UNIT I – HIGHWAY PLANNING AND ALIGNMENT

PART - A

1. State any contributions made by Jayakar committee for the road development in India.(APRIL/MAY 10)

The two major contributions made by Jayakar committee are:

i)Classification of roads in India into five categories.

- National highways
- State highways
- Major district roads
- Other district roads
- Village roads

ii) Creation of central road fund

2. Define ruling gradient and exceptional gradient.(APRIL/MAY 10)

Ruling gradient

This is the desirable upper limit of gradient adopted in the normal course of design. This adoption of ruling gradient should balance the cutting and filling of earth work which will give an economical design. Different factors which are to be considered in the choice of ruling gradient is type of terrain, the length of the grade, the speed. Pulling capacity of vehicles and the presence of horizontal stretches of road.

Exceptional gradient

In some ground conditions it will be inevitable to provide a gradient steeper then limiting gradient such gradients are referred to as exceptional gradient.

3. What are the important modifications made in macadam's method of road construction? (APRIL/MAY 11)

Following are the important modifications made in macadam's method:

- Realizing the importance of sub grade drainage and compaction, the sub grade was prepared with sufficient cross slope.

- Heavy foundation stones were replaced with broken stones and with adequate drainage arrangements.
- The total thickness is comparatively less and the order of 25 cm.

The size of brocks tones used for the layer was based on the stability under animal drawn vehicles.

4. Mention the functions of medians in urban roads. (APRIL/MAY 11)

Separators or medians are provided the head on collision between two vehicles moving in opposite directions in the adjacent lanes. These medians may be in the form of pavement markings, physical dividers or area separators. Out of these three pavements making is the cheapest.

5. What are the objectives of highway research board? (MAY/JUNE 12)

Highway research board of Indian roads congress was set up in 1973.the constitution of the board primarily aims to serve as national centre for road research with the following role to play.

- To ascertain the nature and extent of research required.
- To correlative research information from various organizations in India and abroad with a view to exchanging publications and information on roads.
- To sponsor basic research through universities and research organizations. To collect and disseminate of research.
- To coordinate and conduct correlation services.
- To involve in any other matter related to road research.

6. State the classification of roads according to Nagpur road plan. (MAY/JUNE 12)

- National highway
- State highway
- Major district
- Other district roads
- Village roads

7. What is ideal alignment? (MAY/JUNE 13)

The alignment should as short and direct possible between the terminal points. This arrangement will be economical in construction, maintenance and operation.The alignment should not interfere to the maximum extent, with agriculture and industries. Further there should be no interference with the utility services like overhead transmission lines, water supply lines, etc.

8. Define camber. (MAY/JUNE 13) (NOV/DEC 13)

Camber, also called as cross fall, is the convexity provided to the cross section of the surface of carriage way. It is the difference in level between the highest point, known as the crown usually located at the centre of the carriage, and the edge.

Camber is provided so as

- To drain surface water
- To separate the traffic in two opposite directions
- To improve the appearance of the road

9. What is carriage way. (NOV/DEC 13)

The pavement width or carriage width depends on the width of traffic lane and number of lanes. The carriage way accommodating one line of traffic movement is called as a traffic lane. The width of the lane is decided based on the width of vehicle and the minimum side clearance may allow more vehicles with high speed.

10. Give some reasons for the poor state of road development in India?

The poor state of road development in India in the past may be due to the following reasons:

i) There was no planned development of roads in the country up to the initiation of Nagpur Road plan in the year 1943.Only during the five-year plans since 1951; the development works were speeded up.

ii) The investment even today on the road development programme is much lower than the revenue from the road transport.

iii) Poor economic conditions of the vast majority of the population in villages prohibit the owing of private vehicles and discourage the use of transport.

PART B (16 MARKS)

1 i) Briefly explain the role of MORTH and IRC in highway development? (APRIL/MAY 10)(NOV/DEC 13)

Ministry of road transport and highways (MORTH)

Ministry of road transport and highways is an apex organization under the central government of India. it is entrusted with the power of formulation and administration of road transport in India in construction with other central ministries/departments, state governments/UT administrations, organizations and individuals. Its policies include organization of road transport and national highways and transport research with a view to increase the mobility and efficiency of the road transport system in the country. The ministry has to wings, viz .,roads and transport wing.

Road wing

Road wing deals with the development and maintenance of national highway in the country. The main responsibilities are:

- Planning, development and maintenance of national highway in India.
- Extending technical and financial support to state governments for the development of state roads of interstate connectivity and economic importance.
- Evolving standard specifications for roads and bridges in the country.

Serving as a repository of technical knowledge on roads and bridges**.**

Transport wing

Transport wing deals with matters connected to road transport. The main responsibilities are:

- Motor vehicle legislation.
- Administration of the motor vehicle act,1988
- Taxation of motor vehicles.
- Implementation of compulsory insurance of motor vehicles. Administration of the road transport corporations, act, 1950.
- Promotion of transport co-operatives in the field of motor transport.
- Formation of road safety standards in the form of a national policy on road safety.
- Preparation and implementation of annual road safety plan.
- Collection and compilation and analysis of road accident statistics and take adequate steps for the development of road safety culture in the country.
- Sanction of grants-in-aid to non-governmental organization in accordance with the laid down guidelines.

New plans and schemes

Recently the ministry has formed new plans and schemes.

- New national permit system.
- Inviting suggestions for automotive industry standards.
- Scheme for strengthening public transport system.
- Original book writing scheme.
- Carriage by road rules 2010.
- Physical and financial targets for 2010-11.
- Guidelines for introduction of expressways.

Indian road congress (IRC)

Indian road congress is the premier technical body of highway engineers in the country. On the recommendations of jayakar committee, Indian road congress was set up in December 1934.as the activities of the IRC expanded; it was formally registered as a society's registration act of 1860.

Role of IRC

The following are the major roles of the congress.

- To promote and encourage the science and practice of construction and maintenance of roads.
- To suggest improved methods of administration, planning, design, construction, operation, use and maintenance of roads.
- To promote the use of standard specifications and to propose specifications. To advice regarding education, experience and research connected with roads.
- To establish, furnish and maintain libraries and museums for furthering the science of road making.

1 ii) State the factor influencing the highway alignment.(APRIL/MAY10) (NOV/DEC 13)

The various factors which control the highway alignment in general may be listed as:

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

Obligatory points

There are control points governing the alignment of the highways. These control points may be divided broadly into two categories.Point through which the alignment is to pass.Points through which the alignment should not pass.

Traffic

The alignment should suit traffic requirements .origin and destination study should be carried out in the area and the desire lane be drawn shown in the trend of traffic flow. The new road to be aligned should keep in view the desired lines, traffic flow patterns and future trends.

Geometric design

Geometric design factors such as gradient, radius of curve and sight distance also would govern the final alignment of the highway. If straight alignment is aimed at, often it may be necessary to provide very steep gradients. As far as possible while aligning a new road, the gradient should be flat and less than the ruling or design gradient.

Thus it may be necessary to change the alignment in view of the design speed, maximum allowable super elevation and coefficient of lateral friction. It may be necessary to make adjustment in the horizontal alignment of roads keeping in view the minimum radius of curve and the transition curves.

Economics

The alignment finalized based on the above factors should also be economical. In working out the economics, the initial cost the cost of maintenance and vehicle operation should be taken into account. The initial cost of construction can be decreased if high embankments and deep cuttings are avoided and alignment is chosen in a manner to balance the cutting and filling.

Other consideration

Various other factors which may govern the alignment are drainage considerations, hydrological factors, political considerations and monotomy.the vertical alignment is often guided by drainage considerations. The subsurface water level, seepage flow and high flood level are the factors to be kept in view.

2. i) Explain the activities of national highway authority of India.

(APRIL/MAY 11)

National highway authority of India was constituted in 1988 by an act of parliament. The responsibility of the authority is for development, maintenance and management of national highways and for matters connected to or incidental there to. The authority was operationalised in February 1995.

Role of NHAI

National highways in India have a total length of about 70500km running in every direction of the country to serve as an arterial network of the country. The national highways authority of India rest as with government of India through the national highway authority of India. it is empowered to implement the national highway development project.

2 ii). Explain the procedure for carrying out road alignment using remote sensing and GIS technique.(APRIL/MAY 11)

Photogrammetry or remote sensing is based on aerial photographs which are a basic working tool for the highway engineer.

Vertical ariel photographs taken with the camera pointed nearly straight down are the most useful for highway aligning or mapping purposes. The area to be covered in photographed in parallel runs with the individual pictures lapped both in the direction of flight and between successive runs. For stereoscopic uses, end lap must be greater than half the picture width in order that the centre of photograph is included in both adjacent photographs.

Several instruments are available for converting data from aerial photographs to maps. It is possible to produce accurate map showing all natural and artificial features. Also contours may be drawn which may be used for aligning.

2 iii). Describe the classifications of urban roads in India. Give the cross section of urban road with all its features. (APRIL/MAY 11)(MAY/JUNE13)

The classification of urban roads in India:

- **National highways**
- **State highways**
- **Major district roads**
- **Other district roads**
- **Village roads**

National highways

National highways are the main highways running through the length and breadth of India, connecting major parts, forgin highways, capital of large states and industrial and tourist centres including roads required for strategic movements for the defense of India.

It was agreed that a first step national trails should be constructed by the centre and that latter's these should be converted into roads to suit the traffic conditions. It was specified that national highways should be the frame on which the entire road communication should be based on that these highways may not necessarily be of same specification, but they must give an uninterrupted road communication through India and should connect the entire road network.

State highways

State highways are the arterial roads of a state, connecting up with the national highways of adjacent state, district headquarters and important cities within the state and serving as the main arteries for traffic to and from district roads.

These highways are considered as main arteries of commerce by roads within a state or a similar geographical unit. In some places they may be even carry heavier traffic than some of the national highways but this will not alter their designation or function. The NH and SH have some design speed and geometric design specification.

Major district roads

Major district roads are the important roads within a district serving

areas of production and markets and providing them with outlet to markets and connecting those with each other or with the main highways of a district. the MDR has lower speed and geometric design specifications than NH/SH.

Other district roads

Other district roads are roads serving rural areas of production and providing them with outlet to market Centre's taluk headquarters block development headquarters or other main roads. These are of lower design specifications then MDR.

Village roads

Village roads are road connecting villages or groups of villages with each other to the nearest road of a higher category.It was specified that these villages roads should be in essence farm tracks, but it was desired that the prevalent practice of leaving such tracks to develop and maintain by themselves should be replaced by a plan for a designed and regulated system

3. Write brief notes on:

i) Central road fund

ii) Indian road congress

iii) Central road research institute (MAY/JUNE 12)

i) Central road fund

-based on the authority of a resolution adopted by the Indian legislature, the central road fund was formed on 1th march 1929.

The consumers of petrol were charged an extra leavy of 2.64 paisa per liter of petrol to build up this road development fund 20 percent of the annual revenue is to be retained as a central reserve ,from which grants are to be given by the central government for meeting expenses on the administration of the road fund, road experiments and research on road and bridge projects of special importance.

The balance 80 percent is to be allotted by the central government to

the various states based on actual petrol consumption or revenue collected.

ii) Indian road congress

At the instance of central government a semi official technical body known as Indian road congress was formed in 1934.this it may be recalled is one of the main recommendations made by the jayakar committee.

The Indian road congress was constituted to provide a forum for regular pooling of experience and ideas onb all matters affecting the planning construction and maintenance of roads in India, to recommend standard specification and to provide a platform for the expression of professional opinion on matters relating to road engineering including such questions as those of organization and administration.

iii) Central road research institute

In the year 1950 the central road research institute was started at New Delhi for research in various aspect of highway engineering.

It may be indicated that one of the recommendations of jayakar committee report was to setup a central organization for research and dissemination of information.

The CRRI is one of the national laboratories of the council of scientific and industrial research. The institute is mainly engaged in applied research and offers technical advice to state governments and the industries on various problems concerning roads.

iv) National highway authority of India

National highway authority of India was constituted in 1988 by an act of parliament. The responsibility of the authority is for development, maintenance and management of national highways and for matters connected to or incidental there to. The authority was operationalised in February 1995.

Role of NHAI

National highways in India have a total length of about 70500km running in every direction of the country to serve as an arterial network of the country. The national highways authority of indiarestas with government of India through the national highway authority of India. it is empowered to implement the national highway development project.

4. Explain the requirement of ideal alignment.(MAY/JUNE 13)

The basic requirement of an ideal alignment between two terminal stations is that it should be:

- Short
- Easy
- Safe
- Economical

Short

It is desirable to have a short alignment between two terminal stations.a straight alignment would be the shortest, though there may be several practical considerations which would be the shortest, through there may be several practical considerations which would cause deviations from the shortest path.

Easy

The alignment should be such that it is easy to construct and maintain the road with minimum problems. Also the alignment would be easy for the operation of vehicles with easy gradient and curves.

Safe

The alignment should be safe enough for construction and maintenance from the view point of stability of natural hill slopes, embankments. Also it should be safe for the traffic operation with safe geometric features.

Economical

The road alignment could be considered economical only if the total cost including initial cost, maintence cost and vehicle operation cost is lowest. All these features should be given due consideration before working

out the economics of each alignment.

5 i) Briefly explain the Tresaguet and Macadam's method of road construction?

Tresaguet construction:

Pierre Tresaguet (1716-1796) developed an improved method of construction in France by the year 1964.The main feature of his proposal was that the thickness of construction need be only in the order of 30 cm.Tresaguet was the inspector General of roads in France from 1775 to 1785.So his method of construction was implemented in that country in 1775.The typical cross section of tresaguets road construction is given in fig. and the construction steps may be enumerated as below.

i) The sub grade was prepared and layers of large foundation stones were laid on edge by hand. At the two edges of the pavement large stones were embedded edge wise to serve as submerged kerbs stones.

ii) The corners of the heavy foundation stones were hammered and then the interstices filled with smaller stones.

iii) The top-wearing course was made of smaller stones and compacted to a thickness of about 5 cm at the edges and gradually increased towards the center.

iv) The shoulders were also provides cross slope to drain the surface water to the side drain.

Macadam Construction

John Macadam put forward an entirely new method of road construction as compared to all the previous methods. A typical cross section of Macadam construction:

i) The importance of sub grade drainage and compaction were recognized and the sub grade was compacted and was prepared with a cross slope of 1 in 36.

ii) Macadam was the first person to suggest the heavy foundation stones are not at all necessary to be placed at the bottom layer of construction.

iii) Though the total thickness of construction was less than previous

methods. This technique could serve the purpose in a better way.

iv) The size of broken stones for the top layer was decided based on the stability under animal drawn vehicles.

Macadam's method is the first method based on scientific thinking

The construction steps are:

i) Sub grade is compacted and prepared with a cross slope of 1 in 36 up to a desired width.

ii) Broken stones of a strong variety, all passing through 5 cm size sieve were compacted to a uniform thickness of 10cm.

iii) The second layer of strong broken stones of size 3.75 cm was compacted to thickness of 10 cm.

iv) The top layer consisted of stones of size less than 2 cm compacted to a thickness of about 5 cm. The cross slope of pavement surface was also 1 in 36.

5 ii. Briefly explain the engineering surveys needed for locating a new highway?

The stages of the engineering surveys are:

a) Map study.
b) Reconnaissance.
c) Preliminary surveys.
d) Final location and detailed surveys.

Map study: -

In the topographic map, to suggest the likely routes of roads. In India topographic maps are available from the survey of India with 15 or 30-meter contour intervals. The main feature like rivers, hills, and valleys etc. The probable alignment can be located on the map from the following details available on the map.

Reconnaissance:-

The second stage of surveys for highway location is the reconnaissance to examine the general character of the area for deciding the most feasible routes for detailed studies.

Some of the details to be collected during reconnaissance are given below:.

- Approximate values of gradient, length of gradients and radius of curves of alternate alignments.
- Number and types of cross drainage structures maximum flood level and natural groundwater level along the probable routes.
- Soil type along the routes from field identification tests and observation of geological features.
- Sources of construction materials water and location of stone quarries.
- When the road passes through hilly or mountainous terrain, additional data regarding the geological formation types of rocks, dip of strata, seepage flow etc.

Preliminary survey: -

The main objectives of the preliminary surveys are:

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

The procedure of the conventional methods of preliminary surveys the given steps:

Primary survey: -

For alternate alignments either secondary traverses (or) independent primary traverses may be necessary.

Topographical features: -

All geographical and other man made features along the traverse and for a certain width on either side surveyed and plotted.

Leveling work: -

Levelling work is also carried out side by side to give the centerline profiles and typical cross sections. The leveling work in the preliminary survey is kept to a minimum just sufficient to obtain the approximate earthwork in the alternate alignments.

Drainage studies: -

Drainage investigations and hydrological data are collected so as to estimate the type, number and approximate size of cross and drainage structures.

Soil survey: -

The soil survey conducted at this stage helps to working out details of earthwork, slopes, suitability of materials, subsoil and surface drainage requirements and pavement type and the approximate thickness requirements.

Material survey: -

The survey for naturally occurring materials like stone aggregates, soft aggregates etc and identification of suitable quarries should be made.

Traffic survey: -

Traffic surveys conducted in the region from basis for deciding the number of traffic lanes and roadway width, pavement design and economic analysis of highway project.

Final location and detailed survey: -

The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centerline. The detailed survey should be carried out for collecting the

information technology for the preparation of plans and construction details.

Location: -

- The centerline of the road finalized in the drawings to be translated on the ground during the location survey.
- Major and minor control points are established on the ground and center pegs are driven, checking the geometric design, requirements.

Detailed survey: -

- Levels along his final centerline should be taken at all staked points. Leveling work is to great importance as the vertical alignment.
- A detailed soil survey is carried out to enable drawing of the soil profile. The data during the detailed survey should be elaborate and complete for preparing detailed plans, design and estimates of the project.

5 iii) Write short notes on:

i) Right of way

ii) Carriage way

iii) Camber

iv) Krebs

Right of way:

Right of way is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development. A minimum land width has been prescribed for each category of road. The land width is governed by the following factor:

i) Width of formation depending on the category of highway and width of roadway and road margins.

ii) Height of embankment or depth of cutting which is governed by the topography and the vertical alignment.

iii) Side slopes of embankment (or) cutting which depend on

the height of the slope.

Drainage system and their size. Which depends on the rainfall, topography and runoff.

Carriage way (or) Width of pavement:

he pavement or carriageway width depends on the width of traffic lane and number of lanes. The carriage way intended for one line of traffic movement may be called a traffic lane.Keeping all these in view a width of 3.75m is considered desirable for a road having single lane for vehicles of maximum width 2.44m.For pavements having two or more lanes, width 0f 3.5m per lane is considered sufficient.The maximum width of vehicle as per IRC specification is 2.44m.If a single carriageway of width 3.8m is provided, a side clearance of 0.68m would be obtained.In the case of two lane pavement of width 0.7m a minimum clearance between two lanes of traffic would be 1.06m for the widest vehicles on the road. The number of lanes required in a highway depends on the predicted traffic volume and the design traffic volume of each lane.

Camber:

Camber (or) cross slope is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface. The pavement surface by providing cross slope is considered important because of two reasons.

i) To prevent the entry of surface water into the sub grade soil through pavement. ii) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping.

iii) To improve the rainwater from the pavement surface as quickly as possible and to allow the pavement to get dry soon after the rain.

The rate of camber or cross slope is usually designated by 1 in n which means that the transverse sloe is in ratio 1 vertical to n horizontal. Camber is also expressed as a percentage.The required camber of a

pavement depends on:

i) The type of pavement surface

ii) ii) The amount of rainfall

The minimum camber needed to drain off surface water may be adopted keeping in view the type of pavement surface and the amount of rainfall in the locality.

Too step cross slope is not desirable because of the following reasons:

i) Transverse of flit of vehicles causes uncomfortable side thrust and a drag on the steering of automobiles.

ii) Discomfort causing throw of vehicle when crossing the crown during overtaking operations.

iii) Problems of toppling over of highly laden bullock carts and trucks.

iv) Formation of cross ruts due to rapid flow of water.

v) Tendency of most of the vehicles to travel along the center line.

Kerbs:

Kerbs indicate the boundary between the pavement and shoulder (or) sometimes island or foot path or kerb parking space.There is variety of kerb designs; kerbs may be mainly divided in to three groups based on their functions.i) Low (or) mountable type kerbs which though encourage traffic to remain in the through traffic lanes, yet allow the driver to enter the shoulder area with little difficulty. This type of kerb is provided at medians and channelization schemes and is also useful for longitudinal drainage system.Semi-barrier type kerb is provided on the periphery of roadway where the pedestrian traffic is high.This type of kerb has a height of about 15cm above the pavement edge with a batter of 1:1 on the top 7.5 cm.This kerb prevents encroachment of parking vehicles. But at acute emergency it is possible to drive over this kerb with some difficulty.Barrier

type kerb is provided in built up areas adjacent t foot paths withconsiderable pedestrian traffic. The height of kerb stone is about 20 cm above the pavement edge with a steep batter of 1.0 vertical 0.25 horizontal.

5. iv). Explain the third twenty year road plan.

Third Twenty-Year Road Development Plan

1981-2001: -Policies and objectives:

The Third Twenty Year Road development Plan 1981-2001(also Known as Lucknow Road Plan) was finalized and the plan document was published by the year 1984.The major policies and objectives of this road plan are listed below:

a) The feature road development should be based on the revised classification of road system consisting of primary, secondary and tertiary road systems.

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

c) The overall road density in the country should be increased to 82 km per 100-sq.km areas by the year 2001.

d) The national highway network should be expanded to form square grids of 100 km sides so that no part of the country is more than 50 km away from a NH.

e) The lengths of SH and MDR required in a state or region should be decided based on both areas and number of towns with population above 5,000 in the state or region.

f) Expressways should be constructed along major traffic corridors provide fast travel. g) Roads should also be built in less industrialized areas to attract the growth of industries.

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

UNIT II – GEOMETRIC DESIGN OF HIGHWAYS

PART - A

1. What do you understand by non-passing sight distance? (APRIL/MAY 10)

The minimum sight distance available on a highway at any spot should be of sufficient length to stop a vehicle travelling at design speed, safety without collision with any other obstruction. The absolute minimum sight distance is therefore equal to the stopping sight distance, which is also sometimes called non passing sight distance.

2. Write down the requirements of an ideal transition curve.(APRIL/MAY 10)

The main requirement of an ideal transition curve is that the super elevation should be increased uniformly with the increase of centrifugal force.

That is the centrifugal force is proportional to the transition curve and super elevation is also proportional to the length of the transition curve. Hence the fundamental condition for a curve to be a transition curve is that the radius of curvature should be inversely proportional to the lengths.

3. What is mean by minimum gradient in highway? Why it is provided? (APRIL/MAY 11)

A road with less gradient or level may not be in a position to drain easily. The surface water may drain to the side drains due to the camber. But a longitudinal slope is needed to drain the water on the surface and from the side drain. Hence it is essential to have a certain minimum gradient on roads from drainage point of view provided topography permits. The minimum gradient depends on the factors like rainfall, runoff, type of soil, topography and other site conditions.

4. What is the factor governing super elevation of a road surface? (APRIL/MAY 11)

In order to counter balance the centrifugal force the outer edge of the road is raised which is known as the super elevation or cant or banking.

Factors governing super elevation are:

- Centrifugal force
- Weight of the vehicle and its speed
- Friction of the road surface
- Radius of the curve of the road
- Drainage condition

5. What is mean by super elevation? (MAY/JUNE 12) (MAY/JUNE 13)

In order to counterbalance the centrifugal force the outer edge of the road is raised which is known as super elevation or cant or banking. This transverse slope is provided throughout the length of the horizontal curve. The super elevation is expressed as the ratio of the outer edge with respect to the horizontal width..

6. Define stopping sight distance. (MAY/JUNE 12)

Stopping sight or absolute sight distance is the sight distance needed when the visibility should be such that a driver travelling at the design speed has sufficient length of the road ahead to stop vehicle after seeing the object without collision or accident.

7. State PIEV theory. (MAY/JUNE 13)

Reaction time of the driver is the time taken from the time the object is seen by the driver to the time the breaks are effectively applied.PIEV theory considers the reaction time to comprise of

- Perception
- Intellection
- Emotion
- volition

8. What is transition curve? (NOV/DEC 13)

A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve. When a transition curve is introduced between a straight and circular curve, the radius of the

transition curve decreases becomes minimum at the beginning of the circular curve. The rate of change of radius of the transition curve will depend on the equation of the curve or its shape.

9. Briefly explain illumination sight distance.(NOV/DEC 13)

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

10. What is mean by geometric design?

The geometric design of highway deals with the dimensions and layout of visible features of the highway such as alignment, sight distance and intersections. The geometrics of highway should be designed to provide optimum efficiency in traffic operations.

PART B

1 i) a valley curve is formed due to two gradients +3.5% and -2.75%.if the design speed of this highway is 80kmph, determine the stopping sight distance and design the valley curve to fulfill both comfort and head light distance conditions. (APRIL/MAY 10)

Solution:

$N = +3.5 - (-2.75) = 6.25/100$

$V = 80$ kmph i.e., $v = 80/3.6 = 22.2$ m/sec

Assume $C = 0.6$ m/sec^3

i) Comfort Condition

$$L = 2\left[\frac{Nv^2}{C}\right]^{\frac{1}{2}} = 2\left[\frac{6.25}{100} \times \frac{22.2^3}{0.6}\right]^{\frac{1}{2}}$$

$$= 61.51 \text{ m}$$

ii) Head Light Sight Distance Condition

Assume t = 2.5 sec, f = 0.35

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

$$= 22.2 \times 2.5 + \frac{22.2^2}{2 \times 9.8 \times 0.35} = 127.3 \text{ m}$$

If L > SSD, then

$$L = \frac{NS^2}{1.5 + 0.35S} = \frac{6.25}{100} \frac{127.3^2}{1.5 + 0.035 \times 127.3}$$

$$= 131.75 \text{ m}$$

L is greaterthan SSD of 127.3 m. Hence the assumption is correct.

The valley curve length based on head light sight distance (131.75 m) is highe than the length based on comfort condition (61.5 m).

Hence the length of valley curve may be taken as 132 m.

1 ii) what are the objectives of widening of road pavement at horizontal curves? Derive an expression for the extra widening.(APRIL/MAY 10)

In horizontal curves, especially when the radii of the curves are low, it is the practice to widen the pavement width a little extra for safe driving.

Reason for widening

- Majority of vehicles have the facility to turn only the front wheels and have a rigid wheel base. Jeep like vehicles has four wheel drive facility. When vehicle with two wheel drivefacility take a turn to negotiate a horizontal curve, the rear do not follow the same path on that of the front wheels. This is referred to as off tracking.Rear wheels follow the inner path on the curve. That is, when the inner front wheel takes a path on the inner edge of a pavement at a curve, inner rear wheel will be off pavement on the inner shoulder.
- At high speeds when adequate super elevation and lateral friction are not available, there will be some transverse skidding and the rear wheel may take paths on the outside of those traced by the front wheels.

- The drivers may have a tendency in general to follow the curved path with larger radius and to have a greater visibility at curve.
- While negotiating an oncoming vehicle or overtaking a horizontal curve there is a psychological tendency for the drivers to adopt a greater clearance between the vehicles.

Thus to take care of these aspects, it has been the practice to widen the pavement on the horizontal curves when the radius of the curve is less than 300m.the extra widening needed comprises of two parts, viz.

- Mechanical widening
- Psychological widening

Mechanical widening

Mechanical widening is provided to account for off tracking due to the rigidity of the wheel base.

Psychological widening

The psychological widening is mainly provided for greater maneuverability of the vehicle. This is particularly important in pavements with more than one lane.

Extra widening

The extra widening is introduced gradually starting from the tangent point in curves with transition curve. If the curve is provided with a transition curve, then it is started from the beginning of the transition curve and provided with uniform rate till the full value of W_e is reached. This is the point where the full super elevation is provided. The widening is provided equally on either side of the curve at every cross section up to a value of $W_e/2$.

On horizontal curves without transition curve, two thirds of the widening is provided at the end of the straight section and one thirds is provided on the circular curve beyond the tangent point. In this case the widening is provided only on the inside of the curve.

2 i) What is the need for transition curve? How its length is determined? (APRIL/MAY 11)

t is an arc between a straight and a circular curve or between twoarcs of a compound curve. The radius of a transition curve varies from infinity to a fixed value.Vehicles passing from straight into a circular curve experience jerk due to the effect of centrifugal force. The centrifugal force always acts in a direction perpendicular to the axis of rotation. In order to counter act the above effect the outer edge of the road or the rail is raised which is called the super elevation or cant. This super elevation is provided gradually along the transition curve.

Advantages:

- Introduces super elevation gradually from zero at the tangent point to the value on the circular curve.
- Maintains a constant proportional between super elevation and rate of change of curvature.
- Eliminates discomfort overturning and side slipping vehicles.
- Eliminates discomfort to passengers.

Requirements

- The transition should be tangential to the straight.
- The curvature amount of super elevation should be zero at the origin of the straight.
- The curvature of the transition curve should increase at the same rate as that of the super elevation.
- The exact amount of super elevation should be attained at the junction with the circular curve.

Length of transition curve

Length of a transition curve is calculated based on one the following considerations.

- By adopting a particular rate of super elevation.
- By considering arbitrary rate of super elevation.

- By considering rate of change of radial acceleration.

By adopting a particular rate of super elevation

The definite rate of super elevation varies from 1 in 300 to 1 in 1000.

Length of transition curve, L=ne/100 m

Where

e=amount of super elevation in centimeters

n=rate of super elevation

By considering arbitrary rate of super elevation.

Length of transition curve, L= (exV)/x

Where

e=amount of super elevation

V=speed in meters per second

x=time rate in centimeters per second

By considering rate of change of radial acceleration

Radius acceleration on circular curve=V^2/R

Time taken by the vehicle to cover transition curve=L/V s

If the change of radial acceleration is K m/s^3 then,

Time taken to attain maximum radial acceleration=$V^2/(KR)$ s

From equation

$L/V= V^2/(KR)$

$L=V^3/(KR)$

2 ii) Explain the procedure for calculating the length of valley curve. (APRIL/MAY 11)

Length of Valley Curve

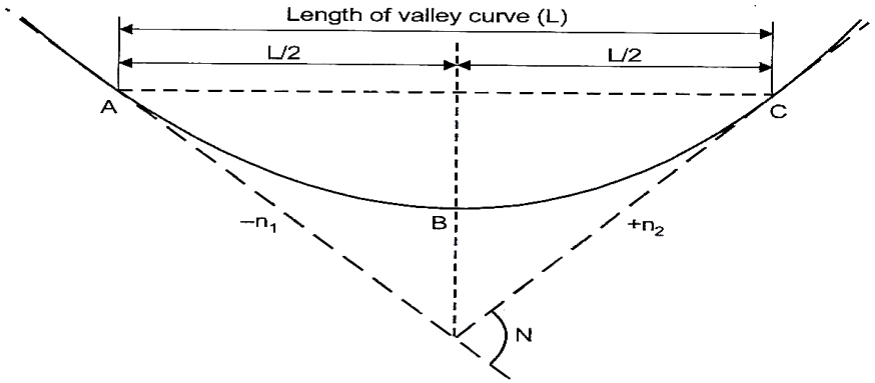
The length of a valley curve is designed on the basis of two criteria :

i) the allowable rate of change of centrifugal acceleration is 0.6 m/sec^2 and

ii) the head light sight distance.

High value of length based on the above two criteria is adopted. Generally, the second criterion gives the higher value.

Figure 4.47 shows the transition curve, ABC with AB and BC are two equal transition curves with, $L_s = L/2$, having the minimum radius R at the common point B.



Details of valley or sag curve

For Comfort Condition

The length of transition curve L for comfort condition is given as

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

Value of R at length $L_s = L_s/N = \frac{L}{2N}$

Substituting in the above equation

$$L_s = \frac{v^3}{C L_s} N \quad \text{or} \quad L_s^2 = \frac{N v^3}{C}$$

i.e., $$L_s = \sqrt{\left[\frac{N v^3}{C}\right]}$$

i.e., $$L = 2L_s = 2\sqrt{\left[\frac{N v^3}{C}\right]}$$

where v = speed in m/sec

C = allowable rate of change of centrifugal acceleration

Taking C = 0.6 m/sec^2 and taking speed in kmph.

Then

$$L_s^2 = \frac{N V^3}{0.6 \times 3.6^3}$$

i.e., $$L_s = 0.19\sqrt{(N V^3)}$$

i.e., $$L = 2\,L_s\,0.38\,\sqrt{N V^3}$$

The minimum radius (R in metres) of the valley curve for cubic parabola given as

$$R = \frac{L_S}{N} = \frac{L}{2N}$$

ii) For Head – Light Sight Distance Condition

The length of valley curve has to be determined for the two conditions : the total length of valley curve L is greater than the stopping sight distance *(SSD)* b) when L is less than *SSD*, as given below.

a) L > SSD

The length of valley curve L is assumed to be greater than the head-light distance which should be atleast equal to *SSD*.

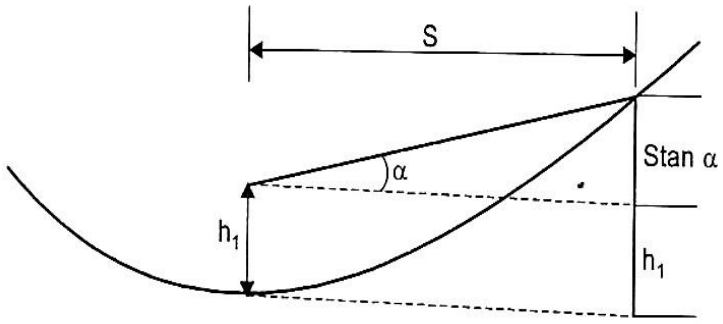


Figure 4.48: Details of head-light sight distance when L > S

The sight distance will be minimum when the vehicle is at the lowest point on the curve. Assuming the valley curve as a parabola, then $y = ax^2$ and

$$h_1 + S \tan \alpha = a S^2 = \frac{NS^2}{2L} \qquad \text{(Since } a = N/2L\text{)}$$

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

h_1 = height of the head light

α = beam of head-light inclination

N = deviation angle $(n_1 + n_2)$ with slopes $-n_1$ and $+n_2$

Substituting for $\alpha = 1°$, $h_1 = 0.75$ m

$$L = \frac{NS^2}{(1.5 + 0.035S)}$$

L < SSD

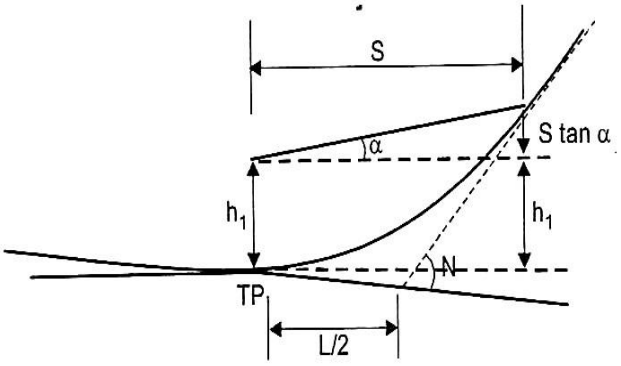
Let the vehicle be at the start of the valley curve or at the tangent point, *TP*, for minimum sight distance. Then

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

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

Substituting for $\alpha = 1°$, $h_1 = 0.75$ m

$$L = 2S - \frac{(1.5 + 0.35S)}{N}$$



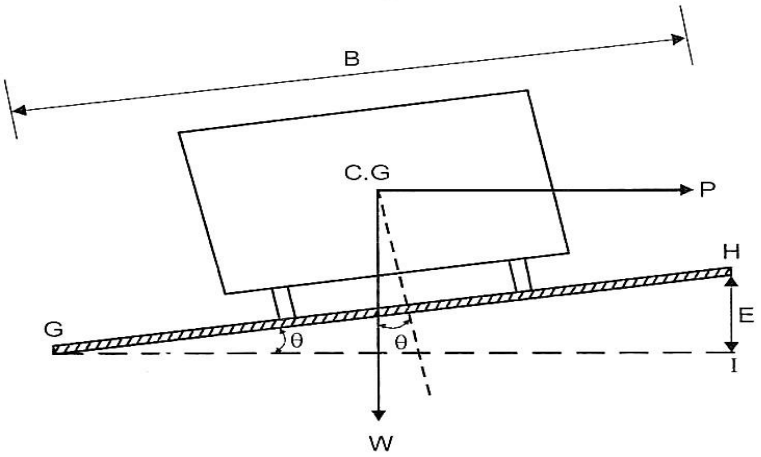
Head light right distance when LKS

In order to provide the cross drainage facility, the lowest point on the valley should be located. If the gradients are equal, then the lowest point will lie bisector of the angle between the curves. On unequal grades the lowest point the side of the flatter gradient.

3 i) Derive the formula for calculating super elevation on horizontal curves. (MAY/JUNE 12)

Superelevation

In order to counter balance the centrifugal force the outer edge of the road is raised which is known as the superelevation or cant or banking. This transverse slope is provided through out the length of the horizontal curve. The superelevation e is expressed as the ratio of the height of the outer edge with respect to the horizontal width. Figure 4.26 shows the details of superelevation.



Superelevated section of pavement

$$e = \frac{HI}{GI} = \tan\theta.$$

The value of e is very small and of the order of 0.07, hence $\tan\theta = \sin\theta$, then

$$e = \tan\theta = \sin\theta = \frac{HI}{GH} = \frac{E}{B}$$

which is the height to width ratio of the pavement.

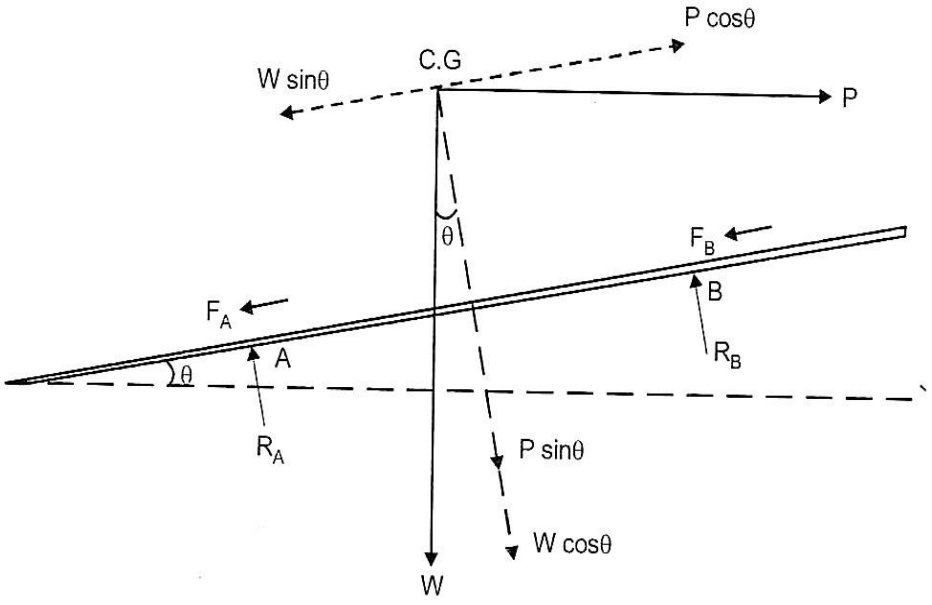
Total rise in outer edge of the pavement with respect to the inner edge $HI=E=e\,B$. Hence as stated above e is the super elevation rate and E is the total superelevated height of outer edge.

Now all the forces acting are summarised below (Fig. 4.27) along with the components.

i) the centrifugal force, $P = \frac{Wv^2}{gR}$, acting horizontally through the *C.G.*

ii) the weight W of the vehicle acting vertically, downwards through the *C.G.*

iii) the friction developed between the wheels and the pavement, F_A and F_B acting parallel to pavement elevated position.



Forces acting on a moving vehicle on a superelevated pavement

Considering the equilibrium of forces acting parallel to the pavement.

$$P \cos \theta = W \sin \theta + F_A + F_B \qquad (4.15)$$

Considering the equilibrium of forces acting perpendicular to the pavement

$$R_A + R_B = W \cos\theta + P \sin \theta \qquad (4.16)$$

Rewriting Eq. (4.15)

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

Substituting for $R_A + R_B$ from Eq. (4.16)

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

i.e., $P (\cos \theta - f \sin\theta) = W \sin\theta + f W \cos\theta$

Dividing by $W \cos \theta$ throughout

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

i.e.,
$$\frac{P}{W} = \frac{\tan\theta + f}{1 - f \tan\theta} \qquad (4.17)$$

The coefficient of lateral friction is generally taken as 0.15 and tan θ seldom exceeds 1/15. Hence f tan θ is less than 0.01. Thus the denominator of the centrifugal ratio Eq. (4.17) $1 - f \tan \theta = 0.99$ which can be approximated to 1, then

$$\frac{P}{W} = \tan \theta + f = e + f \qquad (4.18)$$

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

i.e.,
$$e + f = \frac{v^2}{gR} \qquad (4.19)$$

The Eq. (4.19) can be represented taking V in kmph as

$$e + f = \frac{(0.278V)^2}{9.8R} = \frac{V^2}{127R} \qquad (4.20)$$

Neglecting the coefficient of friction, the *equilibrium superelevation* required to countract the centrifugal force fully is given as

$$e = \frac{v^2}{gR} \qquad (4.21)$$

$$e = \frac{V^2}{127R} \qquad (4.22)$$

Once this superelevation is provided the pressure on the inner and outer wheels will be equal. This condition will result in a very high value of superelevation.

As lateral friction cannot be ignored completely f is always taken into account.

In some field situations it may not be possible to provide superelevation (i.e., $e = 0$), then the later friction alone should counter act the centrifugal force. In such situations.

$$f = \frac{v}{8R} \qquad (4.23)$$

or $$v = \sqrt{f g R} \qquad (4.24)$$

and $$f = \frac{V^2}{127R} \qquad (4.25)$$

or $$V = \sqrt{127 f R} \qquad (4.26)$$

3 ii) Explain the factors influencing overtaking sight distance. (MAY/JUNE 12)

Vehicles moving at the design speed should be able to safety overtake the vehicle moving at slow speed at reasonable intervals without causing obstruction or hazard to traffic coming from opposite direction. This situation may not arise if the entire vehicles are moving at the design speed.

It may not be possible to provide the facility of overtaking throughout the length of the road. However, the overtaking facility should be provided at frequent intervals.

Overtaking sight distance is the minimum sight distance that should be available for driver to overtake another vehicle safety on a two way road. This is also referred to as safe passing sight distance.

The following are the factors affecting overtaking sight distance:

- Speeds of overtaken and overtaking vehicles.
- Other vehicles coming from the opposite direction.

- Space between overtaking and overtaken vehicles.
- Skill and reaction time of the driver.
- Rate of acceleration of overtaking vehicle.
- Slope of the road.

4 i)Calculate the stopping sight distance required to avoid head on collision of two cars approaching opposite directions at a speed of 75kmph and 85kmph.assume that the reaction time of drivers be 2.5 secs and co-efficient between road surface and tyres be 0.4. (MAY/JUNE 12)

Solution:

Stopping Distance for car with 75 kmph:

$$SD\ (\text{m}) = v\,t + \frac{v^2}{2gf}$$

$$v = \frac{75}{3.6} = 20.83\ \text{m/sec}$$

$$SD\ (\text{m}) = 20.83 \times 2.5 + \frac{(20.83)^2}{2 \times 9.8 \times 0.4}$$

$$= 51.075 + 55.343$$

$$= 106.42\ \text{m}$$

Stopping Distance for car with 80 kmph

$$v = \frac{80}{3.6} = 22.22\ \text{m/sec}$$

$$SD\ (\text{m}) = 22.22 \times 2.5 + \frac{(22.22)^2}{2 \times 9.8 \times 0.4}$$

$$= 55.55 + 62.976$$

$$= 118.53\ \text{m}$$

Mininimum stopping sight distance to avoid collision

$$= 106.42 + 118.53$$

$$= 224.95\ \text{m}$$

4 ii) Explain the factors affecting sight distances.(MAY/JUNE 13) (NOV/DEC13) The following are the factor affecting sight distance:

- Total reaction time of the driver
- Speed of the vehicle
- Efficiency of breaks
- Frictional resistance between the road and the tyres
- Gradient of the road

Total reaction time of the driver

Reaction time of the driver is the time taken from the instant the object is visible to the driver to the breaks are effectively applied. The amount of time gap depends on several factors. During this time the vehicle travels a certain distance at the original speed or the design speed. Thus stopping distances increases in reaction time of the driver. The total reaction time may be split up into two parts.

Perception time Break reaction time

The perception time is the time required for a driver to realize that breaks must be applied it is the time from the instant the object comes on the line of sight of the driver to the instant he realizes that the vehicle needs to be stopped.

The break reaction time also depends on several factors including the skill of the driver, the type the problems and various other environmental factors.

Speed of the vehicle

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

Efficiency of breaks

The breaking efficiency is said to be 100 percent if the wheels are fully locked preventing them from rotating on application of the breaks.This will result in 100 percent skidding which is normally undesirable, except in utmost emergency. Also skidding is considered to be dangerous, as it is not possible to control a skidding vehicle. Hence avoid skid, the breaking forces should not exceed the frictional force between the wheels and tyres.

Frictional resistance between road and tyres

The frictional resistance developed between road and tyres or the skid resistance depends on the tyre and condition of the road surface and the tyres.The breaking distance increases with decrease in skid resistance.IRC has specified a design friction co efficient of 0.35 to 0.4 depending upon the speed to be used for finding the breaking distance in the calculation of stopping sight distance. This value apart from having sufficient safety factor: permits a rate of retardation which is fairly comfortable for passengers.

5 i) Explain the steps involved in the design of hill roads.(MAY/JUNE 13)

The following are the steps involved in design of hill road:

- Alignment of hill road
- Alignment survey

Design

- Rock cutting
- Precipice work
- Retaining walls
- Revetment walls
- Pavement type
- Drainage in hill roads

Alignment of hill road

The hill road alignment should link up the obligatory points and control points fitting well in the landscape and satisfying the geometric requirements. The best alignment for a hill road is one where in the total sum of the ascents and descends between extreme points is the least. It is permissible to increase the length as much as 50 times the height saved by a detour.

Some particulars of special significance are discussed below:

- Resisting length
- Trace cut for hairpin bends
- Geological considerations

Alignment survey

The alignment of hill road is fixed in three stages:

- Reconnaissance
- Trace cut
- Detailed survey

Design of hill road

Rock cutting

• If the rock stratum slopes downward into the hill side, the rock is permitted to overhang the road forming a half tunnel. Blasting is done either from face or from one or both sides.

• If the strata are inclined towards the hill slope, cutting is continued until the inner slope is at a safe angle to prevent slipping.

Precipice work

Where the time available does not allow for blasting and tunnel work, cliff galleries and cradles are restored for the negotiation of cliffs and precipices. These are suitable only for light vehicles or foot traffic and considered only for short term use and not as a permanent road way for regular traffic. It is an important that the strata should dip inwards from the face in order to ensure safe attachments for the jumpers and holdfasts and to

lessen the risk of rock falls.

Retaining walls

Retaining walls are the most important structure in hill road construction to provide adequate stability to the roadway and to the slope. Retaining walls are constructed on the valley side of the roadway and also on the cut hill side to prevent land slide towards the roadway.

Pavement walls

The embankment slopes are normally protected with rough stone pitching about 30cm thick in order to avoid erosion due to flow of water.If the stopping length is too long it is preferable to construct a toe wall .to support the embankment and depending upon the slope available. Where the cutting slope is steep and contains loose or scourable soils, slips are likely to occur.

Pavement type

Because of the high intensity of rain fall generally throughout the year in the hill regions, an important type of pavement proves more effective, through the initial cost may be high. A permeable surface such as W.B.M gets eroded by the heavy rains and regular maintenance cost comes out to be high.The bituminous pavements are therefore preferred on hill road. Cement concrete pavements are not considered suitable because of its high initial cost and delay in construction.

5 ii) Explain the general principles to be followed in the design of horizontal alignment.(NOV/DEC 13)

General:

Often changes in direction are necessitated in highway alignment due to obligatory points. Various design factors to be considered in the horizontal alignment are

- Design speed
- Radius of circular curve

- Type and length of transition curve
- Super elevation
- Widening of pavement of curves

The alignment should enable consistent, safe and smooth movement of vehicle operation at design speed. It is hence necessary to avoid those sharp curves and reverse curves which could not be conveniently negotiated by vehicle at design speed. Improper design of horizontal alignment of roads would necessitate speed changes resulting in increased vehicle operation cost and higher accident rate.

Design speed

The overall design of geometrics of any highway is a function of the design speed.The design speed is the main factor on which geometric design elements depends. The sight distances, radius of horizontal curve, super elevation, extra widening of pavement, length of horizontal transition curve and the length of summit curve are all dependent on design speed. The design speed of roads depends upon

- Class of the road
- Terrain

The speed standard of particular class of road thus depends on the classification of the terrain through its passes. The terrain have been classified as plain, rolling, mountainous and steep, depending on the cross slope of the country as given below.

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

The design speed (ruling and minimum) standardized by the IRC for

different classes of roads on different terrains in rural areas are given in table. The ruling design speeds are the guiding criteria for the geometric design. However, minimum design speeds may be accepted where site conditions or economic considerations warrant. The ruling design speed suggested for the national and state highways of our country passing through plain terrains in 100 kmph and through rolling terrain is 80 kmph.

The recommended design speeds for different classes of urban roads are:

- For arterial roads 80 kmph.
- Sub arterial roads 610 kmph,
- Collector streets 501 kmph,
- Local streets 30 kmph.

UNIT III-FLEXIBLE AND RIGID PAVEMENT

PART - A

1. How do you calculate the ESWL at a given depth below the pavement for a dual wheel assembly? (APRIL/MAY 10)

Let P be the single wheel load

d be the spacing between the tyres

S be the centre to centre spacing of tyres

A plot is made in log-log scale with depth on z-axis which gives a linear releationship.two coordinates A (d/2, P) and B (2S, 2P).

Let z_1 be the depth at which ESWL is needed. From the plot for a depth of z_1 the ESWL, P_1 read.

2.What is the radius of resisting section? (APRIL/MAY 10)

Westergaard's suggested an equivalent radius of resisting section, b, in terms of radius of load distribution and slab thickness, as

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

Where a=radius of wheel load distribution, cm

h=slab thickness

When a is greater than 1.72h, the value of b=a

3. State the components of the flexible pavements. (NOV/DEC 13)

Flexible pavement is based on the principle that the wheel load of vehicles is dissipated to the natural soil through successive layers of granular materials.

Highest quality material is placed on the top. The components of the pavement from the top are surface course, base course and sub base course. The strength of sub grade decides the thickness of flexible pavement.

4. How change in temperature produce frictional stresses in rigid pavements? (APRIL/MAY 11)

Temperature in concrete pavement produces warping stresses and frictional stresses. When the concrete pavement slab experiences different temperatures at top and bottom,the slab tents to warp downwards or upwards including warping stresses.As the concrete pavement is in contact with the sub grade, the movement of slab at the bottom is restrained due to friction and causing frictional stress.

5. What is rigidity factor in the design of Highway Pavements? (MAY/JUNE 12)

The ratio of contact pressure to tyre pressure is defined as rigidity factor. the rigidity factor is equal to unity when the tyre pressure is 7.0 kg/cm^2.this value is higher than unity for low tyre pressure and less than unity for tyre pressure higher that $7kg/cm^2$.

6. Define ESWL. (MAY/JUNE 13) (MAY/JUNE 12)

In order to have maximum wheel load, dual wheel assembly is provided to the rear axles of the load vehicle. Because of this the load due to the both the wheels are not to be transferred to the pavement. But there will be overlap pressure after a certain depth. The actual effect is in between a single wheel load and the double the load carried by any one wheel.

7. Explain rigid pavement. (MAY/JUNE 13)

Cement concrete pavements represent the group of rigid pavement. Here the load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab itself

8. List the application of rigid pavement. (NOV/DEC 13)

- The rigid pavement load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab itself.
- The rigid pavement has the slab action and is capable of transmitting the wheel load stresses through a wider area below.

9. Define Pavement?

The Pavement consisting of a few layers of Pavement material is constructed over a prepared soil sub grade to serve as a carriageway.One of the objectives of a designed Pavement is to keep this elastic deformation of the Pavement within the Permissible limits.

10. Define gradient.

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x. Sometimes the gradient is also expressed as a percentage.

PART B

1.i) State the limitations of CBR method of pavement design.(APRIL/MAY 10)

- CBR is an adhoc penetration test which does not consider any of the sub grade properties directly.
- As the method is empirical, it is not essentially related to any particular value of axle load or wheel load repetitions.
- The design curves provided in the method are not meant to be made use of on the basis of traffic immediately carried by the road or that anticipated (in the case of new constructions).
- This method gives the total thickness requirement of the
- pavement above a sub grade and the thickness is same irrespective of the quantity of materials used in the component layers

1.ii) what are the objectives of joints in cement concrete pavements? Sketch the different types of joints used in pavement construction. Indicate the principle of design.

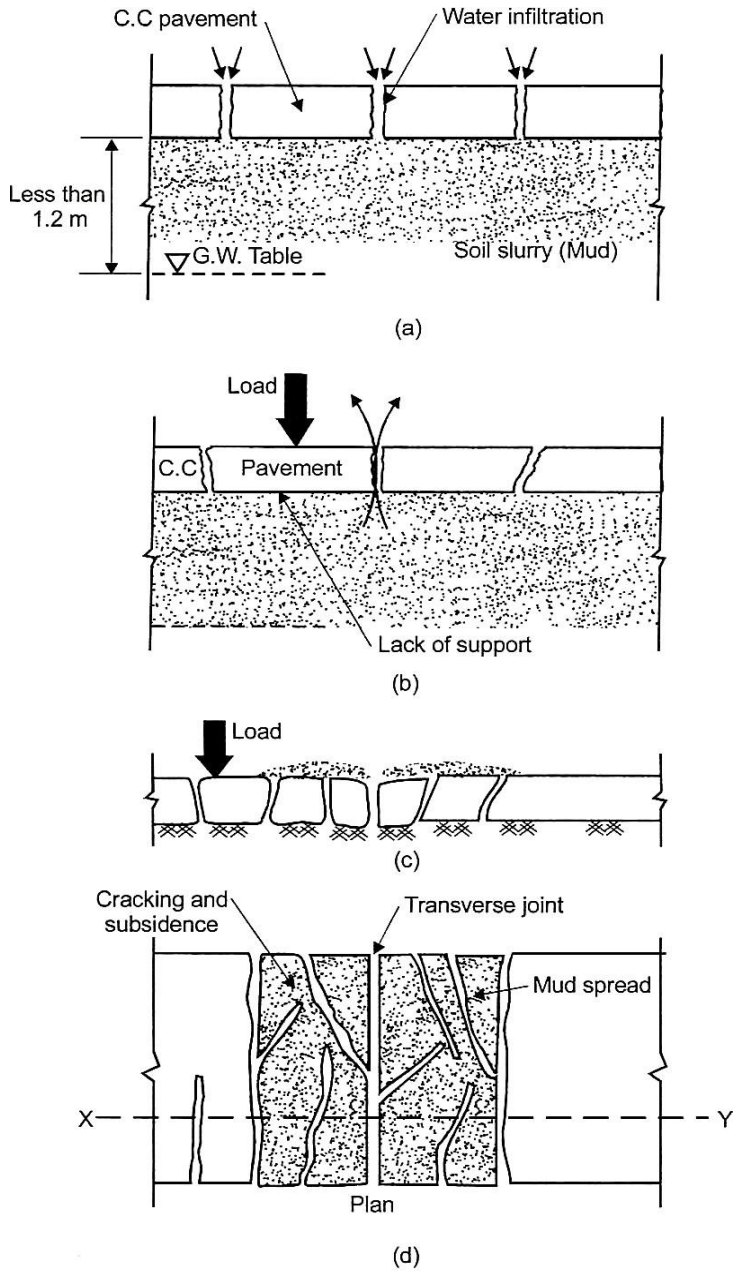
In general, joints are provided in cement concrete pavements to reduce temperature stresses.

- 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

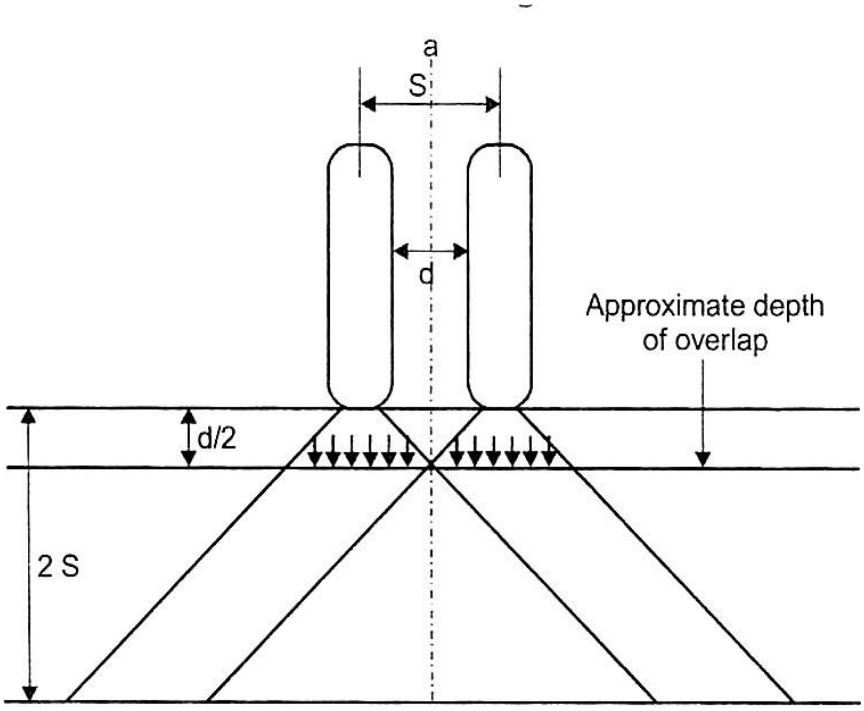
Pumping is generally noticed in clayey sub grades with soon after the rains.Due to repeated loading an initial space formed underneath the pavement slab develops and spreads and form a place for collection of water. Since the sub grade soil is clayey which has less permeability retain the water and forms soil slurry or soil suspension in water or the mud.Subsequent movement of traffic causes the pavement slab to defect at critical location and pushes out the part of mud every time. Continued loosing of sub grade soil due to ejection of mud and application of wheel loads to sub grade support. Ultimately the pavement fails at more places. Thus the pavement cracking due to mud pumping is generally aprogressive type of pavement failure.



Stages of formation of mud pumping

2.ii) define ESWL and lane distribution factor and explain their significance.

In order to have maximum wheel load, dual wheel assembly is provided to the rear axles of the load vehicles. Because of this, the load due to both the wheels is not to be transferred to the pavement. But there will be overlap pressure after a certain depth. The actual effects is in between a single wheel load and double the load carried by any one wheel. Stress overlap is presented in fig below.



Stress overlap due to dual wheels

It is assumed that up to a depth of d/2 the loads act independently beyond which the stresses overlap. The area of overlap becomes more beyond a depth of 2S.hence it may be considered that the load the total stress due to the dual wheels at any depth greater than 2S, is to be equivalent to a single wheel load of 2P magnitude. However, this stress due to 2P is to be slightly greater than the duel wheel assembly which is on the safe side.This equivalent single wheel load can be determined by equivalent deflection or equivalent deflection or equivalent stress criterion. For example, based on deflection criterion it is to state that the maximum deflection

caused at a particular depth z (say, depth equivalent to the thickness of pavement) by a dual wheel load Assembly is also caused by an equivalent single wheel load acting at the surface of the pavement.Similarly by the stress criterion the ESWL producing the same stress value at a depth z as that produced by a dual wheel load assembly.

linear relationship is assumed between the ESWL and the depth in a log- log scale. A linear plot is got, as shown in fig. By plotting a point A with coordinates z=d/2 and P and point B with coordinates z=2S and 2P.Line AB represents the locus of point where any single wheel load is equivalent to a certain set of dual wheels.

In order to use the graph, for an assumed thickness of pavement and ESWL is got from the graph. This ESWL is used in the design calculations and the thickness of pavement is obtained. If this thickness and assumed thicknesses are same then the ESWL assumed is correct. If not the design is repeated and by trial and error the correct thickness of pavement is obtained. This calculation is valid for the given wheel load configuration. For different wheel load assembly different ESWL plots may be made.

3 i) Describe the factors influencing the design of flexible pavements. (APRIL/MAY 11)

The various factors to be considered for the design of flexible pavements are given below:

- **Design wheel**
- **load Sub grade soli**
- **Climatic factors**
- **Pavement component**
- **materials**
- **Environmental factors**
- **Special factors**

Design wheel load

- The thickness design of pavement primarily upon the design wheel load.

Higher wheel load obviously need thicker pavement provided other design factors are the same. While considering wheel load, the effects of total static load on each wheel, multiple wheel load assembly, contact pressure, load repetition and the dynamic effects of transient loads are to be taken into account.

As the speed increases the rate of application of the stress is also increased in resulting in a reaction in the pavement deformation under the load: but on uneven pavements, the impact increases with speed. Some of the important design factors associated with the traffic wheel loads have been explained in the subsequent article.

Sub grade soil

The properties of the sub grade soil are important in deciding the thickness requirements of pavements sub grade with lower stability requires thicker pavement to protect it from traffic loads. The variation in stability and volume of the sub grade soil with moisture changes are to be studied as these properties are dependent on the soil characteristics. The stress strain behaviors of the soil under static and repeated loads have also significance. Apart from the design the pavement performance to a great extent depends on the sub grade soil properties and the drainage.

Climate factors

Among the climate factors, rainfall affects the moisture conditions in the sub grade and the pavement layers. The daily and seasonal variation in temperature has significance in the design and performance of rigid pavements. Where freezing temperature is prevalent during winter, the possibility of frost action in the sub grade and the damping effects should be considered at the design stage itself.

Pavement component materials

The stress distribution characteristic of the pavement components layers depends on characteristics of the materials used. The fatigue behavior of these materials and their durability under adverse conditions of

weather should also be given due consideration.

Environmental factors

The environmental factors such as height of embankments and its foundations details. Depth of cutting, depth of sub surface water table, etc...Affect the performance of the pavement. The choice of the bituminous binder and the performance of the bituminous pavement depending on the variations in pavement temperature with the seasons in the region.

3.ii) Explain the recommended design procedure for the design of rigid pavements by IRC. (APRIL/MAY 11)

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

$A_d=P^1(1+r)^{n+20}$

Where

A_d=number of commercial vehicles per day for laden weight greater than 3 tonnes. P^1=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.

Traffic classification

Traffic classification	*Design traffic intensity, A_d (number of vehicles of wt> 3 tonnes per day) at the end of design life*	*Adjustment in design thickness of cement concrete pavement, cm*
A	0 to 15	– 5
B	15 to 45	– 5
C	45 to 150	– 2
D	150 to 450	– 2
E	450 to 1500	0
F	1500 to 4500	0
G	> 4500	+2

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 sub grade 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/cm^3 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/cm^3.The cube strength of concrete should be 280kg/cm^2, modulus of elasticity E=3X10^5 and poisons ratio=0.15.these properties may also be determined experimentally.

Co efficient of thermal expansion may be taken as 10x10^{-6}per ^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 Westergaards 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.

m15cm thickness slab with steel reinforcement of 2.7kg/cm^2 and 14m spacing for 20cm thick slabs with steel reinforcement of 3.8kg/cm^2.

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+δ).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/cm^2 and in plain bars 17.5kg/cm^2.allowable working stress in tensile steel is taken as 1500kg/cm^2.

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=dist6ance 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.

3. iii) Difference between flexible and rigid pavements.

S.no	**characteristics**	**Flexible pavement**	**Rigid pavement**
1	Normal loading	Undergoes deformation under the load	Resists deformation and acts as a cantilever beam.
2	Excessive loading	Local depression take p[lace	A crack on the surface may appear due to rupture
3	After effects of heavy load	Pavement is flexible and thus adjusts itself by deformation.	Permanent rupture or cracks forms and remains

4	Temperature effects	Not affected	Stresses produced based on temperature
5	Sub grade strength	Uniform sub grade is necessary	Sub grade may be non uniform

i. Explain the design consideration's for spacing of expansion and construction joints. (MAY/JUNE 12)

Expansion joints

The width or gap in expansion joints depends upon the length of slab. Greater the distance between the expansion joints, the greater is the width required of the gap for expansion. The use of wide expansion joint space should be avoided as it would be difficult to keep them properly filled in when the gap widens during winter season. The dowels would develop high bending and bearing stresses with wider openings. It is recommended not to have a gap more than 2.5 cm in any case. The IRC has recommended that the maximum spacing between expansion joints should be not exceeding 140m for rough interface layer.

If δ is the maximum expansion in a slab of length L_e with a temperature rise from T_1 to T_2.

$\delta = L_e C (T_1 - T_2)$ Where

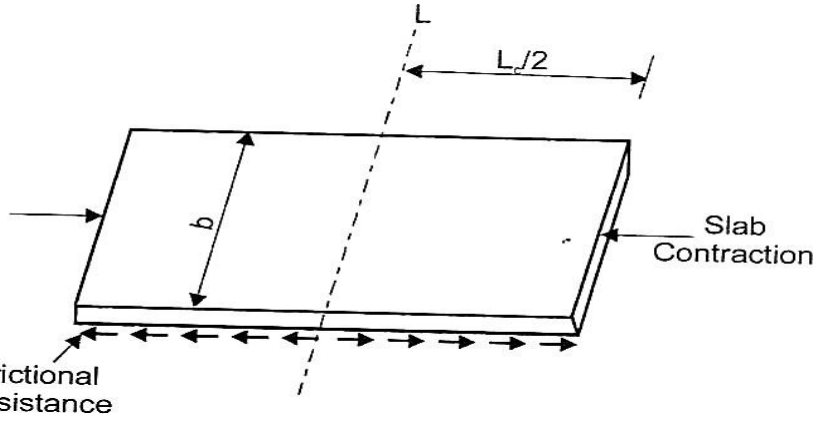
C is the thermal expansion of concrete per degree rise in temperature.

The joint filler may be assumed to be compressed up to 50 percent of its thickness and therefore the expansion joint gap should be twice the allowable expansion in concrete, i.e., 2δ is half the joint width the spacing of expansion joint L_e is given by equation:

$L_e = \delta / (100C (T_1 - T_2))$

Construction joint

The slab contracts due to fall in slab temperature below the construction temperature. Also during the initial curing period, shrinkage occurs in cement concrete. This movement is resisted by the sub grade drug or friction between the bottom fiber of the slab and the sub grade. Total frictional resistance up to distance



$L_c/2=W \times b \times L_c/2 \times (h/100) \times f$

Low able tension in cement concrete=$S_c x h x b x 100$

Equating the above two values

$W \times b \times L_c/2 \times (h/100) \times f = S_c x h x b x 100$

Length of slab to resists the frictional drag, i.e., spacing of construction joints,

$L_c=(2S_c/(Wf))x10^4$ Here

L_c=slab length or spacing between construction joints, m

H=slab thickness, cm

W=unit weight of cement concrete, kg/m^3

S_c=allowable stress in tension in cement concrete, kg/cm^2

Since the contraction or shrinkage cracks develop mainly during initial period of curing. A very low value of S_c is considered in design. The permissible stresses are generally kept as low as about $0.8kg/cm^2$.

4.ii) Explain in detail about the IRC method of flexible pavement design. Discuss the limitation of this method.(MAY/JUNE 12)

Indian road congress (IRC: 37-1970) has recommended some important aspects to be considered while using the design chart. Following are the recommendations:

- The specimen to be tested CBR should be remolded specimen prepared preferably by static compaction wherever possible or dynamic compaction. The standard test procedure should be strictly followed.
- In situ test specimens are not recommended.
- For new roads the sub grade soil specimen should be compacted to

proctor density at OMC. If the compaction equipment is not available in the field, the specimen may be compacted to the expected field density.

- For the existing roads the specimen should be compacted to field density of sub grade soil at water content equal to OMC or field moisture content.
- For all new constructions the specimen should be soaked for four days prior to testing. This condition is not mandatory for arid climatic regions or regions with annual rainfall is less than 50cm or the water table is very deep or when thickness of impermeable bituminous surfacing is provided.
- At least three specimens should be tested with identical specimens. If the variation is maximum beyond the norms, then average of six specimens CBR values should be taken.

The specimen limits of maximum variation in CBR values are

3% for CBR value up to 10%

5% for CBR value 10 to 30%

10% for CBR value 30 to 60%

The top 50cm of sub grade should be compacted with density equal to 95 to 100% of proctor density.

Keeping in view the existing traffic and the anticipated growth in traffic should be calculated for at least 10 years of life period.

The following formula may be used:

$$A=P(1+r)^{n+10}$$

Where

A=number of heavy vehicles per day for design (laden weight>3 tones)

P=number of heavy vehicles per day at least count.

r=annual rate of increase of heavy vehicles

n=number of years between the least count and the year of completion of constructions. The value P has to be found for seven day heavy

vehicles obtained from 24 hours count. If a reasonable value of r is not available a value of 7.5% may be assumed for rural roads.

- The traffic obtained from the above equation has to be used in choosing the appropriate design curve (A to G).
- The design thickness corresponding to a single axle load up to 8200kg and tandem axle load up to 14500kg is adopted.
- Substandard sub bases with substantial proportion of aggregates of size above 20mm should not be used in design.
- Thin layers of wearing course such as surface dressing or open graded premixed carpet up to 2.5cm thickness should not be counted towards total thickness as these materials do not contribute to the structural capacity of the pavement.

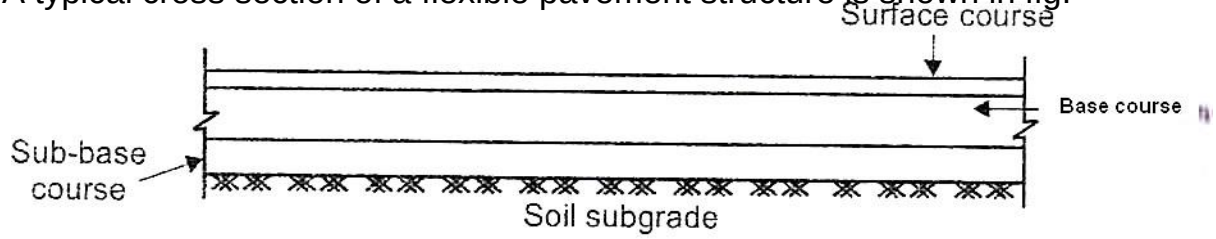
4.iii)Explain the functions of the components of the flexible pavements.(MAY/JUNE 13) Flexible pavements are those which on the whole have low or negligible flexural strength and

are rather flexible in their structural action under the loads. The flexible pavement layers reflect the deformation of the lower layers on to the surface of the layer. Thus if the lower layer of the pavement or soil sub grade is undulated, the flexible pavement surface also gets undulated. A typical;

flexible pavement consists of four components:

- Soil sub grade
- Sub base course
- Base course
- Surface course

A typical cross section of a flexible pavement structure is shown in fig.



Flexible pavement

This consists of a wearing surface at the top, below which is the base course followed by the sub base course and the lowest layer consists of the soil sub grade which has the lowest stability among the four typical flexible pavement components. Each of the flexible pavement layers above the sub grade, viz. sub base, base course and the surface courses may consist of one or more number of layers of the same or slightly different materials and specifications.

Flexible pavements are commonly designed using empirical design charts or equations taking into account some of the design factors. There are also semi empirical and theoretical design methods. According to this the flexible pavement may be constructed in a number of layers and the top layer has to be strongest as the highest compressive stresses are to be sustained by this layer, in addition to the wear and tear due to the traffic.

The lower layers have to take up only lesser magnitude of stresses and there is no direct wearing action due to traffic loads, therefore inferior materials which lower cost can be used in the lower layer.

The lowest layer is the prepared surface consisting of the local soil itself, called sub grade.

The vertical compressive stress is maximum on the pavement surface directly under the wheel load and equal to the contact pressure under the wheel.

Due to the ability to distribute the stresses to a longer area in the shape of a truncated cone, the stresses get decreased at the lower layers. Therefore by taking full advantages of the stress distribution characteristic of the flexible pavement, the layer system concept was developed.

According to this the flexible pavement is constructed in a number of layers and the top layer has to be strongest as the highest compressive stresses are to be sustained by this layer.

5. Explain the factors governing the structural design of pavements. (MAY/JUNE 13)

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