of A and B are joined, (i.e., zero percent passing of material A is joined with 100 percent passing of B) Similarly the opposite ends of balancing lines of B and C are joined

10. The points where these two lines meet the sloping line desired gradation line) indicate the proportions in which the materials A, B and Care to be mixed. These values may be read from the Y-axis (or from the line parallel to the Y-axis) by projecting the points of intersection of the sloping line, as shown in Fig. below.

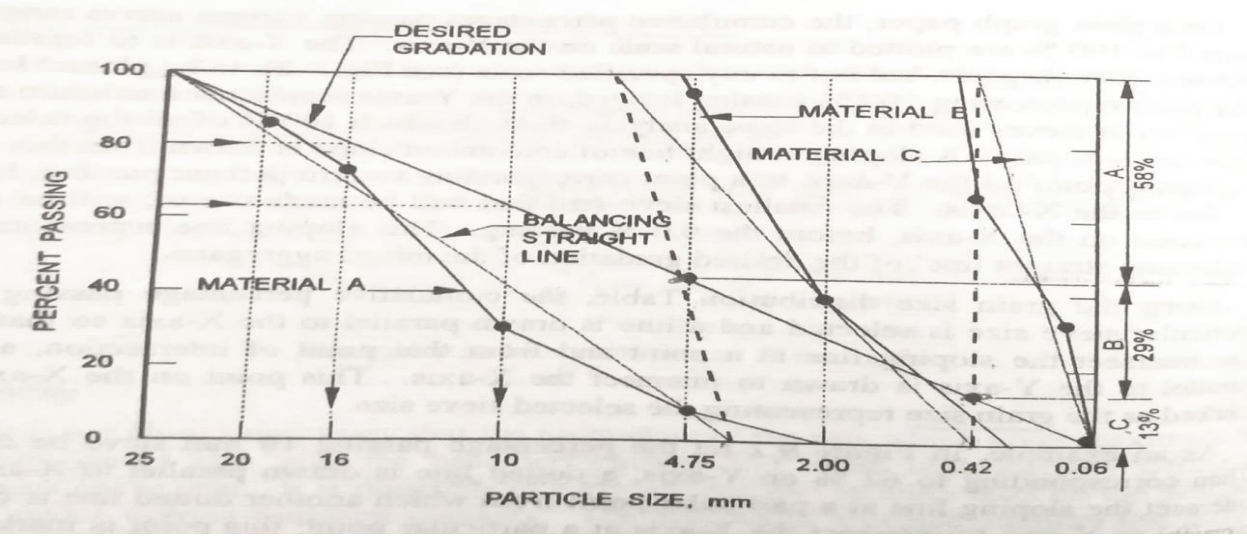
11. The proportion in which the three materials A. B and C are to be mixed as per this example are given below

Material A- 58%

Material B-29% &

Material C 13%

Total mix= 100%



e) Preparation of Specimen or Sample

The preparation of specimen depends on the stability test method employed. Hence the size of the specimen, compaction and other specification should be followed as specified in the stability test method. The stability test methods which are in common use for the design mix are Marshall, Hubbard-Field and Hveem. Hence after deciding the test methods, the specimens are moulded as per specification.

f) Determination of Specific Gravity of Compacted Specimen

Knowing specific gravity of aggregate mix 'Ga' and that of bituminous binder 'Gb', the theoretical maximum specific gravity of the sample or specimen is determined using the equation Gt=100((100−Wb)+(Wb)Gb)

g) Stability Tests on Compacted Specimens

One of the stability tests is carried out based on the design method selected.

h) Selection of Optimum Bitumen Content

The optimum bitumen content is selected based on the test method adopted and the design requirements considered.

Bituminous mix design methods

Different methods are available for testing the compacted specimens of bituminous mixes in the laboratory and for the design of bituminous mixes. These include,

(i) Marshall stability test and mix design method
(ii) Hveem stabilometer test and mix design method
(iii) Hubbard Field test method and
(iv) Super-pave mix design method.

Marshall mix design method has been specified by the IRC and MORTH Specifications for use in India.

CEMENT CONCRETE AS A PAVEMENT MATERIAL

Introduction

Cement concrete is a mixture of coarse aggregates, fine aggregates, cement and water in suitable proportions. Sometimes admixtures are also added to achieve specific behaviour/ property of the material. The components of cement concrete are briefly introduced in the following sections.

Portland cement concrete (PCC) pavements (or rigid pavements) consist of a PCC slab that is usually supported by a granular or stabilized base, and a subbase. In some cases the PCC slab may be overlaid with a layer of asphalt concrete.

Portland cement concrete is produced at a central plant and transported to the job site in transit mixers or batched into truck mixers directly and then mixed at the project site. In either case, the PCC is then dumped, spread, leveled, and consolidated, generally using concrete slip-form paving equipment.

Materials: Basic components of PCC include coarse aggregate (crushed stone or gravel), fine aggregate (usually natural sand), Portland cement, and water. The aggregate functions as a filler material, which is bound together by hardened Portland cement paste formed by chemical reactions (hydration) between the Portland cement and water. In addition to these basic components, supplementary cementitious materials and chemical admixtures are often used to enhance or modify properties of the fresh or hardened concrete.

Concrete Aggregate: The coarse and fine aggregates used in PCC comprise about 80 to 85 percent of the mix by mass (60 to 75 percent of the mix by volume). Proper aggregate grading, strength, durability, toughness, shape, and chemical properties are needed for concrete mixture strength and performance.

Portland cement and Supplementary Cementitious Materials: Portland cements are hydraulic cements that set and harden by reacting with water, through hydration, to form a stone like mass. Portland cement typically makes up about 15 percent of the PCC mixture by weight. Portland cement is manufactured by crushing, milling, and blending selected raw materials containing appropriate proportions of lime, iron, silica, and alumina. Most Portland cement particles are less than 0.045 mm (No. 325 sieve) in diameter.

Portland cement combined with water forms the cement paste component of the concrete mixture. The paste normally constitutes about 25 to 40 percent of the total volume of the concrete. Air is also a component of the cement paste, occupying from 1 to 3 percent of the total concrete volume, up to 8 percent (5 to 8 percent typical) in air entrained concrete. In terms of absolute volume, the cementing materials make up between about 7 and 15 percent of the mix, and water makes up 14 to 21 percent.

Supplementary cementitious materials are sometimes used to modify or enhance cement or concrete properties. They typically include pozzolanic or self-cementing materials.

Pozzolanic materials are materials comprised of amorphous siliceous or siliceous and aluminous material in a finely divided (powdery) form, similar in size to Portland cement particles that will, in the presence of water, react with an activator, typically calcium hydroxide and alkalis, to form compounds possessing cementitious properties. Descriptions of various kinds of pozzolans and their specifications are provided in ASTM C618. Self-cementing materials are materials that react with water to form hydration products without any activator.

Supplementary cementitious materials can affect the workability, heat released during hydration, the rate of strength gain, the pore structure, and the permeability of the hardened cement paste.

Coal fly ash that is produced during the combustion of bituminous coals exhibits pozzolanic properties. Silica fume is also a pozzolanic material consisting almost entirely (85 percent or more) of very fine particles (100 times smaller than Portland cement) that are highly reactive.

Coal fly ash produced during the combustion of subbituminous coal exhibits self-cementing properties (no additional activators, such as calcium hydroxide, are needed). Similarly, ground granulated blast furnace slag reacts with water to form hydration products that provide the slag with cementitious properties.

Coal fly ash and ground granulated blast furnace slag can be blended with Portland cement prior to concrete production or added separately to a concrete mix (admixture). Silica fume is used exclusively as an admixture.

Chemical and Mineral Admixtures

An admixture is a material, other than Portland cement, water and aggregate, that is used in concrete as it is mixed to modify the fresh or hardened concrete properties. Chemical admixtures fall into three basic categories. They include water-reducing agents, air-entraining agents, and setting agents. Chemical admixtures for concrete are described in ASTM C494.

Water-reducing agents are chemicals that are used to reduce the quantity of water that needs to be added to the mix, at the same time producing equivalent or improved workability and strength.

Air entrainment increases the resistance of concrete to disintegration when exposed to freezing and thawing, increases resistance to scaling (surface disintegration) that results from deicing chemicals, increases resistance to sulfate attack, and reduces permeability. Air entrainment can be accomplished by adding an air-entraining admixture during mixing. There are numerous

commercial air entraining admixtures manufactured. Descriptions and specifications are described in ASTM C260.

Setting agents can be used to either retard or accelerate the rate of setting of the concrete. Retarders are sometimes used to offset the accelerating effect of hot weather or to delay the set when placing of the concrete may be difficult. Accelerators are used when it is desirable to gain strength as soon as possible to support design loads. Calcium chloride is an active material that is most commonly used as an accelerator. Setting agents (retarders and accelerators) are described in greater detail in ASTM C494.

Concrete paving material

The mix proportions for concrete paving mixtures are determined in the laboratory during mix design testing. This involves determination of the optimum characteristics of the mix in both the plastic and hardened states to ensure that the mix can be properly placed and consolidated, finished to the required texture and smoothness, and will have the desired properties necessary for pavement performance. Properly designed, placed, and cured concrete paving mixtures should be evaluated for the following properties:

Freshly Mixed (Plastic) Concrete

Slump – slump is an indication of the relative consistency of the plastic concrete. Concrete of plastic consistency does not crumble but flows sluggishly without segregation.

Workability – workability is a measure of the ease of placing, consolidating, and finishing freshly mixed concrete. Concrete should be workable but not segregate or bleed excessively.

Setting Time – knowledge of the rate of reaction between cementing materials and water (hydration) is important to determine setting time and hardening. The setting times of concrete mixtures do not correlate directly with the setting times of the cement paste because of water loss and temperature differences.

Air Content – the amount of entrapped or entrained air in the plastic concrete can influence the workability of the concrete mixture and reduce its propensity for bleeding.

Hardened Concrete

Strength – concrete pavements must have adequate flexural strength to support the design traffic loads (repetitions of loaded axles) that will be applied over the service life of the facility. While compressive strength can also be measured, flexural strength is more relevant to the design and performance of concrete pavements.

Density – the density of concrete paving mixes varies depending on the amount and relative density of the aggregate, the amount of air that is entrained or entrapped, and the water and cementing materials content of the concrete.

Durability – the hardened concrete pavement must be able to resist damage from freezing and thawing, wetting and drying, and chemical attack (e.g., from chlorides or sulfates in deicing salts).

Air Content – the finished and cured concrete should have adequate entrained air in the hardened cement paste to be able to withstand cycles of freezing and thawing.

Frictional Resistance – for user safety, the surface of an exposed concrete pavement must provide adequate frictional resistance and resist polishing under traffic. Frictional resistance is a function of the aggregates used and the compressive strength of the concrete.

Volume Stability – concrete paving mixtures must be volumetrically stable and must not expand due to alkali aggregate reactivity. Concrete paving mixtures should not shrink excessively upon drying.

Earthwork:

Construction Procedure -

1. Setting out - After the site has been cleared, the work should be set out. The limits of embankment are marked by fixing batter pegs on both sides at regular intervals. The subgrade should be wider than the design dimension so that surplus material may be trimmed.

2. Dewatering - If the foundation of the embankment is in area with stagnant water, it is feasible to remove it by bailing out or pumping.

3. Stripping & Storing top soil - In localities where most of the available embankment materials are not conductive to plant growth, the top soil from all areas of cutting shall be stripped to specified depths not exceeding 150mm & stored in stock piles of height not exceeding 2m for covering embankment slopes.

4. Compacting ground supporting embankment / subgrade - where necessary, the original ground shall be leveled to facilitate placement of first layer of embankment, scarified, mixed with water and then compacted by rolling so as to achieve minimum dry density as given in table. In case difference in subgrade level and ground level is less than 0.5m & the ground does not have 97% relative compaction, the ground shall be loosened up to a level 0.5m below the subgrade level, watered & compacted in layers to not less than 97% of dry density.

Table 1: Density requirements of embankment and subgrade materials

Sl.no.	Type of work	Max lab dry unit weight when tested as per IS- 2720
1	Embankment upto 3m height, not subjected to extensive flooding	Not less than 15.2 kN/m^3
2	Embankment exceeding 3m height or embankments of any height subject to long period of inundation.	Not less than 16.0 kN/m^3
3	Subgrade & earthern shoulders/verger/backfill	Not less than 17.5 kN/m^3

Table 2: Compaction requirements for embankment and subgrade

Sl.no.	Type of work	Relative compaction %max lab dry density
1	Subgrade and earthen shoulders	Not less than 97
2	Embankment	Not less than 95
3	Expansive soils Subgrade & 500 mm portion just below the subgrade Remaining portion of embankment	 Not allowed Not less than 90

In high embankments, resting of suspect foundation as revealed by borehole logs shall be out in a manner and to the desired depth.

5. Spreading material in layers & bringing to appropriate moisture content

a. The embankment & subgrade material shall be spread in layers of uniform thickness not exceeding 200mm compacted thickness over the entire width of embankment by mechanical means, finished by a motor grader & compacted.

b. Moisture content of the material shall be chocked at this site of placement prior to commencement of compaction; water shall be sprinkled from a water tanker filled with sprinkler capable of applying water uniformly.

c. Moisture content of each layer should be checked with respect to table-1 in accordance with IS-2720.

d. Clods or hard lumps of earth shall be broken to have max size of 75mm when placed in embankment & max size of 50 mm when placed in subgrade.

e. Embankments & other areas of unsupported fills shall not be constructed with steeper side slopes, or to greater widths.

f. Whenever fills is to be deposited against the face of a natural slope, steeper than 1 verticle on 4 horizontal, such faces shall be benched

6. Compaction :

a. Smooth wheeled vibratory, pneumatic tyred, sheep foot or pad foot rollers of suitable size and capacity should be used for different types & grades of materials.

b. Mostly compaction will be done with vibratory toller of 80 to 100KN static weight or heavy pneumatic tyred roller.

c. Each layer of the material shall be thoroughly compacted to the densities in table-1, subsequent layers should be laid only after the finished layer has been tested.

d. The measurement of field dry density is recorded by nuclear moisture / density gauge.

e. When density measurement revel any soft areas in embankment, further compaction is carried out

7. Drainage

The surface of embankment at all times during construction shall be maintained at such across fall as will shed water and prevent ponding.

8. Repairing of damages caused by rain / spillage of water:

a. The soil in the affected portion shall be removed in such areas before next layer is laid & refilled in layers & compacted using small vibratory roller, plate compactor or power rammer to achieve the required density.

b. Tests shall be carried out to ascertain the density requirements of the repaired area.

9. Finishing operations

a. It shall include the work of shaping & dressing the shoulders /verge / road bed & side slopes to conform to alignment, levels, cross sections & dimensions.

b. Both the upper & lower ends of side slopes shall be rounded off & to merge the embankment with adjacent terrain to improve appearances.

c. The top soil, removed & conserved earlier shall spread over the fill slopes, before spreading the slopes should be roughened and moistened slightly to provide bond and is provided to a depth of 75mm to 150mm for plant growth.

d. When earthwork is completed, the road area shall be cleared of all debris & ugly scars.

Quality Control Tests

Quality control tests for Embankments, Subgrade construction.

Sl.no.	Type of test	Frequency of tests
1	Sand content	2 tests per 3000 cubic meter of soil
2	Plasticity test	2 tests per 3000 cubic meter of soil
3	Density test	2 tests per 3000 cubic meter of soil
4	Deleterious content	As and when required
5	Moisture Content	1 test for 250 cubic meter of soil
6	CBR test (Soaked and Unsoaked)	1 test per 3000 cubic meter of soil

Compaction Control - At least one measurement of density for each 1000 sqm of compacted area, test locations should be chosen with random sampling techniques. Control should be based on the mean value of 5-10 density determinations. The number of tests in one set of measurements shall be 6. For earth work in shoulders at least one density measurement for every 500 sqm for the compacted area should be made and the number of tests in each set shall be at least 10.

2. Granular sub base layer

1. Specification of material:

1. The materials to be used for the work shall be natural sand, moorum gravel, crushed stone or combination depending on grading requirement.

2. The materials shall be free from organic or deleterious constituents & should conform to one of the three grading's given in table 400-1.

3. The gradings in Table 400-1 are in respect of close graded granular sub base materials, & Table 400-2 for coarse graded materials.

Table 400 - 1- Grading for close graded granular sub-base materials

IS Sieve Desination	Percentage by weight passing the IS Sieve		
	Grading- I	Grading-II	Grading-III
75.0mm	100	-	-
53.0mm	80-100	100	-
26.5mm	55-90	70-100	100
9.5mm	35-65	50-80	65-95
4.75mm	25-55	40-65	50-80
2.36 mm	20-40	30-50	40-65
0.425mm	10-25	15-25	20-35
0.075mm	3-10	3-10	3-10
CBR value min	30	25	20

Table 400-2: Grading for coarse graded granular sub-base materials

IS Sieve Designation	Percentage by weight passing the IS Sieve		
	Grading-I	Grading-II	Grading III
75.0mm	100	-	-
53.0mm	-	100	-
26.5mm	55-75	50-80	100
9.5mm	-	-	-
4.75mm	10-30	15-35	25-45
2.36 mm	-	-	-
0.425mm	-	-	-
0.075mm	<10	<10	<10
CBR value min	30	25	20

2. Physical Requirements:

a) The material shall have 10% finer value of 50KN or more.

b) If the water absorption value for coarse aggregates exceeds 2%, soundness test is carried out

c) The material passing 425 micron sieve for all 3 gradings shall have liquid limit & plasticity Index not more than 25 & 6%

3. Construction Operations

a) Preparation of sub grade - Before laying sub base, the sub grade should be prepared by removing vegetation & extraneous matter, lightly sprinkled with water if necessary & rolled with two passes of 80- 100KN smooth wheeler roller

b) Spreading & Compacting -

a) The sub base material should be spread on prepared sub grade with help of motor grader, its blades having controls for maintaining the required slope & grade.

b) When sub-base have combination of materials, mixing is done mechanically, Manual mixing is permitted where the width of laying is small for mechanical operations.

The equipment used for min - in place construction is rotavator.

c) Moisture control of loose material shall be checked with IS -2720 & suitably adjusted by Sprinkling water from truck mounted or trailer mounted water tank.

d) At the time of compaction, water content should be from 1% above to 2% below the optimum moisture content

After adding water it is processed by harrows, rotavators until the layer is uniformly wet.

f) Immediately rolling will start, if the thickness of compacted layer does not exceed 100mm, a smooth wheeled roller is used. For a compacted single layer upto 225mm vibratory roller or heavy pneumatic tyred roller of min 200 to 300KN wt is used.

g) Rolling will start from lower edge & proceed towards upper edge longitudinally to achieve super elevation & unidirectional cross fall & should start at both edges & progress towards centre for portions having cross fall on both sides.

h) Each pass of roller shall uniformly overlap not less than one third of track made in preceding pass. The speed of roller shall not exceed 5 km per hour.

i) Rolling is continued till the density is achieved at least 98% of MDD for the material determined.

j) The surface of any layer of material on completion of compaction shall be will closed free from movement under compaction equipment & from compaction planes, ridges, cracks or loose materials. If so happens it should be re -compacted.

c) Surface Finish & Quality control of work - The surface finish of construction & control on the quality of materials & works shall be in accordance with section 900; the tests to be conducted are as below.

D) Quality control tests on Granular Sub-Base layer

Sl.no.	Type of test	Frequency
1	Gradation	One test per 200m^3
2	Atterberg Limits	One test per 200m^3
3	Moisture content prior to compaction	One test per 250m^3
4	Density of compacted layer	One test per 500m^3
5	Deleterious Constituents	As required
6	CBR	As required

3. Water Bound macadam:

I. Specification of materials –

a) **Coarse aggregates** - It can be either crushed or broken stone, crushed slag, over burnt brick aggregates or naturally occurring aggregates such as Kankar & Laterite: The aggregates shall conform the physical requirements said in table 400 - 6. If the water absorption is greater than 2% the soundness test shall be carried out.

Table 400 - 6 physical requirements of coarse aggregates for water hound Macadam for sab base/base courses.

Sl.no.	Type of test	Test method	Requirements
1	Los angeles abrasion value or Aggregate impact value	Is-2386 Or Is- 5640	40% (Max) 30% (Max)
2	Combined flakiness and elongation index	IS-2386	30% (Max)

Crushed Slag - It is made from air cooled blast furnace slag. It should be angular shape, reasonably uniform in quality & density. The weight of crushed slag shall not be less than 11.2 kN/m3 & percentage of glossy material shall not be more than 20, water absorption should not be more than 10% ,sulphur content should not exceed 2%.

ii. **Crushed or Broken Stone** - It should be hard, durable & free from excess flat, elongated, soft & disintegrated particles, dirt & other deleterious material.

iii. **Over burnt (jhama) brick aggregates** - It should be made from over burnt bricks or brick hats & be free from dust & deleterious materials.

iv. **Grading requirement of coarse aggregates** - The course aggregates shall conform to one of the gradings given in table 400-7 the use of Grading No -1 shall be restricted to sub-base courses only.

Grading No.	Sieve Range	IS Sieve Designation	Percent by weight passing
I	90mm to 45 mm	125mm	100
		90mm	90-100
		63mm	25-60
		45mm	0-15
		22.4mm	0-5
II	63mm to 45mm	90mm	100
		63mm	90-100
		53mm	25-75
		45mm	0-15
		22.4mm	0-5
III	53mm to 22.4mm	63mm	100
		53mm	95-100
		45mm	65-90
		22.4mm	0-10
		11.2mm	0-5

The compacted thickness for a layer with Grading - I shall be 100mm while for layer with other gradings 2 & 3 should be 75mm.

v. Screenings - It is used to fill voids in coarse aggregates which consists of same material as the coarse aggregate. Such as non-plastic materials like moorum or gravel is used provided liquid limit & plasticity Index are below 20 & 6 respectively & fraction passing 75 micron sieve does not exceed 10%. Screenings should conform to the grading serial in table 400 - 8. It should be

omitted in case of soft aggregates such as brick metal, kankar, laterites etc as they get crushed under rollers.

Table 400 - 8 Grading for Screenings:

Grading classification	Size of screenings	IS sieve Designation	Percent by weight passing IS Sieve
A	13.2mm	13.2mm 11.2 mm 5.6 mm 180micron	100 95-100 15-35 0-10
B	11.2mm	11.2mm 5.6mm 180 micron	100 90-100 15-35

Binding Material - It is used as a filler material for WBM having PI value less than 6, the quantity of binding material to be used depend on type of screening. Generally, the quantity required for 75 mm compacted thicknesses will be 0.06 0.09m3/10m2 and for 100mm compacted thickness it will be around 0.08-0.01m3/10m2.

II. Construction Operations

a) Preparation of Base:

- The surface of subgrade/ sub base to receive WBM coarse shall be prepared to specified lines & cross fall & made free of dust & other materials.
- Levelling course is used to correct the irregularities in the profile.
- Laying of WBM over thick bituminous layer is avoided due to the internal drainage of the pavement at the interface of 2 courses.
- Where the intensity of rain is low & the interface drainage facility is efficient WBM can be laid over the existing thin bituminous surface by cutting 50mm X 50mm furrows at an angle of 45° to the centre line at one metre interval.

b) Invented Choke

- If WBM is to be laid directly over subgrade, a 25mm coarse of screening B or coarse sand is spread before application of aggregates.

- In case of find sand or silty or clayey subgrade, it is advisable to lay 100mm of screening or coarse sand on top of fine grained soil.
- As an alternative to inverted choke, geo synthesis are used for separation & drainage over the prepared subgrade.

c) Spreading Coarse Aggregate

- The coarse aggregates shall be spread uniformly & evenly upon the prepared subgrade in thickness not more than 100mm for Grading - 1 & 75mm for Grading - II & III.
- The spreading shall be done from stockpiles along the side of road way to directly from vehicles. No segregation between aggregates is allowed & it must be of uniform gradation with no fine material
- The surface of the aggregates shall be checked carefully by removing or adding aggregates at high or low spots & it is checked with a straight edge.
- The coarse aggregates should not normally be spread more than 3 days,

d) Rolling -

- Rolling is started immediately after spreading by three wheeled power rollers, or tandem or vibratory rollers 80 to 100KN static weight.
- Except on superelevated portions where the rolling will proceed from inner edge to outer & it begins from edges gradually progressing towards centre.
- During rolling, slight sprinkling of water may be done if necessary.
- Rolling is not done when subgrade is soft or yielding or when it cause a wave like motion in the subgrade or sub base course. The rolled surface shall be checked transversely & longitudinally with templates & connected or re-rolled to derived camber & grade.
- Materials getting crushed during compaction should be removed & replaced. Shoulders are built up simultaneously along with WBM courses

e) Application of Screening

- After the coarse aggregate has been rolled, screenings are applied to fill the voids.
- There shall not be damp or wet at the time of application. Dry rolling shall be done while the screenings are being spread so that it will settle into voids.

- The screenings are spread uniformly in thin layers by hand shovels or by mechanical spreaders or from dipper.
- The screening is applied at a slow & uniform rate so as to ensure filling of voids accompanied by dry rolling & brooming with mechanical or hand brooms or both.
- These operations shall continue until no more screenings fills voids of aggregates.
- The spreading, rolling & brooming of screenings could be completed in one day.

f) Sprinkling of water and grouting-

After the screenings are applied, the surface should be sprinkled with water, swept & rolled. Hand brooms are used to sweep & distribute wet screenings evenly. It is continued until coarse aggregate has been thoroughly keyed, well bonded & firmly set in full depth & a grout has been formed of screenings.

g) Application of Binding Material - After application of screening, binding material is applied in 2 or more thin layers at a slow & uniform rate. After each application water is sprinkled & swept with brooms to fill the voids & rolled. This is continued till a wave head of the wheels of the moving roller is formed on slurry.

h) Setting & drying-

- After final compaction of WBM course, the pavement is allowed to dry overnight.
- Next morning spots be filled with screenings or binding materials & lightly sprinkled with water & rolled.
- No traffic shall be allowed on the load until the macadam has set.
- The compacted WBM course should be allowed to completely dry & set before the next pavement course is laid over it.

III. Quality Control Tests on Water Bound Macadam Course:

Sl.no.	Type of test	Frequency (min)
1	Aggragate Impact valiue	1 test per 200m^3 of aggregate
2	Grading	1 test per 100 m^3
3	Flakiness Index and Elongation Index	1 test per 200m^3 of aggregate
4	Atterberg limits od binding materials	1 test per 324m^3 of binding material

The evaluation of density results and acceptance criteria for compaction control shall be on similar lines to those subgrade/ embankment as discussed earlier.

4. Wet Mix Macadam layer

I. Specification of Materials –

a) Physical requirements of aggregates – Coarse aggregates shall be crushed stone & it should conform to the physical requirements said in Table – 400 – 10.

Sl. No.	Type of Test	Test Method	Requirements
1	Los Angeles abrasion value or Aggregate Impact Value	IS – 2386 IS – 2386	40% (Max) 30% (Max)
2	Combined flakiness & Elongation Indices (Total)	IS – 2386	30% (Max)

If the water absorption value of aggregates is greater than 2%, soundness test is carried out.

a) Grading requirements for WMM is given in table below 400 – II.

IS Sieve Designation	% by weight passing IS Sieve
53.00mm	100
45.00mm	95 – 100
26.50mm	-
22.40mm	60 – 80
11.20mm	40 – 60
4.75mm	25 – 40
2.36mm	15 – 30
0.60mm	8 – 2
0.075mm	0 – 8

Materials finer than 425micron shall have plasticity Index not more than 6.

II. Construction Operations –

a) Preparation of base – It is done us the same as WBM layer as we have discussed earlier.

b) Provision of lateral confinement of aggregates – while constructing WMM, arrangement shall be made for lateral confinement of wet mix. This shall be done by laying in adjoining shoulders along with WMM.

c) Preparation of mix – WMM is prepared in mixing plant where pug mill or pan type mixer of concrete batching plant is used. Optimum moisture for mixing is determined at the time of compaction; water in the WMM should not vary from optimum value. The mixed material should be uniformly wet & no segregation is permitted.

d) Spreading of mix –

- Immediately after mixing it is spread uniformly & evenly on prepared subgrade / sub base / base. In no case it should be dumped in heaps.
- The mix may be spread by paver finisher or motor grader.
- The motor grader is capable of spreading the material uniformly so as to achieve the specified slope & grade.
- No segregation of large & fine particles should be allowed.

e) Compaction –

- After the mix has been laid to required thickness, grade & cross fall the same shall be compacted uniformly to the full depth by roller.
- If the thickness is 100mm single layer, smooth wheel roller is used. For compacted single layer up to 200mm vibratory roller is used.
- Same kind of rolling as in WBM is done as we discussed before.
- A long forms, kerbs, walls or other inaccessible places for rollers, mechanical tampers or plate compactor is used.
- Rolling should not be done when the subgrade in soft.
- If irregularities develop during rolling which exceed 12mm when tested with 3m straight edge, the surface should be loosened & premixed material added or removed.

- Rolling shall be continued till the density achieved is at least 98% of the max dry density for the material.
- After completion, the surface of any finished layer is well closed, free from movement under compaction equipment or any compaction planes, ridges, cracks & loose material.
- All loose, segregated area shall be made good to the full thickness of layer & re compacted.

f) Setting & Drying – After final compaction of wet mix macadam course, the road shall be allowed to dry for 24 hours.

g) Opening to traffic – Preferably no vehicular traffic or any kind should be allowed on finished WMM surface till it has dried & the wearing course is laid.

5. Penetration Macadam and Built up spray grout:

Penetration Macadam- Bituminous penetration macadam is used as base or binder course. The course aggregates are first spread & compacted well. The hot bitumen is sprayed at top, it penetrates in voids & binding some stone aggregates together. Depending on quantity of bitumen spread & extent of penetration, it is called “full grout" & “semi grout" when depth is full or half & is adopted in heavy & moderate rain fall regions respectively.

Built up spray grout [BSG] - It consists of 2 layer composite construction of compacted crushed aggregates with application of bituminous binder after each layer with key aggregates at top to provide a total thickness, 75mm. It is used for strengthing of existing bituminous pavement. A suitable wearing course is invariably provided over this & opened to traffic.

I. Construction procedure for penetration Macadam

a) **Preparation of existing surface** - The underlying course is prepared to uniform grade & is lightly scarified & prime coat may be applied if required.

b) **Spreading the coarse aggregate :** It is spread with proper edge protection by mechanical spreader or hand. A template cut to camber profile is used to achieve cross section

c) Rolling -

- Aggregates are dry rolled with 10-tonne roller
- Rolling is commence from edge & proceeded to chat, the overlap bel ng 30cm.
- Dry competed m e a checked for de med profile gam might edge

d) Bitumen Application:

- The binder is spread uniformly either with pressure distributor or mechanical hand sprayer.
- The quantity of bitumen being 50 & 68kg per 10m2 for 50 & 7mm compacted thickness respectively.

e) The key aggregates are spreaded & rolled & cross profile is checked.

f) Seal Coat - It is applied if another surfacing course is not constructed immediately & traffic is to allowed. The pavement is again rolled.

g) Finishing - The constructed pavement section is checked for its cross profile with template & longitudinal profile by straight edge.

h) Opening to traffic - The finished surface is opened to traffic after a period of 24 hours.

II. Construction procedure for Built up spray grout

a. Preparation of existing base - The depression & pot holes are filled and the surface is brought to required grade and prime coat may be applied.

b. Tack Coat - Heated bituminous binder is applied at a rate of 7.5 to 10 km on WMB surface & 6 to 8 kg on black top surface per 10m2 area.

c. Coarse aggregates are spread at a rate of 0.5m3 per 10m2 area.

d. The aggregates are rolled using 8 to 10 tonnes roller.

e. The second layer of coarse aggregates is spread at 0.5m3 per 10m2 & rolled thoroughly starting from edges.

f. Second application of binder is done at 12.5 to 15kg per 10m2.

g. Key aggregates are applied & spread at 0.13m3 per 10m2 & rolled.

h. Surface Finish - The surface unevenness is checked with 3m straight edge. Longitudinal profile should not have undulations exceeding 12mm. BSG should not be exposed to traffic before providing surface.

6. Bituminous Macadam layer

1. Specification of Materials –

- The grades of bitumen used 30/40, 60/70, 80/100 penetration, Road tar RT – 4, cutback & emulsion are used. Binder content 3-4.5% by weight of mix is used.
- Aggregates:

i	Los Angles abrasion value	50%Max
ii	Aggregate Impact Value	30% Max
iii	Flakiness index	15% Max
iv	Stripping @ 40°C	25% Max
v	Loss with Sodium Sulphate	12% Max

For binder coarse, abrasion & impact value are 40 & 30% respectively.
vi. Grading for 75mm compacted thickness for base coarse and binder coarse.

Percent passing Sieve size(mm)	Base Course		Base or Binder Course
	Grading I	Grading II	Grading III
63.0	100	100	-
50.0	-	90-100	-
40.0	35-70	35-65	100
25.0	-	20-40	70-100
20.0	0-15	-	50-80
12.5	-	5-20	-
10.0	-	-	25-50
4.75	-	-	10-30
2.36	0-5	0-5	5-20
0.075	0-3	0-5	0-4
Binder Content	3-4.5	3-4.5	3-4.5

vii. Grading for 50mm compacted thickness for base course and binder.

Percent passing Sieve size(mm)	Base Course		Base or Binder Course
	Grading I	Grading II	Grading III
50	100	100	-
40	-	90-100	-
25	35-70	50-80	100
10	-	-	70-100
12.5	0-15	10-30	35-60
4.75	-	-	15-35
2.36	0-5	-	5-20
0.075	0-3	0-5	0-4
Binder content	3-4.5	3-4.5	3-6.0

The quantity of aggregates required for 10m2 of BM are 0.60 to 0.75m3 & 0.9 to 1m3 respectively for 50 & 75mm compacted thickness

7. Dense Bituminous Macadam layer

I. Specification of Materials –

a) Bitumen – Grade S65 or A65 (60 / 70), S90 (80 / 100) may be used.

b) Coarse aggregates –

1) Los Angles Abrasion Value 40% Max

2) Aggregates Impact Value 30% Max

3) FI & EI 30% Max

4) Stripping Minimum retained

5) Loss with sodium sulphate 12% Max

6) Water absorption 2% Max

c) Fine Aggregates – should be the fraction passing 2.36mm sieve & retained on 75m sieve.

d) Filler:

IS Sieve Size	%passing by weight
600 M	100
300M	95-100
75M	85-100

e) Aggregate Gradation:

Sieve Size	%passing by weight
37.5mm	100
26.5 mm	90-100
13.2mm	56-80
4.75mm	29-59
2.36mm	19-45
300 micron	5-17
75 micron	1-7

Requirement of Mix –

a	Marshall stability	820Kg
b	Marshall flow	2-4
c	% air voids	3-5
d	VMA	10-12%
e	VFB	65-75
f	Binder content	Not less than 4%

Construction Procedure –

a. Preparation of Base – The surface should be swept clean using mechanical broom & is prepared to uniform grade. Prime coat may be used & tack coat are applied over base.Preparation of mix is same as BM as discussed earlier.

b. Spreading – It is spread by self-propelled paver for spreading, tamping & finishing the mix to desired grade, lines.In restricted areas & narrow widths, manual laying of mix or mechanical paver are used. Temperature is 120o – 160oC at the time of laying.

c. Rolling –

- It is compacted initially by smooth wheeled roller, intermediate rolling by vibratory roller or pneumatic roller & finishing rolling is done by tandem roller.
- The rollers shall not be allowed to stand on pavement which has not been full compacted & temperature is more than 70oC.
- The wheels of roller shall be kept moist to prevent adhesion.
- Rolling with start from edge to centre line of pavement, both directions.
- Each pass of roller shall overlap one by half the width of rear wheel.
- Rolling shall be continued till the density achieved is at least 98%.
- It is completed in all respects before the temp of mix falls below 100oC.

d. Opening to traffic –

- Traffic may be allowed after completion of the final rolling is done.
- DBM is provided with proper wearing course before opening to normal traffic or rain.

8. Bituminous Concrete

I Specification of Materials –

1) Bitumen – Same as DBM

Bitumen, Fine aggregates, Filler, Coarse aggregate are all same as DBM but Grading changes.

IS Sieve (mm)	% passing the Sieve by Weight
26.5	100
19.0	90 – 100
9.5	56 – 80
4.75	35 – 65
2.36	23 – 49
0.3	5 – 19
0.075	2 – 8

Mix Design –

1) Marshall Stability	820Kg (Min)
2) Marshall Flow	2 – 4
3) # air voids	3 – 5
4) VMA	11 – 13%
5) VFB	65 – 75
6) Binder Content	Min 45
7) Water Sensitivity	Min 75%
8) Swell Test	1.5% Max

II. Construction Operations –

- Preparation of Base – The base on which bituminous concrete is to be laid shall be prepared, shaped & conditioned to the specified levels, grade and crossfall (Camber).
- The surface shall be thoroughly swept clean free from dust and other matter using mechanical broom and dust removed by mechanical means or blown off by compressed air. In portions where mechanical means cannot reach, other approved method is used.

- Applying tack coat, preparation of mix, spreading, rolling are same as DBM layer as we have discussed earlier.
- Opening to Traffic – Traffic may be allowed immediately after completion of final rolling when the mix has cooled down to surrounding temperature.

9. Semi Dense Bituminous Concrete:

Specification of Materials -

a) Bitumen - Same as BM (30/40 to 80/100) grade materials are almost same as BM & DGBM course layers which we have discussed earlier.

b) Coarse aggregates, fine aggregates, filler same specification as dense grade bituminous macadam.

c) Mix Design –

1) Marshall Stability	820Kg (Min)
2) Marshall Flow	2 – 4
3) # air voids	3 – 5
4) VMA	13– 15%
5) VFB	65 – 75
6) Binder Content	Min 44%

d) Grading:

Sieve size(mm)	**% by weight passing**		
	Grading I	**Grading II**	**Grading III**
22.4	-	100	100
13.2	100	85-100	79-100
11.2	88-100	70-92	58-90
5.6	42-64	42-64	33-55
2.8	22-38	22-38	22-38
710M	11-24	11-24	6-22
355M	7-18	7-18	4-14
180M	5-13	5-13	2-9
90M	3-9	3-9	0-5

II. Construction Operation:

Construction is similar to Dense BM as discussed earlier.

a) Preparation of Base - The base on which SDBC is to be laid shall be prepared, shaped & conditioned to the specified lines, grades and cross sections. Tack Coat, preparation of mix, rolling is same as DBM

b) Opening to traffic - Traffic may be allowed after completion of final rolling when the mix has cooled down to surrounding temperature.

10. Seal Coat

a) Scope - This work shall consist of application of seal coat for sealing the voids in bituminous surface.

b) Specification of Materials –

• Binder - Suitable grade appropriate to region, traffic, rainfall & other environmental conditions.

• Stone chippings for type (A) & type (B) seal coat- It should consists of angular fragments of clean, hard, durable, tough and free from dust, soft or flaky elongated material, organic matter. It should be 6.7mm size and 0.18mm size respectively,

c) Purpose –

i. To seal the surfacing against the ingress of water.

ii. To develop skid resistance texture.

iii. To enliven an existing dry or weathered bituminous surface,

11. Surface Dressing -

a) Scope: This work shall consists of the application of one coat or 2 coats of surface dressing, each coat consisting of a layer of bituminous binder sprayed on base followed by cover of chippings rolled to form wearing course.

b) Specification of Materials

i. Binder - It should be of suitable grade appropriate to region, traffic, rainfall.

ii. Stone Chipping The stone polishing value should not be less than 55 & water absorption restricted to 1%.

iii. Quantities of Materials For single coat or the first coat of 2 coat surface dressing, 13.2mm size where it passes 100% 22.4min & retained on 11.2mm IS Sieve. For second coat, 11.2mm passing 100% 13.2mm Sieve & retained on 5.6mm Sieve.

c) Purpose

i. To serve as a thin wearing course of pavement & to protect the base course,

ii. To water from the pavement surface and to prevent infiltration of water.

iii. To provide dust - free pavement surface in dry weather & mud-free pavement in wet weather.

Specifications and method of cement concrete pavement construction.

Specification of Materials

For concrete slabs cement, coarse aggregates, fine aggregates and water are required. If reinforcement is provided, steel wire fabric are used & for construction of joints, joint filler & sealer are used.

1. Cement – Ordinary Portland cement is used. In case of urgency rapid hardening cement is used.

2. Coarse Aggregates – The max size should not exceed 1/4th slab thickness. The gradation may range from 50 – 4.75 or 40 – 4.75. The aggregates should be free from iron, purities, cola, mica, clay, alkali, etc., For Physical properties desire limits are –

a) Aggregate Crushing Value : 30% Max

b) Aggregate Impact Value : 30% Max

c) Los Angeles abrasion Value : 30% Max

d) Soundness for sodium sulphate : 12% Max

3. Fine aggregates – Natural sands, crushed stones etc., are used.

4. Proportioning of Concrete – It is proportioned so as to obtain a minimum modulus of rupture of 40Kg/cm2 on field or to develop minimum compressive strength of 280 Kg/cm2 at 28 days.

Construction method

a) Preparation of subgrade and sub base –

- No soft pots are present in subgrade or sub base.
- It should extent atleast 30cm on either side of width to be connected.
- Subgrade is properly drained; minimum modulus of subgrade reaction is 5.54Kg/Cm2.
- The layers should be kept moist when cement concrete is placed.
- Water proof paper may also be used when CC is laid directly.

b) Placing of Forms –

- The steel or wooden forms are used.
- The steel forms are M.S. Channel sections and their depts. Is equal to thickness of pavement and length atleast 3m except on curves < 45m radius.
- Wooden forms are dressed on side, these have minimum base width of 100n for slab thickness or 20cm.
- The forms are jointed neatly and are set with exactness to the required grade and alignment.

c) Batching of Material & Mixing –

- The proportioned mixture is placed into holper in weigh batching plant.
- All batching of material is done on the basis of one or more whole bags of cement, wt of one bag is 50 kg or unit wt of cement is taken as 1440Kg/m3.
- The mixing of concrete is done in batch mixer. So that uniform distribution, uniform is color and homogenous mix is obtained.
- The batch of cement, fine aggregate and coarse aggregate is led together into the mixer. Water for mixing is introduced into the drum within fifteen seconds of mixing.

d) Transportation & Placing of Concrete –

- The cement concrete is mixed in quantities required for immediate use.
- It should be seen that no segregation of materials results while transporting.
- Spreading is done uniformly; certain amount of redistribution is done with shovels.

e) Compaction & Finishing –

- The surface of pavement is compacted either by means of power driven finishing machine or by vibrating hand screed.
- Areas where width of slab is small, hand consolidation and finishing is adopted.
- The concrete is further compacted by longitudinal float. It is help parallel to carriage way and passed gradually from one site to other.
- The slab surface is tested for its grade and level with straight edge.
- Just before the concrete becomes hard, the surface is belted with two ply canvas belt.

- Broom finish is given with fibre broom brush and it is done perpendicular to centerline of pavement.
- Before concrete develop initial set, the edges of slab are carefully finished with an edging tool.

f) Curing of cement concrete –

- **Initial curing** – The surface of pavement is entirely covered with burlap cotton or jute mats prior to placing it is saturated with water and wet side is placed on pavement.
- **Final curing** – Curing with wet soil exposed edges of slabs are banked with soil berm. A blanket of sandy soil free from stones is placed. The soils are thoroughly kept saturated with water for 14 days.
- In impervious membrane method, use of impervious membrane which does not impart a slippery surface to the pavement is used. Liquid is applied under pressure with a spray nozzle to cover the entire surface with a uniform film. It hardness within 30 minutes after its application. The liquid applied immediately after surface finishing.
- When the concrete attains the required strength or after 28days of curing the concrete road is opened to traffic

Quality Control Tests

A) Quality control tests for materials used –

1	Cement	Physical & Chemical Tests	One for each source of supply and occasionally
2	Coarse aggregates & fine aggregates	(i) Gradation (ii) Deleterious constituents	One test for every day work of each fraction of coarse aggregate and fine aggregate.

B) Quality control tests for levels, alignment and texture

1	Level Tolerance	+5mm
2	Width of pavement & position of paving edges	-6mm +-10mm
3	Alignment of joints, widths, depths of dowel groves	To be checked @ one joint per 400m length
4	Surface regularity both transversely	Once a day or one day's work
5	Alignment of dowel bars and tie bars	To be checked in trail length

MODULE-5

HIGHWAY DRAINAGE

INTRODUCTION

Highway drainage is the process of removing and controlling excess surface and subsoil 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:-

1. 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.

2. Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.

3. In some clayey soils variation in moisture content causes considerable variation in flume of subgrade. This sometimes contributes to pavement failure.

4.One of the most important causes of pavement failure by the formation of waves and corrugations in flexible pavements is due to poor drainage.

5. 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.

6. 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.

7. Erosion of soil from top of unsurfaced roads and slopes of embankment, cut and hill side is also due to surface water.

Requirements of Highway Drainage System

1. The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to subgrade.

2. The surface water from the adjoining land should be prevented from entering the roadway.

3. The side drain should have sufficient capacity and longitudinal slope to carry away all the surface water collected.

4. Flow of surface water across the road and shoulders and along slopes should not cause formation of cress 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 islands and 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 (See Fig. 4.9). 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:

1. Hydrologic analysis

2. 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.

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:

1.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.

2.The values of coefficients of run-off C1, C2, C3 etc. from drainage areas A1, A2, A3 etc. are found and the weighted value of C is computed.

3.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. Figure 11.3 may be used for this purpose.

4.Time of flow along the longitudinal drain T2 is. Determined for the estimated length of longitudinal drain L up to the nearest cross drainage or a water course and for the allowable velocity of flow V in the drain i.e., T2 = L.

5.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 = T1 + T2.

6.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.

7.The required longitudinal slope S of the drain is calculated using Manning's formula adopting suitable value of roughness coefficient n.

Example 1

The distance between the farthest point in the turf covered drainage area (with an average slope of 1.5 % towards the drain) and the point of entry to side drain is 200 m. The weighted average value of the run-off coefficient is 0.25. The length of the longitudinal open drain in a sandy clay soil from the inlet point to the cross drainage is 540m. 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-years 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 culver is 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 table seepage flow, percolation of rain water and movement of capillary water and even water vapour. 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 drainage systems. drained by the usual 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 at least 1.0 to 1.2 m the subgrade. In places where water table is high (almost at ground level at times) the best remedy is to 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.

INTRODUCTION

Better highway system provides varied benefits to the society. Improvements in highway results in several benefits to the road users such as :

1. Reduction in vehicle operational cost per unit length of road.

2. Saving travel time and resultant benefits in terms of time cost of vehicles and the passengers

3. Reduction in accident rates.

4. Improved level of service and ease of driving.

5. 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 increasing need for analysis to indicate justification of the expenditure required and the comparative worth of proposed 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 Finance deals with various methods of raising and or providing money for the highway projects.

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:

1.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 and accelerating; 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 improvement in general amenities, social and educational aspects, development of and 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:

1. 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.

2. 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.

3. Cost dependent on speed include cost of fuel, oil and tyre per vehicle-km-time-cost of vehicles, travel time value of passengers, etc.

4. 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.

5. Accident costs.

The costs of vehicle operation and time for unit distance may be taken as:

$T = a + (b+c)$

Speed

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

Therefore the operation costs may be considered to consist various components like motor fuel cost, lubricating oil consumption, tyre costs, vehicle repair and maintenance, depreciation, cost

due to slowing, stopping, idling and standing delays, costs related to pavement surface and its condition, grades, curves and traffic volumes. Also the time costs and accident costs are taken into consideration.

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

1. Right of way

2. Grading drainage, minor structures

3. Major structures like bridges

4. Pavement and appurtenances

5. 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.

Annual Highway Cost

The items to be included while computing annual highway cost are

1. Administration (a portion) Personal service, building, equipment operation, office, insurance etc.

2. Highway operation Equipment. building vehicle operation including capital costs of vehicle.

3. Highway maintenance

4. 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.

5. 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.

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.

The first cost of a capital improvement is converted into equivalent uniform annual cost by the formula:

i(1 - i)n

Cr = P (1+i) n-1 = P (CRF)

Where

Cr = receipt in a uniform series for n periods to cover P at a rate of interest i

P = first cost of improvement of an element of a highway

i = rate of interest per unit period

n = period of time in number of interest periods

i(1 - i)n

CRF = Capital recovery factor = (1+i)n-1

At the end of the service life of road pavement, some of the items could be assigned some salvage value. However the salvage value of some other items may be negligible.

The average annual capital cost Cr for a project considering salvage value may be estimated by the use of the formula (for the capital-recovery with salvage value):

i(1 - i)n

Cr = (C-Vs) (1+i) n-1 + I Vs

= (C- Vs) CRF + i Vs (14.4)

Where C = total in

vestment on construction

Vs = salvage value at the end of n years

i = interest rate applicable

n = number of years of expected use of the facility

The compound amount accumulated sum S on the principal sum of proposed improvement cost or single payment P, including interest rate, i in n years is given by:

s = P (1 + i)

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 – R1)/(H1 – H)

Where R = total annual road user cost for axisting highway

R1 = total annual road user cost for proposed highway improvement

H = total annual cost of existing road

H1 = 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 benefit-cost solutions.

Total annual road user cost for proposal B = RB = Rs. 2491,125

Benefit-cost ratio,

B = RA-RB = 3081,330 - 2491.125 = 590,205 = 2.874

A HB-HA = 381,900 - 176,527 205, 373

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 other agencies. 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 Vehicles registration tax.

Special taxes on commercial vehicles Other road user taxes Property taxes Toll taxes

Other funds set apart for highways

There should be an equitable distribution of revenues available for highways.

BOT (build-operate-transfer)

Private Partnership Policy

"A partnership between the public and private sectors with clear agreement on shared objectives for the delivery of public infrastructure and/or public services."

Public Private Partnership means an arrangement between a government / statutory entity / government owned entity on one side and a private sector entity on the other, for the provision of public assets and/or public services, through investments being made and/or management being undertaken by the private sector entity, for a specified period of time, where there is well defined allocation of risk between the private sector and the public entity and the private entity receives performance linked payments that conform (or are benchmarked) to specified and pre-determined performance standards, measurable by the public entity or its representative."

"There is no single PPP engagement model that can satisfy all conditions concerning a project's location setting and its technical and financial features. The most suitable model should be selected taking into account the country's political, legal and socio-cultural circumstances, maturity of the country's PPP market and the financial and technical features of the projects and sectors concerned."

The below are the top ten prevalent PPP Engagement Models in India

1. BOT-Toll (Build Operate Transfer – Toll).
2. BOOT (Build Operate Own Transfer).
3. Joint Venture (JV).
4. Management Contract (MC).
5. BOT (Build Operate Transfer).
6. BOT – Annuity (Build Operate Transfer – Annuity).
7. BOO (Build Own Operate).
8. DBFOT (Design Build Finance Operate Transfer).
9. PPP (Public Private Partnership)
10. BOOST (Build Operate Own Share Transfer)

What is BOT?

The BOT scheme is essentially a form of leasing, where the government (project sponsor) allows a private entrepreneur (project promoter) to design, finance, and build an infrastructure facility. In return, the project promoter is permitted to collect tolls (user fee) and operate the facility for a specified period (called the concession period), during which he is expected to recover all of his costs and earn a reasonable profit. At the end of the concession period, the

ownership of the facility is transferred to the government. This arrangement facilitates the implementation of capital intensive infrastructure projects by the government with funds from outside the budget allocation, while transferring the risks involved to the private sector.

The concession period is determined primarily by the length of time needed for the facility's revenue stream to pay off the company's debt and provide a reasonable rate of return for its effort and risk.

Types BOT project procurement structures

Build Own Operate Transfer (BOOT)

The service provider is responsible for design and construction, finance, operations, maintenance and commercial risks associated with the project.

The service provider owns the project throughout the concession period. The asset is transferred back to the government at the end of the term, often at no cost.

Build Own Operate (BOO)

Similar to BOOT projects, but the service provider retains ownership of the asset in perpetuity. The government only agrees to purchase the services produced for a fixed length of time

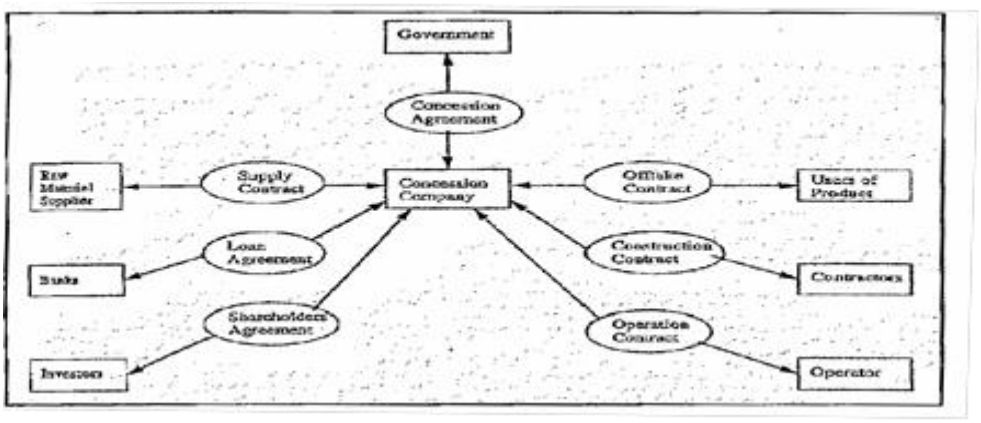
Design Build Operate (DBO)

A design and construction contract linked to an operation and maintenance contract. The service provider is usually responsible for financing the project during construction.

The government purchases the asset from the developer for a pre-agreed price prior to (or immediately after) commissioning and takes all ownership risks from that time.

BOT Contractual Structure

Flow chart shows the typical contractual structure for a BOT project



A BOT mechanism is a complex structure comprising multiple, inter-dependent agreements among various participants. Major participants in BOT project include government, private company called concessionaire, lenders (Banks), equity investors, contractors, suppliers, operators and financial advisers. Typically the government grants concession to the private sector (concessionaire). The concession is awarded through concession agreement. The concessionaire is responsible for design, finance, construction, and operation of the facility. The concessionaire retains he title of ownership during the concessionary period, which is normally 10-50 years, after which the title of ownership is transferred back to the government.

A BOT project has the following agreements

1. Concession agreement.

2. Loan agreement.

3. Shareholders agreement.

4. Construction contract.

5. Supply contract (Equipment/Material/Fuel supply contract).

6. Off-take agreement.

7. O & M agreement.

Concession Agreement

The concession agreement is between the government and the concessionaire. The concession agreement is regarded as the "heart" of a BOT project as it determines the commercial viability and profitability.

A concession agreement includes the following:

1. The concession period.

2. The construction duration.

3. Toll/tariff structure with toll/tariff revision provisions.

4. Rights and obligations of both parties.

5. Government guarantees: The host government offers guarantees to the project promoters (concessionaire) like supporting loans, guarantees of minimum operating income etc.

Loan Agreement

The loan agreement is between the lenders (i.e. Banks) and the concessionaire. The Banks provide the much necessary debt to the concessionaire. Bank debt is the primary source of financing for a BOT infrastructure project.

Shareholder Agreement

The shareholder agreement is between the equity investors and the concessionaire

Construction Contract

The construction contract is between the contractor and the concessionaire. The contract is usually let under fixed price turnkey contract.

Supply Contract (Equipment/Material)

An agreement between the supplier and the concessionaire. The supplier in a supply contract is often government agency that supplies raw material such as coal to power plant and oil.

Off-take Agreement

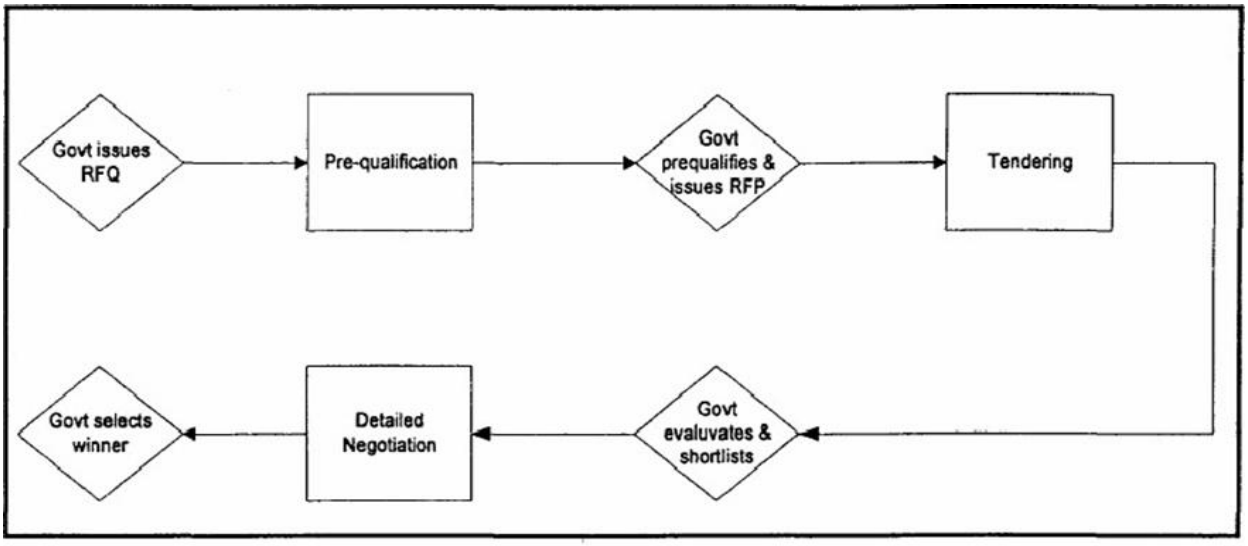
An agreement between the government and the concessionaire to purchase minimum quantity of services such as electricity, water at fixed price for fixed term.

Operation and Maintenance Contract (O & M Contract)

An agreement between the concession company and the operator. The operation phase Plays a very important role in the success of BOT project as is success is tied to its revenue generating ability. The operation phase of build-operate-transfer projects presents the great management challenge and demands the highest level of attention.

Competitive Tendering Process / Bid Evaluation Procedures

The typical evaluation and selection process in a competitive tender is shown in Figure below. Pre-qualification: The main aim of the request for qualification (RFQ) is to shortlist a of competitive proposals by consortia that consists of reputable and experienced operators and bankers. Nonetheless pre-qualification would eliminate and discourage the non-serious promoters.



The figure shows the: Selection Process in a Competitive Tender of BOT Project

Critical Success Factors (CSF):

BOT projects are characterized by high risk and cost overruns. Tiong et al (1992) identified six Critical Success Factors (CSF) that are vital for project promoters in winning a BOT contract. These factors are:

1. Entrepreneurship and leadership

2. Right project identification

3. Strength of consortium

4. Technical solution advantage

5. Financial package differentiation

6. Differentiation in guarantees

Reasons why government adopt BOT project procurement strategy

1. The involvement of private sector and experienced commercial lenders ensures an in-depth review as an additional sign of project feasibility.

2. Project risk and burden that would otherwise have to be borne by the public sector is allocated to the private sector.

3.The use of private sector capital, initiative and know-how reduces project construction costs, shortens schedules and improves operating efficiency.

4. The development of projects that would otherwise have to wait, and compete for, scarce sovereign resources is accelerated.

Characteristics of BOT Project

BOT projects have unique characteristics that distinguish them from other project delivery methods. The following are some of their unique characteristics:

1. BOT projects are financed on a project finance basis with limited recourse. Typically in limited recourse financing, the lenders provide debt to the concession company solely based upon expected cash flow/revenue generating capacity of the project. Financing is provided on the merit of the revenue generating capacity of the project rather than the assets of the concessionaire company.

2. A key characteristic of BOT projects is rising of finance entirely by the private sector without the involvement of government. The private sector is fully responsible for a design, construction, finance and operation and maintenance.

3. BOT projects are complex structures comprising multiple interdependent agreements among the various participants.

4. BOT projects are typically large-scale infrastructure projects. Transaction costs amount on average 5 to 10% of total project cost.

5. BOT projects are associated with uncertainties and high risk.

6. BOT projects transfer the risk to the private sector.

7. BOT formula can be applied to any sector of the economy. But it has been used widely in power plant sector, transportation and telecommunications.

The economic costs associated with BOT projects include the following:

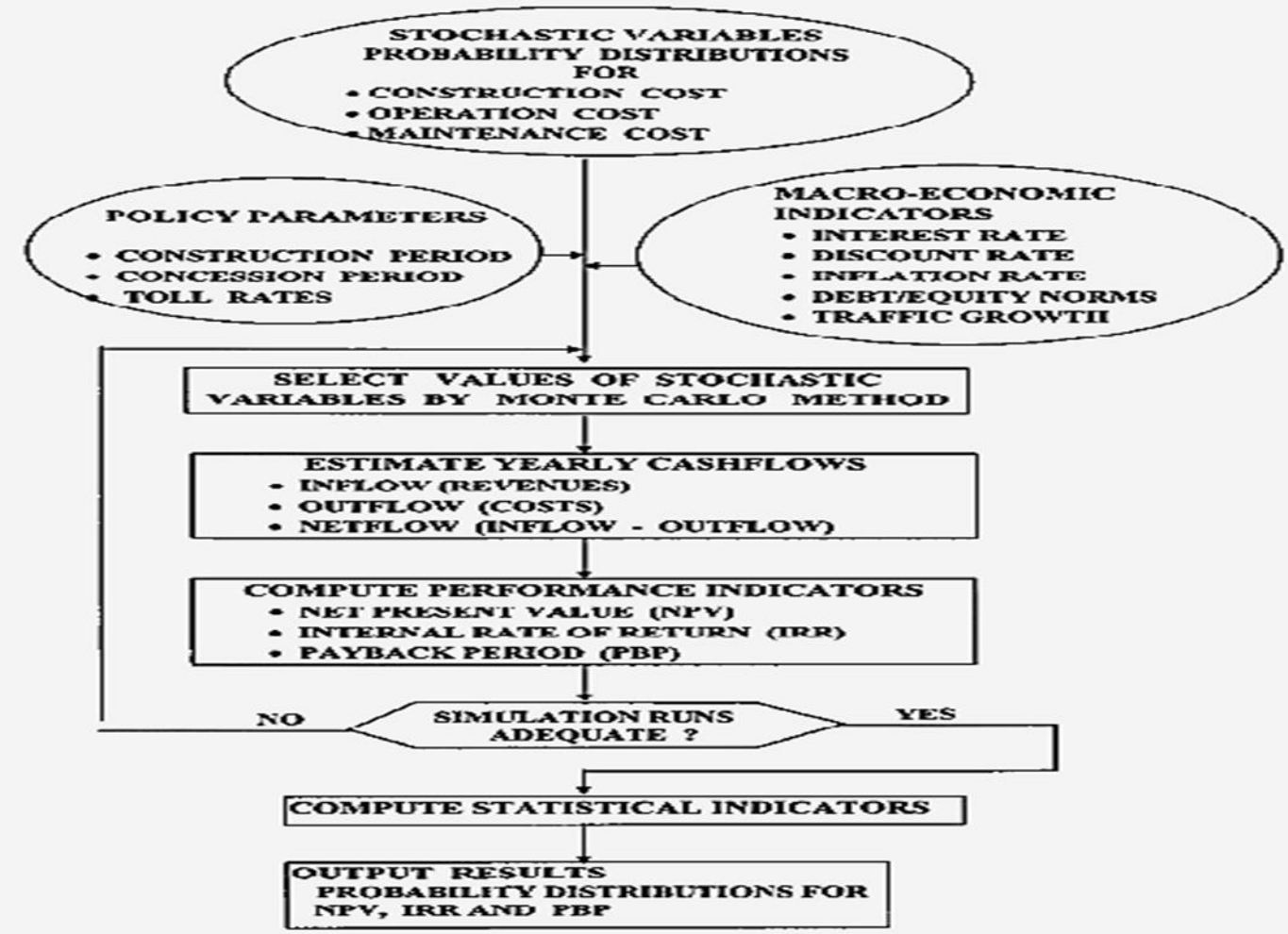


FIG. 1. Simplified Flowchart for Simulation Model

1. Costs due to imbalance in experience. Governments with little experience in BOT contracts are advised to initiate BOT projects on a manageable scale and seek professional advice to compensate the often greater experience of the private sector.

2. User costs imposed for the first time or increased to match market rates. The economic costs of public services, once covered by the Government, and then become financial costs for the user.

3. Overpriced supplies. Potential conflicts of interest on pricing among the project sponsors must be monitored. Care must be taken to ensure that sponsors who supply goods or services to the project do so on a fully competitive basis.

4. High financing costs. Financing costs for BOT projects tend to be high, as the legal fees associated with their contractual arrangements are much higher than those of standard

commercial contracts. The complexity of the credit means that lenders need more time than usual to assess a project's merits and will tend to charge higher fees.

Given the importance of infrastructure investment to national development it is essential that the wider socio-economic costs and benefits associated with a BOT scheme are taken into account when designing the legal framework to promote private sector investment in such projects.

Acceptance Criteria for BOT Projects

A BOT transport infrastructure project may be considered as financially viable, when the following three conditions are simultaneously satisfied:

1. The NPV (net present value) for the project should be positive. The discount rate for financial analysis may include a risk premium over the current commercial lending rate. The financial IRR should have a value greater than the discount rate.

2. The cash flow (liquidity) situation in each year of the concession period should be satisfactory. In other words, the cash balance at the end of every year should be positive.

3. For conditions prevailing in India, the discount rate for financial analysis may be assumed at 20%, corresponding to an interest rate of 18% for long-term debt.

Types of Risk:

The major types of risk in BOT project are:

1. Political risk.

2. Currency and foreign exchange risk.

3. Cost overrun risk.

4. Delay risk.

5. Tariff adjustment risk.

6. Market risk.

7. Operation risk.

8. Force majure risk.

Advantages of BOT project

1.Use of private sector financing to provide new sources of capital, which reduces public borrowing and direct spending and which may improve the host government's credit rating.

2. Ability to accelerate the development of projects that would otherwise have to wait for, and compete, for sovereign resources.

3. Use of private sector capital, initiative and know-how to reduce project construction costs, shorten schedules and improve operating efficiency.

4. Allocation to the private sector of project risk and burden that would otherwise have to be borne by the public sector.

5. The involvement of private sponsors and experienced commercial lenders, which ensures an in-depth review and is an additional sign of project feasibility.

6. Technology transfer, the training of local personnel and the development of national capital markets.

7. In contrast to privatization, government retention of strategic control over the project, which is transferred to the public at the end of the contract period.

8. The opportunity to establish a private benchmark against which the efficiency of similar public sector projects can be measured and the associated opportunity to enhance public management of infrastructure facilities.

Disadvantages of BOT

1. Transaction costs are high; they amount to 5-10% of total project cost.

2. Not suitable for smaller projects. Victorian Government of Australia has suggested that projects with a value of less than Australian dollar $15m are unlikely to gain benefits from BOT delivery method.

3. The success of BOT project depends upon successful raising of necessary finance. Various costs such as cost of construction, equipment, maintenance should be committed during the life of the project.

4. BOT projects are successful only when substantial revenues are generated during the operation phase.