BALASORE COLLEGE OF ENGINEERING AND TECHNOLOGY,
SERGARH, BALASORE

Lecture Notes

On

TRANSPORTATION ENGINEERING

2^{nd} Year

4^{th} Semester

Prepared by -:

Mr. Sanjeeb Kumar Chaudhury, Asst. Professor

Civil Engineering Department

Checked by

MODULE WISE DISTRIBUTION OF LOADS

Module	Chapter with title	Assigned Hour (as per BPUT)	Actual Session Needed	Range of Marksof Questions to be being asked (BPUT)
I	Modes of transportation, importance of highway transportation, history of road construction. Principle of highway planning, road development plans, highway alignments requirements, engineering surveys for highway location. Geometric design.	10	13	35-45
II	Highway Materials: - Properties of subgrade, sub-base, base course and surface course materials, test on subgrade soil, aggregates and bituminous materials. Traffic Engineering: - definition, fundamentals of traffic flow, traffic management, prevention of road accidents, elements of transport planning, highway drainage.	10	14	15-20
III	Design of Highway Pavements: Flexible pavements and their design, review of old methods, CBR method, IRC:37-2012, equivalent single wheel load factor, rigid pavements, stress in rigid pavement, IRC design method (IRC:58-2011).	9	10	20-30
IV	Highway Construction: Construction of various layers, earthwork, WBM, GSB, WMM, various types of bituminous layers, joints in rigid pavements, Hot Mix Plants, Construction of Rigid Pavements.	9	11	15-20
V	Highway Maintenance: Various type of failures of flexible and rigid pavements.	7	9	15-20
TOTAL		**45 hours**	**57 hours**	**100 marks**

SYLLABUS

Module-I **(10 hrs)**

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

Module-II **(10 hrs)**

Highway Materials: - Properties of subgrade, sub-base, base course and surface course materials, test on subgrade soil, aggregates and bituminous materials.

Traffic Engineering: - definition, fundamentals of traffic flow, traffic management, prevention of road accidents, elements of transport planning, highway drainage

Module-III **(9 hrs)**

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

Module-IV **(9 hrs)**

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

Module-V **(7 hrs)**

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

Books:

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

MODULE-I **Chapter-1**
Session-1

Learning Objectives
1.1 Introduction

HISTORY OF TRANSPORTATION

1.1 Introduction:

From the beginning of history, human sensitivity has revealed an urge for mobility leading to a measure of Society's progress. For any country to develop with right momentum modern and efficient Transport as a basic infrastructure is a must. Transportation is the movement of people and goods from one place to another. The term is derived from the Latin word Trans ("across") and port ("to carry").

Road transport is one of the most common modes of transport. Roads in the form of track ways, human pathways etc. were used even from the pre-historic times. Since then many experiments were going on to make the riding safe and comfort. Thus road construction became an inseparable part of many civilizations and empires. In this chapter we will see the different generations of road and their characteristic features. Also we will discuss about the highway planning in India.

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

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

MODULE-I

Chapter-1

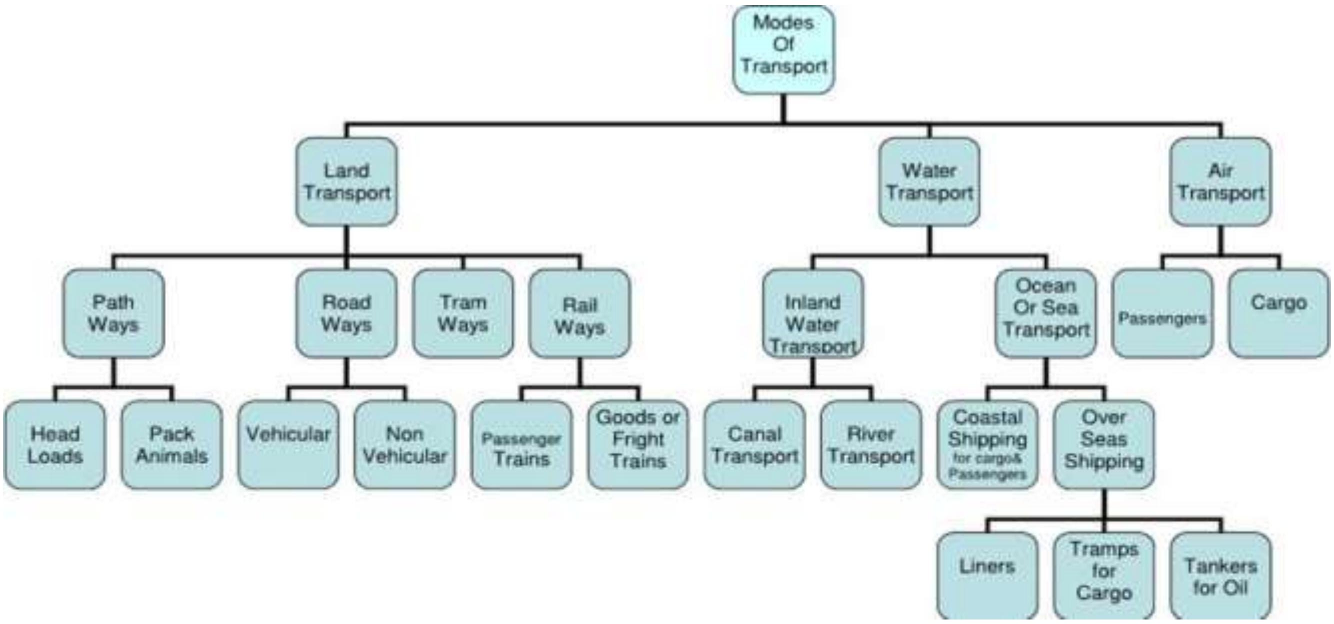
Session-2

Learning Objectives

1.2 Modes of transportation

1.3 Importance of highway transportation

1.2 Modes of transportation



1.3 Importance of highway transportation

1. They facilitate conveyance of people, goods, raw-materials, manufactured articles, etc. speedily and easily in the different parts of a country.
2. They act as the only source of communication in regions of high altitude i.e. in mountainous regions.
3. They help in growth of trade and other economy activities in and outside the villages and towns by establishing contact between towns and villages.
4. They help in providing efficient distribution of agricultural products and natural resources all over the country.
5. They help in price stabilization of commodities due to mobility of products all over the country.
6. They help in social and cultural advancement of people and making the villagers active and alert members of the community.
7. They help in promoting the cultural and social ties among people living in different part of a country and thus strengthen the national unity.
8. They help in providing improved medical facilities quickly to human beings, especially to those who live in rural areas.
9. They provide more employment opportunities.
10. They serve as feeders for Airways, Waterways and Railways.

MODULE-I

Chapter-1

Session-3

Learning Objectives

1.4 History of road construction
1.4.1 Ancient Roads
1.4.2 Roman roads
1.4.3 French roads
1.4.4 British roads
1.4.5 Modern roads

1.4 History of road construction:

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

1.4.1 Ancient Roads

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

1.4.2 Roman roads

The earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome. They were a remarkable achievement and provided travel times across Europe, Asia Minor, and North Africa. Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship. Their roads were very durable, and some still exist. Roman roads were always constructed on a ram - formed sub grade strengthened where necessary with wooden piles. The roads were bordered on both sides by longitudinal drains. The next step was the construction of the aggregate. This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during the side drain construction. This was then topped with a sand leveling course. The pavement structure on the top of the aggregate varied greatly. In the case of heavy traffic, a surface course of large 250 mm thick hexagonal stones were provided.The main features of the Roman roads are that they were built straight regardless of gradient and used heavy foundation stones at the bottom. They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

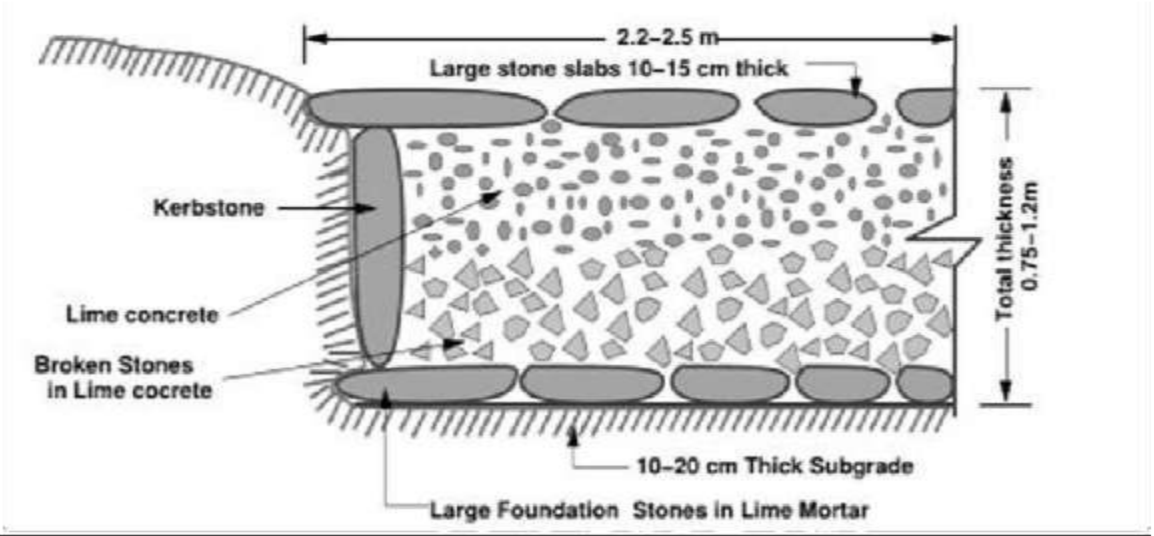


Fig. 1.1 Roman roads

1.4.3 French roads

The significant contributions were given by Tresaguet in 1764 and a typical cross section of this road is given in Figure 1.2. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200 mm pieces of quarried stone of a more compact form and shaped such that they had at least one at side which was placed on a compact formation. Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally, the running layer was made with a layer of 25 mm sized broken stone. Allthis structure was placed in a trench in order to keep the running surface level with the surrounding country side. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

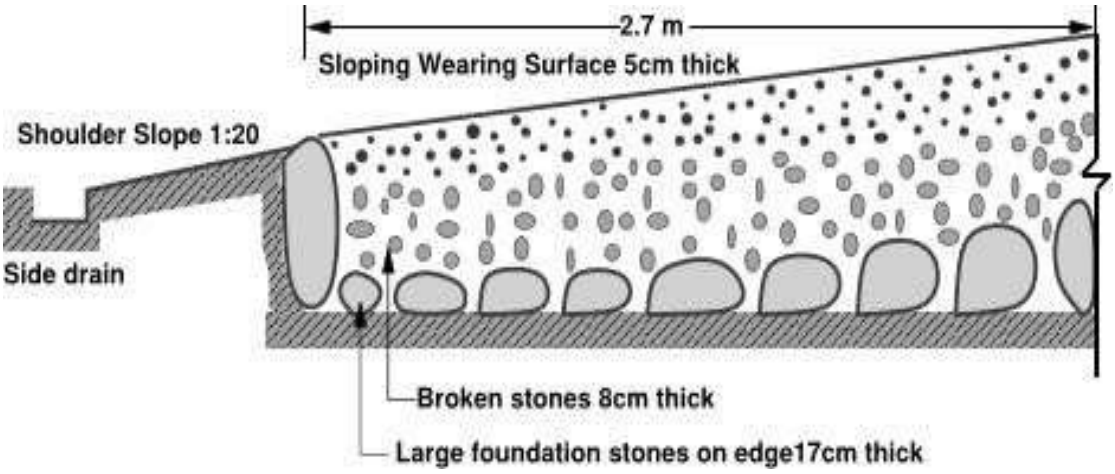


Fig. 1.2 French roads

1.4.4 British roads

The British government also gave importance to road construction. The British engineer John Macadam introduced what can be considered as the first scientific road construction method. Stone size was an important element of Macadam recipe. By empirical observation of many roads, he came to realize that 250 mm layers of well compacted broken angular stone would provide the same strength a better running surface than an expensive pavement founded on large stone blocks. Thus he introduced an economical method of road construction. A typical cross section of British roads is given in Fig. 1.3.

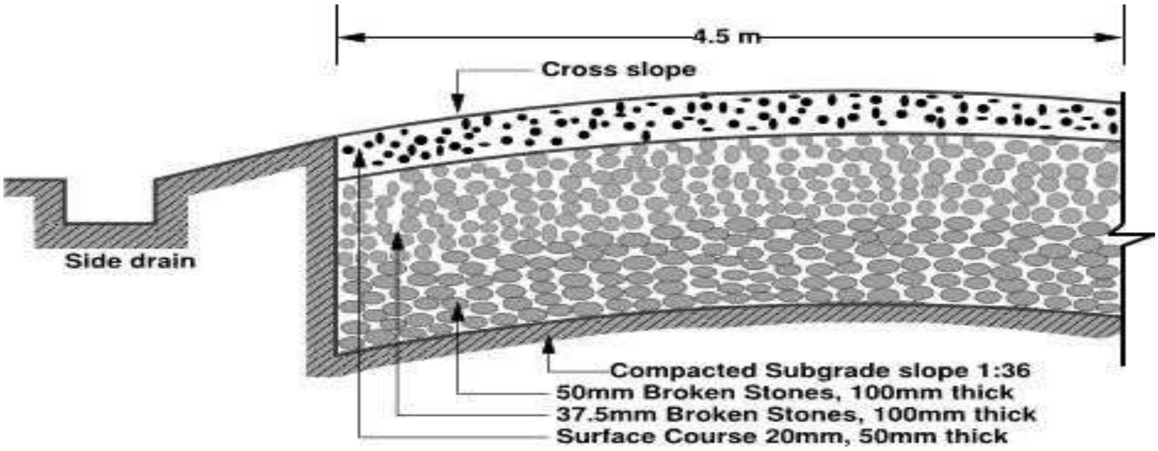


Fig. 1.3 British roads

1.4.5 Modern roads

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

MODULE-I

Chapter-1
Session-4

Learning Objectives

1.5 Principle of highway planning

1.6 Stages of Highway Development

1.5 Principle of highway planning

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

1.6 Stages of Highway Development

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

MODULE-I

Chapter-1

Session-5

Learning Objectives

1.7 Road development plans

1.7.1 Jayakar Committee

1.7.2 Nagpur road congress 1943

1.7.3 Bombay road congress 1961

1.7.4 Lucknow road congress 1984

1.7 Road development plans

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

1.7.1 Jayakar Committee

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

- Committee found that the road development of the country has become beyond the capacity of local governments and suggested that Central government should take the proper charge considering it as a matter of national interest.
- They gave more stress on long term planning programme, for a period of 20 years (hence called twenty year plan) that is to formulate plans and implement those planswith in the next 20 years.
- One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for theestablishment of a semi-official technical body called Indian Road Congress (IRC) in 1934
- The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation, license fees for vehicles plying for hire. This led to the introduction of a development fund called Central road fund in 1929.

1.7.2 Nagpur road congress 1943

A twenty year development programme for the period (1943-1963) was finalized. It was the first attempt to prepare a co-ordinated road development programme in a planned manner.

The roads were divided into four classes:

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

The committee planned to construct 2 lakh kms of road across the country within 20 years. They recommended the construction of star and grid pattern of roads throughout the country. One of the objective was that the road length should be increased so as to give a road density of 16kms per 100 sq.km.

1.7.3 Bombay road congress 1961

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

- It was the second 20 year road plan (1961-1981). The total road length targeted to construct was about 10 lakhs. Rural roads were given specific attention.
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km. The construction of 1600 km of expressways was also then included in the plan.

1.7.4 Lucknow road congress 1984

Some of the salient features of this plan are as given below:

- This was the third 20 year road plan (1981-2001). It is also called Lucknow road plan. It aimed at constructing a road length of 12 lakh kilometers by the year 1981 resulting ina road density of 82kms/100 sq.km
- The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth five year plan periods.It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.
- One of the goals contained in the plan was that expressways should be constructed onmajor traffic corridors to provide speedy travel.

MODULE-I

Chapter-1

Session-6

Learning Objectives

1.8 Highway alignments requirements
1.9 Engineering surveys for highway location

1.8 Highway alignments requirements

The requirements of an ideal alignment are:

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

1.9 Engineering surveys for highway location

To determine the geometric features of road design, the following surveys must be conducted after the necessity of the road is decided. A variety of survey and investigations have to be carried out by Road engineers andmultidiscipline persons.

A. Transport Planning Surveys
- Traffic Surveys
- Highway inventories
- Pavement Deterioration Study
- Accident study

B. Alignment and Route location surveys
- Desk study
- Reconnaissance
- Preliminary Survey
- Final location survey

C. Drainage Studies
- Surface run- off : Hydrologic and hydraulic
- Subsurface drainage: Ground water & Seepage
- Cross–drainage: Location and waterway area required forthe cross-drainage structures.

D. Soil Survey
- Desk study
- Site Reconnaissance

E. Pavement Design investigation Soil property and strength, Material Survey.

POSSIBLE SHORT QUESTIONS FOR CHAPTER-1

1. Define highway engineering?

Ans: Highway engineering is an engineering discipline branching from civil engineering that involves the planning, design, construction, operation, and maintenance of roads, bridges, and tunnels to ensure safe and effective transportation of people and goods.

2. Explain the importance of highway engineering?

Ans:

a. They facilitate conveyance of people, goods, raw-materials, manufactured articles, etc. speedily and easily in the different parts of a country.

b. They act as the only source of communication in regions of high altitude i.e. in mountainous regions.

c. They help in growth of trade and other economy activities in and outside the villages and towns by establishing contact between towns and villages.

d. They help in providing efficient distribution of agricultural products and natural resources all over the country.

e. They help in price stabilization of commodities due to mobility of products all over the country.

f. They help in social and cultural advancement of people and making the villagers active and alert members of the community.

g. They help in promoting the cultural and social ties among people living in different part of a country and thus strengthen the national unity.

3. What is the sequence of four stages of survey in a highway alignment?

Ans: The sequence of four stages of survey in a highway alignment is

(a) reconnaissance,

(b) map study

(c) preliminary survey

(d) Detailed survey.

4. What is the effect of grade on safe overtaking sight distance?

Ans**:** Appreciable grades increase the sight distance required for safe passing. Passing is easier for the vehicle traveling downgrade because the overtaking vehicle can accelerate more rapidly that on the level and thus can reduce the time of passing. But overtaken vehicle can also accelerate easily so that a dangerous situation may result.

POSSIBLE LONG QUESTIONS FOR CHAPTER-1

1. Briefly discuss about different types of roads?
2. Explain briefly about Jayakar Committee?
3. Give a short description about road development plans implemented in India?

MODULE-I

Chapter-2

Session-7

Geometric design of highway

Learning Objectives

2.1 Basic Concept of Geometric design

2.2 Factors affecting geometric design

2.1 Basic Concept of Geometric design

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

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

2.2 Factors affecting geometric design

- **Design speed:** Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.
- **Topography:** It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain.
- **Traffic factors:** It is of crucial importance in highway design, is the traffic data both current and future estimates. Traffic volume indicates the level of services (LOS) for which the highway is being planned and directly affects the geometric features such as width, alignment, grades etc., without traffic data it is very difficult to design any highway
- **Design Hourly Volume and Capacity:** The general unit for measuring traffic on highway is the Annual Average Daily Traffic volume, abbreviated as AADT. The traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to the highest value during the peak hour.
- **Environmental and other factors: -** The environmental factors like air pollution, noise pollution, landscaping, aesthetics and other global conditions should be given dueconsiderations in the geometric design of roads.

MODULE-I

Chapter-2

Session-8

Learning Objectives

2.3 Highway cross section elements

2.3 Highway cross section elements

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

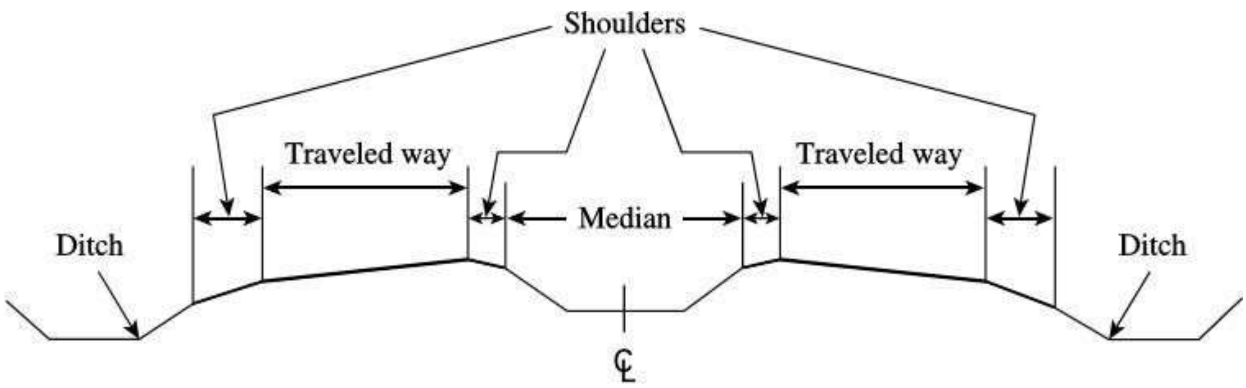


Fig.2.1 Divided highway cross section, depressed median, with ditches.

Pavement surface characteristics

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

Friction

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

Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction. Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road. Various factors that act friction are:

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

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.

Cross slope or camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain rain water from road surface. Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n%(Ex. 1 in 50 or 2%) and the value depends on the type of pavement surface.

Kerbs

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

Low or mountable kerbs: These types of kerbs are provided such thatthey 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.

MODULE-I

Chapter-2

Session-9

Learning Objectives

2.4 Road margins

2.5 Road width

2.4 Road margins

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

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

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 likefreeways 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 thespeed of the traffic in those lanes is not reduced.

Cycle track

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

Footpath

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

Guard rails

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

2.5 Road width

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. However, the side clearance required is about 0.53m, on either side or 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane

Table 1: IRC Specification for carriage way width

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

MODULE-I

Chapter-2

Session-10

Learning Objectives

2.6 Sight distance
2.6.1 PIEV Process
2.6.2 Stopping sight distance
2.6.3 Overtaking sight distance

2.6 Sight distance

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

Three sight distance situations are considered for design:

- Stopping sight distance (SSD)
- Intermediate sight distance (ISD)
- Overtaking sight distance (OSD)

The computation of sight distance depends on:

- Reaction time of the driver
- Speed of the vehicle
- Efficiency of brakes

2.6.1 PIEV Process

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

PIEV Process

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

2.6.2 Stopping sight distance

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

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

Where, SSD = required stopping sight distance, m.
v = Speed in mps.
t = perception-reaction time in sec., typically 2.5 sec. for design
f = coefficient of friction
g = 9.81mps

2.6.3 Overtaking sight distance

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

- Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.
- Spacing between vehicles, which in-turn depends on the speed.
- Skill and reaction time of the driver.
- Rate of acceleration of overtaking vehicle.

MODULE-I

Chapter-2
Session-11

Learning Objectives
2.7 Horizontal alignment
2.7.1 Factors Affecting Alignment
2.7.2 Horizontal curve
2.7.3 Design of super-elevation
2.7.4 Maximum Super-elevation
2.7.5 Attainment of super-elevation
2.7.6 Radius of Horizontal Curve
2.8 Extra widening
2.9 Horizontal Transition Curves
2.9.1 The need for Transition Curves
2.9.2 Design length of transition curve

2.7 Horizontal alignment

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. Horizontal alignment design involves the understanding on the design aspects such as design speed and the effect of horizontal curve on the vehicles. Thehorizontal curve design elements include design of super elevation, extra widening at horizontal curves, design of transition curve, and set back distance.

2.7.1 Factors Affecting Alignment

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

2.7.2 Horizontal curve

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

2.7.3 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.

2.7.4 Maximum Super-elevation

Max range from flat to mountainous of 0.06 – 0.12 respectively but most authorities limit to 0.10. In urban areas limit max values to 0.04-0.05, minimum Super-elevation should be elevated to at least the cross-fall on straights i.e. 3% (0.03).

2.7.5 Attainment of super-elevation

There are two methods of attaining super-elevation

1. Elimination of the crown of the cambered section by: rotating the outer edge about the crown shifting the position of the crown

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

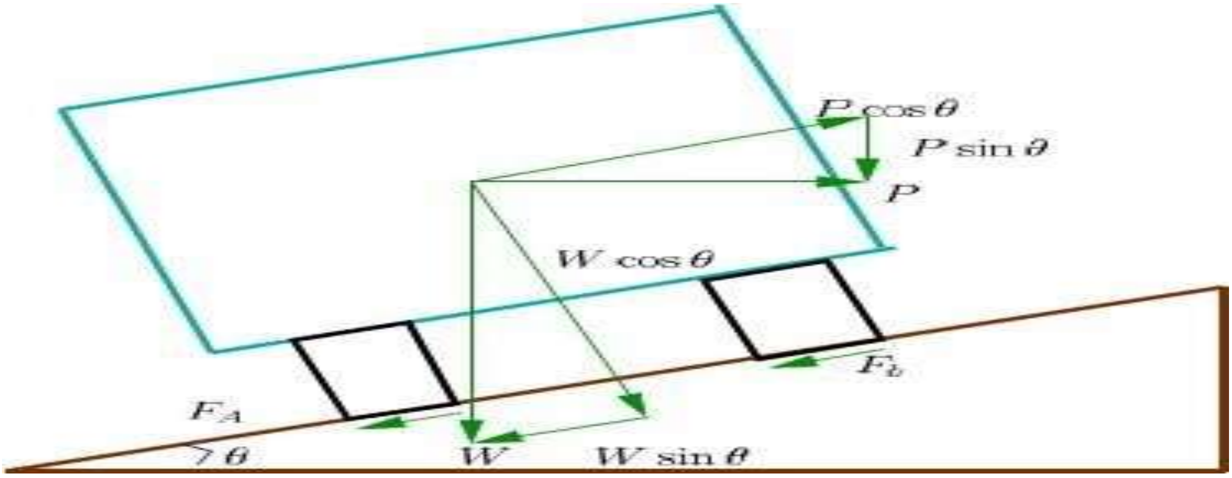


Fig.2.2 Analysis of super elevation

P the centrifugal force acting horizontally out-wards through the center of gravity, W the weight of the vehicle acting down-wards through the center of gravity, and mF the friction force between the wheels and the pavement, along the surface inward. At equilibrium, by resolving theforces parallel to the surface of the pavement we get,

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

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

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

2.7.6 Radius of Horizontal Curve

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

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

2.8 Extra widening

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

Mechanical widening

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

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

Where, n=number of lanes, l=length of wheel of wheel base in meter, R=radius of curve

Psychological widening

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

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

V=speed in Kmph, R=radius of curve in meter

2.9 Horizontal Transition Curves

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

2.9.1 The need for Transition Curves

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

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

- ✓ To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
- ✓ To enable the driver turn the steering gradually for his own comfort and security,
- ✓ To provide gradual introduction of super elevation, and
- ✓ To provide gradual introduction of extra widening.
- ✓ To enhance the aesthetic appearance of the road.

2.9.2 Design length of transition curve

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

A. Rate of change of centrifugal acceleration

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

$$L_s = \frac{V^3}{cR}$$

Where, $c = \frac{80}{75+V}$ and V is in Kmph.

B. Rate of introduction of super-elevation

Raise (E) of the outer edge with respect to inner edge is given by E = eB = e (W + We). The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve (typical range of N is 60-150). Therefore, the length of the transition curve L_S is:

$$L_s = N\, e\, (W + W_e)$$

C. By empirical formula

IRC suggest the length of the transition curve is minimum for a plain and rolling terrain:

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

MODULE-I

Chapter-2

Session-12

Learning Objectives

2.10 Vertical alignment
2.10.1 Gradient
2.10.2 Valley curve
2.10.2.1 Design considerations
2.10.2.2 Length of the valley curve

2.10 Vertical alignment

The vertical alignment of a transportation facility consists of tangent grades (straight lines in thevertical plane) and vertical curves. Vertical alignment is documented by the profile. Just as a circular curve is used to connect horizontal straight stretches of road, vertical curves connect two gradients. When these two curves meet, they form either convex or concave. The former is calleda summit curve, while the latter is called a valley curve.

2.10.1 Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. The effect of long steep gradient on the vehicular speed is considerable. This is particularly important in roads where the proportion of heavy vehicles is significant. Due to restrictive sight distance at uphill gradients the speed of traffic is often controlled by these heavy vehicles. As a result, not only the operating costs of the vehicles are increased, but also capacity of the roads will have to be reduced. Further, due to high differential speed between heavy and light vehicles, and between uphill and downhill gradients, accidents abound in gradients.

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

Table 2 IRC Specifications for gradients for different roads

2.10.2 Valley curve

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

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

2.10.2.1 Design considerations

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

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

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

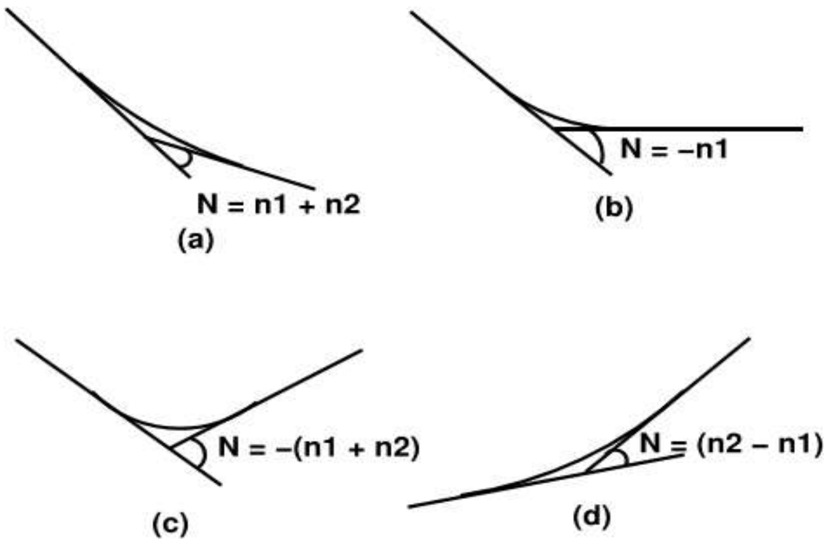


Fig.2.3 Types of valley curve

2.10.2.2 Length of the valley curve

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

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

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

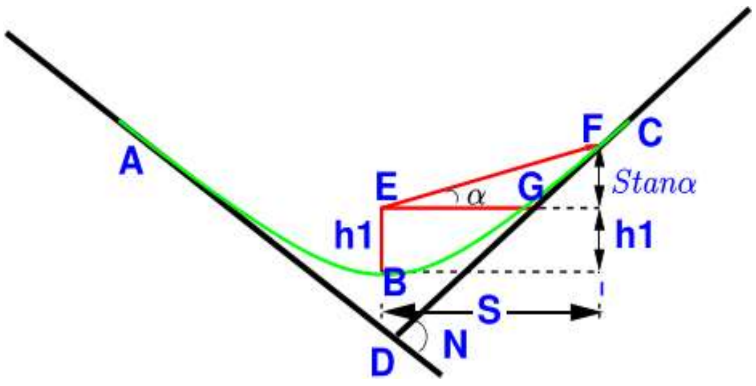


Fig.2.4 Valley curve (L > S)

i. For (L > S)

$$L_V = \frac{NS^2}{4.4}$$

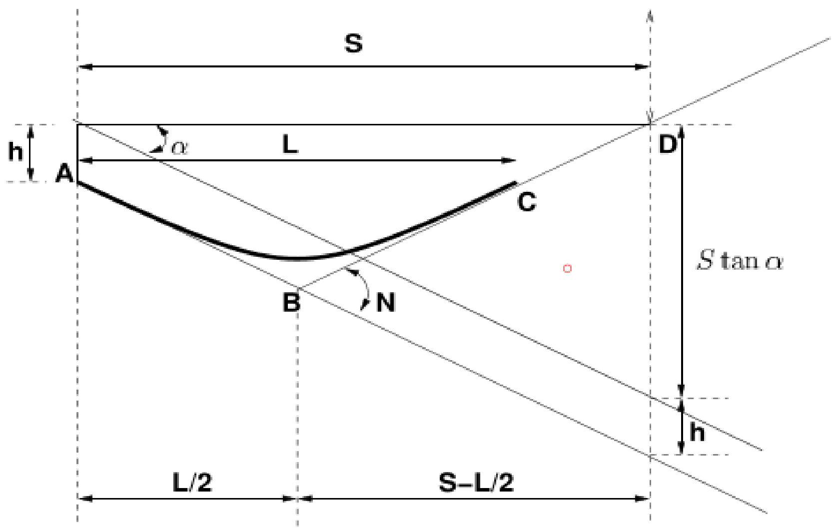


Fig.2.5 Valley curve (S >L)

ii. For (S >L)

$$L_V = 2S - \frac{4.4}{N}$$

POSSIBLE SHORT QUESTIONS FOR CHAPTER-2

1. Write a short note on kerbs used in highway alignment?

Ans: Different types of kerbs are:

Low or mountable kerbs: These types of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder areawith 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. Theirheight 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 ata height of 20 cm above the pavement edge with a steep batter.

2. What do you mean by cross slope or camber?

Ans: Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain rain water from road surface. Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Ex. 1 in 50 or 2%) and the value depends on the type of pavement surface.

3. What is the need of transition curve?

Ans:

- ✓ To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle. This increases the comfort of passengers.
- ✓ To enable the driver turn the steering gradually for his own comfort and security,
- ✓ To provide gradual introduction of super elevation, and
- ✓ To provide gradual introduction of extra widening.
- ✓ To enhance the aesthetic appearance of the road.

4. What do you mean by gradient of road?

Ans: Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided designing the vertical curve. The effect of long steep gradient on the vehicular speed is considerable. This is particularly important in roads where the proportion of heavy vehicles is significant.

POSSIBLE LONG QUESTIONS FOR CHAPTER-2

1. Briefly explain about the cross-sectional elements of a highway?
2. What do you mean by geometric design and what are the factors affecting it, discuss briefly?
3. Write a short description about the elements of road margin?

MODULE-II **Chapter-3**
Session-13

Highway Materials

Learning Objectives

3.1 Introduction

3.2 Sub grade soil

3.2.1 Desirable properties

3.1 Introduction to highway materials

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 provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting 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. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

3.2 Sub grade soil

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.

3.2.1 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
5. Good drainage
6. Ease of compaction

Soil particles

The description of the grain size distribution of soil particles according to their texture (particle size, shape, and gradation). Major textural classes include, very roughly:

- gravel (>2 mm);
- sand (0.1 –2 mm);
- silt (0.01 –0.1 mm);
- Clay (< 0.01 mm).

MODULE-II **Chapter-3**

Session-14

Highway Materials

Learning Objectives

3.3 Properties of base course and surface course materials

3.3 Properties of base course and surface course materials

Various transfer functions relating flexible pavement structural responses (stresses, strains, displacements) and pavement performance have been proposed for use in mechanistic flexible pavement design procedures. Appropriate material and soil inputs are essential for good flexible pavement analysis and design. The major recent emphasis in granular material and subgrade soil characterization/evaluation has been on repeated load testing. Resilient moduli and permanent deformation behaviour of granular materials and subgrade soils can be quantified based on appropriate repeated load testing data. In a well-designed high-type flexible pavement system the permanent strain accumulated per load cycle is very small compared to the resilient strain. Base course granular material quality is controlled by specification requirements. Typical material specifications consider L.A. Abrasion, soundness, degree of crushing (relates to the geometric properties of shape, angularity, and surface texture), gradation, liquid limit and PI (or sand equivalent), and some measure of strength (CBR is frequently used). The specifying agency can thus control granular base quality and characteristics within narrow limits. In sharp contrast to "well controlled" granular materials, the subgrade is an in-situ material. Adequate subgrade characterization requires consideration of the fluctuations of subgrade soil properties as a function of space (various depths in a subgrade and transverse and longitudinal location along the project) and time (seasons of the year and year-year climatic variation).

MODULE-II **Chapter-3**

Session-15

Learning Objectives

3.4 Tests on Soil

3.5 Pavement materials

3.4 Test on Soil

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests. The tests used to evaluate the strength properties of soils may be broadly divided into three groups:

1. Shear tests
2. Bearing tests
3. Penetration test

Shear tests

Shear tests are usually carried out on relatively small soil samples in the laboratory. In order to find out the strength properties of soil, a number of representative samples from different locations are tested. Some of the commonly known shear tests:

- Direct shear test,
- Tri-axial compression test,
- Unconfined compression test.

California Bearing Ratio (CBR)

This test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements.

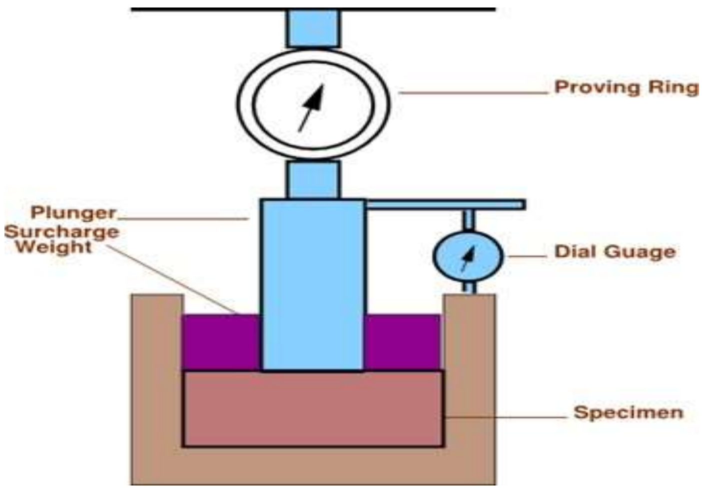


Fig 3.1 CBR Test

Plate Bearing Test

Plate bearing test is used to evaluate the support capability of sub-grades, bases and in some cases, complete pavement. Data from the tests are applicable for the design of both flexible and rigid pavements. In plate bearing test, a compressive stress is applied to the soil or pavement layer through rigid plates relatively large size and the deflections are measured for various stress values

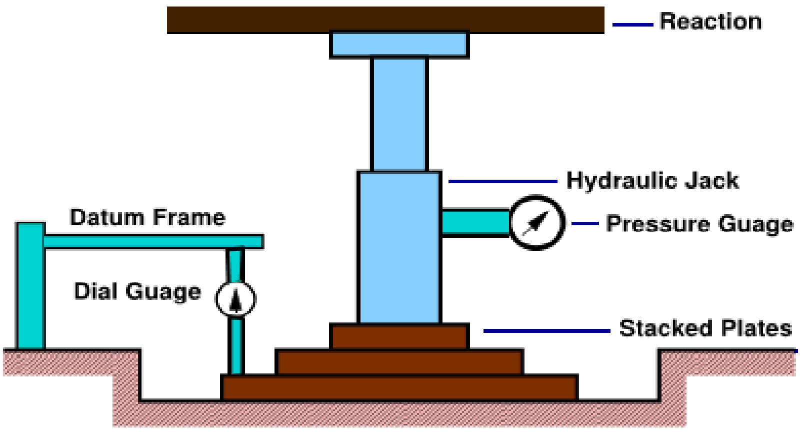


Fig.3.2 Plate load test

3.5 Pavement materials

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

Strength

The aggregates used in top layers are subjected to

(i) Stress action due to traffic wheel load,

(ii) Wear and tear,

(iii) Crushing.

Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles moves over the aggregates exposed at the top surface.

Toughness

Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes severe impact on the aggregates.

Shape of aggregates

Aggregates which happen to fall in a particular size range may have rounded cubical, angular, flaky or elongated particles. It is evident that the aky 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.

Adhesion with bitumen

The aggregates used in bituminous pavements should have less a nity with water when comparedwith bituminous materials, otherwise the bituminous coating on the aggregate will be stripped o in presence of water.

Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action

Freedom from deleterious particles

Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of at or elongated pieces, dust, clay balls and other objectionable material. Similarly aggregates used in Portland cement concrete mixes must be clean and free from deleterious substances such as clay lumps, chert, silt and other organic impurities.

MODULE-II **Chapter-3**

Session-16

Test on Aggregates

Learning objectives

3.6 Aggregate tests

3.6 Aggregate tests

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

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

Crushing test

One of the model in which pavement material can fail is by crushing under compressive stress. A test isstandardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually appliedcrushing load.

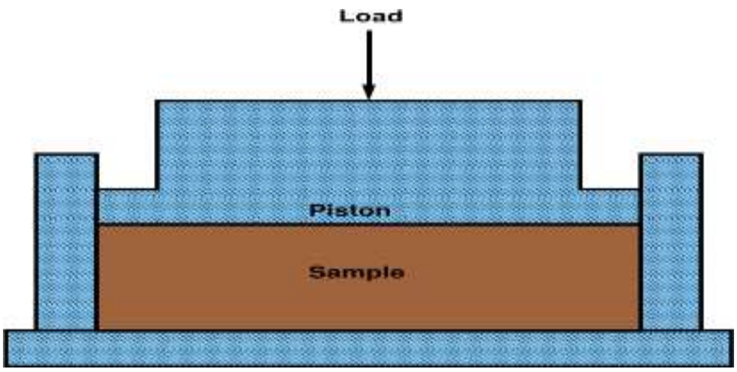


Fig.3.3 Crushing test setup

Abrasion test

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS: 2386 part-IV).

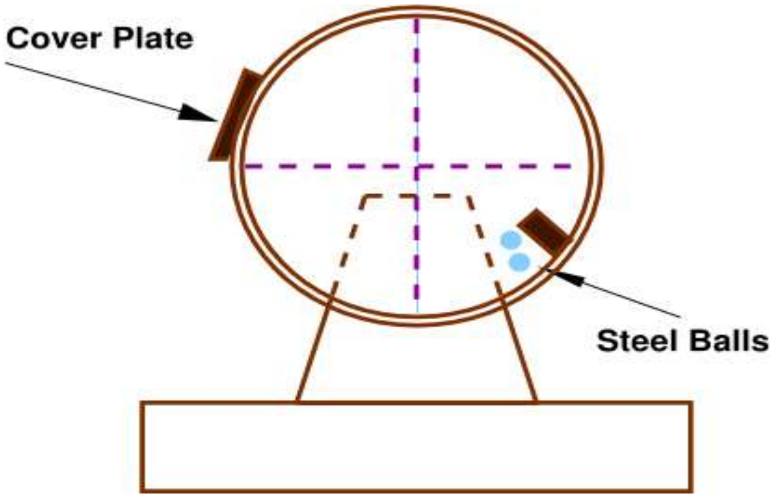


Fig.3.4 Los Angeles abrasion test setup

Impact test

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows.

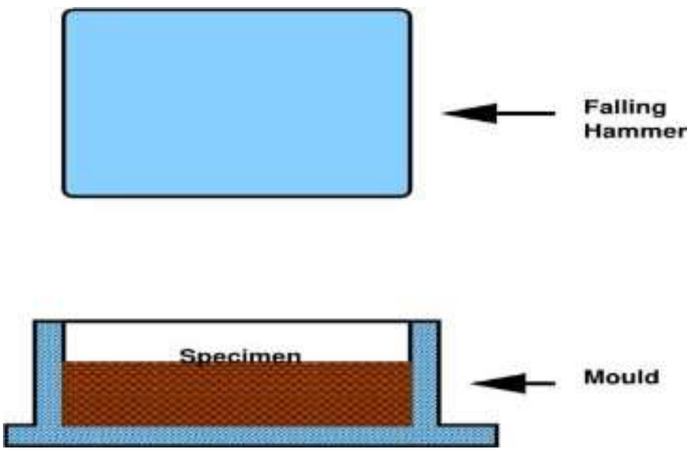


Fig.3.5 Impact test setup

Shape tests

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes. The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. Test procedure had been standardized in India (IS:2386 part-I).

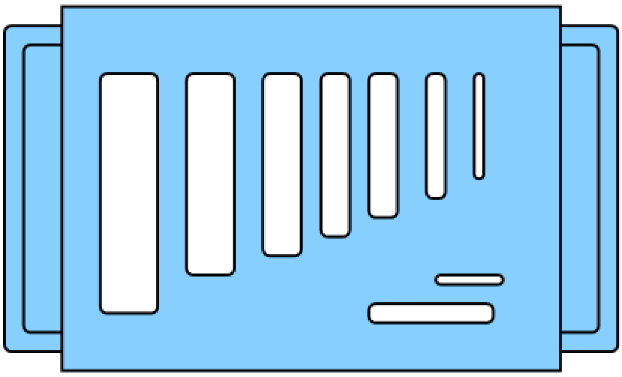


Fig.3.6 Flakiness gauge

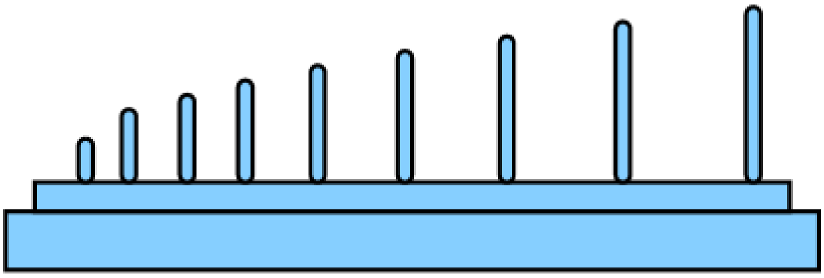


Fig.3.7 Elongation gauge

Specific Gravity and water absorption

The Specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The Specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature.

- Apparent Specific Gravity
- Bulk Specific Gravity

Water absorption, The difference between the apparent and bulk specific gravities is nothing butthe water- permeable voids of the aggregates.

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 2.9. Waterabsorption values ranges from 0.1 to about 2.0 percent for aggregates normally used in road surfacing.

Bitumen adhesion test

Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold.

Property of aggregate	Type of Test	Test Method
Crushing strength	Crushing test	IS : 2386 (part 4) -1963
Hardness	Los Angeles abrasion test	IS : 2386 (Part 5)-1963
Toughness	Aggregate impact test	IS : 2386 (Part 4)-1963
Durability	Soundness test- accelerated durability test	IS : 2386 (Part 5)-1963
Shape factors	Shape test	IS : 2386 (Part 1)-1963
Specific gravity and porosity	Specific gravity test and water absorption test	IS : 2386 (Part 3)-1963
Adhesion to bitumen	Stripping value of aggregate	IS : 6241-1971

Table 3.1 Tests for Aggregates with IS codes

MODULE-II **Chapter-3**

Session-17

Test on Bitumen

Learning objectives

3.7 Tests on Bitumen

Pavement materials: Bitumen

Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost.

Production of Bitumen

Bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties.

Vacuum steam distillation of petroleum oils

In the vacuum-steam distillation process the crude oil is heated and is introduced into a large cylindrical still. Steam is introduced into the still to aid in the vaporization of the more volatile constituents of the petroleum and to minimize decomposition of the distillates and residues. The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed. The residues from this distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils. The bottom fraction from this unit is the vacuum-steamed asphalt cement.

Different forms of bitumen 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.

There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC).

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. Three types 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.

Bituminous primers

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

Modified Bitumen

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999.

Requirements of Bitumen

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should possess following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable gradesor by heating the bitumen and aggregates prior to mixing.

- There should be adequate affinity and adhesion between the bitumen andaggregates used in the mix.

3.7 Tests on bitumen

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

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

Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position.

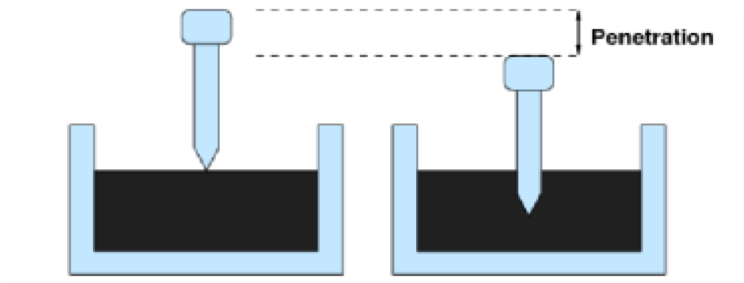


Fig. 3.8 Penetration Test Setup

Ductility test

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking.

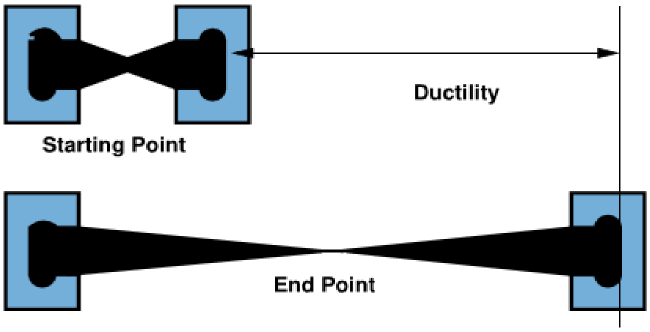


Fig. 3.9 Ductility Moulds

Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus.

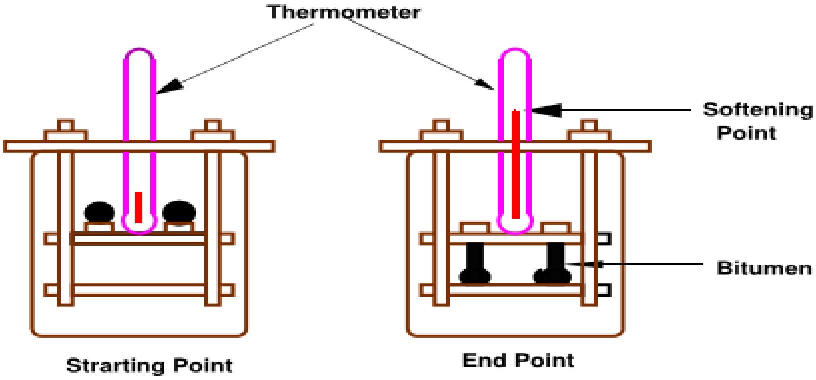


Fig. 3.10 Softening Point Test Setup

Specific gravity test

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

Viscosity test

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resists the compactive effort and therebyresulting mix is heterogeneous, hence low stability values.

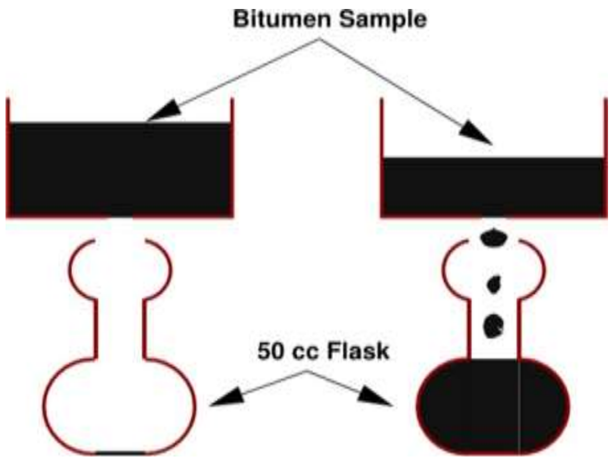


Fig.3.11 Viscosity apparatus

Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And this volatile catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade.

Float test

Normally the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used.

Water content test

It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water. The water in bitumen is determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling of the water.

Loss on heating test

When the bitumen is heated it loses the volatility and gets hardened. About 50gm of the sample is weighed and heated to a temperature of 163^{0}C for 5hours in a specified oven designed for this test.

POSSIBLE SHORT QUESTIONS FOR CHAPTER-3

1. What do you mean by Sub-grade soil?

Ans: 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.

2. What are the desirable properties of sub-grade soil?

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

- Stability
- Incompressibility
- Permanency of strength
- Minimum changes in volume and stability
- Good drainage
- Ease of compaction

3. What do you mean by bitumen emulsion?

Ans: 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. Three types 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.

POSSIBLE LONG QUESTIONS FOR CHAPTER-3

1. What are the desirable properties of aggregate used in pavement materials?
2. Briefly discuss any two laboratory test carried out on aggregate used in pavement materials?

3. Give a short description on test carried out on bitumen?

MODULE-II **Chapter-4**

Session-18

Traffic Engineering

Learning objectives

4.1 Traffic stream parameters

Introduction to traffic engineering

Traffic engineering pertains to the analysis of the behavior of traffic and to design the facilities for the smooth, safe and economical operation of traffic. Understanding traffic behavior requires a thorough knowledge of traffic stream parameters and their mutual relationships.

4.1 Traffic stream parameters

The traffic stream includes a combination of driver and vehicle behavior.

1. Speed

Speed is considered as a quality measurement of travel as the drivers and passengers will be concerned more about the speed of the journey than the design aspects of the traffic.

- Spot Speed
- Running speed

Time mean speed and space mean speed

Time mean speed is defined as the average speed of all the vehicles passing a point on a highway over some specified time period. Space mean speed is defined as the average speed of all the vehicles occupying a given section of a highway over some specified time period.

2. Flow

There are practically two ways of counting the number of vehicles on a road. One is flow or volume, which is defined as the number of vehicles that pass a point on a highway or a given lane or direction of a highway during a specific time interval.

Types of volume measurements

I. Average Annual Daily Traffic(AADT)

II. Average Annual Weekday Traffic(AAWT)

III. Average Daily Traffic(ADT)

IV. Average Weekday Traffic(AWT)

3. Density

Density is defined as the number of vehicles occupying a given length of highway or lane and is generally expressed as vehicles per km/mile.

Time headway

The microscopic character related to volume is the time headway or simply headway. Time headway is defined as the time difference between any two successive vehicles when they cross a given point.

Distance headway

Another related parameter is the distance headway. It is defined as the distance between corresponding points of two successive vehicles at any given time.

Travel time

Travel time is defined as the time taken to complete a journey.

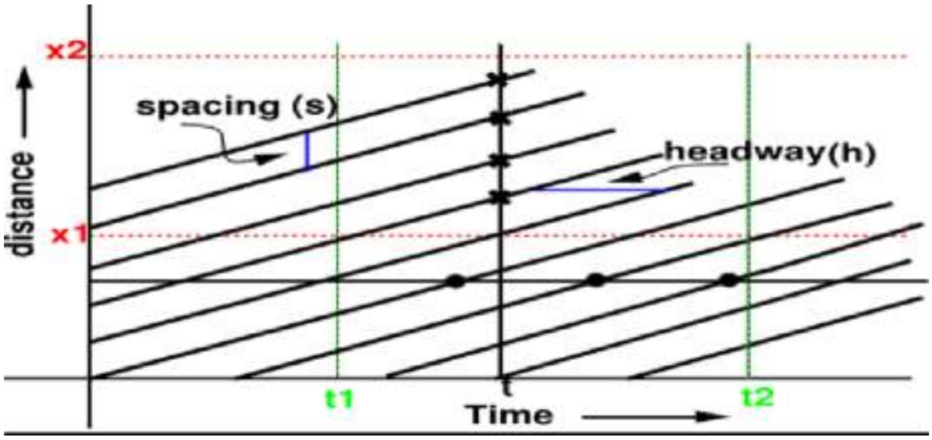


Fig. 4.1 Many vehicle

Time-space diagram

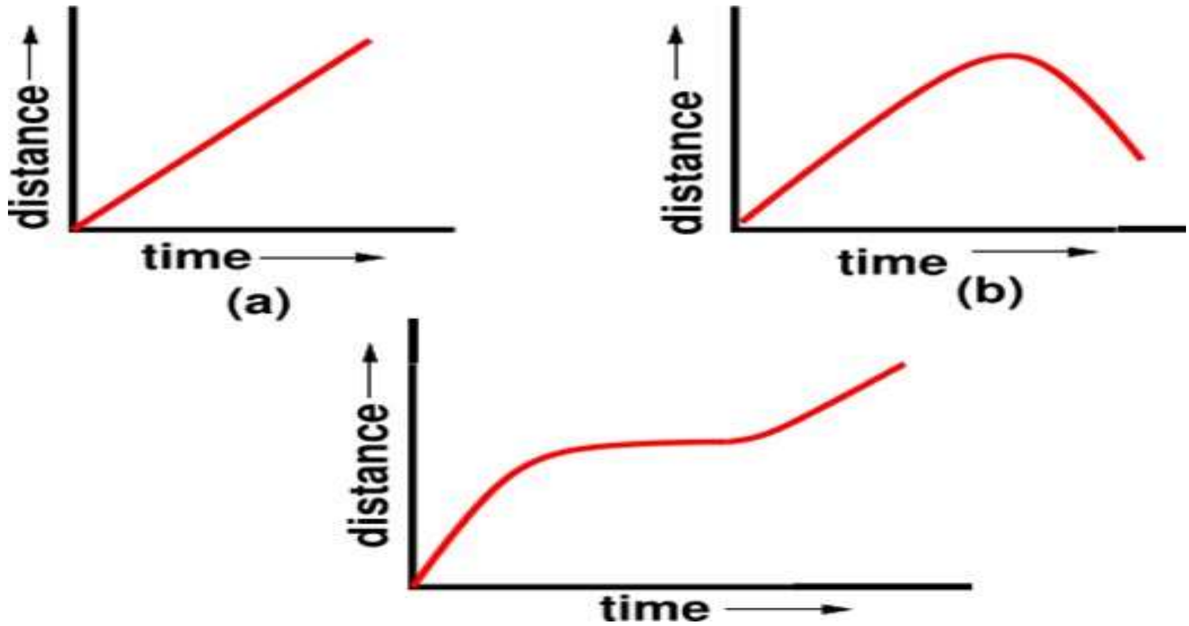


Fig. 4.2 Single vehicle

Learning objectives

4.2 Fundamental relation of traffic parameter

4.2.1 Fundamental diagrams of traffic flow

4.2 Fundamental relation of traffic parameter

Speed is one of the basic parameters of traffic flow and time mean speed and space mean speed are the two representations of speed.

- ✓ Time mean speed (v_t)
- ✓ Space mean speed (v_s)

4.2.1 Fundamental diagrams of traffic flow

The flow and density varies with time and location. The relation between the density and the corresponding flow on a given stretch of road is referred to as one of the fundamental diagram of traffic flow. Some characteristics of an ideal flow-density relationship is listed below:

1. When the density is zero, flow will also be zero, since there is no vehicles on the road.
2. When the number of vehicles gradually increases the density as well as flow increases.
3. When more and more vehicles are added, it reaches a situation where vehicles can't move. This is referred to as the jam density or the maximum density. At jam density, flow will be zero because the vehicles are not moving.
4. There will be some density between zero density and jam density, when the flow is maximum.

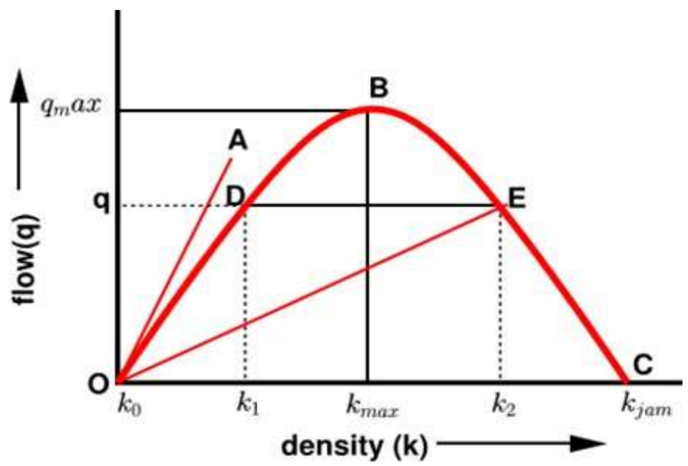


Fig.4.3 Flow density Curve

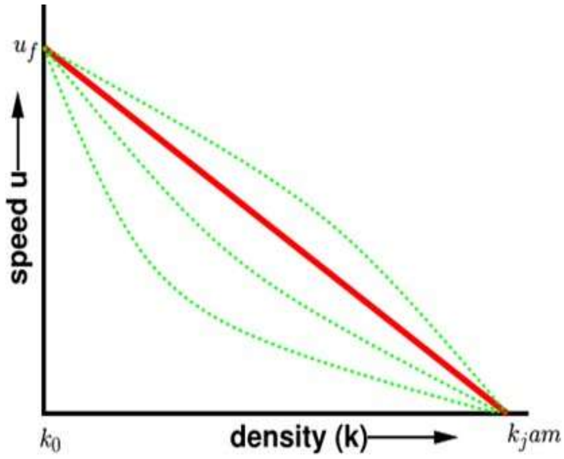


Fig.4.4 Speed-density diagram

Speed-density diagram

Similar to the flow-density relationship, speed will be maximum, referred to as the free flow speed, and when the density is maximum, the speed will be zero. The simplest assumption is that this variation of speed with density is linear.

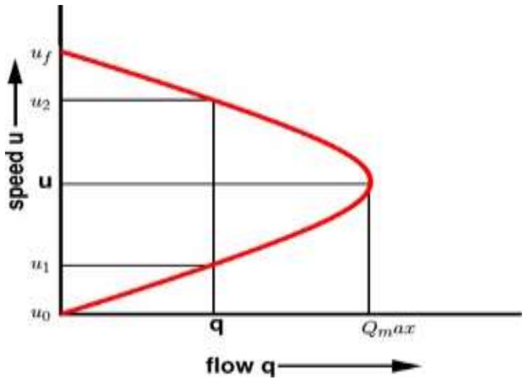


Fig.4.5 Speed-flow diagram

MODULE-II **Chapter-4**

Session-20

Traffic management

Learning objectives

4.3 Capacity and Level of Service

4.3 Capacity and Level of Service

Capacity and Level of service are two related terms. Capacity analysis tries to give a clear understanding of how much traffic a given transportation facility can accommodate. Level of service tries to answer how good the present traffic situation on a given facility is.

Capacity

Capacity is defined as the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under given conditions with a reasonable expectation of occurrence. Some of the observations that are found from this definition can be now discussed.

Level of service

A term closely related to capacity and often confused with it is service volume. When capacity gives a quantitative measure of traffic, level of service or LOS tries to give a qualitative measure.

Highway capacity

Highway capacity is defined by the Highway Capacity Manual as the maximum hourly rate at which persons or vehicles can be reasonably expected to traverse a point or a uniform segment ofa lane or roadway during a given time period under prevailing roadway, traffic and control conditions.

- ✓ Traffic conditions:
- ✓ Road way characteristics:
- ✓ Control conditions:

Factors affecting level of service

Level of service one can derive from a road under different operating characteristics and traffic volumes. The factors affecting level of service (LOS) can be listed as follows:

- Speed and travel time
- Traffic interruptions/restrictions
- Freedom to travel with desired speed
- Driver comfort and convenience
- Operating cost.

MODULE-II Chapter-4

Session-21

Learning objectives

4.4 Elements of transport planning

4.4 Elements of transport planning

For transportation to take place, four components are essential:

- **Modes**: They represent the conveyances, mostly taking the form of vehicles that are used to support the mobility of passengers or freight. Some modes are designed to carry only passengers or freight, while others can carry both.

- **Infrastructures**: The physical support of transport modes, where routes (e.g. rail tracks, canals, or highways) and terminals (e.g. ports or airports) are the most significant components. Infrastructures also include superstructures, which are movable assets that usually have a shorter lifespan. For an airport, the infrastructure would be assets such as the runways, while the superstructure would be the terminals and control equipment. For a port, the infrastructure would be piers and navigation channels while the superstructure would be cranes and yard equipment.

- **Networks**: A system of linked locations that are used to represent the functional and spatial organization of transportation. This system indicates which locations are connected and how they are serviced. Some locations within a network are more accessible (more connections) than others (fewer connections).

- **Flows**: Movements of people, freight, and information over their respective networks. Flows have origins, intermediary locations, and destinations. An intermediary location is often required to go from an origin to a destination. For instance, flying from one airport to another may require a transit at the hub airport.

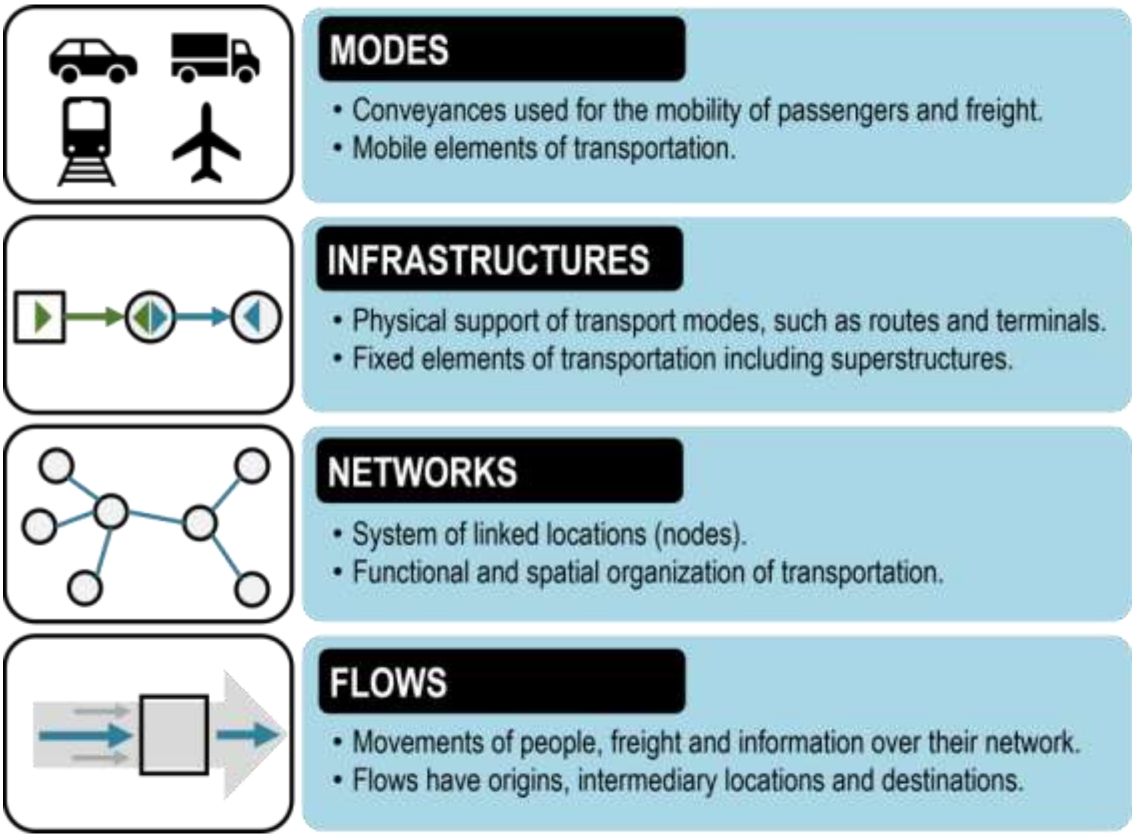


Fig. 4.6 Elements of transport planning

MODULE-II **Chapter-4**

Session-22

Traffic management

Learning objectives

4.5 Traffic Sign

4.6 Classification of road markings

4.7 Parking

4.8 Traffic Signal Design

4.5 Traffic Sign

Traffic control device is the medium used for communicating between traffic engineer and road users. Unlike other modes of transportation, there is no control on the drivers using the road. Here traffic control devices come to the help of the traffic engineer. The major types of traffic control devices used are-

1. Traffic signs
2. Road markings
3. Traffic signals
4. Parking control.

Requirements of traffic control devices

1. The control device should fulfill a need

2. Road users must respect the signs

3. The control device should provide adequate time for proper response from the road users

Types of traffic signs

1. Regulatory signs
2. Warning signs
3. Informative signs

Regulatory signs

These signs are also called mandatory signs because it is mandatory that the drivers must obey these signs. If the driver fails to obey them, the control agency has the right to take legal action against the driver.

- Right of way series
- Speed series
- Movement series
- Parking series

- Pedestrian series
- Miscellaneous

Warning signs

Warning signs or cautionary signs give information to the driver about the impending road condition. They advise the driver to obey the rules.

Informative signs

Informative signs also called guide signs are provided to assist the drivers to reach their desired destinations. These are predominantly meant for the drivers who are unfamiliar to the place. The guide signs are redundant for the users who are accustomed to the location.

Fig.4.7 Examples of informative signs

Road Sign

The essential purpose of road markings is to guide and control traffic on a highway. They supplement the function of traffic signs. The markings serve as a psychological barrier and signify the delineation of traffic path and its lateral clearance from traffic hazards for the safe movement of traffic. Hence they are very important to ensure the safe, smooth and harmonious flow of traffic.

4.6 Classification of road markings

The road markings are defined as lines, patterns, words or other devices, except signs, set into applied or attached to the carriageway or kerbs or to objects within or adjacent to the carriageway, for controlling, warning, guiding and informing the users. The road markings are classified as

- Longitudinal markings
- Transverse markings
- Object markings
- Word messages
- Marking for parking
- Marking at hazardous locations

Longitudinal markings

Longitudinal markings are placed along the direction of traffic on the roadway surface, for the purpose of indicating to the driver, his proper position on the roadway.

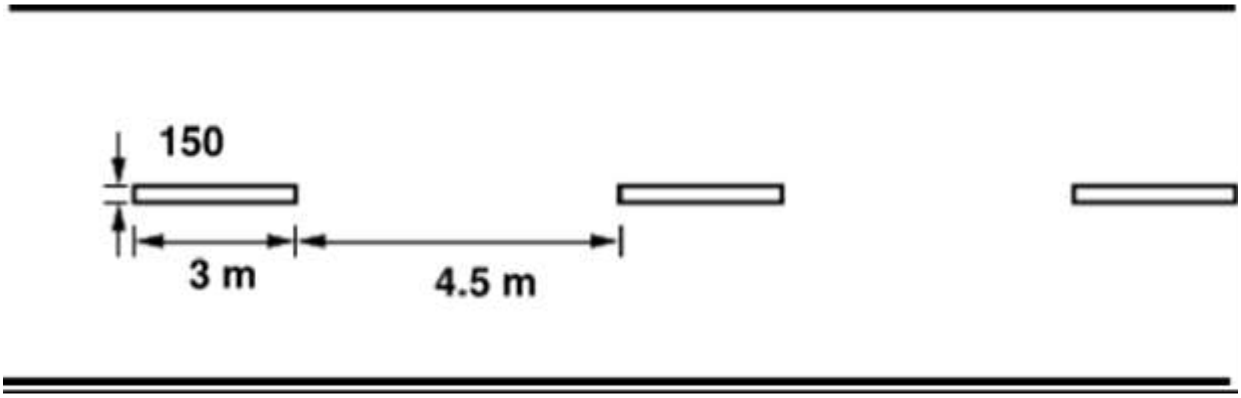


Fig.4.8 Centre line marking for a two lane road

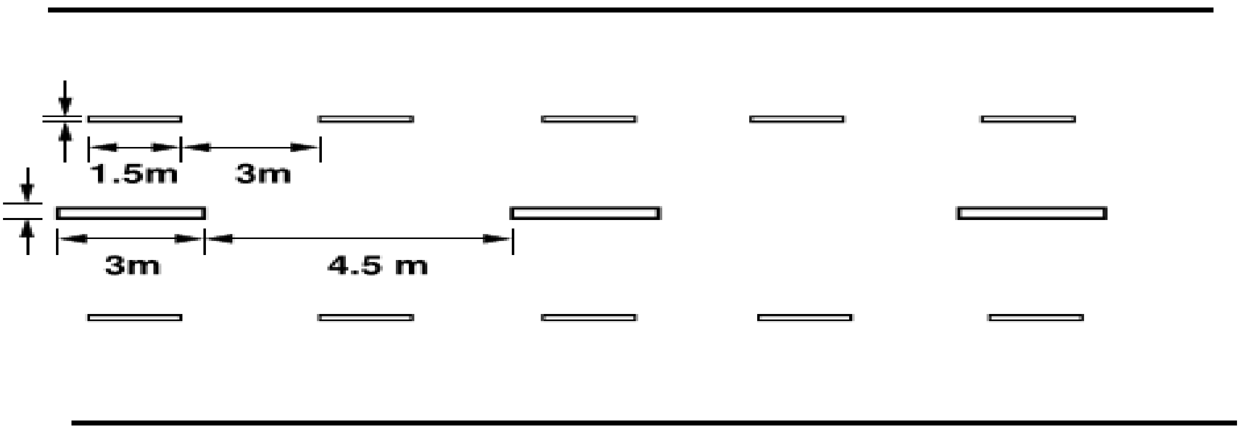


Fig.4.9 Centre line and lane marking for a four lane road

Centre line

Centre line separates the opposing streams of traffic and facilitates their movements. Usually no centre line is provided for roads having width less than 5 m and for roads having more than four lanes. The centre line may be marked with either single broken line, single solid line, double broken line, or double solid line depending upon the road and traffic requirements.

Traffic lane lines

The subdivision of wide carriageways into separate lanes on either side of the carriage way helps the driver to go straight and also curbs the meandering tendency of the driver.

No passing zones

No passing zones are established on summit curves, horizontal curves, and on two lane and three lane highways where overtaking maneuvers are prohibited because of low sight distance. It may be marked by a solid yellow line along the centre or a double yellow line.

4.7 Parking

Parking is one of the major problems that are created by the increasing road traffic.

Parking studies

Before taking any measures for the betterment of conditions, data regarding availability of parking space, extent of its usage and parking demand is essential. It is also required to estimate the parking fares also.

- Parking statistics
- Parking accumulation
- Parking volume
- Parking load
- Average parking duration
- Parking turnover
- Parking index

Parking surveys

- In-out survey
- Fixed period sampling
- License plate method of survey

On street parking

- ✓ Parallel parking
- ✓ 30 degree parking
- ✓ 45 degree parking
- ✓ 60 degree parking
- ✓ Right angle parking

Off street

Parking In many urban centres, some areas are exclusively allotted for parking which will be at some distance away from the main stream of traffic. Such a parking is referred to as off-street parking.

4.8 Traffic Signal Design

The conflicts arising from movements of traffic in different directions is solved by time sharing of the principle. The advantages of traffic signal include an orderly movement of traffic, an increased capacity of the intersection and require only simple geometric design. However the disadvantages of the signalized intersection are it affects larger stopped delays, and the design requires complex considerations.

Phase design

The signal design procedure involves six major steps.They include the,

1. phase design
2. determination of amber time and clearance time
3. determination of cycle length
4. apportioning of green time
5. pedestrian crossing requirements,
6. the performance evaluation

Two phase signals

Two phase system is usually adopted if through traffic is significant compared to the turning movements.

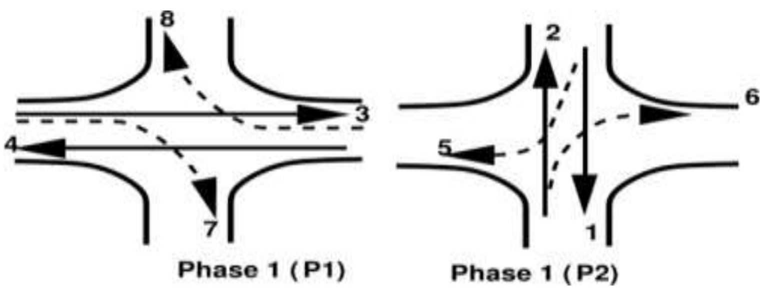


Fig. 4.9 Two phase signal

Four phase signals

There are at least three possible phasing options.

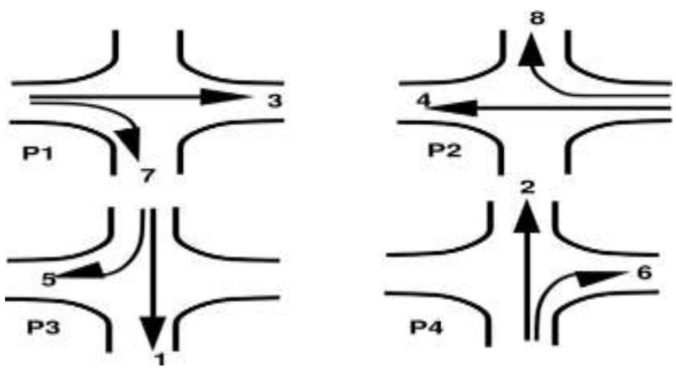


Fig.4.10 One way of providing four phase signals

MODULE-II **Chapter-4**

Session-23

Learning objectives

4.9 Prevention of road accidents

4.9 Prevention of road accidents

1. Drive in the prescribed speed limits on the various roads. Always remember that **"Speed thrills but kills".**
2. Always put on helmets, seat belts and other safety equipment before driving a bicycle/ motor cycle/vehicle. Always remember that **"Safety saves".**
3. Do not drink and drive. Always remember that "**You cannot hold a pen properly after two pegs, what about the driving wheel?"**
4. Never use mobile phones or ear phones while driving. Always remember **"A mobile call on the road may be the last call of your life".**
5. Know the traffic signs, signals, lights and traffic safety rules before you hit the road. Always remember that **"Road safety rules are best tools to avoid accidents".**
6. Do not drive for long hours in a stretch. Have proper beaks after every 2 hours of continuous driving. Always remember that **"Man is a man and not a machine".**

MODULE-II **Chapter-4**

Session-24

Learning objectives

4.10 Highway Drainage

4.10 Highway Drainage

Provision for adequate drainage is of paramount importance in road design and cannot be overemphasized. The presence of excess water or moisture within the roadway will adversely affect the engineering properties of the materials with which it was constructed. Cut or fill failures, road surface erosion, and weakened subgrades followed by a mass failure are all products of inadequate or poorly designed drainage. As has been stated previously, many drainage problems can be avoided in the location and design of the road: Drainage design is most appropriately included in alignment and gradient planning.

Importance of Drainage

Water has a number of unhelpful characteristics which impact on highway performance.

- It is a lubricant reducing the effectiveness of tyre grip on the carriageway wearing surface which can increase stopping distances.

- Spray from rainwater being thrown up by car tyres can reduce visibility which canlead to delays in reacting to events on the carriageway.

- Drag on car tyres from local rainwater ponding can alter the balance of vehicles travelling at speed which can be alarming or cause skidding.
- It is incompressible therefore standing water effectively acts as a jackhammer onthe wearing course right through to the sub-base when vehicles pass over head.
- It expands when frozen pulling apart the carriageway construction which then fallsapart when it warms up
- In extreme storms, rainwater can simply wash away roads on embankment shouldthe culvert become blocked or lack capacity.

POSSIBLE SHORT QUESTIONS FOR CHAPTER-4

1. What is meant by condition diagram?

Ans: A condition diagram is a drawing to scale showing all important physical conditions of an accident location to be studied. The important features generally to be shown in this diagram with suitable dimensions marked there in an roadway limits, curves, kerb lines, bridges and culverts and all details of roadway conditions, obstruction to vision, signs and signals etc.

2. Define Collision Diagram

Ans: These are diagrams show the approximate path of vehicles and pedestrians involved in the accident. Collision diagrams are most useful to compare the accident pattern before and after the remedial measures have been taken.

3. What are the safety measures of accident taken related to engineering?

Ans: The following safety measures are taken related to engineering

1. Road design
2. Preventive maintenance of vehicles
3. before and after studies
4. Road lighting

4. What are the Objectives Of Accident Studies?

Ans:

1. To study the causes of accidents and to suggest corrective treatment at potential location
2. To evaluate existing design
3. To support proposed design
4. To carry out before and after studies and to demonstrate the improvement in the problem

5. What do you mean by Time mean speed and space mean speed?

Ans: Time mean speed is defined as the average speed of all the vehicles passing a point on a highway over some specified time period. Space mean speed is defined as the average speed of all the vehicles occupying a given section of a highway over some specified time period.

POSSIBLE LONG QUESTIONS FOR CHAPTER-4

1. What are the elements of transport planning?
2. Briefly discuss the fundamental diagrams of traffic flow?
3. What are the different types of traffic signs used in the signal design?
4. Briefly discuss the importance of highway drainage?
5. What are the preventive measures used in road accidents?

MODULE-III **Chapter-5**

Session-25

INTRODUCTION TO HIGHWAY PAVEMENTS

Learning objectives

5.1 Highway Pavements

5.2 Requirements of a pavement

5.1 Highway Pavements:

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 provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting 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. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

5.2 Requirements of a pavement:

- An ideal 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, and
- Long design life with low maintenance cost.

MODULE-III **Chapter-5**
Session-26

Learning objectives

5.3 Types of pavements

5.4 Failure of flexible pavements

5.5 Failure criteria of rigid pavements

5.6 Pavements are a conglomeration of materials

5.3 Types of pavements:

The pavements can be classified based on the structural performance into two catagories,

1. Flexible pavements
2. Rigid pavements

In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road).

On the contrary, in rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads).

In addition to these, composite pavements are also available. A thin layer of flexible pavement over rigid pavement is an ideal pavement with most desirable characteristics. However, such pavements are rarely used in new construction because of high cost and complex analysis required.

5.4 Failure of flexible pavements:

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting:

one to limit the vertical compressive strain on the top of subgrade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low-temperature cracking and thermal fatigue cracking.

5.5 Failure criteria of rigid pavements:

Traditionally fatigue cracking has been considered as the major or only criterion for rigid pavement design. The allowable number of load repetitions to cause fatigue cracking depends on the stress ratio between flexural tensile stress and concrete modulus of rupture. Of late, pumping is identified as an important failure criterion. Pumping is the ejection of soil slurry through the joints and cracks of cement concrete pavement, caused during the downward movement of slab under the heavy wheel loads. Other major types of distress in rigid pavements include faulting, spalling, and deterioration.

5.6* 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 understanding pavement. 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.

MODULE-III Chapter-5 Session-27

Learning objectives

5.7 Flexible pavements

5.8 Types of Flexible Pavements

5.7 Flexible pavements:

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure. The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear. The lower layers will experience lesser magnitude of stress and low quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways). Flexible pavement layers react the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

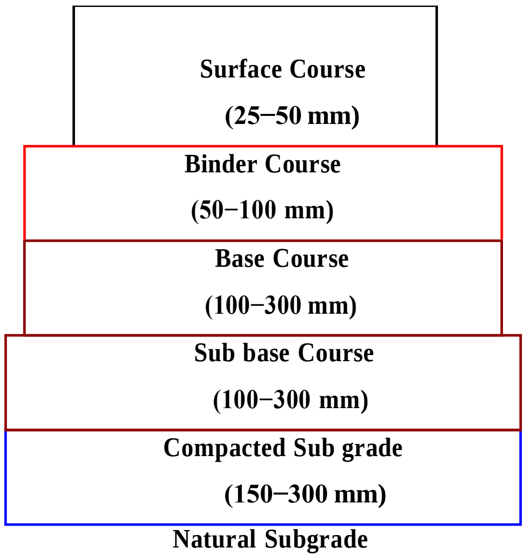


Figure 5.1: Typical cross section of a flexible pavement

5.8 Types of Flexible Pavements

The following types of construction have been used in flexible pavement:

1. Conventional layered flexible pavement
2. full - depth asphalt pavement
3. Contained rock asphalt mat (CRAM).

Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

Full - depth asphalt pavements are constructed by placing bituminous layers directly on the soil sub-grade. This is more suitable when there is high traffic and local materials are not available.

Contained rock asphalt mats are constructed by placing dense/open graded aggregate layers in between two asphalt layers. Modified dense graded asphalt concrete is placed above the sub-grade will significantly reduce the vertical compressive strain on soil sub-grade and protect from surface water.

MODULE-III

Chapter-5
Session-28

Learning objectives

5.9 Typical layers of a flexible pavement

5.9 Typical layers of a flexible pavement:

Typical layers of a 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.

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 layers 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 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, and reduce the intrusion from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more can serve as a leer 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, sub-grade may not need the additional features by a sub-base course. In such situations, sub-base course may not be provided.

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.

Learning objectives

5.10 Equivalent single wheel load

5.10 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.

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.

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}\left(\frac{z}{d/2}\right)}{\log_{10}\left(\frac{2S}{d/2}\right)}$$

Where, S= center to center spacing between the wheels

P= wheel load

d= Gap between wheels

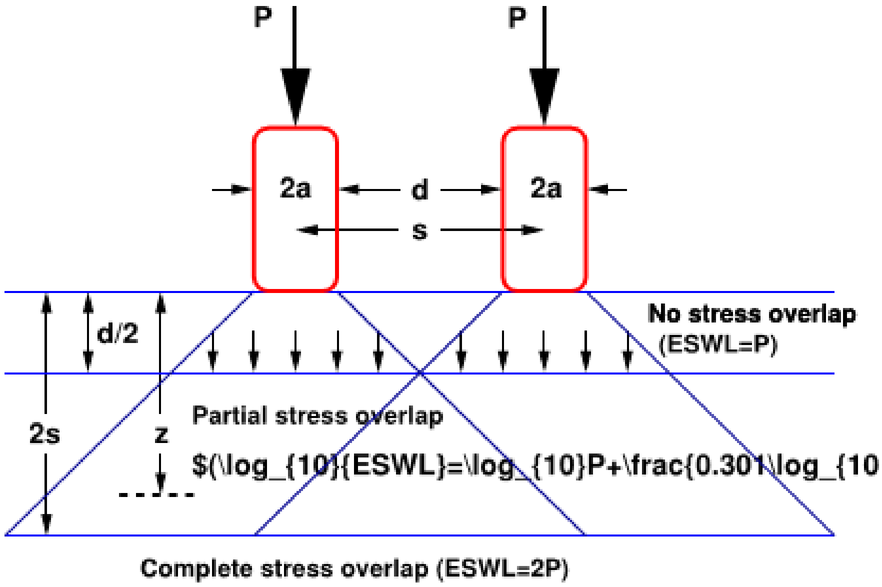


Fig. 5.2 ESWL-Equal stress concept

$$\text{Equivalent single axle load, ESAL} = \sum_{i=1}^{m} F_i n_i$$

MODULE-III **Chapter-5**

Session-30

Learning objectives

5.11 California Bearing Ratio Test

5.12 Definition of C.B.R.

5.11 California Bearing Ratio Test

Objective

To determine the California bearing ratio by conducting a load penetration test in the laboratory.

Need and scope

The California bearing ratio test is penetration test meant for the evaluation of subgrade strength of roads and pavements. The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

This instruction sheet covers the laboratory method for the determination of C.B.R. of undisturbed and remoulded /compacted soil specimens, both in soaked as well as unsoaked state.

Equipment and tool required:

1. Cylindrical mould with inside dia 150 mm and height 175 mm, provided with a detachable extension collar 50 mm height and a detachable perforated base plate 10 mm thick.

2. Spacer disc 148 mm in dia and 47.7 mm in height along with handle.

3. Metal rammers: Weight 2.6 kg with a drop of 310 mm (or) weight 4.89 kg a drop 450 mm.

4. Weights. One annular metal weight and several slotted weights weighing 2.5 kg each, 147 mm in dia, with a central hole 53 mm in diameter.

5. Loading machine. With a capacity of atleast 5000 kg and equipped with a movable head or base that travels at an uniform rate of 1.25 mm/min. Complete with load indicating device.

6. Metal penetration piston 50 mm dia and minimum of 100 mm in length.

7. Two dial gauges reading to 0.01 mm.

8. Sieves. 4.75 mm and 20 mm I.S. Sieves.

9. Miscellaneous apparatus, such as a mixing bowl, straight edge, scales soaking tank or pan, drying oven, filter paper and containers.

5.12 Definition of C.B.R.:

It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

C.B.R. = (Test load/Standard load)* 100

The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%

Penetration of plunger (mm)	Standard load (kg)
2.5	1370
5.0	2055
7.5	2630
10.0	3180
12.5	3600

The test may be performed on undisturbed specimens and on remoulded specimens which may be compacted either statically or dynamically.

MODULE-III **Chapter-5**
Session-31

Learning objectives

5.13 Preparation of Test Specimen

5.13 Preparation of Test Specimen:

Undisturbed specimen

Attach the cutting edge to the mould and push it gently into the ground. Remove the soil from the outside of the mould which is pushed in . When the mould is full of soil, remove it from weighing the soil with the mould or by any field method near the spot.

Determine the density

Remoulded specimen

Prepare the remoulded specimen at Proctor maximum dry density or any other density at which C.B.R> is required. Maintain the specimen at optimum moisture content or the field moisture as required. The material used should pass 20 mm I.S. sieve but it should be retained on 4.75 mm I.S. sieve. Prepare the specimen either by dynamic compaction or by static compaction.

Dynamic Compaction

- Take about 4.5 to 5.5 kg of soil and mix thoroughly with the required water.

Fix the extension collar and the base plate to the mould. Insert the spacer disc over the base (See Fig.38). Place the filter paper on the top of the spacer disc.

- Compact the mix soil in the mould using either light compaction or heavy compaction. For light compaction, compact the soil in 3 equal layers, each layer being given 55 blows by the 2.6 kg rammer. For heavy compaction compact the soil in 5 layers, 56 blows to each layer by the 4.89 kg rammer.
- Remove the collar and trim off soil.
- Turn the mould upside down and remove the base plate and the displacer disc.
- Weigh the mould with compacted soil and determine the bulk density and dry density.
- Put filter paper on the top of the compacted soil (collar side) and clamp the perforated base plate on to it.

Static compaction

Calculate the weight of the wet soil at the required water content to give the desired density when occupying the standard specimen volume in the mould from the expression.

$$W = \text{desired dry density} * (1+w)\, V$$

Where, W = Weight of the wet soil

w = desired water content

V = volume of the specimen in the mould = 2250 cm^3 (as per the mould available inlaboratory)

Procedure:

- Take the weight W (calculated as above) of the mix soil and place it in the mould.
- Place a filter paper and the displacer disc on the top of soil.
- Keep the mould assembly in static loading frame and compact by pressing thedisplacer disc till the level of disc reaches the top of the mould.
- Keep the load for some time and then release the load. Remove the displacer disc.

- The test may be conducted for both soaked as well as unsoaked conditions.
- If the sample is to be soaked, in case of compaction, put a filter paper on the top of the soil and place the adjustable stem and perforated plate on the top of filter paper.
- Put annular weights to produce a surcharge equal to weight of base material and pavement expected in actual construction. Each 2.5 kg weight is equivalent to 7 cm construction. A minimum of two weights should be put.
- Immerse the mould assembly and weights in a tank of water and soak it for 96 hours. Remove the mould from tank.
- Note the consolidation of the specimen.

Procedure for Penetration Test

- Place the mould assembly with the surcharge weights on the penetration test machine.
- Seat the penetration piston at the centre of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the piston on the sample is established.
- Set the stress and strain dial gauge to read zero. Apply the load on the piston so that the penetration rate is about 1.25 mm/min.
- Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10 and 12.5 mm. Note the maximum load and corresponding penetration if it occurs for a penetration less than 12.5 mm.
- Detach the mould from the loading equipment. Take about 20 to 50 g of soil from the top 3 cm layer and determine the moisture content.

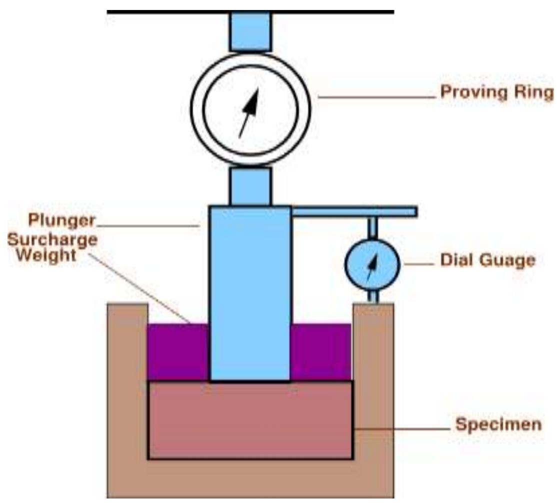


Fig 5.3 CBR Test

MODULE-III Chapter-5
Session-32

Learning objectives

5.14 Rigid pavements

5.15 Types of Rigid Pavements

5.14 Rigid pavements:

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure 19:3. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure 19:4). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load, temperature variation and the resulting tensile and flexural stress.

5.15 Types of Rigid Pavements:

Rigid pavements can be classified into four types:

1. Jointed plain concrete pavement (JPCP),
2. Jointed reinforced concrete pavement (JRCP),
3. Continuous reinforced concrete pavement (CRCP), and Pre-stressed concrete pavement

Jointed Plain Concrete Pavement: These are plain cement concrete pavements constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally have a joint spacing of 5 to 10m.

Jointed Reinforced Concrete Pavement: Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcement's help to keep the slab together even after cracks.

Continuous Reinforced Concrete Pavement: Complete elimination of joints are achieved by reinforcement.

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 It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

MODULE-III Chapter-5 Session-33

Learning objectives

5.16 Stresses in Rigid Pavement

5.16 Stresses in Rigid Pavement:

As the name implies, rigid pavements are rigid i.e., they do not flex much under loading like flexible pavements. They are constructed using cement concrete. In this case, the load carrying capacity is mainly due to the rigidity ad high modulus of elasticity of the slab (slab action).

Modulus of sub-grade reaction

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection.

Relative stiffness of slab to sub-grade

A certain degree of resistance to slab deflection is offered by the sub-grade. The sub-grade deformation is same as the slab deflection. Hence the slab deflection is direct measurement of the magnitude of the sub-grade pressure.

Critical load positions

There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

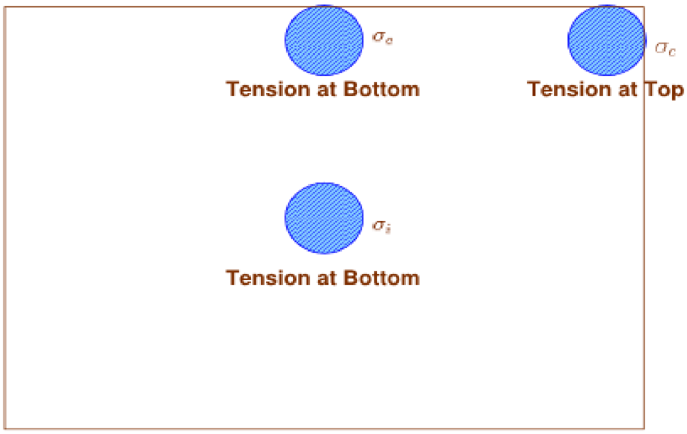


Fig.5.4 Critical stress locations

<u>Temperature stresses</u>

Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. This is caused by

(i) Daily variation resulting in a temperature gradient across the thickness of the slab

(ii) Seasonal variation resulting in overall change in the slab temperature.

<u>Combination of stresses</u>

The cumulative effect of the different stress give rise to the following thee critical cases

- Summer, mid-day: The critical stress is for edge region
- Winter, mid-day: The critical combination of stress is for the edge region.
- Mid-nights: The critical combination of stress is for the corner region.

POSSIBLE SHORT QUESTIONS FOR CHAPTER-5

1. What do you mean by conglomeration of materials?

Ans: 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 understanding pavement. 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.

2. What do you mean by ESWL?

Ans: 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.

3. Define C.B.R.?

Ans: It is the ratio of force per unit area required to penetrate a soil mass with standard circular piston at the rate of 1.25 mm/min. to that required for the corresponding penetration of a standard material.

4. What do you mean by temperature stresses?

Ans: Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. This is caused by:

(i) Daily variation resulting in a temperature gradient across the thickness of the slab

(ii) Seasonal variation resulting in overall change in the slab temperature.

POSSIBLE LONG QUESTIONS FOR CHAPTER-5

1. **What are the requirements of a pavement?**
2. **What are the various types of pavements and describes the failure happening on it?**
3. **Briefly explain the CBR test?**
4. **Draw a neat sketch of different layers of flexible pavements and explain briefly?**
5. **Briefly explain about rigid pavement?**
6. **What are the various stresses affecting the pavement, explain briefly?**

MODULE-IV **Chapter-6**

Session-34

Learning objectives

6.1 Highway Construction

6.1.1 Types of Highway Construction

6.1 Highway Construction

The science of highway engineering raises some fundamental questions as to what is a road or highway, how is it planned and designed and lastly how is it built. By now in the preceding chapters, depending upon the desired strength of the pavement, the aggregate gradations and the type and proportion of binders are decided. These three basic binder medium give rise to a number of construction methods.

6.1.1 Types of Highway Construction

The highway types are classified as below:

(i) Earth road and gravel roads

(ii) Soil stabilized roads

(iii) Water bound macadam (WBM) road

(iv) Bituminous or black-top roads

(v) Cement concrete roads

The roads in India are classified based on location and functions. All the roads do not cater for the same amount of traffic volume or intensity. Since the funds available at hand for financing the construction projects are also meager, it is necessary to have roads which cost less. The adoption of low cost roads is now preferred in developing countries like India where large lengths of roads are to be constructed in the rural areas with the limited finances available in the country. Earth roads and stabilized roads are typical examples of low cost roads. Stabilized soil roads are gaining importance in the form of low cost roads.

EARTHWORK

General

The subgrade soil is prepared by bringing is to the desired grade and camber and by compacting adequately. The subgrade may be either in embankment or in excavation, depending on the topography and the finalized vertical alignment of the road to be constructed.

Excavation

Excavation is the process of cutting or loosening and removing earth including rock form its original position. Transporting and dumping it as a fill or spoil bank. The excavation or cutting mat is needed in soil, soft rock or even in hard rock, before preparing the subgrade.

Embankment

When it is required to raise the grade line of a highway above the existing ground level it becomes necessary to construct embankments. The grade line may be raised due to any of the following reasons

i) To keep the subgrade above the high ground water table.

ii) To prevent damage to pavement due to surface water and capillary water.

iii) To maintain the design standards of the highway with respect to the Vertical alignment.

The design elements in highway embankments are:

a) Height

b) Fill material

c) Settlement

d) Stability of foundation, and

e) Stability of slopes

Height

The height of the embankment depends on the desired grade line of the highway and the soil profile or topography. Also the height of the fill is sometimes governed by stability of foundation, particularly when the foundation soil is weak.

Fill Material

Granular soil is generally preferred as highway embankment material. Silts, and clays are considered less desirable. Organic soils, particularly peat are unsuitable. The best of the soils available locally is often selected with a view to keep the lead and lift as low as possible. At times light-weight fill material like cinder may be used to reduce the weight when foundation soil is weak.

Settlement

The embankment may settle after the completion of construction either due to consolidation and settlement of the foundation or due to settlement of the fill or due to both. If the embankment foundation consists of compressible soil with high moisture content, the consolidation can occur due to increase in the load. The settlement of the fill is generally due to inadequate compaction during construction and hence by proper compaction this type of settlement may be almost eliminated. Whatever be the type of settlement, it is desirable that the settlement is almost complete before the construction of pavement.

Stability of Foundation

When the embankment foundation consists of weak soil just beneath or at a certain depth below in the form of a weak stratum, it is essential to consider the stability of the foundation against a failure. This is all the more essential in the case of high embankments.

a) The foundation stability is evaluated and the factor of safety is estimated by any of the following approaches:

b) Estimating the average shear stress and strength at the foundation layers by approximate methods and estimating the factor of safety.

c) Using theoretical analysis based on elastic theory.

The factor of safety in the case of compressible soil foundation is likely to be minimum just after the completion of the embankment. Later due to consolidation of foundation and consequent gain in strength there will be an increase in the foundation factor of safety.

Stability of Slopes

The embankment slopes should be stable enough to eliminate the possibility of a failure under adverse moisture and other conditions. Hence the stability of the slope should be checked or the slope should be designed providing minimum factor of safety of 1.5. Often much flatter slopes are preferred in highway embankments due to aesthetic and other reasons.

MODULE-IV Chapter-6

Session-35

Learning objectives

6.2 Construction of pavements

6.2.1 Wet Mix Macadam (WMM) construction procedure

6.2 CONSTRUCTION OF PAVEMENTS

Various equipment's for construction of the pavements:

1. Bull dozer
2. Scrapper
3. Power shovel
4. Hoe
5. Dragline
6. Clamp shell
7. Pavers

Construction of Flexible pavement

Material for construction Flexible pavement/Bituminous pavement:

The common types of flexible pavements in India are made from wet mix macadam (WMM) and (WBM) water bound macadam.

6.2.1 Wet Mix Macadam (WMM) construction procedure

Steps

1. The compaction test is conducted in the laboratory using the selected WMMmaterial.
2. The optimum moisture content of the WMM material is found out in thelaboratory under heavy compaction.
3. The selected WMM material is prepared in a pug mill by adding water equal tothe optimum moisture content.
4. Then the WMM material is transported to the field and spread over the site by using a paver to attain required slope, thickness & grade.
5. Then the compaction is done using the vibratory roller of minimum weight 10 times and with a rolling speed of 5 Kmph.
6. The WMM layer is checked for defects before the construction of the bituminous surface course.
7. After the WMM layer is dried in a dry weather for 24 hours the bituminous pavement layer is applied & the real is opened for traffic.

MODULE-IV **Chapter-6**

Session-36

<u>Learning objectives</u>

6.3 Water Bound Macadam Construction

6.3 WATER BOUND MACADAM (WBM) CONSTRUCTION

Material used for the WBM construction

a) Coarse aggregate

b) Screening

c) Binding material Construction process Steps

1. The soil surface prepared by leveling & filling of the depressions and patching the pot holes up to the required grade and slope.
2. The dust and other loose materials are cleaned.
3. The total boundary for the formation of the pavement was confined by constructing the shoulders.
4. Then the coarse aggregates are properly spread to a uniform profile and thickness.
5. The compaction is done by using power rollers of 3-10 tons by vibration & rolling, starting from the edge towards the center line.
6. After the compaction is over the dry screening are applied on the surface to fill the interspaces in 3-4 applications.
7. The surface is sprinkled with water & rolled. The rolling is done till the coarse aggregates get firmly bonded.
8. The binding material is applied at a uniform & slow rate followed with sprinkling of water. Then rolled to desired level.
9. After the final compaction the layer is allowed for drying 24 hours. The bituminous surfacing is layered which comprises of tar & aggregate of range (1-1.5 cm) in hot condition.
10. Then the rolling is done followed by sprinkling of additional bitumen & after the drying of road completely this is made open to the traffic.

MODULE-IV **Chapter-6**

Session-37

<u>Learning objectives</u>

6.4 Constructions of cement concrete/rigid pavements

6.4 <u>CONSTRUCTION OF CEMENT CONCRETE/RIGID PAVEMENTS</u>

Construction of C.C. pavements can be done in two methods:

1. **<u>Alternate bay method</u>**

   Here the C.C slabs are layered alternatively after an interval of 1 week or 2 days in case of rapid hardening cement (High alumina cement).

2. **<u>Continuous construction</u>**

   In this method all the bays of one traffic lane are laid continuously without any break.

   Materials required for the construction of C.C. pavements

   a) Cement – OPC & Rapid hardening (High alumina cement)

   b) Coarse aggregate

      - Abrasion value < 35 %
      - Impact value < 30 %
      - Crushing value < 30 %
      - Soundness value < 12

   Note: The maximum size of the aggregate used should be ¼ th the slab thickness.

   c) Fine aggregate – Natural sand, Crushed gravel/stone

   d) water

Construction procedure

Normally the C.C. pavements are constructed in the dry weather at temperature between (4 – 40^0C).

Step 1: Subgrade preparation

The foundation should be compacted & well graded. Generally the subgrade or sub-base preparation is done till a depth of 30 cm.

Step 2: Formwork fixing

Timber/ wood frameworks were previously used as formwork in C.C. pavement construction but now-a-days steel formworks of length 3 m are used. The formworks were made to stand vertically & fixed by the help of stiffeners at the backside and arranged in a straight line. Then the line & levels were ensued.

Step 3: The coarse aggregate, fine aggregate and cement are mixed in required preparation by weight in the batching plant properly.

Step 4: Mixing of materials

Concrete mixing is done using power driven mixers for uniform distribution of all materials in mixture. The workability is also determined for the prepared mix.

Step 5: Transportation & spreading

The concrete should be immediately placed between the formwork within 20 minutes after mixing & compacted properly. The concrete should not be dropped from a height of 90 cm (to avoid segregation).

Step 6: Compaction

The compaction must be done by using a vibrating screed while continuing this process over vibration is avoided as to prevent coming of excess mortar & water to the top. This step should be completed within 75 minutes after mixing.

Step 7: Curing

After the final setting time is over, Wet jute mats were placed over the pavement for initial curing of 24 hrs. and after that sand is sprayed and watered over the pavement for final curing of 14 days. After 28 days the pavement is opened for traffic.

MODULE-IV **Chapter-6**

Session-38

Learning objectives

6.5 Pavement engineering

6.5 Pavement engineering

Pavement is the durable surface material laid down on an area intended to sustain vehicular load or foot traffic, such as a road or walkway.

- Pavement means surfacing layer only.
- In terms of highway design, it means the total thickness of road including surfacing, base & surface, if any.
- Thus pavement includes all the structural layers of road structure lying on subgrade of the road.

It is of two types

- Flexible pavement or bituminous pavement or black top pavement
- Rigid pavement or cement concrete pavement or white surface pavement

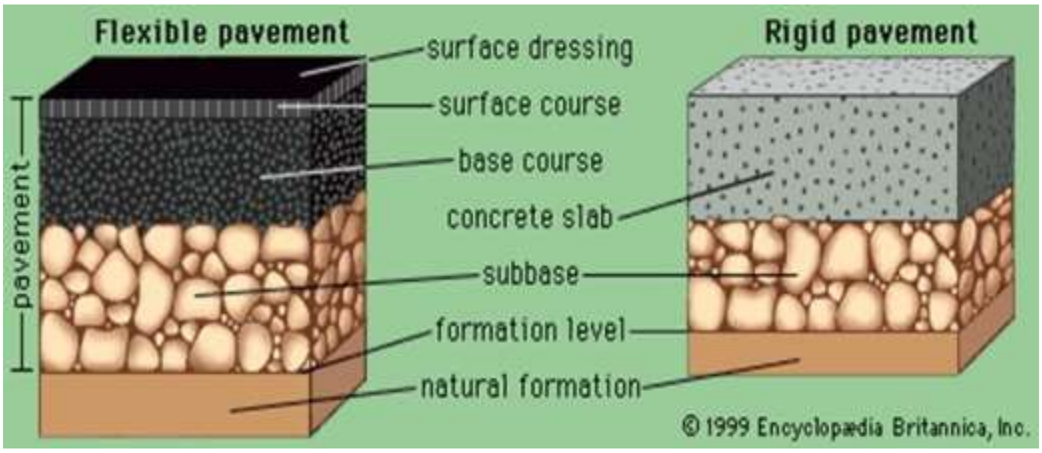


Figure 6.1 Parts of various types of pavements

COMPARISON OF FLEXIBLE PAVEMENT & RIGID PAVEMENT

The comparisons are:

I) Design precision:

A cement concrete pavement is amerable to a much more precise structural analysis than a flexible pavement. Flexible pavements designs are mainly empirical. Computer aided analysis of layered system is making the flexible pavement design more exact than hitherto.

II) Life:

Cement concrete slabs of a thin section constructed in the early 1940's are still in existence in India though many of them have cracked badly and a few of them have been ripped open and rebuilt in recent ties.

A major project in cement concrete road construction between Agra and Mathura can safely be said that a well-designed concrete slab has a life of about 40 years.

Compared to this the life of a flexible pavement generally varies from 10 to 20 years.

III) Maintenance:

• A well-designed cement concrete pavement needs very little maintenance. The only maintenance needed is I respect of joints.

• The surface is unaffected by spillage of oil and lubricants, bituminous surfaces on the other hand, need great inputs in maintenance.

• The surface is affected by spillage of oil and lubricants. The surface is also affected by natural weathering agents like air, water ad temperature changes.

• A cement concrete pavement on the other hand needs a small amount for maintaining joints.

IV) Initial cost:

• The argument so far used against a cement concrete slab is that it is much costlier thana flexible pavement.

• The latter specifications no doubt represent the rock-bottom needs of a road in India, but these specifications can hardly provide a smooth and durable surface.

V) Stage construction:

• Road construction is generally done adopting a policy of stage construction especially for low volume roads. As traffic grows, additional layers in the form of water bound macadam and superior surfacing are added on.

• Initial outlay is minimum and additional outlays are in keeping with traffic growth. This is a great advantage when dealing with new roads in an atmosphere of austerity.

VI) Availability of materials:

• Cement, bitumen, stone aggregates and gravel/sand are the major materials involved in pavement Construction. Cement has been in serious short supply in the country for the past many decades.

• Bitumen is also not available plentifully in India. There is also the danger of the entire oil reserves in the world shrinking during the next two or three decades.

• In locations where stone aggregates are scarce, cement concrete may have an advantage for flexible pavements

VII) Surface characteristics:

• A good cement concrete surface is smooth and free from rutting, potholes and corrugations. In a bituminous surface it is only the asphaltic concrete surface that can give Comparable rideablity.

• A well-constructed cement concrete pavement surface can have a permanent nonskid surface. A bituminous surface can also be designed to have a good skid resistant surface.

VIII) Utility location:

• In cement concrete slabs, proper thought has to be given to locate utilities, such as water pipes, telephone lines and electric cables.

• It is difficult to rip open the slab and restore it to be the original condition, if any changes in the utilities lines are to be made.

IX) Glare and night visibility:

• Concrete pavements have a gray colour which can cause glam under sunlight. Coloured cement can reduce the grave.

• On the other hand, bituminous roads need more street lighting.

X) Traffic dislocation during construction:

• A cement concrete pavement requires 28 days before it can be thrown open to traffic. On the other hand, a bituminous surface can be thrown open to traffic shortly after it is rolled.

XI) Environmental considerations during construction:

• The process of heating of bitumen and aggregates and mixing them together on hot mix plants can prove to be much more hazardous to the environment than cement concrete construction where no heating of any material is involved.

XII) Overall economy on a life cycle basis:

• A good road is costly to construct but once constructed such a road requires little maintenance and results in savings in vehicle operating costs.

• The comparative economy of a flexible pavement and a rigid pavement has proved that on overall economic considerations.

MODULE-IV Chapter-6

Session-39

Learning objectives

6.6 Difference between flexible and rigid pavement

Properties	Flexible	Rigid
Design principle	Empirical method based on load distribution characteristics of the components.	Designed and analyzed by using the elastic theory
Material	Granular material	Made of cement concrete either plain, reinforced or pre-stressed concrete
Flexural strength	Low or negligible flexible strength	Associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of subgrade soil.
Normal loading	Elastic deformation	Acts as beam or cantilever
Excessive loading	Local depression	Causes cracks

Stress	Transmits vertical and compressive stresses to the layers	Tensile stress and Temperature increase
Design practice	Constructed in number of layers	Laid in slabs with steel reinforcement
Temperature	No stress is produced	Stress is produced
Force of friction	Less. Deformation in the sub grade is not transferred to the upper layers.	Friction force is high.
Opening to traffic	Road can be used for traffic within 24 hours.	Road cannot be used until 14 days of curing.
Surfacing	Rolling of the surfacing is needed.	Rolling of the surfacing is not needed.

FLEXIBLE PAVEMENT	**RIGID PAVEMENT**
1. Have low flexural strength 2. Load is transferred by grain to grain contact 3. Surfacing cannot be laid directly on the sub grade but a sub base is needed 4. No thermal stresses are induced 5.expansion joints are not needed 6.Design life 10-15 years 7.Initial cost of construction is low 8.Maintenance cost is high 9. Road can be used for traffic within 24 hours 10. Damaged by Oils and Certain Chemicals	1. Have more flexural strength 2. No such phenomenon of grain to grain load transfer exists 3. Surfacing can be directly laid on the sub grade 4. Thermal stresses are induced 5.expansion joints are needed 6.Design life 20-30 years 7.Initial cost of construction is high 8.Less maintenance cost 9. Road cannot be used until 14 days of curing 10. No Damage by Oils and other chemicals

MODULE-IV **Chapter-6**

Session-40

<u>Learning objectives</u>

6.7 Rigid Pavements

6.7.1 Types of Rigid Pavements

6.7 <u>Rigid Pavements</u>

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure below. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material.

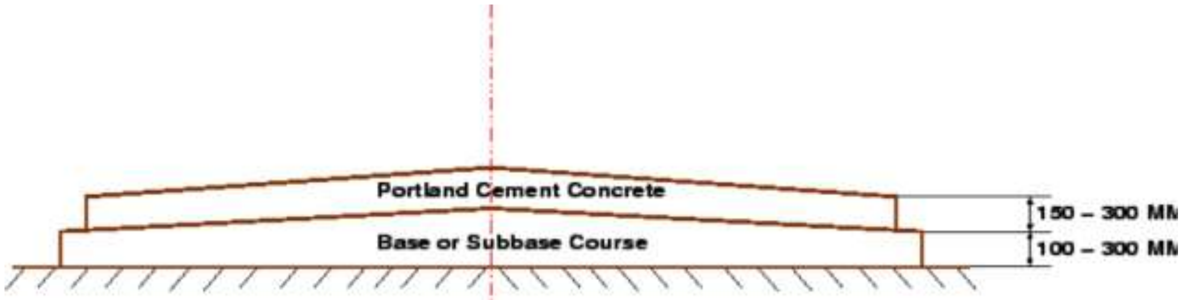
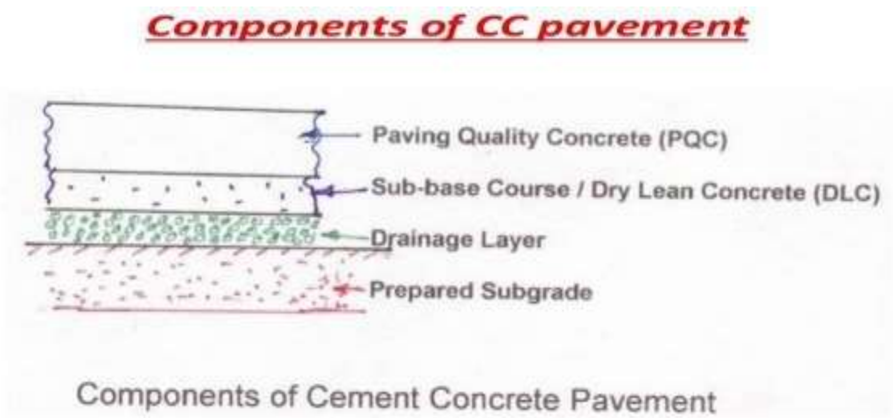


Figure 6.2 Typical C/S of Rigid Pavement

Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course. In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on viscous medium rigid pavements is constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory.



6.7.1 Types of Rigid Pavements

Rigid pavements can be classified into four types:

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),
- Continuous reinforced concrete pavement (CRCP), and
- Pre-stressed concrete pavement (PCP).

Jointed Plain Concrete Pavement: are plain cement concrete pavements constructed with closely spaced contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They normally have a joint spacing of 5 to 10m.

Jointed Reinforced Concrete Pavement: Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load transfer. Reinforcement's help to keep the slab together even after cracks.

Continuous Reinforced Concrete Pavement: Complete elimination of joints are achieved by reinforcement.

FACTORS AFFECTING PAVEMENT DESIGN

Traffic and loading:

Traffic is the most important factor in the pavement design. The key factors include contact pressure, wheel load, axle configuration, moving loads, load, and load repetitions.

Contact pressure:

The tire pressure is an important factor, as it determines the contact area and the contact pressure between the wheel and the pavement surface. Even though the shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

Wheel load:

The next important factor is the wheel load which determines the depth of the pavement required to ensure that the subgrade soil is not failed. Wheel configuration affects the stress distribution and deflection within a pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

Axle configuration: The load carrying capacity of the commercial vehicle is further enhanced by the introduction of multiple axles.

Moving loads:

The damage to the pavement is much higher if the vehicle is moving at creep speed. Many studies show that when the speed is increased from 2 km/hr to 24 km/hr, the stresses and deflection reduced by 40 per cent.

Repetition of Loads:

The influence of traffic on pavement not only depends on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these

Environmental factors:

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation.

MODULE-IV Chapter-6

Session-41

Learning objectives

6.8 Design of Rigid Pavements

6.8 Design of Rigid Pavements:

Stresses in Rigid Pavement

Rigid pavements are rigid i.e., they do not flex much under loading like flexible pavements. They are constructed using cement concrete. In this case, the load carrying capacity is mainly due to the rigidity ad high modulus of elasticity of the slab (slab action).

Modulus of sub-grade reaction

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection.

Westergaard's Modulus of sub-grade reaction

$$K = \frac{p}{\Delta}$$

$$= \frac{p}{0.125}\, kg/cm^2$$

Where, $\Delta$is the displacement level taken as 0.125 cm and p is the pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm.

Equivalent radius of resisting section

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard's gives a relation for equivalent radius of the resisting section in cm in the equation

$b = \sqrt{1.6a^2 + h^2} - 0.675h$ if $a < 1.724h$

Otherwise $b = a$ if $a > 1.724h$

Where, a = the radius of the wheel load distribution in cm

h = the slab thickness in cm

b = equivalent radius of resisting section in cm

Type of concrete used for cement concrete pavement

- Normally M40 grade is used for C.C. pavements.
- Minimum flexural strength of 45 kg/cm^2.
- For low volume roads M35 concrete may be used.

Design approach for rigid pavements

Cement concrete roads provides a highly rigid surface and hence for the success of such roads, following two conditions should be satisfied.

1. They should rest on non-rigid surface having uniform bearing capacity.
2. The total thickness or depth of the concrete pavement & the non-rigid base should be sufficient to distribute the wheel load on a sufficient area of sub-base so that the pressure on unit area remains with the permissible SBC of the soil.

Concrete slab has high modulus of elasticity, high rigidity & flexural strength, so wheel loads are distributed over large areas of subgrade. This leads to small deflections and also leads compressive stresses imposed on the subgrade.

- This leads to fatigue damage in concrete slab in form of development of micro cracks, due to repeated application of traffic loads.
- This is arrested by limiting flexural stresses and increasing the concrete mix grade.

MODULE-IV Chapter-6

Session-42

Learning objectives

6.9 Design steps (parameters)

6.9 Design steps (parameters)

1. Traffic parameters: Design wheel load, Traffic intensity
2. Environmental parameters: Temperature differential (CRRI table)
3. Foundation strength k (modulus of subgrade reaction)
4. Foundation surface characteristics (As per IRC)
5. Concrete characteristics (IRC:58 -1988)
6. Modulus of elasticity
7. Co-efficient of thermal expansion
8. Design slab thickness

Recommended design procedure for the design of rigid pavements by IRC Wheel load

The design wheel load may be taken as 4100 kg with a tyre inflation pressure of 5.3 to 6.3 kg/cm^3.

Traffic volume

The growth of traffic volume after 20 years of construction has to be considered in the design. The following formula may be used to estimate the demand

$$A = P (1 + r)^{n}$$

Where

A= number of commercial vehicles per day

P = the number of commercial vehicles per day at least count.

r = annual rate of increase in traffic intensity

n = number of years between the last traffic count and the commissioning of new cement concrete pavement.

Annual temperature

The mean daily and annual temperature cycles are to be collected. The temperature difference, depending on the place where the road is intended to be constructed is taken from the standard table provided for various states and regions for a given thickness of slab.

Modulus of subgrade reaction

Modulus of sub grade reaction, K, is determined using a 75 cm diameter plate and the pressure corresponding to 0.125cm deflection. If the pavement is to be laid on the sub grade soil then K should be not less than 5.5kg/cm3 otherwise a suitable sub base course is to be provided.

Properties of concrete

The flexural strength of cement concrete to be used for the pavement should be less than 40 kg/cm3.

The cube strength of concrete should be 280 kg/cm2, modulus of elasticity E = 3X105 and poisons ratio = 0.15 these properties may also be determined experimentally.

Co-efficient of thermal expansion may be taken as 10x10-6per oC for design purpose.

Computation of stresses

•Wheel load stresses at the edge and corner regions are calculated as per modified Westergaard's analysis.

•Temperature stress at the edge region is calculated as per Westergaard's analysis using Bradbury's coefficient.

Slab thickness

•The length and width of slab are decided based on the joint spacing's and lane width.

•A trial thickness of slab is assumed. The warping stress at edge region is calculated which is deducted from the allowable flexural stress. The resulting strength in the pavement has to support the edge loads.

•The stress due to load at the edge is calculated. The factor of safety is computed comparing the strength and the edge stress. If the factor of safety is less than one, thickness is increased and the calculations are repeated till the factor of safety is above1.this is the design thickness h.

•The stress due to corner load is computed and checked using the above h. if this stress value is less than allowable flexural stress in concrete then the slab thickness h is adequate. If not the thickness may be suitably increased till the above condition is satisfied.

•The design thickness h is then adjusted for traffic intensity as given in table to obtain the final adjusted slab thickness.

MODULE-IV Chapter-6

Session-43

Learning objectives

6.9 Design steps (parameters)

Joint spacing

•For all slab thicknesses with rough foundation the maximum spacing recommended for 25mm wide expansion joint is 140m. For smooth foundation the maximum spacing may be 90m for slab thickness up to 20cm,

•120m for slab thickness up to 25cm when the construction is made in summer. If the construction is made in winter the spacing may be restricted to 50 and 60m respectively.

•In unreinforced slab for all slab thicknesses the spacing of construction joint is 4.5m.in reinforced slab the spacing is 13m for m15cm thickness slab with steel reinforcement of 2.7kg/cm2 and 14m spacing for 20cm thick slabs with steel reinforcement of 3.8kg/cm2.

Dowel bars

•Dowel bars are designed based on Bradbury's analysis for shear, bending and bearing in concrete.

•The minimum dowel length is taken as ($L_d + \delta$). The load bearing capacity of the dowel system is assumed to be 40% of the design wheel load. The dowel bars is considered to be effective 1.8 times the radius of relative stiffness l on the either side of the load position.

•Dowel bars are provided for thickness of slab more than 15cm or more. IRC recommends 2-5cm dia bars of 50cm length with 20cm spacing for 15cm thick slab and spaced at 30cm in case of 20cm thick slab.

Tie bars

Designed for longitudinal joints with permissible bond stress in deformed bars 24.6kg/cm2 and in plain bars 17.5kg/cm2. Allowable working stress in tensile steel is taken as 1500kg/cm2.

Reinforcement

Nominal reinforcement in cement concrete pavements is intended to prevent deterioration of the cracks. It is not provided to increase the flexural strength of uncracked slab. The area of longitudinal and transverse steel required per meter width or length of slab is computed using the following formula.

A=Lfw/ (2S) Where

A = area of steel required per meter width or length of the slab, cm^2

L = distance between free transverse joints for longitudinal or transverse steel, m. w = weight of unit area of pavement slab, kg/cm^2.

The reinforcement is to be provided at 5cm below the surface of slab.it is continued across dummy groove joints to serve the purpose of tie bars. The reinforcement is kept at least 5cm away from the face of joint or edge.

Joints in cement concrete pavements

In general, joints are provided in cement concrete pavements to reduce temperature stresses.

•Expansion joint is provided to permit increase in the length of a slab due to temperature increase.

•Contraction joints are provided (i) to control cracking of the slab resulting from contraction and (ii) to relieve warping stresses.

•Longitudinal joints are provided to prevent the formation of irregular longitudinal cracks and to allow for transverse warping and unequal settlement.

•Construction joints are provided at the abrupt end of a day's work unexpectedly interrupted due to breakdown of plant or onset of bad weather.

Warping joints are provided if expansion joint and contraction joints are not effective.

Expansion joint is designed based on the maximum temperature variations expected and the width of joint. The design of contraction joint is governed by the anticipated frictional resistance and allowable tensile stress in concrete. Longitudinal joints are designed with tie bars.

MODULE-IV Chapter-6

Session-44

Learning objectives

6.10 Design of joints

6.10.1 Expansion joints

6.10.2 Contraction joints

6.10 Design of joints

6.10.1 Expansion joints

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature.

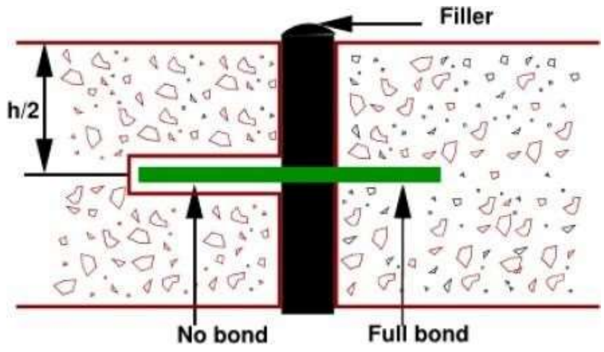


Figure 6.3: Expansion joint

6.10.2 <u>Contraction joints</u>

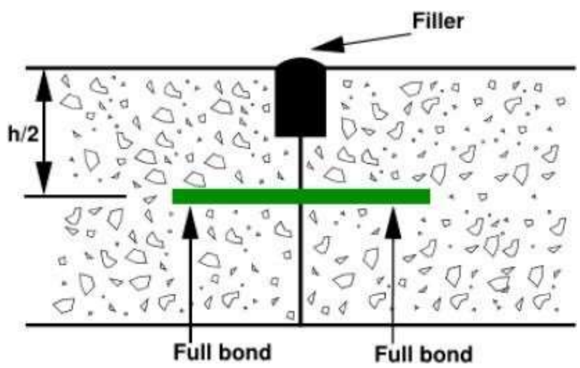


Figure 6.4: Contraction joints

Dowel bars

The purpose of the dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height.

Tie bars

In contrast to dowel bars, tie bars are not load transfer devices, but serve as a means to tie two slabs. Hence tie bars must be deformed or hooked and must be firmly anchored into theconcrete to function properly.

POSSIBLE SHORT ANSWER TYPE QUESTIONS

1. **What are the various types of highway construction?**

Ans: The highway types are classified as below:

(i) Earth road and gravel roads

(ii) Soil stabilized roads

(iii) Water bound macadam (WBM) road

(iv) Bituminous or black-top roads

(v) Cement concrete roads

2. **What are the design elements of highway embankments?**

Ans: The design elements in highway embankments are:

(i) Height

(ii) Fill material

(iii) Settlement

(iv) Stability of foundation, and

(v) Stability of slopes

3. **What is the various equipment's for construction of the pavements?**

Ans:

i. Bull dozer

ii. Scrapper

iii. Power shovel

iv. Hoe

v. Dragline

vi. Clamp shell

vii. Pavers

4. **Why joints provided in cement concrete pavements?**

Ans: In general, joints are provided in cement concrete pavements to reduce temperature stresses. Expansion joint is provided to permit increase in the length of a slab due to temperature increase. Contraction joints are provided (i) to control cracking of the slab resulting from contraction and (ii) to relieve warping stresses.

POSSIBLE LONG ANSWER TYPE QUESTIONS

1. **Give a short description on highway construction?**
2. **Write the design procedure of Wet Mix Macadam (WMM)?**
3. **Write the design procedure of Water Bound Macadam (WBM)?**
4. **What are the factors affecting pavement design?**
5. **Draw the C/S profile of flexible pavement?**
6. **Give a brief description on design parameters of rigid pavements?**
7. **Write a short note on joints in rigid pavements?**

MODULE- V **Chapter - 7**

Session-45

HIGHWAY MAINTENANCE

Learning objectives

7.1 Introduction

7.2 Road Maintenance Components.

7.3 General Causes of Pavement Failures.

7.3.1 Basic Maintenance Objective

7.1 Introduction

Road maintenance is essential in order to (1) preserve the road in its originally constructed condition, (2) protect adjacent resources and user safety, and (3) provide efficient, convenient travel along the route. Unfortunately, maintenance is often neglected or improperly performed resulting in rapid deterioration of the road and eventual failure from both climatic and vehicle use impacts. It follows that it is impossible to build and use a road that requires no maintenance. Preserving and keeping each type of roadway, roadside, structures as nearly as possible in its original condition as constructed or as subsequently improved and the operation of highway facilities and services to provide satisfactory and safe transportation, is called Road Maintenance or Maintenance of Highways.

Road maintenance is the one of the most important components of the road system. It involves the assessment of road condition, diagnosis of the problems and adopting the most appropriate maintenance step. Even if the highways are well designed, they may require maintenance due to its less design life. Various types of failures occur in the pavement which ranges from minor to major distresses.

7.2 Road Maintenance Components.

The various road maintenance function includes:

1.Surface maintenance.

2.Roadside and drainage maintenance

3. Shoulder and approaches

maintenance4.Snow and ice control

5.Bridges maintenance

6. Traffic service.

Highway maintenance is closely related to the quality of construction of original road. Insufficient pavement or base thickness or improper construction of these elements soon results in expensive patching or surface repair. Shoulder care becomes a serious problem where narrow lanes force heavy vehicle to travel with one set of wheels off the pavement.

Improperly designed drainage facilities, mean erosion or deposition of material and costly cleaning operation or other corrective measures. For regular highways maintenance and repair sharp ditches and steep slopes require manual maintenance as compare to cheap repair of flatter ditch and soil by machine. In snowy country, improper location extremely low fills and narrow cuts leave no room for snow storage, creating extremely difficult snow removal problems.

7.3 General Causes of Pavement Failures

Some of the general causes of pavement failures needing maintenance measures may be classified as given below:

(i) Defects in quality of materials used, construction method and quality control during construction.

(ii) Inadequate surface or subsurface drainage

(iii) Increase in the magnitude of wheel loads and the number of load repetitions due to increase in traffic volume.

(iv) Settlement of foundation of embankment

(v) Environmental factors including heavy rainfall, soil erosion, high water table, snow fall, frost action etc.

1. **Poor soil: -** It is the most common problem in the pavement design. The most common soil problem in the Southeast is a high water table. If not accounted for at the time of construction, a high water table will

erode the soil and eventually lead to pavement failure.

2. **Inferior material quality: -** If the material laid on the ground is not good enough, will be leads to severe defects and failures.
3. **Improper geometry: -** Due to improper geometry of road, lot of factors may arise which keeps the pavement deformation.
4. **Overloading of vehicles: -** A vehicle is said to be heavy loaded when it is being loaded more than its carrying capacity. Acc. to IRC, the max. wheel load for standard axle is 80 KN. Due to heavy movement of vehicles or overloaded vehicles or increase traffic volume, severe distresses takes place.
5. **Environmental Factors: -** It includes heavy rainfall, soil erosion, high water table, snow fall, frost action etc.
6. **Inadequate drainage: -** Due to improper drainage resulting in stagnation of water in the subgrade which could be the main reason pavement failure in future.

Maintenance of Highway

Various maintenance operations are as follows:

(i) Routine maintenance:

- These include filling up of pot holes and patch repairs, maintenance of shoulders and the cross slope, up-keep of the road side drains and clearing choked culverts, maintenance of miscellaneous items like road signs, arboriculture, inspection bungalows etc.

(ii) Periodic maintenance:

- These include renewals of wearing course of pavement surface and preventive maintenance of various items.

(iii) Special repair:

- These include strengthening of pavement structure or overlay construction, reconstruction of pavement, widening of roads, repairs of damages caused by floods, providing additional safety measures like islands, signs etc.

7.3.1 Basic Maintenance Objective

The basic objective of maintenance functions is to maintain and operate the highway system in a manner such that:

(i) Comfort, convenience and safety are afforded to the public.

(ii) The investment in roads, bridges and appurtenances is preserved.

(iii) The aesthetics and compatibility of highway system with the environment is preserved.
(iv) The necessary expenditure of resources is accomplished with continuing emphasis on economy.

MODULE- V **Chapter - 7**

Session-46

VARIOUS TYPES OF FAILURES OF FLEXIBLE PAVEMENT

Learning objectives

7.4 Failure in Flexible Pavement.

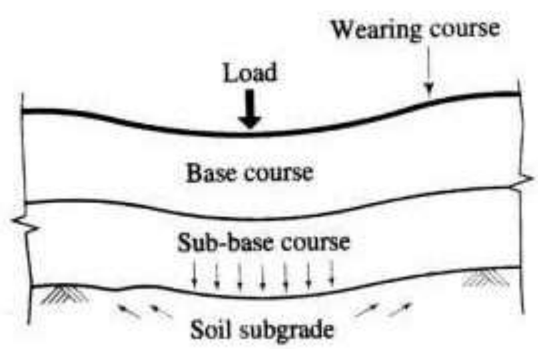
7.4 Failure in Flexible Pavement

One of the prime causes of flexible pavement failure is excessive deformation in subgrade soil. This can be noticed in the form of excessive undulations or waves and corrugations in the pavement surface.

The lateral shoving of pavement near the edge along the wheel path of vehicle is due to insufficient bearing capacity or a shear failure in subgrade soil. The failure of subgrade may be attributed due to inadequate stability and excessive stress application.

(i) Failures in subgrade:

Following are the two main reasons for failures in the subgrade



Failure in subgrade

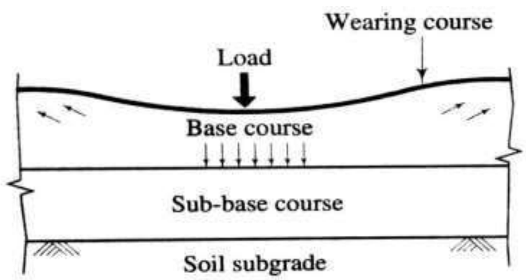
a) Excessive stress application: If the pavement thickness is inadequate or the loads are in excess of the design value, the excessive stress is developed and it harms as load repetitions are increased.

(b) Inadequate stability: The resistance to deformation. under stress is known as stability. The inadequate stability of the subgrade is developed due to the inherent weakness of the soil itself or excessive moisture or improper compaction.

(i) Failures in sub-base or base courses:

The main reasons which contribute to the failures in sub-base or base courses can be mentioned as follows:

(a) **Inadequate strength*:*** The poor mix proportioning or inadequate thickness of pavement may lead to the lack of stability or strength of sub-base or base course.



(b) **Inadequate wearing course:** If the wearing course is of inadequate thickness or if it is totally absent, the sub-base or base courses are exposed to the damaging effects of the climatic agencies and the traffic.

(c) **Lack of lateral confinement:** If lateral confinement is not provided for granular sub-base or base courses, the action of traffic causes the materials of these courses to spread out.

(d) **Loss of binding action:** The repeated stress applications lead to the internal movements of aggregate in sub base or base courses and ultimately the composite mass or structure of the layers gets disturbed. Thus, the loss of binding action is developed and it leads to the low stability and poor load transmitting property of the pavement layer.

(e) **Loss of materials:** If the base course is not covered with a wearing course or if the wearing course has completely worn out, there are chances of loss of base course materials due to action of traffic and it leads to the formation of pot holes on the surface. Use of inferior materials: If the materials employed in the construction of flexible pavements do not comply with the standard requirements, the structural behavior of the pavement is affected.

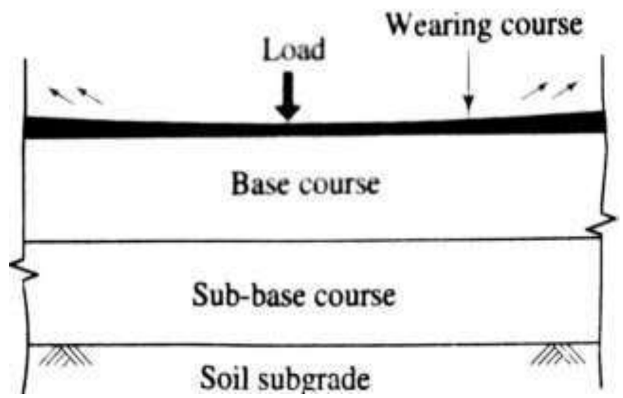
(ii) Failures in wearing course:

The failures in wearing course are attributed to the following reasons:

(a) Lack of proper mix design: If the mix design does not provide for adequate binder content, the bituminous surface will exhibit poor performance under the action of traffic.

Quality control: It is necessary to provide a high degree of quality control in bituminous construction.

The resulting paving mix should contain just enough binder content only

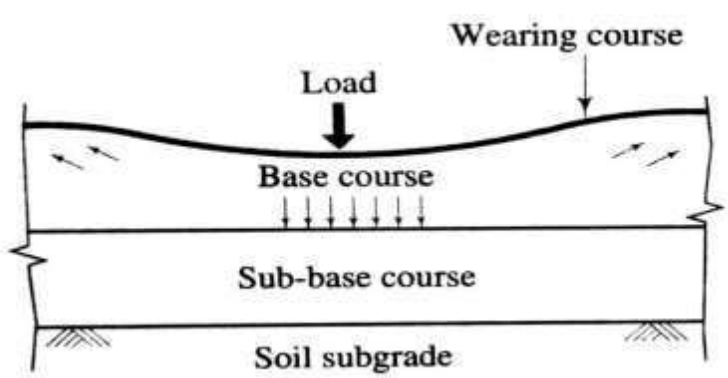


(a) Excessive stress application: If the pavement thickness is inadequate or the loads are in excess of the design value, the excessive stress is developed and it harms as load repetitions are increased

(b) Inadequate stability: The resistance to deformation. under stress is known as stability. The inadequate stability of the subgrade is developed due to the inherent weakness of the soil itself or excessive moisture or improper compaction.

(ii) **Failures in sub-base or base courses:** The main reasons which contribute to the failures in sub-base or base courses can be mentioned as follows:

(a) **Inadequate strength*:*** The poor mix proportioning or inadequate thickness of pavement may lead to the lack of stability or strength of sub-base or base course.



failure in Base course

(b) **Inadequate wearing course:** If the wearing course is of inadequate thickness or if it is totally absent, the sub-base or base courses are exposed to the damaging effects of the climatic agencies and

the traffic.

(c) **Lack of lateral confinement:** If lateral confinement is not provided for granular sub-base or base courses, the action of traffic causes the materials of these courses to spread out.

(d) **Loss of binding action:** The repeated stress applications lead to the internal movements of aggregate in sub base or base courses and ultimately the composite mass or structure of the layers gets disturbed. Thus, the loss of binding action is developed and it leads to the low stability and poor load transmitting property of the pavement layer.

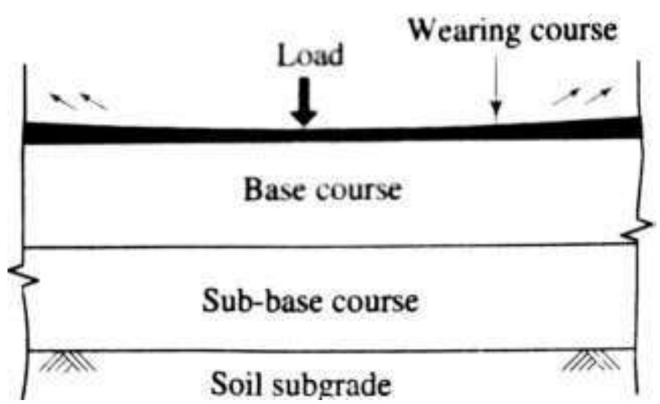
(e) **Loss of materials:** If the base course is not covered with a wearing course or if the wearing course has completely worn out, there are chances of loss of base course materials due to action of traffic and it leads to the formation of pot holes on the surface. Use of inferior materials: If the materials employed in the construction of flexible pavements do not comply with the standard requirements, the structural behavior of the pavement is affected.

(iii) Failures in wearing course:

The failures in wearing course are attributed to the following reasons:

(a) **Lack of proper mix design:** If the mix design does not provide for adequate binder content, the bituminous surface will exhibit poor performance under the action of traffic.

(b) **Quality control:** It is necessary to provide a high degree of quality control in bituminous construction. The resulting paving mix should contain just enough binder content only.



Failure in wearing course

(c) **Volatilization and oxidation of binder:** The bituminous surface becomes brittle due to volatilization and oxidation of binder. It results in the cracking of the pavement surface which further permits the seepage of rainwater to cause damage to the underlying layers.

Causes of premature failures: -

- Rutting due to high variation in ambient temperature.
- Uncontrolled heavy axle loads.
- Limitation of pavement design procedures to meet local environmental conditions.

MODULE- V **Chapter-7**

Session-47

Learning objectives

7.5 Common Flexible Pavement Failure/ Distresses

7.5.1 Types of defects in flexible pavement.

7.5 Common Flexible Pavement Failure/ Distresses

- Cracking
- Deformation
- Deterioration
- Mat problems
- Problems associated with seal coats

Category	Distress type
1. Cracking	Longitudinal, Fatigue, Transverse, reflective, block, edge
2. Deformation	Rutting, Corrugation, Shoving, depression, overlay bumps
3. Deterioration	Delamination, Potholes, Patching, raveling, stripping, Polished aggregate, Pumping
4. Mat Problems	Segregation, Checking, Bleeding
5. Seal coats	Rock loss, Segregation, bleeding/fat spots, Delamination

7.5.1 Types of Defects in Flexible Pavement

The types of defects in flexible pavement are grouped under four categories:

1. **Surface defect:** These are associated with the surfacing layers and may be due to excessive or deficient quantity of bitumen in these layers. It includes fatty surfaces, smooth surfaces, streaking and hungry surfaces.
2. **Crack:** It contains hair line crack, alligator crack, longitudinal crack, edge crack, shrinkage crack and reflection crack.
3. **Deformation:** It includes slippage, rutting, corrugation, shoving, shallow, depression, settlement and upheaval.
4. **Disintegration:** It covers stripping, loss of aggregates, ravelling, potholes and edge cracking.

A brief description of the defects, symptoms, probable causes, and possible treatment is given in the Table 10.3, extracted from "IRC; 82-1982: „Code of Practice for maintenance of bituminous surfaces‟, Indian Roads Congress, New Delhi, 1982"

MODULE- V Chapter - 7

Session - 48

Learning objectives

7.6 Failure in Flexible Pavement. (continues)

7.6.1 Failures in sub grade.

7.6.2 Failures in sub base or base course.

7.6.3 Failures of wearing course

7.6 Failure in Flexible Pavement

A flexible pavement failure is defined by formation of pot holes, ruts, cracks, localized depressions and settlements. The localized depression normally is followed with heaving in the vicinity.

The failure of any one or more components of the pavement structure develops the waves and corrugations on the pavement surface or longitudinal ruts and shoving. Pavement unevenness may itself be considered, as a failure, when it is excessive.

The aging and oxidation of bituminous films lead to the deterioration of bituminous pavements. Deterioration actions in pavements are rapidly increased when excess water is retained in the void spaces of bituminous pavements or in the cracks and joint of the cement concrete pavements.

7.6.1 Failures in sub grade:

One of the prime causes of flexible pavement failure is excessive deformation in sub grade soil. It is the form of excessive undulation or waves and corrugations in the pavement surface and also depressions followed by heaving of pavement surface.

The lateral shoving of pavement near the edge along the wheel path of vehicles is due to insufficient bearing capacity or a shear failure in sub grade soil.

The failure of sub grade maybe attributed due to two basic reasons:

i) Inadequate stability

ii) Excessive pavement thickness

Inadequate stability may be due to inherent of the soil and excessive moisture condition and improper compaction. Stability is the resistance to deformation under the stress.

Excessive stress application is due to inadequate pavement thickness or loads in excess of design value.

The deformation due to the load would be elastic or fully recovered when the load is released. In part of the compaction of the layers is not adequate with reference to subsequent loading part of the deformation may be permanent due to compaction of soil this may be called as consolidation deformation.

7.6.2 Failures in sub base or base course:

Following are the chief types of sub-base or base course failures:

i) Inadequate stability or strength

ii) Loss of binding action.

iii) Loss of base course materials

iv) Inadequate wearing course

v) Use of inferior materials and crushing of base course materials

vi) Lack of lateral confinement for the granular bass course.

7.6.3 Failures of wearing course:

Failure of wearing course is observed due to lack of proper mix design. Improper gradation of aggregates, inadequate binder content and inferior type of binder result in a poor bituminous surfacing.

Besides the design project the bituminous construction requires a high degree of quality control since over or under estimated binder content are both greatly damaging to the resulting paving mix including temperature controls.

Vocalization and oxidation of binder also makes the bituminous surfacing brittle and cause cracking of the pavement surface which further allows seepage of rain water to harm the underlying layers.

MODULE- V   Chapter - 7

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Learning objectives

7.7 Various types of flexible pavement failures

7.8 Pavement failure

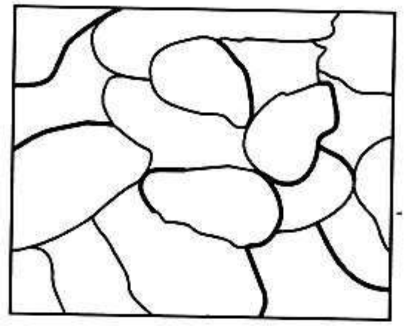
7.7 Various types of flexible pavement failures

Following are the some of the flexible pavement failures:

- Alligator(map) cracking.
- Consolidation of pavement layers
- Shear failure
- Longitudinal cracking
- Frost heaving
- Lack of binding to the lower course Reflection cracking
- Formation of waves and corrugation.

Alligator (map) cracking

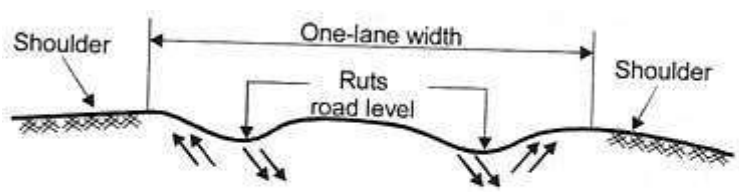
This is the most common type of failure and occurs due to relative movement of pavement layer materials. This may be caused by the repeated application of heavy wheel load resulting in fatigue failure or due to the moisture variations resulting in swelling and shrinkage of sub grade and other pavement materials. Localized weakness in the under laying base course would also cause a cracking of the surface course in this pattern.



Map cracking

Consolidation of pavement layers

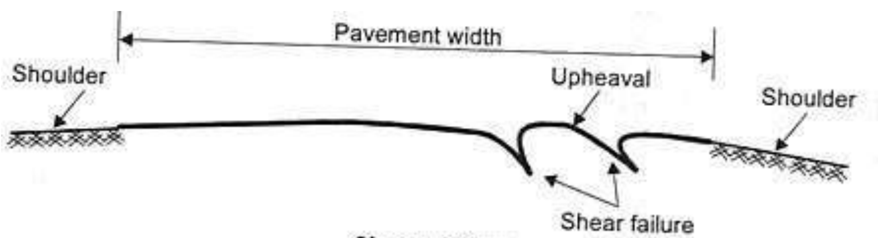
Formations of ruts are mainly attributed to the consolidation of one or more layers of pavement. The repeated application of loads along the same wheel path cause cumulative deformation resulting in consolidation deformation or longitudinal ruts. Shallow ruts on the surfacing course can also be due to wearing along the wheel path. Depending upon the depth and width of ruts, it can be estimated whether the consolidation deformation has been caused in the sub grade or in subsequent layers.



Formation of ruts due to consolidation

Shear failure and cracking

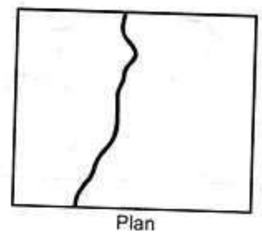
Shear failures are associated with the inherent weakness of pavement mixtures, the shearing resistance being low due to inadequate stability or excessively heavy loading. The shear failure causes upheaval of pavement materials by forming a fracture or cracking.



Shear failure cracking

Longitudinal cracking

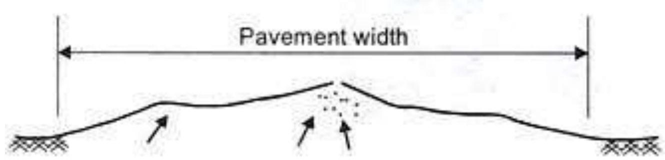
Due to frost action and differential volume changes in sub grade longitudinal cracking is caused in pavement traversing through the fall pavement thickness. Settlement of fill and sliding of side slopes also would cause this type of failure.



Longitudinal cracking due to differential volume change

Frost heaving

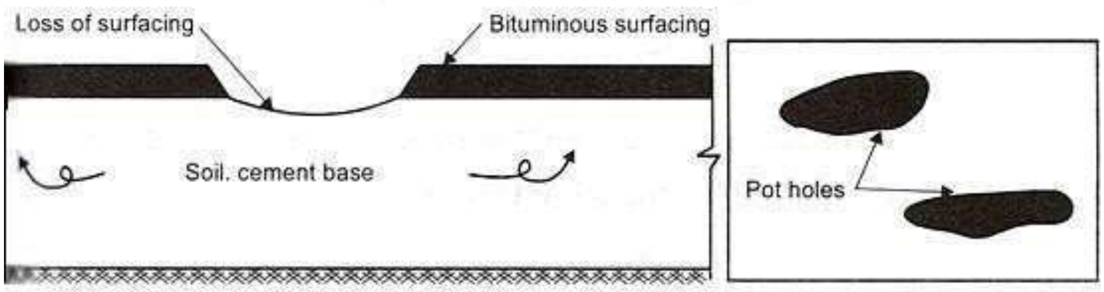
Frost heaving is often misunderstood for shear or other types of failure. In shear failure, the upheaval of portion of pavement is followed with a depression. In the case of frost heaving, there is mostly a localized heaving up pavement portion depending upon the ground water and climate conditions.



Failure due to frost heave

Lack of binding with lower layer

Slipping occurs when the surface course is not keyed/bound with the under laying base. This results in opening up and loss of pavement materials forming patches or pot holes. Such conditions are more frequent in case when the bituminous surfacing is provided over the existing cement concrete base course or soil cement course. This condition is more pronounced when the prime/tack coat in between two layers is lacking.

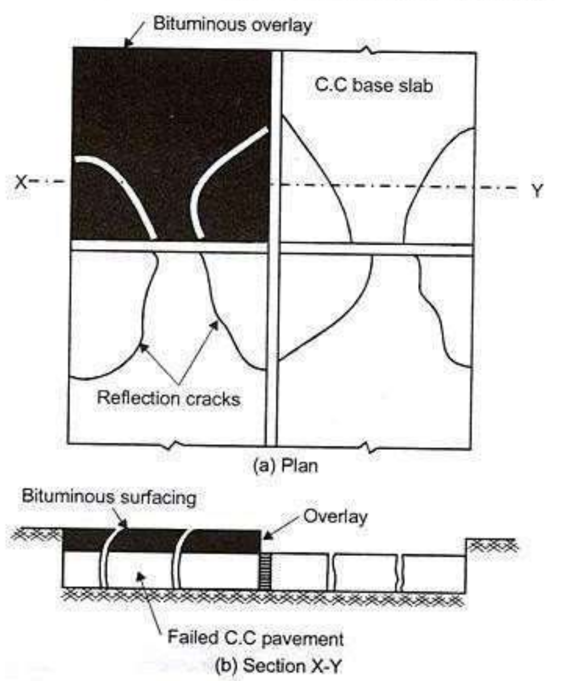


Failure due to lack of binding

Reflection cracking

This type of cracking is observed in bituminous overlays provided over existing cement concrete pavements. The crack patterns as existing in cement concrete pavements are mostly reflected on bituminous surfacing in the same pattern. Structural action of the total pavement section is not much influenced by the presence of reflection cracks but since the cracks appear at the surface, these allow surface water to seep through and cause damage to the soil sub grade or resulting in mud pumping.

(a) and (b) show the pattern of reflection cracking.



Reflection cracking

MODULE- V **Chapter - 7**

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Learning objectives

*7.9 **Pavement Failure***

*7.10 **Different types of cracking***

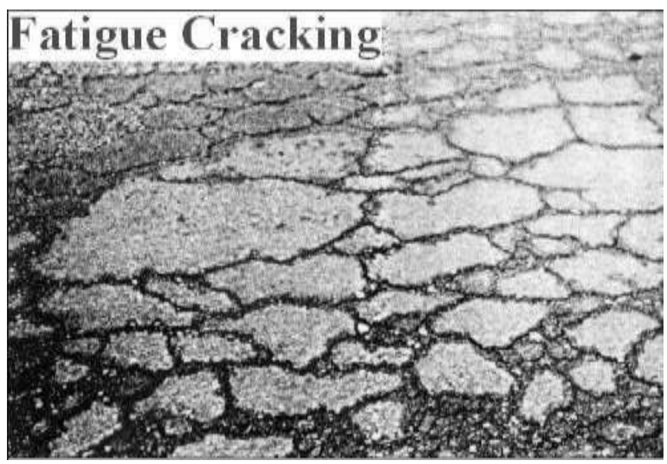
7.8 PAVEMENT FAILURE

Pavements fail prematurely because of many factors. When boiled down to the basics, there are four primary reasons pavements fail prematurely:

- Failure in design
- Failure in construction
- Failure in materials
- Failure in maintenance

7.10 DIFFERENT TYPE OF CRACKING

1. **Fatigue Cracking (Alligator Cracking):-** Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue).



2. **Longitudinal Cracking: -** Longitudinal cracks are long cracks that run parallel to the canter line of the roadway. These may be caused by frost heaving or joint failures, or they may be load induced. Understanding the cause is critical to selecting the proper repair.

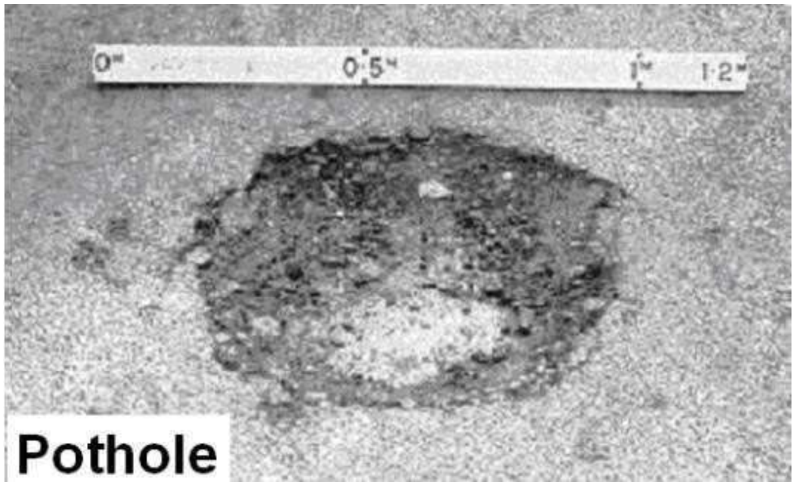
3. **Transverse Cracking: -** Transverse cracks form at approximately right angles to the centre line of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced (over 20 feet apart). They usually begin as hairline or very narrow cracks and widen with age.

4. **Block Cracking: -** Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction. Low severity block cracking may be repaired by a thin wearing course.

1. **Edge cracking: -** Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture.
2. **Rutting: -** Rutting is the displacement of pavement material that creates channels in the wheelpath. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a sub grade failure.

3. **Potholes: -** Potholes are bowl-shaped holes similar to depressions. They are a progressive failure. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage, as seen in Figure Potholes are formed

   when the pavement disintegrates under traffic loading, due to inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water.



4. **De-lamination: -** De-lamination is a failure of an overlay due to a loss of bond between the overlay and the older pavement. Common causes of de-lamination include: wet or dirty surface during paving of the overlay, failure to use a tack coat, or poor compaction of the overlay. Proper paving techniques, including cleaning the surface and use of tack coat, will reduce the chances of de- lamination.

   Other issues that need treatment before maintenance: Oil Spots – oil spots are a common problem in parking lots and driveways. These areas must be treated before sealcoating or the oil and chemicals will seep up through the newly applied material and render your sealed surface ineffective. There are number of great products for treating these types of issues. Ask your material supplier what they offer. Grass – Poorly maintained parking lots will often have grass growing up through the cracks. Cleaning the cracks should be standard practice before sealing them. Use a heat lance to burn out the crack and/or blow out the cracks depending on the severity of the problem. Mud, tree sap, berry stains, etc. Anything that would sit between the asphalt and the sealer must be removed. Without removing it the sealer cannot properly adhere to the asphalt and will eventually (sooner than later most likely) peel off. Blowers, push brooms, pressure washers, and gas powered brooms are all tools you should have in your pavement maintenance arsenal.

MODULE- V

Chapter - 7

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Learning objectives

7.11 Failure of Rigid Pavement.

7.12 Types of failure in rigid pavement.

7.11 Failure of Rigid Pavement.

Failure in rigid pavement (or cement concrete pavement) can be identified by formation of cracks on the pavement surface. The two prime factors responsible for rigid pavement failure are

1. Use of poor quality material
2. Inadequate stability of the pavement structure

Poor quality of material consist of following items

- Using soft aggregate
- Poor quality of sub-grade soil
- Poor joint filler R sealer materials

Inadequate stability of the pavement structure can be due to following reason

- Inadequate pavement thickness
- Lack of sub-grade support
- Improper compaction of sub-grade
- Improper spacing of joints

7.12 TYPES OF FAILURE IN RIGID PAVEMENT

The following 5 form of failures are commonly found in rigid pavement

1. Scaling of cement concrete
2. Shrinkage cracks
3. Joint spalling
4. Warping cracks
5. Pumping

1. SCALING OF CEMENT CONCRETE

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. This may be due to the following reasons

- Improper mix design
- Excessive vibration during compaction of concrete
- Laitance of concrete
- Performing finishing operation while bleed water is on surface

2. SHRINKAGE CRACKS

Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks. Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.

3. JOINT SPALLING

Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- Faulty alignment of incompressible material below concrete slab
- Insufficient strength of concrete slab near joints
- Freeze-thaw cycle
- Excessive stress at joint due to wheel load

4. WARPING CRACKS

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause formation of warping cracks of the concrete slab near the joint edge. This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.

5. PUMPING

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping. The common reasons for this defect are

- Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.
- When there is void space between slab and the underlying base of sub-grade layer
- Poor joint sealer allowing infiltration of water
- Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support.

When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks. This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.

<u>Learning objectives</u>

7.13 Pavement Failure & Maintenance

7.13 PAVEMENT FAILURE & MAINTENANCE

The no. of factors that causes pavement failure are

- Increase in traffic
- Environmental charges
- Design and construction deficiency
- Maintenance deficiency

Pavement failures:

Unsatisfactory performance of a pavement such that it can no longer be serviceable.

Pavement failure may be structural and functional failures.

- Structural failure means the collapse of the pavement
- Functional means the pavement is not able to discharge the traffic freely.

Maintenance of pavements:

Maintenance is the process which tends to keep the pavement in serviceable condition as long as possible.

- For proper inspection & maintenance each state should have a highway maintenance cell which will focus on construction, repair, maintenance & inspection works.

Earth roads:

The usual damages caused in the earth roads needing frequent maintenance are:

i) Formation of dust in dry weather.
ii) Formation of longitudinal ruts along wheel path or vehicles
iii) Formation of cross ruts along the surface after monsoons due to surface water.

Thus, dust nuisance may be remedied y the following methods:

a) Frequent sprinkling of water
b) Treatment with calcium chloride
c) Use of other dust palliatives.

Application of calcium chloride retains some water due to the hygroscopic nature of mix.

Oiled earth roads are also common these days.

Periodical maintenance by spreading moist soil along ruts and reshaping of the camber is necessary. Formation of cross ruts may be due to excessive cross slope.

Hence either these ruts should be repaired from time to time during and after the monsoon or a surface treatment or stabilized layer be provided on the top.

- Sprinkling water
- Rolling
- Adding new material over the older one followed by compaction.

Maintenance of WBM roads:

- Spreading a thin binder layer after monsoon.
- Applying surface dressing.
- Using filling materials such as dust.

Maintenance of bituminous road such as patch work and resurfacing

In addition to standard causes such as traffic, weather and ingress of water for the deterioration of earth, gravel and WBM roads, loss of volatiles, oxidation of the binder material and inadequacy of the specification and construction standards also could be the reasons for distress and disintegration of bituminous pavements.

Depending upon the degree of deterioration of the highway facility, the nature of the maintenance operations for bituminous pavements could be: (a) Patch repair (b) Surface treatment (c) Resurfacing

Maintenance of bituminous surfaces:

Mainly the maintenance works of bituminous surfacing consists of:

i) Patch repairs
ii) Surface treatments
iii) Resurfacing

Patch repairs:

Patch repairs are carried out on the damaged or improper roads surface. Localized depression and pot holes may be formed in the surface layers due to defects in materials and construction.

An inadequate or defective binding material causes removal of aggregates during monsoons. Patching may be done on affected localized area or sections using a cold premix.

Pot holes and repairs:

Pot holes are cut to rectangular shape and the affected materials in the section is removed until the sound materials are encountered.

The excavated patches are cleaned and painted with bituminous binder. A premixed material isthen placed in the sections. Generally, cutback or emulsion is used as binder.
Bituminous emulsions could be used even when the pavement surface and the aggregates arewet during monsoons.

The materials so places in the pot hole, is well compacted by ramming to avoid any raveling.
The materials in out holes are places in layers of thickness of 6 cm.
it is however necessary to replace the base course materials with similar new materials if the failure has been detected in the base curse layer. The finished level of the patched is kept slightly above original level to allow for subsequent compaction under traffic.

Surface treatment:

Excess of bitumen in the surface materials bleeds and the pavement becomes patchy and slippery. Corrugations or rutting or shoving develop in such pavement surface. It is customary to spread blotting materials such as aggregate chips of maximum size of about 10mm or coarse sand during summer.

Resurfacing:

In the event when the pavement surface is totally worn out and develops a poor riding surface, it may be more economical to provide an additional surface course on the existing surface.
In case of the pavement is of inadequate thickness due to increase in traffic loads and strengthening is necessary, than an overlay of adequate thickness should be designed and constructed.
A brief description of the defects, symptoms, probable causes, and possible treatment is given in the Table 10.3, extracted from "IRC; 82-1982: „Code of Practice for maintenance of bituminous surfaces‟, Indian Roads Congress, New Delhi, 1982": Defects, Symptoms, Causes and Treatment of Defects in Bituminous Surfacing.

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Learning objectives

7.13 Maintenance of Bituminous pavements

7.14 Maintenance of concrete pavements

7.13 Maintenance of Bituminous pavements:

- Cutting the defective areas in rectangular shape.
- Cleaning & applying primer.
- Filling the excavated area with premixed material by applying emulsions and compacted.
- Bituminous surface with minute cracks are treated by providing a completely new surface over it.

7.14 Maintenance of concrete pavements– (filling cracks, repairing joints, maintenance of shoulders (berm), maintenance of traffic control devices)

A cement concrete pavement needs very little maintenance if it is well-designed and properly constructed. In fact, this is considered to be the most important advantage which offsets the high initial cost. However, defects are likely to occur due to ingress of water, especially through ill-maintained joints and cracks, inadequate pavement thickness and poor workmanship.

Maintenance of cement concrete roads:

Various types of cracking have been explained:

Treatment of cracks:

The cracks are developed in cement concrete (CC) may be classified into two groups:

i) Temperature cracks which are initially fine cracks or hair cracks formed across the slab in between a pair of transverse or longitudinal joints, dividing the slab length into two or more approximately equal parts due to the temperature stresses like the shrinkage stress warping stress etc.

ii) Structural cracks formed near the edge and corner regions of the slabs, due to combined wheel load and warping stresses in the slab.

The repeated application of heavy wheel loads and the variations in temperature and moisture conditions the cracks get widened and further deterioration becomes repaid.

Once the surface water starts getting into the pavement and the sub grade through the widened cracks, progressive failure or the pavement is imminent.

Therefore, before these cracks get wide enough to permit infiltration of water, they should be sealed off to prevent rapid deteriorations

The formation of structural rocks in CC slabs should be viewed seriously and needs immediate attention as these indicate possible beginning of pavement failure. The maintenance work in such a case involves first remedy of the basic cause of the failure and then recasting the failed slabs.

Maintenance of joints:

Joints are the weakest pars in CC pavements. The efficiency of the pavement is determined by the proper functioning of the joint.

During the summer the joint sealer material is squeezed out of the expansion joints due to the expansion of the slabs. Subsequently as the slabs contract during winter, the joint gap opens out and cracks are formed in the old sealer material.

The joint filler material at the expansion joints may get damaged or deteriorated after several years of pavement life. The repair consists of removal of the sealer and deteriorated filler and sealer materials from the expansion joints cleaning up replacement with new filter board a sealing the top of the joints with suitable sealer materials.

Patch Repair of Slabs:

Sealing, spalling, depressions and irregularities can occur in a slab locally. Immediate patching up of such defective slabs can arrest further deterioration. Premix bituminous materials are commonly used for this purpose, but they do not provide a satisfactory result. The best materials are epoxy resin mortars and concrete for such patch repair work. The sides of the area of the slab to be patched are trimmed, made vertical, and fresh concrete is laid and tamped; the areas are usually made of regular geometrical shapes like rectangles.

Mud-Pumping:

When water gets collected in the subgrade, heavy axle loads cause ejection of mud through joints, cracks and edges. This phenomenon is commonly known as mud-pumping and blowing. When this is observed, defective joints and wide cracks should be refilled and sealed. To prevent further damage and recurrence, grouting of the slab is done through holes drilled in it; the grout can be of cement mortar (1:3.5 mix) or of bituminous material (the latter is preferred since it is effective in filling the void spaces between the slab and the subgrade), and raising the slab to the desired level. This process is called mud-jacking and is popularly used in advanced countries.

Restoration of Anti-Skid Surface:

When the surface becomes smooth and slippery, anti-skid surface can be restored by cutting grooves by grooving machines or by grinding machines.

Crack Repair:

A patching mix of epoxy mortar can be filled and compacted after chipping off the area and cleaning it thoroughly by using compressed air. This is adequate only when the crack depth is not more than one-third of the depth of the slab. However, when the crack extends almost to the entire depth of the slab, cross-stitching with inclined tie-bars or stapling with U-bars may be adopted; the former is shown schematically in Fig. 10.9

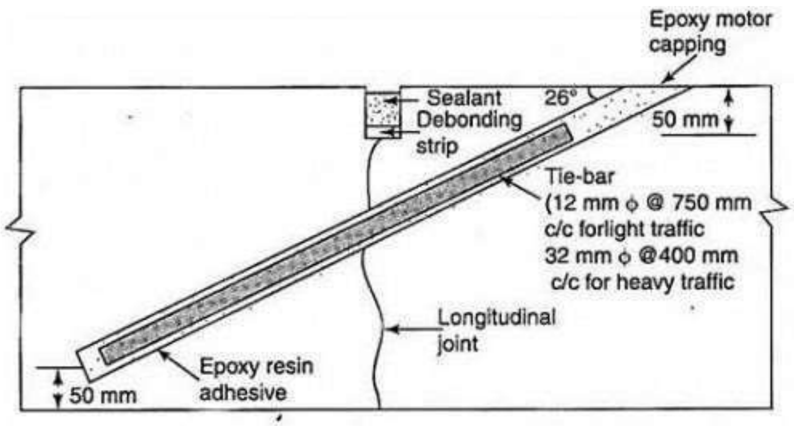

FIG. 10.9 *Crack repair by cross-stitching*

Mechanized Maintenance of Roads:

In India, road maintenance is mostly labour-oriented; however, mechanical maintenance of roads also can be practiced with indigenous equipment for speedy implementation and better- quality control.

MODULE- V

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Learning objectives

7.15 Maintenance of concrete pavements.

7.16 Methods of repairing the defects.

7.15 Maintenance of concrete roads:

- Wide pavement cracks can be maintained by first cleaning the cracks & applying a coat of kerosene then filled with suitable fillers.
- Slabs may be repaired using epoxy rasin sand ratio of 1:8 to 1:10 to a desired level.

7.16 Methods of Repairing the Defects

The repair methods are generally fall under two categories

(i) Seal coat:

Seal coat is a single thin application of bitumen which may or may not be covered with aggregate. Sealing can take the form of the following treatments:

(a) Liquid seal:

It is an application of binder at 9.8 kg/10m^2 followed up with a spread of cover aggregates (6.3 mm nominal size) at a rate of 0.09cu-m/10m^2 and rolling in position.

(b) Fog seal:

It is a spray of slow setting emulsion diluted with equal amount of water at a rate 0.5- 1 litre/m^2.Traffic is allowed after the seal sets in. It is used to increase the binder content of bituminous surface. It can also be used as an emergency treatment measure for hungry surfaces.

(a) **Slurry seal:**

It is an application of a slurry composed of slow setting emulsion, water and aggregates to a thickness of 5 -10 mm. The emulsion and water are 18-20 % and 10- 12 % respectively of the weight of aggregate. The slurry is spread at the rate of 200m^2 per tonne.

Table-8.2 : Specification for sealing materials

Treatment	Binder	Aggregate	Specification in brief
Liquid seal	Penetration grade, or cut-back emulsion	6.3 mm size	Spray binder uniformly at 9.8 kg/ 10 sqm spread aggregate at 0.09 cu m/ 10 sq m and roll.
Fog seal	Slow setting emulsion RS diluted with equal amount of water.		Spray at 0.5 to 1 litre/sq m. Allow traffic after the seal sets.
Slurry seal	Slow setting emulsion	Well graded material between 4.75 mm and 75 micron (grading specified).	Apply tack coat with diluted emulsion at 2.5 to 3.5 kg/ 10 sq m. Apply slurry mix consisting of 18 to 20% water by weight of aggregate at the rate of 200 sq m per tonne.

(ii) Patching:

Patching is the application of bituminous materials for filling potholes, shallow depressions, rutting and edge irregularities.

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Learning objectives

7.17 Special Repairs in Flexible Pavement

7.18 Evaluation of pavements

7.17 Special Repairs in Flexible Pavement

(i) Waves and Corrugations: Following are the factors which contribute to the formation of waves and corrugations:

(a) Defective Rolling: If the rolling during construction stage in improper thus leaving the formation of waves, then the process being progressive, the wave formation would continue indefinitely. However, the subsequent traffic operations would also cause similar effects if the rolling is inadequate during the construction stage.

(b) Poor subgrade conditions: Subgrade consisting of poor soils including highly plastic or organic soils and high water table close to subgrade surface may cause non uniform and inadequate subgrade stability. When boulders are used as soling course in such subgrade there is differential settlement or sinking of these stones. All these would contribute to formation of corrugated pavement surface.

(c) Poor gradation: Defective gradation or mix for the surface layer is another factor which gives rise to the wave formation pushing and pulling caused due to the vehicular movement enhance the defect further more.

(d) Compaction temperature: Viscous state of the bitumen binder greatly depends upon the temperature and thus very high temperature during mixing and compaction of bituminous mix would make the resulting pavement surface layers with low stability and wavy surface is formed during rolling.

(e) Unstable underlying layers: Weak underlying layers also cause the formation of waves due to repeated lying of vehicles on such road. Failure of any one of the pavement layers can cause surface deformations.

Remedial measures to be taken for the wave and corrugations are:

(a) There appears to be no way to improve the road surface once the waves and corrugations are already formed. Usually, another layer of surface course is laid after laying a levelling course. but often waves and corrugation again develop, unless the basic reason for this problem is investigated and proper measure is taken.

(b) If the instability of underlying layer is due to excessive moisture conditions suitable subsurface drainage system is warranted to remedy the defect permanently.

(c) If the failure is due to improper compaction of the lower layers this would need complete reconstruction.

(d) If the failure is due to subgrade soil which may be a highly plastic expansive clay the solution may be by subgrade treatment using a modifying agent for stabilization.

(ii) Skidding of pavement surface:

(a) Skid resistance property of pavement surface is essential requirement for highway safety. The skid resistance or the friction of pavement surface may be measured by using any one of the devices such as the pendulum type friction recorded or the skid testing device attached to test vehicle or the instrument mounted dynamic skid resistance tester towed by another vehicle.

(b) Water, clay, dust, dry sand, oil ad grease on the pavements are few factors which cause skidding. These materials on the pavement surface cause a reduction in grid between tyre and the pavement surface.

(c) Skidding is of three types straight skidding, impending skidding and sideway skidding. The straight skidding occurs in the direction of travel when the sudden brakes are applied. Impending skidding is encountered when the braking is gradual and wheel continues to revolve. Sideway skidding occurs on curves where sufficient super elevation is not provided or when the coefficient of friction is inadequate.

Highways can develop sufficient skid resistance if they are maintained clean and dry. But the presence of water film, debris and polishing characteristics of aggregate influence the skid resistance properly. Rough surfaces or textures like those of gravel road, WBM and cement concrete roads offers sufficient amount of skid resistance. Bituminous pavements are more prone to skidding.

7.18 Evaluation of Pavements

Evaluation: Evaluation of pavement is done under following categories:

i. Functional Evaluation
ii. Structural Evaluation
iii. Material durability
iv. Shoulder condition
v. Extent of maintenance activity performance in last
vi. Variation of pavement condition

The structural evaluation of pavement can be broadly classified into two major categories, namely, Destructive Evaluation and Nondestructive (NDT) Evaluation. In Non-destructive evaluation the structural strength of the pavement is evaluated without causing any damage to the pavement or disruption of traffic. A number of Non-destructive devices have been developed for the structural evaluation of pavement. The Non-destructive equipment is used to determine

- In -situ module of pavement layers,
- Load transfer efficiency at joints in the concrete pavements, and
- Location and extent of void in a pavement structure.

Destructive Evaluation:

Pavement is cut open for in-situ and lab tests (e.g. density, moisture, strength)

Non-destructive Evaluation:

Pavement subjected to applied loading and the structural response is measured (e.g.Benkelman Beam, Dynaflect, FWD, GPR).

Non destructive tests (NDT) – The application of load can be in different modes

(i) Static load (Plate Load Test)

(ii) Slow moving or creep load (Benkelman Beam Deflection Test)

(iii) Vibratory load (Dynaflect)

(iv) Impulse load (Falling Weight Deflectometer) Electromagnetic wave transmission and reflection in layered media

(v) Ground Penetrating Radar (GPR).

POSSIBLE SHORT ANSWER TYPE QUESTIONS

1. Mention the reason for the development of cracks in rigid pavement?

Cracks formed in rigid pavement are shrinkage cracks, warping cracks and structural cracks. Shrinkage cracks are formed in cement concrete pavements during curing operation. These

1. cracks develop both in longitudinal and transverse directions.
2. Formation of excess warping stress at the edge causes the slab to develop cracks at the edges in an
3. irregular pattern. Design of thickness should be made property considering different aspects like wheel load, temperature, sub grade conditions, etc…if the thickness is inadequate structural cracks are liable to occur.

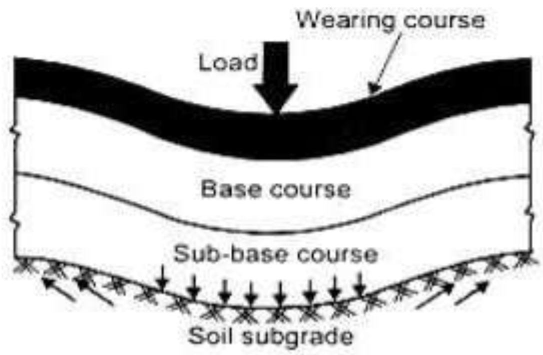
2. What is unevenness index?

Unevenness index is the cumulative vertical undulations of the pavement surface recorded per unit horizontal length of the road. This may be mentioned as cm per km. it is desirable that the pavement surface an unevenness index less than 150 cm/km.

3. What is mean by mud pumping?

Ejection of soil slurry through cracks formed on the pavement slab due to wheel load or otherwise. This is caused due to more slab deflection, type of sub grade soil and amount of free.

4. **Draw the figure for failure in sub grade of flexible pavement?**



Failure of subgrade

5. **What is mean by spalling of joint?**

During construction time cement concrete pavements are sometimes provided with preformed filler material at the joints. During concreting these filler materials may be disturbed and placed at an angle. As the filler materials are not properly alignment, which form an overhang of a concrete layer on the top side and the joint later on shows excessive cracking and subsidence**.**

6. **Give examples for surface defects in pavements?**
   - Cracks
   - Uneven undulations
   - Patches
   - Lake of binding
   - Ruts

7. **What is pavement evaluation?**

Pavement evaluation involves a thorough study of various factors such as sub grade support, pavement composition and its thickness, traffic and environmental conditions. The primary objective of pavement condition evaluation is to asses as to whether and to what extent the pavement fulfils the intended requirements so that the maintenance and strengthening jobs could be planned in time. The studies therefore investigate the structural adequacy of pavements and also the requirements for providing safe and comfortable traffic operations.

8. **List out the types of defects in flexible pavements.**
   - Cracks
   - Spalling
   - Ruts
   - Scalling
   - Lack of binding.

9. **Define the various general causes in pavement failures?**

The general causes are:

a) Defects in the quality of materials used

b) Effects in construction method and quality control

c) Inadequate surface (or) Sub surface drainage

d) Increase in the magnitude of wheel loads

e) Settlement of foundation of embankment

f) Environmental factors.

10. What are the failures in flexible pavement?
The failures are

1) Failures in sub grade
2) Failures in sub base
3) Failure in wearing course.

POSSIBLE LONG ANSWER TYPE QUESTIONS

1. Classify the different types of failures in flexible pavement and mention the important causes of each.?

2. Explain briefly different types of failures in rigid pavement?

3. Explain briefly the maintenance of bituminous surface?

4. What is meant by rutting? Explain the symptoms, causes and treatment.?