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CE8604 HIGHWAY ENGINEERING L T P C

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OBJECTIVE:

To give an overview about the highway engineering with respect to, planning, design, construction and maintenance of highways as per IRC standards, specifications and methods.

UNIT I HIGHWAY PLANNING AND ALIGNMENT 9

Significance of highway planning – Modal limitations towards sustainability - History of road development in India – factors influencing highway alignment – Soil suitability analysis - Road ecology - Engineering surveys for alignment, objectives, conventional and modern methods - Classification of highways – Locations and functions – Typical cross sections of Urban and Rural roads

UNIT II GEOMETRIC DESIGN OF HIGHWAYS 9

Cross sectional elements - Sight distances – Horizontal curves, Super elevation, transition curves, widening at curves – Vertical curves - Gradients, Special consideration for hill roads - Hairpin bends – Lateral and vertical clearance at underpasses.

UNIT III DESIGN OF FLEXIBLE AND RIGID PAVEMENTS 9

Pavement components and their role - Design principles -Design practice for flexible and rigid Pavements (IRC methods only) – Embankments- Problems in Flexible pavement design.

UNIT IV HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE 9

Highway construction materials, properties, testing methods – CBR Test for subgrade - tests on aggregate & bitumen – Test on Bituminous mixes-Construction practice including modern materials and methods, Bituminous and Concrete road construction, Polymer modified bitumen, Recycling, Different materials – Glass, Fiber, Plastic, Geo-Textiles, Geo-Membrane (problem not included) – Quality control measures - Highway drainage – Construction machineries.

UNIT V EVALUATION AND MAINTENANCE OF PAVEMENTS 9

Pavement distress in flexible and rigid pavements – Types of maintenance – Pavement Management Systems - Pavement evaluation, roughness, present serviceability index, skid resistance, structural evaluation, evaluation by deflection measurements – Strengthening of pavements –Highway Project formulation.

TOTAL: 45 PERIODS

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OUTCOMES:

Students will be able to

- Get knowledge on planning and aligning of highway.
- Geometric design of highways
- Design flexible and rigid pavements.
- Gain knowledge on Highway construction materials, properties, testing methods
- Understand the concept of pavement management system, evaluation of distress and maintenance of pavements.

TEXTBOOKS:

1. Khanna.S. K., Justo.C.E.G and Veeraragavan A. "Highway Engineering", Nemchand Publishers, 2014.

2. Subramanian K.P., "Highways, Railways, Airport and Harbour Engineering", Scitech Publications (India), Chennai, 2010

3. Kadiyali. L.R. "Principles and Practice of Highway Engineering", Khanna Technical Publications, 8th edition Delhi, 2013.

REFERENCES:

1. Indian Road Congress (IRC), Guidelines for the Design of Flexible Pavements, (Third Revision), IRC: 37-2012

2. Indian Road Congress (IRC), Guidelines for the Design of Plain Jointed Rigid Pavements for Highways, (Third Revision), IRC: 58-2012

3. Yang H. Huang, "Pavement Analysis and Design", Pearson Education Inc, Nineth Impression, South Asia, 2012

4. Ian D. Walsh, "ICE manual of highway design and management", ICE Publishers, Ist Edition, USA, 2011

5. Fred L. Mannering, Scott S. Washburn and Walter P.Kilareski, "Principles of Highway Engineering and Traffic Analysis", Wiley India Pvt. Ltd., New Delhi, 2011

6. Garber and Hoel, "Principles of Traffic and Highway Engineering", CENGAGE Learning, New Delhi, 2010

7. O'Flaherty.C.A "Highways, Butterworth – Heinemann, Oxford, 2006

8. IRC-37–2012,The Indian roads Congress, Guidelines for the Design of Flexible Pavements, New Delhi

9. IRC 58-2012. The Indian Road Congress, Guideline for the Design of Rigid Pavements for Highways, New Delhi

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UNIT-I

HIGHWAY PLANNING AND ALIGNMENT

PART-A

1. Write short notes on Highway Research Board. (NOV/DEC 2019), (May/June 2016)

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

2. Write the functions of Indian Road Congress (NOV/DEC 2019), (April/May 2015)

Indian Road Congress provides the following services

(i) It provides a forum for expression of collective opinion of its members for all matters affecting the construction and maintenance of roads in India.

(ii) It promotes the use of the standard specifications and practices.

(iii) It provided with the suggestions for the better methods of planning, designing, construction, administration and maintenance of roads.

(iv) It conducts periodical meetings to discuss technical problems regarding roads.

(v) It makes the laws for the development, improvement and protection of the roads.

(vi) It furnishes and maintains libraries and museums for encouraging the science of road making.

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3. Write the functions of Central Road Research Institute (CRRI)

(i) To carry out the basic and applied research for investigation, design, construction and maintenance of different types of roads and runways.
(ii) To carry out research on road traffic and transportation, including traffic safety and transport economics.
(iii) To render technical advice and consultancy services to various organizations.
(iv) To arrange for utilization of results of research by extension unit, display centers etc.
(v) To conduct refresher and training courses for staff of other research Institutions, Universities and highway Departments.

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4. How are roads classified in Nagpur plan? (April/May 2019), (April/May 2017), (Nov/Dec 2016)

In Nagpur road plan classified the roads in India based on location and function into the following five categories and described below.

i) National Highways (NH)

ii) State Highways (SH)

iii) Major District Roads (MDR)

iv) Other District Highways (ODR)

v) Village Roads (VR)

5. What are the recommendations of Jayakar Committee? (April/May 2019) (April/May 2018), (April/May 2017)

The most important recommendations made by the committee are:

i) The road development in the country should be considered as a national interest as the capacity of provincial governments and local bodies.

ii) An extra tax should be levied on petrol from the road users to develop a road development fund called central road fund in the year 1929.

iii) A semi official technical body should be formed to pool technical know-how from various parts of the country and to act as an advisory body on various aspects of roads.

iv) A research organization should be instituted to carry out research and development work pertaining to roads and to be available for consultations.

6. Define Central Road Fund. (Nov/Dec 2016)

The Central Road Fund (CRF) was formed on 1st 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.

The accounts of the central road fund are maintained by the Accountant General Revenue. The CRF has been revised in order to augment the revenue under this fund.

7. What are the objective of Highway planning (April/May 2018) (Nov/Dec 2017)

The objective of highway planning are given below

(i) To plan overall road network for efficient and safe traffic operation, but at minimum cost. Here the cost of construction, maintenance and resurfacing or strengthening of pavement layers and vehicle operation cost are to be given due consideration.

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(ii) To divide the overall plan into phases and to decide priorities.

(iii) To work out suitable financing system.

8. Write the classification of roads (Nov/Dec 2018), (Nov/Dec 2017).

The classification of roads two type's urban and rural roads in India:

(I) The rural roads are as follows

a. National highways
b. State highways
c. Major district roads
d. Other district roads
e. Village roads

(II) The urban roads are as follows

The road system within urban areas is classified as urban roads. The urban roads, other than express ways are classified as:

a. Arterial roads
b. Sub-arterial roads
c. Collector roads
d. Local roads

9. Write any four model limitations highways mode towards sustainability (Nov/Dec 2018). (Nov/Dec 2015).

The four mode of transportation are

(i) Road Transportation
(ii) Rail Transportation
(iii) Air Transportation
(iv) Water transportation

The following limitations are as below

(i) Innovational Barrier
(ii) Social Barrier
(iii) Political Barrier
(iv) Economical & Financial Barrier
(v) Poor monitoring and evaluation system
(vi) Institutional Barrier

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10. What are shoulders (May/June 2016)

Shoulders are provided on both sides of the pavement all along the road in the case of undivided carriageway. Shoulders are provided along the outer edge of the carriageway in the case of divided carriageway. The minimum shoulder width recommended by the IRC is 2.5m.

11. What is Right of Way (April/May 2015)

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.

11. List four parameters enumerated in traffic survey for the alignment and design of highway (April/May 2015)

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

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PART-B

1. List out the types of Highways as classified in the Indian Context starting from the Expressways upto Village/Rural Roads; for Each type, briefly state its specifications. (NOV/DEC 2019)

The Indian Highways as classified in types of roads are as follows.

(i) Expressway (E Way)
(ii) National Highways (NH)
(iii) State Highways (SH)
(iv) Major District Roads (MDR)
(v) Other District Highways (ODR)
(vi) Village Roads (VR)

(i) Express way

- For Speedy and heavy traffic
- Pedestrians not allowed
- Connect main markets, important places
- Complete separation of opposite moving traffic by a divider or median
- Level crossings, sharp curves, steep gradients avoided
- Telephone facility, Highway Police, Servicing Stations, Refreshment Facility available at regular intervals

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(ii) National highways

National highways are the main highways running through the length and breath 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.

(iii) 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.

(iv) 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.

(v) 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.

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(vi) 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.

The Each type of roads from Expressway , National Highways (NH), State Highways (SH), Major District Roads (MDR), Other District Highways (ODR), Village Roads (VR , briefly presented its specifications in below the table.

Specifications	Expressway	National Highways	State Highways	Major District Roads	Other District Roads	Village Roads
Right of way	90-100m	45m	45m	25m	15m	12m
Carriage way	11.25m	12m	12m	9m	7.5m	7.5m
Speed	120 km/hr	100 km/hr	80 km/hr	60 km/hr	50 km/hr	40 km/hr
Horizontal curve	700-2600m	360m	360m	230m	155m	90m
Vertical curve (Minimum)	0.5 %	0.6 %	0.8 %	1.0 %	1.2 %	1.5 %
Camber	2.5%	2.5 %	2.5 %	2.5 %	2.5 %	2.5 %
Median	12-15m	4m	2m	1m	0.5m	Nil
Shoulder	2.5-3.0 m	2.5m	1m	0.5m	0.5m	Unpaved
Super elevation	7%	7%	7%	7%	7%	7%

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2. ii) List the effects on Environment and Ecology of the surroundings due to a highway project. (NOV/DEC 2019).

S.NO.	Change Due to Roads	Consequence	Affected Ecosystem Good	Affected Ecosystem Service
1	**Chemical input from roads to water bodies**	Degradation of water quality, bioaccumulation	Clean water	Water purification, pollution abatement
2	**Chemical inputs to air shed**	Degradation of air quality	Clean air	Pollution abatement
3	**Chemical input to soils**	Bioaccumulation	Soil fertility	Pollution abatement
4	**Climate**	Increased temperature and rainfall	Water	Climate stability
5	**Hydrological processes**	Fluvial dynamics, sediment transport, floodplain ecology	NA	Flood and drought mitigation, nutrient cycling
6	**Modified habitat**	Plant species composition (natives and nonnatives)	Biodiversity	Nutrient cycling, soil fertility, seed dispersal
7	**Habitat quality, wildlife mortality**	Density and composition of animal species and populations	Biodiversity	Crop pollination, aesthetics, ecotourism

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3. b) Illustrative with neat sketches and Explain, How obligatory points control a highway alignment. (NOV/DEC 2019), (April/May 2018), (Nov/Dec 2016)

Requirements of ideal alignment are

a)Short

It is desirable to have a short alignment between two terminal stations.

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b) Easy

The alignment should be such that it is easy to construct and maintain the road with minimum problems

c)Safe

The alignment should be safe enough for construction and maintenance from the view point of stability of natural hill slopes.

d) Economical

The road alignment should be considered economical only if the total cost including initial cost, maintenance cost.

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

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

In hill roads additional care has to be given for

- Stability
- Drainage
- Geometric standards of hill roads
- Resisting length.

<u>Obligatory Points: -</u>

These control points may be divided in to two categories:

i) Points through which the alignment is to pass

ii) Points through which the alignment should not pass.

Obligatory points through which the road alignment has to pass may cause the alignment to often deviate from the shortest (or) easiest path. In fig.1.shows how the straight alignment AB is deviated along the hillside pass, thus avoiding a tunnel (or) heavy cutting.

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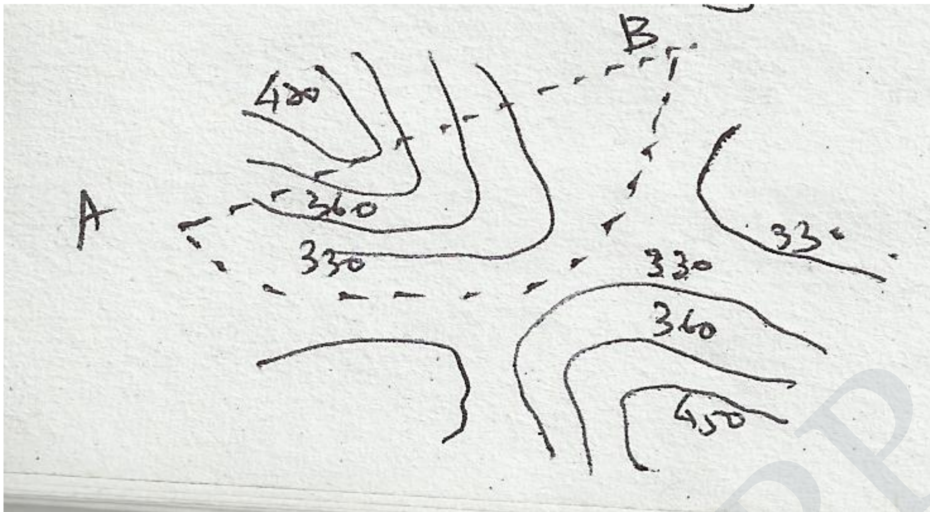

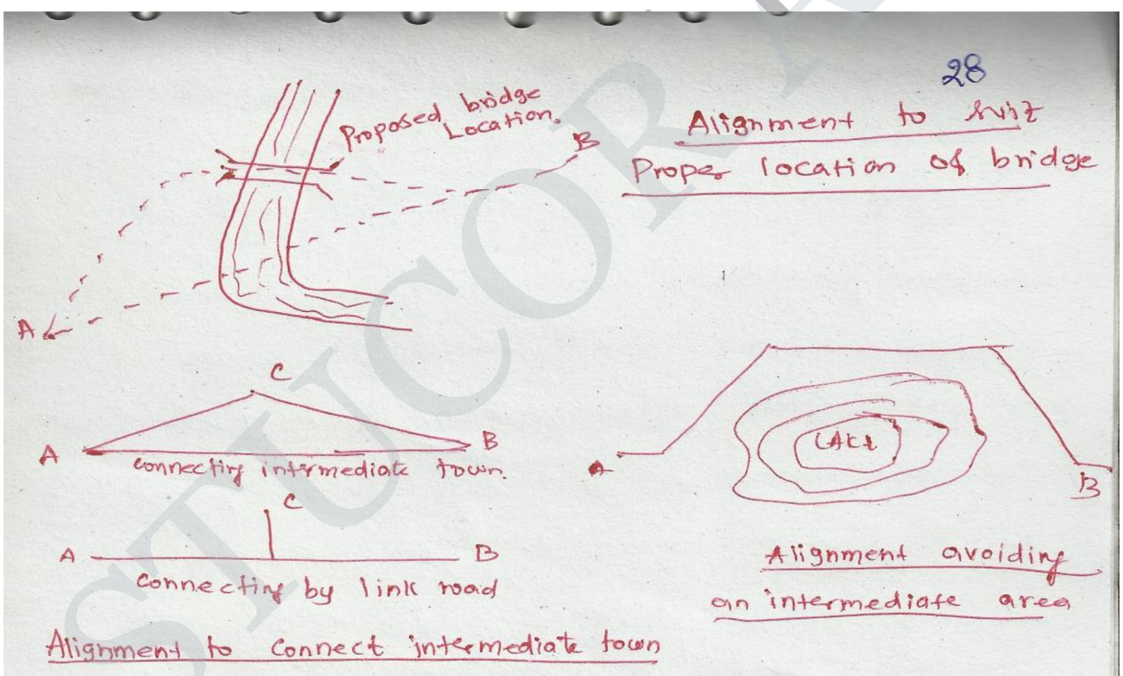

In fig.2.shows that the straight alignment between stations A and B which passes across the river band is to be deviated along the path shown in order to cross the river at a proper bridge location.

ii) Obligatory points through which the road should not pass also may make it necessary to deviate from the proposed shortest alignment.

The obligatory points, which should be avoided while aligning a road, include religious places, very costly structures.

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However if there is no alternative and the alignment has to be taken across such an area, the construction and maintenance costs are likely to be very high.

Traffic: -

The alignment should suit traffic requirements origin and destination study should be carried out in the area and the desire lines be drawn showing the trend of traffic flow.

Geometric design: -

- Geometric design factors such as gradient, radius of curve and sight distance also would govern the final alignment of the highway.

- The absolute minimum sight distance, which should invariably be available in every section of the road, is the safe stopping distance for the fast moving vehicles.

Economy: -

- The alignment finalized based on the above factors should also be economical.
- The initial coast of construction can be decreased if high embankments and deep cuttings are avoided and the alignment is choosing in a manner to balance the cutting and filling.

Other considerations: -

- Various other factors, which may govern the alignment, are drainage considerations, hydrological factors, political considerations and monotony.
- The vertical alignment is often guided by drainage considerations.
- In a flat terrain it is possible to have a very long stretch of road, absolutely straight without horizontal curves.

Special considerations: -

Stability: -

While aligning hill roads, special care should be taken to align the road along the side as the hill, which is stable. The cutting and filling of earth to construct roads on hillside causes steepening of existing slopes and affect its stability

Drainage: -

Numerous hillside drains should be provided for adequate drainage facility across the road. But the cross drainage structures being costly, attempts should be made to align the road.

Geometric standard of hill roads: -

Different sets of geometric standards are followed in hill roads with reference to gradient, curves and speed and they consequently influence the sight distance, and radius of curve and other related features.

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Resisting length: -

The resisting length of a road may be calculated from the total work to be done to move the loads along the route taking the horizontal length. The actual difference in levels between the two stations and sum of ineffective rise and fall in excess of floating gradient.

4. Briefly explain the engineering surveys needed for locating a new highway?(April/May 2015)

The stages of the engineering surveys are:

a) Map study.

b) Reconnaissance.

c) Preliminary surveys.

d) Final location and detailed surveys.

a) . 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.

- Alignment avoiding valleys, ponds or lakes
- When the road has to cross a row of hills, possibility crossing through a mountain pass.
- Approximate location of bridge site for crossing rivers, avoiding bend of the river.
- When a road is to be connected between two stations one of the top and the other on the foot of the hill then alternate routes can be suggested keeping in view the permissible alignment.
- Suppose the scale of the contour map is known, and then the contour intervals it is possible to decide the length of road required between two consecutive contours keeping the gradient within allowable limits.
- In the fig. Let A and B be two stations to be connected by road. AB is the shortest route (Straight line) APQB is a steep route in which the gradient positively exceeds 1 in 20 as the distance between the contour intervals is only about 200 meter.

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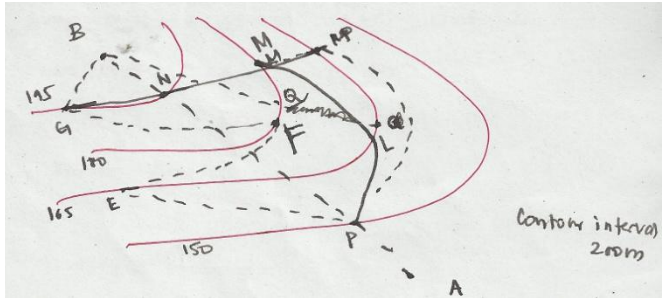

- APLMNB is a route with an approximate slope of 1 in 20 whereas APEFGB is an alternate alignment with the same gradient.
- Thus the map study also is possible to drop a certain route in view of any unavoidable obstructions (or) undesirable ground enroute.

b).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:

- Valleys, ponds, lakes, marshy, land, ridge, hills, permanent structures and other obstructions along the route, which are not available in the map.
- 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.

C). 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.

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- To estimate quantity of earthwork materials and other construction aspects and to workout 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:

(i) Primary survey: -

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

(ii) Topographical features: -

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

(iii) 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.

(iv) Drainage studies: -

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

(v) 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.

(vi) Material survey: -

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

(vii) 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.

(viii) 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.

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(ix) 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.

(x) Detailed survey: -

- Levels along his final centerline should be taken at all staked points. Levelling 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.

4. Write shortly the significance of Soil suitability analysis and road Ecology in highway planning (April/May 2019), (Nov/Dec 2018), (Nov/Dec 2015)

a) Detailed explain the soil suitability analysis

It is the process of understanding existing site qualities and factors which will determine the locating of a particular highway. The following parameters can be considered for the analysis:

1. Land use/ land cover.

2. Proximity to major road.

3. Proximity to city/ urban built-up land.

4. Soil salinity.

5. Ground water table depth

6. Ground water quality.

7. Slope of the terrain.

Areas with less fertile soil and poor quality of groundwater offer a good choice for the highway development.

b) Procedure to carry out the analysis

i. A detailed soil survey is carried out by groundwater obtaining soil samples 1.5-3m below the ground level.

ii. Sampling should be done to a depth equal to the twice of the height of final embankment.

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iii. Spacing of sampling and type of sampling depends on the soil type or location.

iv. During survey one may cross areas where land is loose or is subjected to slides or may be stretches of rocky strata, all these details are to be recorded.

v. Preparation of highway formation, the primary operation involves excavation and embankments.

vi. Formation of pavements involves construction of embankments.

vii. Soil is obtained from the adjoining areas of the highway within the highway land itself.

viii. For this additional land may be acquired temporarily and after completion of the project, it may be handed over.

c) Explain the Road ecology

1. Road ecology focuses on understanding the interactions between load system and natural environment.
2. Road ecology find ways to minimize the detrimental effects that roads systems can have on plant and animal populations, air and water quality and human communities.
3. Outputs of road ecology includes advances in the management of storm water runoff, transportation and land use planning, and the development of crossing structures that animals use for safe passage across busy roads.
4. The science of road ecology is concerned with understanding how road affect ecological processes, often with the goal of developing strategies for controlling any negative effects that roads may have on the environment.

d) History of road ecology

1. For more than a century, we have allowed expressway, arterials and rural roads to define our landscapes without seriously considering how we might redefine the road. Engineers rarely attempted to incorporate ecological functions.

2. Studies of the impact of roads have existed as long as roads themselves.

3. Early work focused on the threat that motor vehicles posed to wildlife.

4. Broader consideration of the role that roads can have on ecological process was largely ignored until the latter half of the 20^{th} century.

5. Researchers also began presenting result that suggested traffic noise might have profound and far reaching effects on bird population.

e) Elements of road ecology

1. Road ecologists investigate the complex interactions between road and the natural environment how roads act as barriers inhibiting the movement of plans and, animals.

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2. They also help develop emissions and test solutions to these pervasive problems.

3. Highway design process environmental factors in the earliest phases of project design and make extensive use of wildlife crossings and other ecological mitigation infrastructure.

4. **Write in brief the history of road development in India after independence (April/May 2019), (Nov/Dec 2018)(April/May 2015)**

The following road developments are after independence in India

(i) Central Road Research Institute (CRRI, 1950)

(ii) National Highway Act, (1956)

(iii) National Highways Authority of India (NHAI, 1995)

(iv) Second Twenty Year Road Development Plan, (1961-1981)

(v) Third Twenty Year Road Development Plan, (1981-2001)

(vi) Pradhan Mantri Gram Sadak Yojana (PMGSY,2000)

(vii) Road Development Plan: Vision 2021

(viii) Rural Road Development Plan: Vision 2025

(i) Central Road Research Institute (CRRI, 1950)

The main objectives are:

- To carry out the basic and applied research for investigation, design, construction and maintenance of different types of roads and runways.
- To carry out research on road traffic and transportation, including traffic safety and transport economics.
- To render technical advice and consultancy services to various organizations.
- To arrange for utilization of results of research by extension unit, display centers etc.
- To conduct refresher and training courses for staff of other research Institutions, Universities and highway Departments.

(ii) National Highway Act, (1956)

In 1956 the National Highway act was passed

The main features of the act are:

- The responsibility of developing and maintenance of the national highway (NH) to be provisionally taken by the central government.
- The Central Government to be empowered to declare any other highway as NH or to omit any of the existing highway from the list.

(iii) National Highways Authority of India (NHAI, 1995)

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The NHAI was established under the national highway authority of India act 1988.

The objectives are:

- Take responsibility of development and maintenance
- Improve and extend the NH network in an efficient
- Improve road safety including road geometric
- Provide on route facilities for road users.
- To promote the scheme of three plantations along the roads as well as beautify all major intersections and junctions.

(iv) Second Twenty Year Road Development Plan, (1961-1981)

Second Twenty-Year Road Plan (1961-81)

The Nagpur road plan was intended for the period 1943-63,but the target road length was nearly completed earlier in 1961. Hence the next long term plan for the twenty year period commencing from 1961 was initiated by the IRC and was finalized by the subcommittee and this was approved by the Chief Engineers. The Second Twenty Year Road Development plan 1961-81 is also Called Bombay Road Plan.

Salient features of the second 20-year plan (1961-81):-

- This plan is considered to be draw more scientifically in view of development needed in under-developed areas.
- Maximum distance of any place in a developed or agricultural area would be 6.4 km from a metalled road and 2.4 km from any category of roads.
- The maximum distance from any place in a semi-developed area would be 12.8 km from a mettaled road and 4.8 km from any road.
- Every town with population above 2000 in plains and above 1000 in semi-hill areas and above 500 in hilly areas should be connected by a metalled road.
- Expressways have also been considered in this plan and 1600 km of length has been included in the proposed target of national highways
- Length of railway track is considered independent of the road system and hence it is not subtracted to get the road length.
- The development factor of only 5 percent is provided for future development and unforeseen factors.

(v) Third Twenty Year Road Development Plan, (1981-2001)

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Policies and objectives:

a) 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:

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

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

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

e) 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.

f) 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.

g) Expressways should be constructed along major traffic corridors to provide fast travel.

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

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

(vi) Pradhan Mantri Gram Sadak Yojana (PMGSY,2000)

- Pradhan Mantri Gram Sadak Yojana (PMGSY) was launched on 25th December, 2000 as a Centrally Sponsored Scheme to provide road connectivity in rural areas of the country.
- The programme envisages connecting all habitations with a population of 500 persons and above in plain areas and 250 persons and above in Hill States.

(vii) Road Development Plan: Vision 2021

The Indian Roads Congress Have Prepared a Rural Road Development Plan, Vision 2025
The salient features of the Plan
Master Plans should be prepared for Rural Roads showing the core Network which gives accessibility to each village. All future programmes should strictly conform to this network
All habitations with a population of above 100 will be connected by all weather roads.

(viii) Rural Road Development Plan: Vision 2025

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- Rural Road Development Plan: Vision 2025 has been prepared for the 20 year period 2005-2025.
- Rural Road Development Plan was initiative of the Ministry of Rural Development, Government of India.
- District wise rural road development plan have been prepared.
- The vision document targets to provide connectivity to all unconnected habitations of the country in a phase manner, beyond the norms laid down in the PMGSY.
- Lower population limits were fixed for under development limits were fixed for under development regions including hills, deserts and tribal areas.

5. Describe the classification of Highways based on location and function (April/May 2018)

(Refer Part B. Question 1.)

6. Write shorts notes on i) Indian Road Congress ii) Central Road Research Institute (CRRI), and iii) Highway Research Board (April/May 2018)

(Refer Part A- Question no. 1,2 and 3)

7. Explain the Bombay road congress 1961(May/June 2016)

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. The changed economic, industrial and agricultural conditions in the country warranted a review of the Nagpur plan. 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:

i) It was the second 20 year road plan (1961-1981)

ii) The total road length targeted to construct was about 10 lakhs.

iii) Rural roads were given specific attention. Scientific methods of construction were proposed for the rural roads. The necessary technical advice to the Panchayaths should be given by State PWD's.

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iv) They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km

v) The construction of 1600 km of expressways was also then included in the plan.

8. Explain the Jayakar Committee Recommendation (Nov/Dec 2016)

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

i) 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.

ii) They gave more stress on long term planning programme, for a period of 20 years (hence called twenty year plan) that is to formulate plans and implement those plans with in the next 20 years.

iii) One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official technical body called Indian Road Congress (IRC) in 1934

iv) The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation, license fees for vehicles plying for hire. This led to the introduction of a development fund called Central road fund in 1929. This fund was intended for road development.

v) A dedicated research organization should be constituted to carry out research and development work. This resulted in the formation of Central Road Research Institute (CRRI) in 1950.

9. Explain in detail the reconnaissance survey for highway location in rural area (April/May 2017)

(Refer Part B Question No.4)

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10. Explain the classification of urban roads with neat sketches (Nov/Dec 2015)

Classification of urban roads

(i) Arterial roads

(ii) Sub-arterial roads

(iii) Collector Street

(iv) Local Street

(i) Arterials

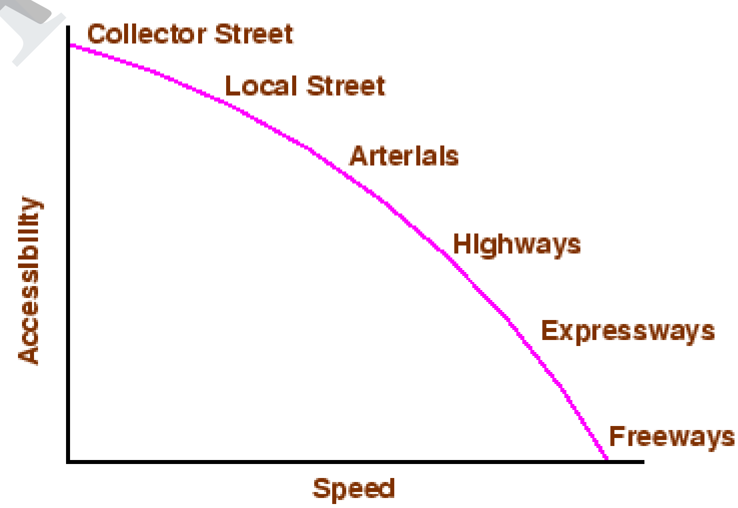
It is a general term denoting a street primarily meant for through traffic usually on a continuous route. They are generally divided highways with fully or partially controlled access. Parking, loading and unloading activities are usually restricted and regulated. Pedestrians are allowed to cross only at intersections/designated pedestrian crossings.

(ii) Local streets

A local street is the one which is primarily intended for access to residence, business or abutting property. It does not normally carry large volume of traffic and also it allows unrestricted parking and pedestrian movements.

(iii) Collector streets

These are streets intended for collecting and distributing traffic to and from local streets and also for providing access to arterial streets. Normally full access is provided on these streets. There are few parking restrictions except during peak hours.



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11. Elaborate the factors affecting the geometric design of highways (Nov/Dec 2017)

(i) 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.

Design speed is defined as the highest continuous speed at which individual vehicles can travel with safety on the highway when weather conditions are conducive. Design speed is different from the legal speed limit which is the speed limit imposed to curb a common tendency of drivers to travel beyond an accepted safe speed. Design speed is also different from the desired speed which is the maximum speed at which a driver would travel when unconstrained by either traffic or local geometry.

Since there are wide variations in the speed adopted by different drivers, and by different types of vehicles, design speed should be selected such that it satisfy nearly all drivers. At the same time, a higher design speed has cascading effect in other geometric designs and thereby cost escalation. Therefore, an 85th percentile design speed is normally adopted. This speed is defined as that speed which is greater than the speed of 85% of drivers. In some countries this is as high as 95 to 98 percentile speed.

(ii) Topography

The next important factor that affects the geometric design is the topography. It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multiform with the gradient and the terrain. Therefore, geometric design standards are different for different terrain to keep the cost of construction and time of construction under control. This is characterized by sharper curves and steeper gradients.

(iii) Other factors

In addition to design speed and topography, there are various other factors that affect the geometric design and they are briefly discussed below:

- **Vehicle:** :The dimensions, weight of the axle and operating characteristics of a vehicle influence the design aspects such as width of the pavement, radii of the curve, clearances, parking geometrics etc. A *design vehicle* which has standard

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weight, dimensions and operating characteristics are used to establish highway design controls to accommodate vehicles of a designated type.

- **Human:** The important human factors that influence geometric design are the physical, mental and psychological characteristics of the driver and pedestrians like the reaction time.
- **Traffic:** It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is determined from the various traffic data collected. The geometric design is thus based on this design volume, capacity etc.
- **Environmental:** Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.
- **Economy:** The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.
- **Others:** Geometric design should be such that the aesthetics of the region is not affected.

12. (i) For a highway alignment, to cross a river, what are the various obligatory and other technical and economical considerations in aligning the highway across the river (Nov/Dec 2015)

The various factors that control the alignment are as follows:

Obligatory points:

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

Bridge site:

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

Mountain:

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

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Intermediate town:

The alignment may be slightly deviated to connect an intermediate town or village nearby. The location should avoid obstructions such as places of cemeteries, archeological, historical monument, public facilities like schools and hospitals, utility services.

Geometric design features

- Facilitate easy grade and curvature
- Enable ruling gradient in most sections
- Void sudden changes in sight distance, especially near crossings
- Avoid sharp horizontal curves
- Avoid road intersections near bend or at the top or bottom of a hill
- Precautions at river and railway crossings
- Bridges should be preferably be located at right angles to the river flow, not located on a horizontal curve
- Crossing railway lines should avoid intersections at gradient, frequent crossing and re crossing

Topographical control points

– The alignment, where possible should avoid passing through

• Marshy and low lying land with poor drainage

• Flood prone areas

• Unstable hilly features

• Avalanche prone areas

– Flat terrain-below 3%

– Rolling terrain -3 to 25%

– Mountainous terrain – above 25%

– A location on high ground should be preferred rather than valley to avoid cross drainage works

Economics

The total cost Construction cost+ maintenance cost+ operation cost) should be kept minimum.

Initial cost-by avoiding high embankments and deep cutting

Maintenance cost-by avoiding unsuitable land Operation cost- by avoiding steep gradient and curves

Other considerations

• Environmental considerations

• Engineering feasibility

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- Social considerations
- Drainage and Hydrological factors
- Political considerations- avoiding into foreign territory
- Monotony- long stretch of straight road leads to driving discomfort

(ii) **Construction of route:**

In roadways, these routes consist of suitable pavement of specified width provided usually with shoulders on either side. In railways, the routes consist of pair of steel rails which are laid parallel to each other on sleepers at fixed distance apart.

Suitability to traffic:

In roadways, routes are meant for movement of different types, of traffic such as buses, trucks, scooters, rickshaws, cycles, pedestrians etc. The railway routes are meant only for movement of trains.

Width of right-of-way:

The roadway routes require more width of right-of-way. The railway routes require less width of right-of-way. Starting and destinations: In roadways, starting and destination points of traffic are not fixed. In railways, starting and destination points of trains are always fixed.

Right of entry:

In roadways, the right of entry is free to all vehicles because their movements are not according to any schedule. In railways, the right of entry is not free to all railway vehicles because their movements are always according to schedule. Strength of route: The required strength of roadways is less. The required strength of railway tracks is more.

Elasticity:

The roadway routes do not require an elastic structure since they are not to withstand impacts of heavy wheel loads. The railway routes require an elastic structure to withstand impact of heavy wheel loads.

Gradients and curves:

In roadways, the routes can be constructed with steep gradients and sharp curves. Thus, route length in their case is less. In railways, these routes cannot be constructed with steep gradients and flat curves. Thus, route length in their case is more.

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Load handling capacity:

The load handling capacity of road vehicles is less and that too at low speeds. Load handling capacity of railway vehicles is more and that too at high speeds.

Requirement of turning devices:

In roadways, no special turning devices are constructed for turning vehicles on these routes. In railways, special turning devices in the form of points and crossings are constructed for turning vehicles on these routes.

Operational control devices:

In roadways, no special operational control devices in the form of signaling and interlocking are required on these routes for safe and efficient movement of vehicles. In railways, special operational control devices in the form of signaling and interlocking are required on these routes for safe and efficient movements of trains as per schedule.

Suitability to transportation of people and goods:

Transportation of people and light goods for short distances (upto 500 km) is convenient and cheap by roadway routes. Transport of people and heavy goods like raw materials, coal, ores, etc. for long distance or manufacturing concerns is convenient and cheap by railway routes.

Adaptability to type and size of goods:

All types and sizes of goods cannot be handled by road vehicles. Almost all types and sizes of goods can be handled by the trains.

Suitability for hilly area:

Roadway vehicles are more suitable for hilly area. Railway vehicles are less suitable for hilly area.

Construction and maintenance cost:

The construction and maintenance cost of roadway vehicles is less. In case of railway vehicles, the cost is more.

(ii) Compare two modes of Transportation –Railways and Highways (Nov/Dec 2015)

(Refer Part –C , Question No.3)

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PART C

1. **Explain the process of engineering survey for a highway alignment through conventional method. (Nov/Dec 2019), (April/May 2018)**

   (Refer Part b- Question no. 4)

2. **Explain PIEV Theory with neat sketch (Nov/Dec 2019)**

   1) Perception

   2) Intellection

   3) Emotion

   4) Violation

   1) Perception

   Time required for the sensations received by the eyes or ears of the driver to be transmitted to the brain through the nervous system & spinal cord or it is the time required to perceive an object or situation.

   2) Intellection

   Time require for the driver to understand the situation it is also the time required for comparing the different thoughts.

   3) Emotion

   Time elapsed during emotional sensational and other mental disturbance such as fear, anger or any other emotional feeling superstition etc

   4) Volition

   Time taken by the driver for the final action such as brake application.

   The total reaction time t=2.5 Second

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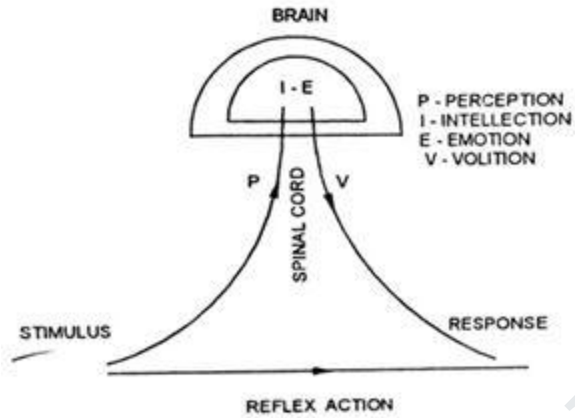

3. **Compare two modes of Transportation –Railways and Highways (Nov/Dec 2019), (Nov/Dec 2015)**

(A) Road Transport

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

(B) **Railway Transport**

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

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4. **Explain in brief the modern methods of laying highway alignment being adopted at present with its merit and demerits.(April/May 2019), (April/May 2018)**

(Refer Part B- Question no. 4)

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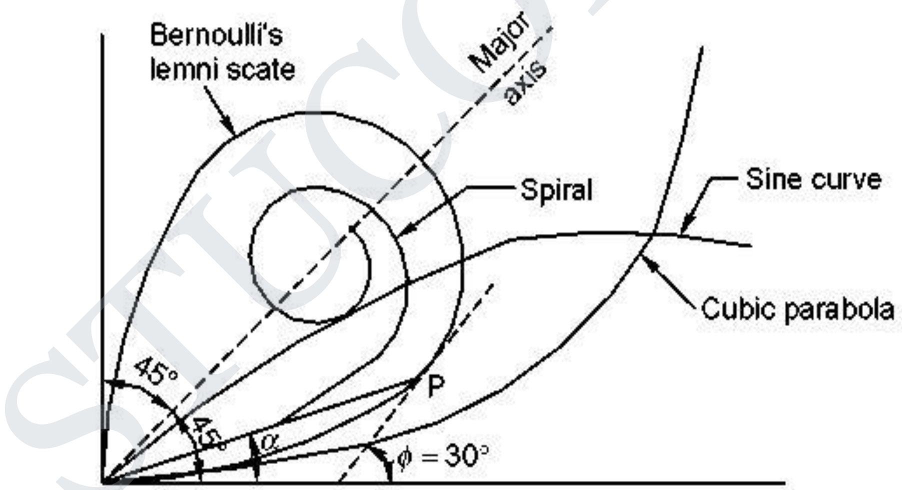
UNIT-II

GEOMETRIC DESIGN OF HIGHWAYS

1. Differentiate between Right of Way and Carriage way (NOV/DEC 2019)

Right of Way	Carriageway
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.	The 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 of 3.5m per lane is considered sufficient

2. Draw a typical Transition curve and mark all its zones (NOV/DEC 2019)



3. What are the fundamental principles of alignment? (April/May 2019)

- Design speed
- Sight distance
- Horizontal curves
- Drainage gradient
- Super elevation

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4. What are the type of sight distance? (April/May 2019), (Nov/Dec 2016)

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

Three sight distance situations are considered for design:

- Stopping sight distance (SSD) or the absolute minimum sight distance
- Intermediate sight distance (ISD) is defined as twice SSD
- Overtaking sight distance (OSD) for safe overtaking operation
- Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
- Safe sight distance to enter into an intersection.

5. What is meant by widening of pavement on horizontal curves? (April/May 2018), (May/June 2016)

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: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve.

6. What is the maximum and Minimum super -elevation?(April/May 2017)

Depends on (a) slow moving vehicle and (b) heavy loaded trucks with high CG.
IRC specifies a maximum super-elevation of 7 percent for plain and rolling terrain, while that of hilly terrain is 10 percent and urban road is 4 percent.

The minimum super elevation is 2-4 percent for drainage purpose, especially for large radius of the horizontal curve.

7. Define camber. (April/May 2017)

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

8. What are the elements involved in Highway geometric design? (May/June 2016)

Geometric design of highways deals with:

i. Cross section elements

ii. Sight distance considerations

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iii. Horizontal alignment details

iv. Vertical alignment details

v. Intersection elements.

9. Briefly explain illumination sight distance. (April/May 2015)

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. Define sag curves (April/May 2015)

Sag vertical curves are curves that connect descending grades, forming a bowl or a sag. Designing them is is very similar to the design of crest vertical curves.

11. What are overtaking zones? (APR/MAY 17)

The intervals or zones on the highways provided for the purpose of safety overtaking operation of fast moving vehicles with slow moving vehicles, without any collision of vehicles from opposite side are called overtaking zones.

12. What are the types of curves in highway geometric design and write any two salient features of any one curve?(Nov/Dec 2018)

I. Horizontal curve

a) Simple curve
b) Compound curve
c) Reverse curve
d) Transition curve

II. Vertical curve

a) Sag curve
b) Summit curve

<u>Salient Features of summit sag curve</u>

a) Safety and
b) Comfort travelling between gradients

13. With neat sketches show the typical cross section of any one urban road as per Indian Road Congress (IRC) standards. (Nov/Dec 2018)

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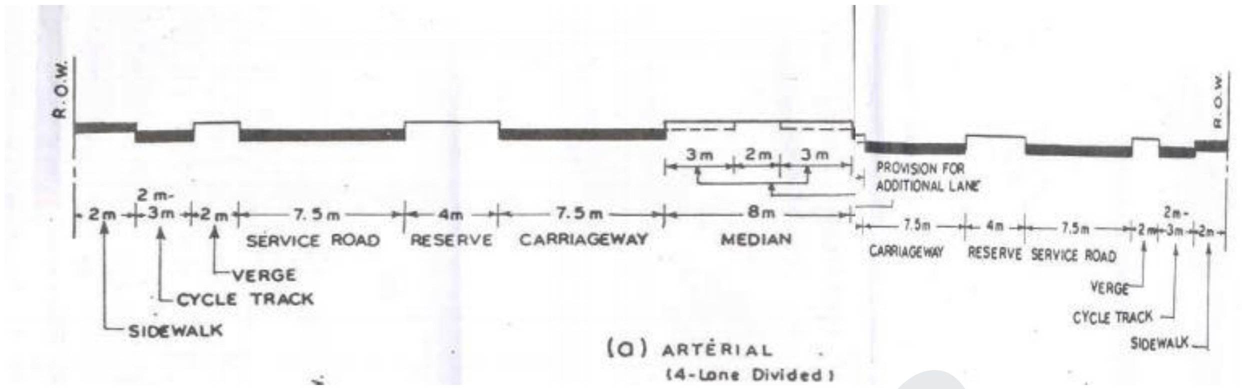
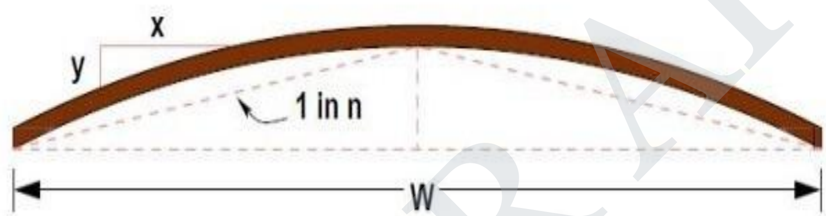


14. State the marit and demerit of parabolic camber (Nov/Dec 2017)



Marit	Demerit
Camber provides quick drainage of rainwater and thus saves the foundation course of the road structure from weakening by percolation of rainwater to it through the road surface.	The roads will wear and tear on the edges. The passengers feel unbalance and discomfort during journey
This prevents rainwater to accumulate in local shrinkages or depressions and forming water pool on the road surface, which are disagreeable to the public as well as to the road structure.	It reduces the road width as everyone will try to move on the middle of the road.

15. Find super elevation on a horizontal circular curve of 150 m radius for design speed of 65Kmph with a coefficient of friction 0.15. (Nov/Dec 2017)

Solution:

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

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$$e + 0.15 = \frac{(65)^2}{127(150)}$$

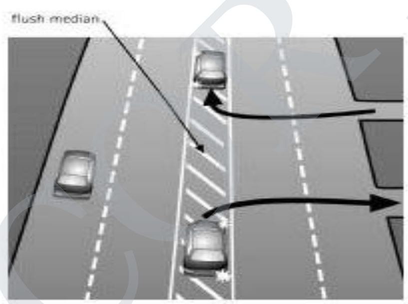
$$e = \frac{4225}{(19050 - 0.15)}$$

$$e = \frac{4225}{(19050 - 0.15)}$$

$$\boldsymbol{e = 0.221\%}$$

16. List any four types of median adopted for highways.

(i) Traversable median
 Flush
(ii) Non transferable median
 Barrier
 Deterring



Flush median

Deterring

Barrier

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17. What are the fundamental principles of alignment? (April/May 2019)

a. Short
b. Safe
c. Convenient

18. Elements of Highway cross section

Elements of Highway Cross-section

The elements of geometric design include:

1. Elements of Cross-section
2. Elements of horizontal alignment
3. Elements of vertical alignment

Elements of Cross section

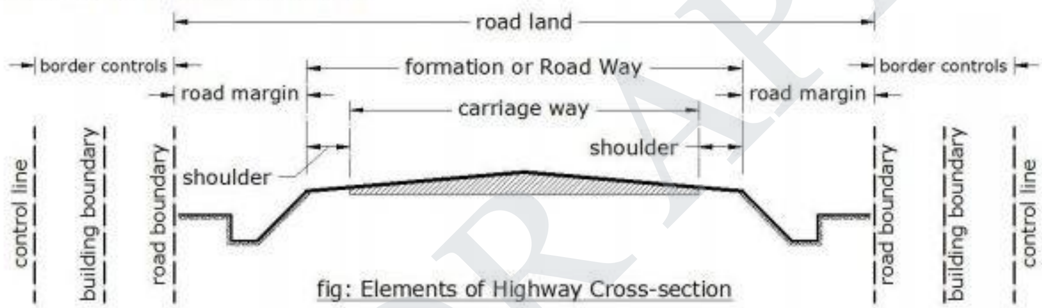

fig: Elements of Highway Cross-section

The main x-sectional elements are:

i) Traffic lane
ii) Carriage way or width of pavement
iii) Shoulder
iv) Road way
v) Width of formation
vi) Side slope of fill or cut
vii) Lay bays
viii) Right of way or land width
ix) Camber
x) Super-elevation

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PART-B

1. Describe briefly about gradient and Its types (Nov/Dec 2018)(Nov/Dec 2016)

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 for designing the vertical curve.

The positive gradient or the ascending gradient is denoted as +n and the negative gradient as −n. The deviation angle N is: when two grades meet, the angle which measures the change of direction and is given by the algebraic difference between the two grades $(n_1 - (-n_2)) = n_1 + n_2 = \alpha_1 + \alpha_2$.

Types of gradients

i) Ruling gradient,
ii) Limiting gradient,
iii) Exceptional gradient and
iv) Minimum gradient

(i) Ruling gradient

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, length of the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In flatter terrain, it may be possible to provide flat gradients, but in hilly terrain it is not economical and sometimes not possible also. The ruling gradient is adopted by the designer by considering a particular speed as the design speed and for a design vehicle with standard dimensions. But our country has a heterogeneous traffic and hence it is not possible to lay down precise standards for the country as a whole. Hence IRC has recommended some values for ruling gradient for different types of terrain.

(ii) Limiting gradient

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

(iii) Exceptional gradient

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

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2.5%. Critical length of the grade The maximum length of the ascending gradient which a loaded truck can operate without undue reduction in speed is called critical length of the grade. A speed of 25 kmph is a reasonable value. This value depends on the size, power, load, grad-ability of the truck, initial speed, final desirable minimum speed etc.

(iv) Minimum gradient

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

2. Explain the Factors influencing the geometric design of Hills roads (Nov/Dec 2018)

Design of hill road

a) Rock cutting

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.

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

b) 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.

c) **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.

d) 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 scour able soils, slips are likely to occur.

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e) **Pavement type**

Because of the high intensity of rain fall generally throughout the year in the hill reigns, 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

3) Calculate the safe OSD for a design speed of 90 Kmph. Take reaction time of driver as 2.5 seconds and acceleration of overtaking vehicle as 2.5 kmph/sec. Draw OSD Zone. (NOV/Dec 2017)

Given data:
Design speed = 90 kmph
Reaction time = 2.5 sec
Acceleration = 2.5 kmph/sec

Solution

Consider the speed of the overtaking vehicle as the design speed (ie)

V= 90Kmph = 90/ 3.6 = 25 m/ sec
V= v_b=25 m/sec

Acceleration a= 2.5 kmph/sec
OSD= $d_1+d_2+d_3$

Reaction time (t) = 2.5 sec
$d_1 = v_b\, t$
= 25x 2.5
= 62.5m

S= [0.7Vb+b]
=[0.7x 25x6]
= 23.5 m

Time $T = \frac{\sqrt{4X\ Vb}}{a}$

$= \frac{\sqrt{4X\ 25}}{2.5}$

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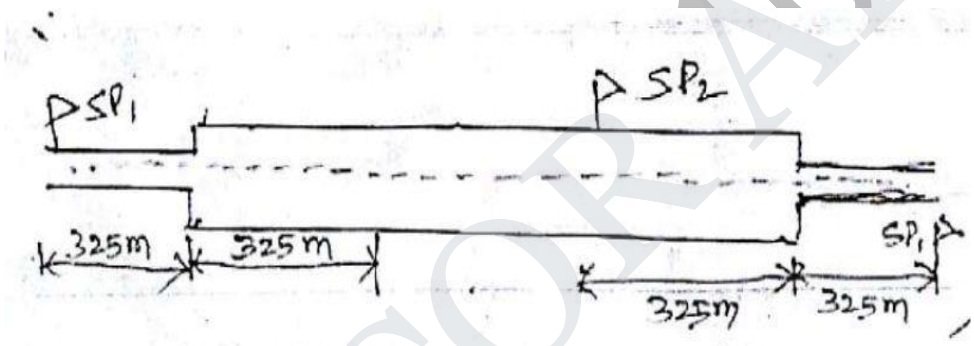
= 6.324 Sec
= 6.3 Sec

d_2 = Vb T+2S

= 25 x 6.3 + 2 x 23.5

= 104.5 m

d_3 = 25x 6.3 = 157.5 m
OSD = 62.5 +104.5 + 157.5
OSD = 62.5 + 104.5 +157.5
OSD = 324.5
OSD =325 m



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4 Calculate the length of the transition curve with the following data (Nov/Dec 2017)
Design speeed= 70 kmph, Radius of circular curve = 250 m
Allowable rate of introduction of super elevation =1 in 150.
Pavement width including extrawidth=7.5m

Given data

Design speed =70kmph

Radius of circular curve = 250m

Allowable rate of introduction of super elevation = 1 in 150

Pavement width including extrawidth=7.5m

Solution :

1. **By adopting a particular rate of super elevation length of transition curve**

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$$L = \frac{ne}{100}$$

$$L = \frac{300X\ 150}{100}$$

$$L = 450\ m$$

2. **By considering orbitary rate of superelevation**

$$L = \frac{e\ X\ V}{x}$$

$$L = \frac{150\ X\ 70}{2.5}$$

$$L = 4200\ m$$

3. **By considering rate of change of accelaration radius on circular curve**

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

$$L = \frac{70^2}{250}$$

$$L = 19.6\ m$$

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4. Explain the steps involved in the geometric design of hills roads (April/May 2015)

Hill road is defined as the one which passes through a terrain with a cross slope of 25% or more. IRC: SP: 73-2015 and IRC: SP: 84-2014 have merged the Mountainous and Steep Terrain having Cross Slope more than 25%.

DESIGN IN HILL ROADS

Design and Construction of Hill roads are more complex than in plain terrain due to factors summarized below:

a) Highly broken relief with vastly differing elevations and steep slopes, deep gorges etc. which increases road length.
b) The geological condition varies from place to place.
c) Variation in hydro-geological conditions.
d) Variation in the climatic condition such as the change in temperature due to altitude difference, pressure variation, precipitation increases at greater height etc.
e) High-speed runoff due to the presence of steep cross slopes.
f) Filling may overload the weak soil underneath which may trigger new slides.
g) Need of design of hairpin bends to attain heights.
h) Need to save Commercial and Residential establishments close to the road.
i) Need to save the ecology of the hills.

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SPECIAL CONSIDERATION IN HILL ROAD DESIGN

(i) Alignment of Hill Roads

The designer should attempt to choose a short, easy, economical and safe comforting route.

(ii) General considerations

When designing hill roads the route is located along valleys, hill sides and if required over mountain passes.

Due to complex topography, the length of the route is more.

In locating the alignment special consideration should be made in respect to the variations in:

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- Temperature
- Rainfall
- Atmospheric pressure and winds
- Geological conditions
- Resettlement and Rehabilitation considerations
- Environment Considerations

(iii) Temperature

a) Air temperature in the hills is lower than in the valley. The temperature drop being approximately 0.5° per 100 m of rising.

b) On slopes facing south and southwest snow disappears rapidly and rain water evaporates quickly while on slopes facing north and northeast rain water or snow may remain for the longer time.

c) Unequal warming of slopes, sharp temperature variations and erosion by water are the causes of slope failure facing south and southwest.

(iv) Rainfall

a) Rainfall generally increases with increase in height from sea level.

b) The maximum rainfall is in the zone of intensive cloud formation at 1500-2500 m above sea level. Generally, the increase of rainfall for every 100 m of elevation averages 40 to 60 mm.

c) In summer very heavy storms/cloud burst may occur in the hills and about 15 to 25% of the annual rainfall may occur in a single rainfall. The effects of these types of rainfall are serious and should be considered in design.

(v) Atmospheric pressure and winds

- Atmospheric pressure decreases with increase in elevation.
- At high altitudes, the wind velocities may reach up to 25-30 m/s and depth of frost penetration is also 1.5 to 2 m.
- Intensive weathering of rocks because of sharp temperature variations.

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(vi) Geological conditions

- The inclination of folds may vary from horizontal to vertical stratification of rock. These folds often have faults. Limestone or sandstone folds may be interleaved with layers of clay which when wetted may cause fracturing along their surface. This may result in shear or slip fold.
- The degree of stability of hill slopes depends on types of rock, degree of strata inclination or dip, occurrence of clay seams, the hardness of the rocks and presence of ground water.
- When locating the route an engineer must study the details of geological conditions of that area and follow stable hill slopes where no ground water, landslides, and unstable folds occur.

(vii) Resettlement and Rehabilitation

- Due to limited availability of flat areas and connectivity issues, most of the residential and commercial activity happens very close to the road leading to large scale R&R and becomes a challenge in alignment design.

(viii) Environment

- Hills are ecologically sensitive areas relatively untouched by human activity. The alignment design must attempt to minimize tree cutting and large scale earth filling/cutting to minimize damage.

(ix) ROUTE SELECTION

Hill road alignment may follow alignment at Valley bottom or on a ridge depending on the feasibility of the road. The first is called **River route** and the second is called **Ridge route.**

a) River route

- Most frequent case of hill alignment as there is a great advantage of running a road at a gentle gradient.
- Runs through lesser horizontal curvature.
- Requirements for the construction of bridges over tributaries.
- Construction of special retaining structures and protection walls on hill side for safe guarding the road against avalanches in high altitude areas.
- Benefit of low construction cost and operation cost.

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Ridge route

- Characterized by the very steep gradient.
- Large number of sharp curves occurs on the road with hair pin bends.
- Extensive earthwork is required.
- The requirement for the construction of special structures.
- High construction and operation cost.

GEOMETRIC DESIGN STANDARDS

The various Design Standards being followed in the India for the design of Hill Road are:

IRC:SP:48-1998 **Hill Road Manual.**

IRC:52-2001 **Recommendations About the Alignment Survey and Geometric Design of Hill Roads.**

IRC:SP:91-2010 **Guidelines for Road Tunnels.**

IRC:SP:73-2015 **Manual of Specifications and Standards for Two Laning of Highways with Paved Shoulder.**

IRC:SP:84-2014 **Manual of Specifications and Standards for Four Laning of Highways through Public Private Partnership.**

Hill Road Capacity

Type of Road	Design Service Volume in PCU per day			
	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73-2015 & IRC:SP:84-2014	
	For Low Curvature (0-200 degrees per km)	For High Curvature (above 0-200 degrees per km)	Level of Service 'B'	Level of Service 'C'
Single lane	1,600	1,400	-	-
Intermediate lane	5,200	4,500	-	-
Two Lane	7,000	5,000	9,000	-
Four Lane	-	-	20,000	30,000

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Design speed

The design speeds for various categories of hill roads are given below:

Road Classification	As per IRC:SP:48-1998 and IRC:52-2001				As per IRC:SP:73-2015 & IRC:SP:84-2014	
	Mountainous Terrain		Steep Terrain		Mountainous and Steep Terrain	
	Ruling	Minimum	Ruling	Minimum	Ruling	Minimum
National and State Highways	50	40	40	30	60	40
Major District Roads	40	30	30	20	-	-
Other District Roads	30	25	25	20	-	-
Village Roads	25	20	25	20	-	-

Sight distance

- Visibility is an important requirement for safety on roads.
- It is necessary that sight distance of sufficient length is available to permit drivers enough time and distance to stop their vehicles to avoid accidents.

Design Speed (Km/h)	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73-2015 & IRC:SP:84-2014	
	Mountainous and Steep Terrain			
	Stopping Sight Distance (m)	Intermediate Sight Distance (m)	Safe Stopping Sight Distance (m)	Desirable Minimum Sight Distance (m)
20	20	40	-	-
25	25	50	-	-
30	30	60	-	-
35	40	80	-	-
40	45	90	45	90
50	60	120	60	120
60	-	-	90	180

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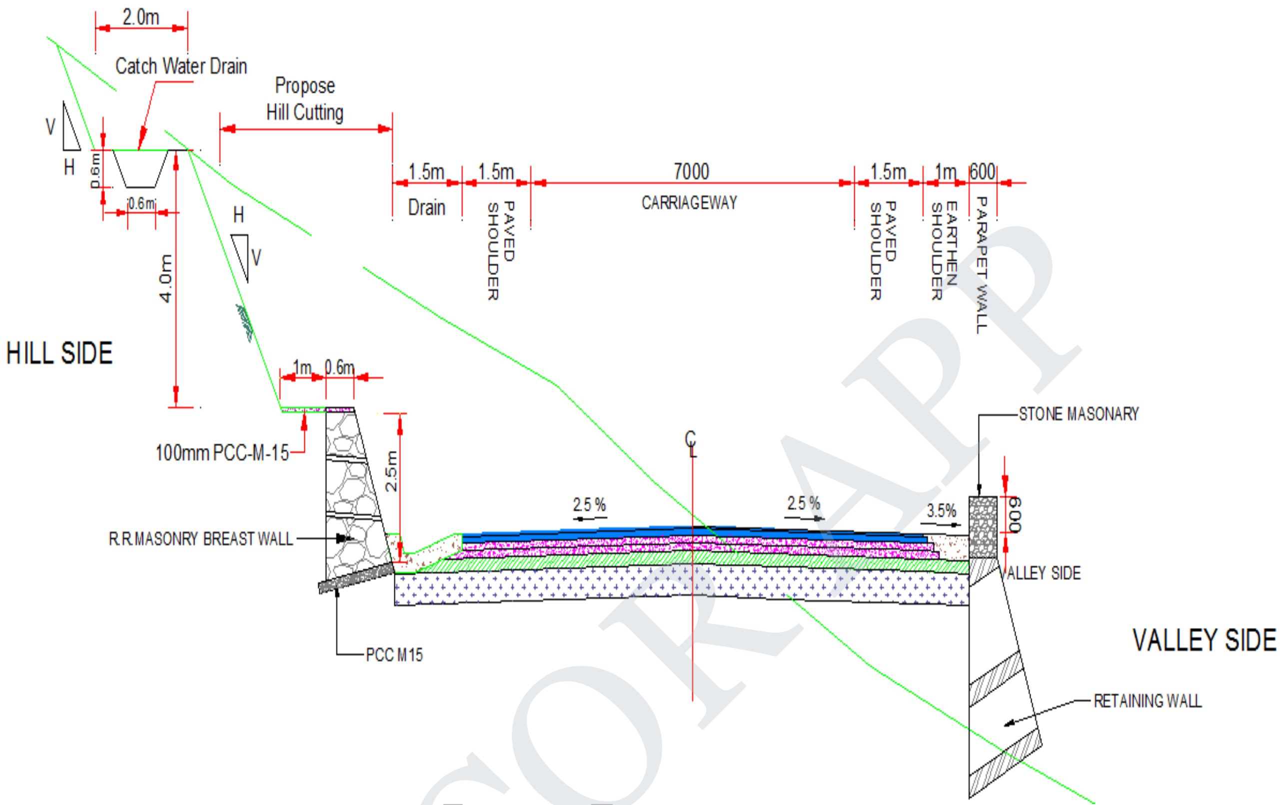
TYPICAL CROSS-SECTIONS – 2 LANE CARRIAGEWAY
(As per IRC:SP:73-2015)



As per IRC:SP:48-1998 and IRC:52- 2001

Road Classification	Carriageway Width (m)	Shoulder Width (m)
National and State Highways		
i) Single lane	3.75	2 x 1.25
ii) Double Lane	7.00	2 x 0.9
Major District Roads and Other District Roads	3.75	2 x 0.5
Village Roads	3.00	2 x 0.5

REVERSE CURVES ARE NEEDED IN DIFFICULT TERRAIN.

It should be ensured that there is sufficient length between the two curves for introduction of requisite transition curves.

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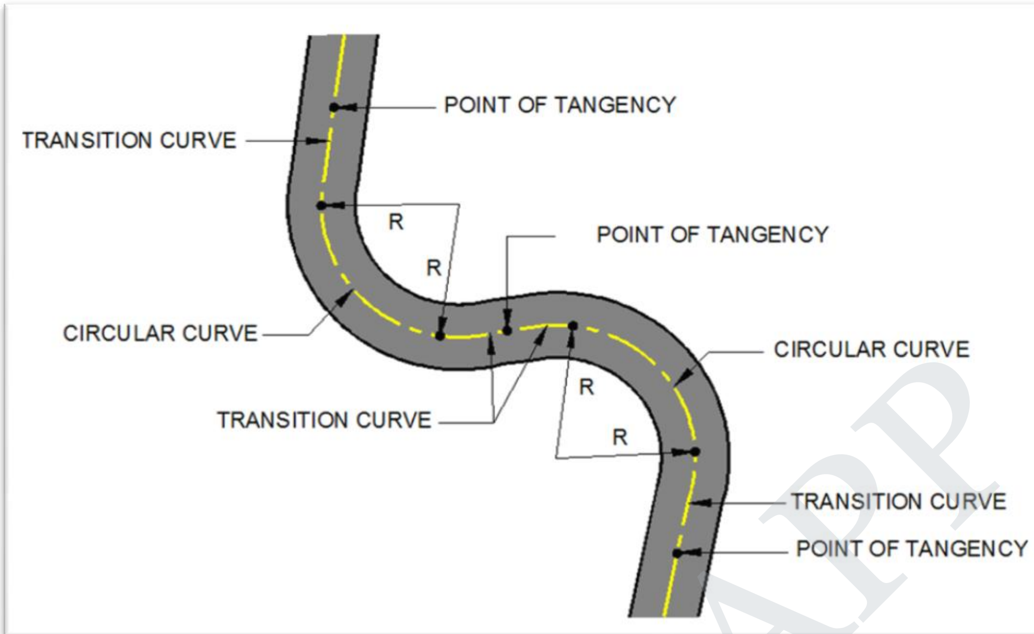
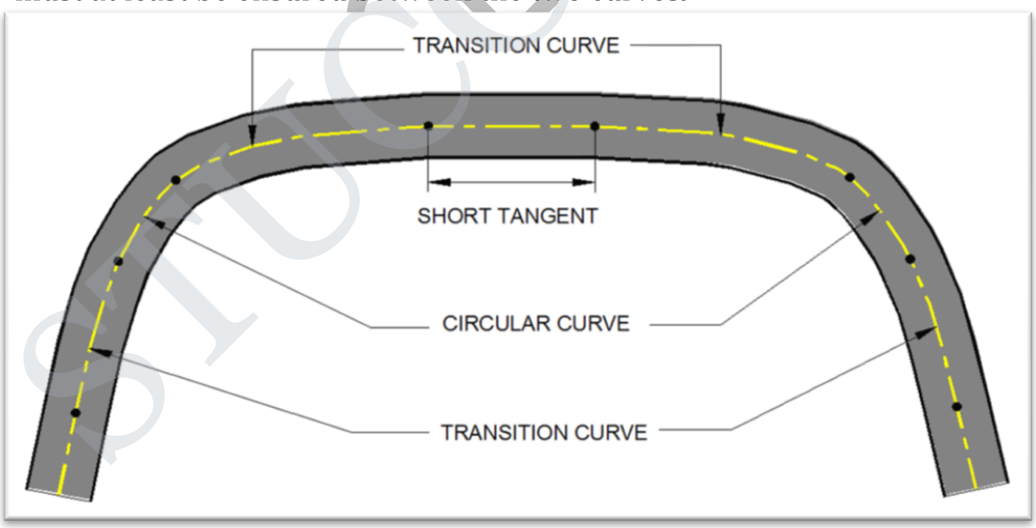


- Curves in same direction separated by short tangents, known as broken – back curves.
- Should be avoided, as far as possible, in the interest of aesthetics and safety and replaced by a single curve.
- If this is not feasible, a tangent length corresponding to 10 seconds travel time must at least be ensured between the two curves.



Vertical Alignment

- Vertical curves are introduced for smooth transition at grade change.
- Both Summit curves and Valley curves should be designed as Square parabola.
- The Length of vertical curves is controlled by sight distance requirements.
- Curves with greater length are aesthetically better.

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Recommended gradients for different terrain conditions, except at hair pin bends, are given below:

Classification of Gradient	As per IRC:SP:48-1998 and IRC:52- 2001		As per IRC:SP:73 & IRC:SP:84	
	Mountainous Terrain and Steep Terrain more than 3000 m above MSL	Steep Terrain up to 3000 m above MSL	Mountainous	Steep
Ruling Gradient	5%	6%	5%	6%
Limiting Gradient	6%	7%	6%	7%
Exceptional	7%	8%	-	-

At unavoidable circumstances Hair-pin Bends may be designed as Circular Curve with Transitions or as Compound Circular curves.

Design Criteria for Hair-pin Bends as per IRC: SP: 48-1998 and IRC: 52- 2001

Description		Criteria
Min Design Speed		20 Km/h
Min Roadway width at apex	NH/SH	11.5m (Double lane) 9.0m (Single lane)
	MDR/ODR	7.5m
	Village Roads	6.5m
Min radius for the inner curve		14 m
Min Length of transition Curve		15 m
Gradient	Maximum	1 in 40 (2.5%)
	Minimum	1 in 200 (0.5%)
Max Super elevation		1 in 10 (10%)
Minimum Intervening distance between the successive hair pin bends		60m

Illustrations of Hair-pin Bends

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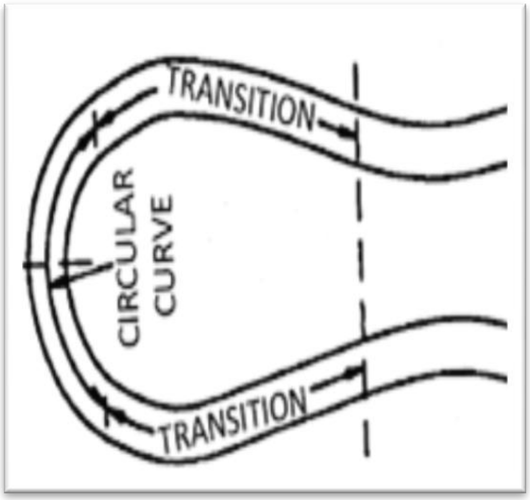

5. **Elaborate the factors affecting the geometric design of highways (April/May 2017), (Nov/Dec 2017)**

(Refer Part-B, Question no.4)

6. **Explain the sight distance and types (April/May 2018)**

Types of sight distance Sight distance available from a point is the actual distance along the road surface, over which a driver from a specified height above the carriage way has visibility of stationary or moving objects. Three sight distance situations are considered for design:

i. Stopping sight distance (SSD) or the absolute minimum sight distance
ii. Intermediate sight distance (ISD) is defined as twice SSD
iii. Overtaking sight distance (OSD) for safe overtaking operation
iv. Head light sight distance is the distance visible to a driver during night driving under the illumination of head lights
v. Safe sight distance to enter into an intersection.

The most important consideration in all these is that at all times the driver traveling at the design speed of the highway must have sufficient carriageway distance within his line of vision to allow him to stop his vehicle before colliding with a slowly moving or stationary object appearing suddenly in his own traffic lane. The computation of sight distance depends on:

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Reaction time of the driver

Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory. In practice, all these times are usually combined into a total perception-reaction time suitable for design purposes as well as for easy measurement. Many of the studies shows that drivers require about 1.5 to 2 secs under normal conditions. However, taking into consideration the variability of driver characteristics, a higher value is normally used in design. For example, IRC suggests a reaction time of 2.5 secs.

Speed of the vehicle

The speed of the vehicle very much affects the sight distance. Higher the speed, more time will be required to stop the vehicle. Hence it is evident that, as the speed increases, sight distance also increases.

Efficiency of brakes

The efficiency of the brakes depends upon the age of the vehicle, vehicle characteristics etc. If the brake efficiency is 100%, the vehicle will stop the moment the brakes are applied. But practically, it is not possible to achieve 100% brake efficiency. Therefore the sight distance required will be more when the efficiency of brakes are less. Also for safe geometric design, we assume that the vehicles have only 50% brake efficiency.

Frictional resistance between the tyre and the road

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

Gradient of the road.

Gradient of the road also affects the sight distance. While climbing up a gradient, the vehicle can stop immediately. Therefore sight distance required is less. While descending a gradient, gravity also comes into action and more time will be required to stop the vehicle. Sight distance required will be more in this case.

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Stopping sight distance

Stopping sight distance (SSD) is the minimum sight distance available on a highway at any spot having sufficient length to enable the driver to stop a vehicle traveling at design speed, safely without collision with any other obstruction. There is a term called safe stopping distance and is one of the important measures in traffic engineering. It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance atleast equal to the safe stopping distance should be provided.

The stopping sight distance is the sum of lag distance and the braking distance. Lag distance is the distance the vehicle traveled during the reaction time t and is given by vt, where v is the velocity in m/sec^2 .

Braking distance is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle.

If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is Fl = fWl where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\frac{1}{2}mv^2 = \frac{1}{2}\frac{Wv^2}{g}$$

$$fWl = \frac{Wv^2}{2g}$$

$$l = \frac{v^2}{2gf}$$

Therefore, the SSD = lag distance + braking distance and given by:

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

Similarly the braking distance can be derived for a descending gradient. Therefore the general equation is given by Equation

$$SSD = vt + \frac{v^2}{2g(f \pm 0.01n)}$$

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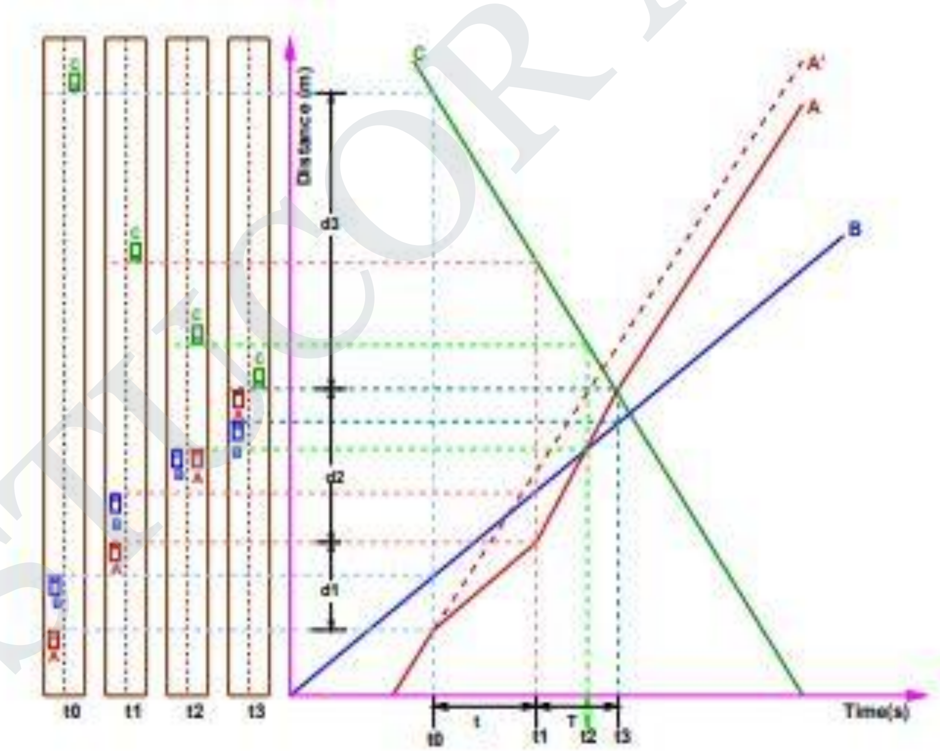
Overtaking sight distance

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
- Gradient of the road



Time-space diagram: Illustration of overtaking sight distance

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The dynamics of the overtaking operation is given in the figure which is a time-space diagram. The x-axis denotes the time and y-axis shows the distance traveled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B.

The trajectory of the vehicle is shown initially with a steeper slope. The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the figure with same slope from t_0 to t_1. Then it overtakes the vehicle B and occupies the left lane at time t_3. The time duration $T = t_3 - t_1$ is the actual duration of the overtaking operation. The snapshots of the road at time t_0, t_1, and t_3 are shown on the left side of the figure.

From the the overtaking sight distance consists of three parts.

d_1 the distance traveled by overtaking vehicle A during the reaction time $t = t_1 - t_0$

d_2 the distance traveled by the vehicle during the actual overtaking operation $T = t_3 - t_1$

d_3 is the distance traveled by on-coming vehicle C during the overtaking operation (T).

Therefore:

$$OSD = d_1 + d_2 + d_3$$

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

$$d_1 = v_b t$$

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

$$s = 0.7v_b + 6$$

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

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

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The distance traveled by the vehicle C moving at design speed v m/sec during overtaking operation is given by: d3 = vT

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

where vb is the velocity of the slow moving vehicle in m/se^{c2} , t the reaction time of the driver in sec, s is the spacing between the two vehicle in m given by equation 13.5 and a is the overtaking vehicles acceleration in m/sec^2 . In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the design speed. On divided highways, d_3 need not be considered

On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD, but only SSD is sufficient.

7. The speed of overtaking and overtaken vehicles is 80 and 50 kmph respectively. On a two way traffic load, the acceleration of overtaking vehicles is 0.99 m/sec^2 . Calculate OSD, mention the minimum length of overtaking zone and draw sketch of the overtaking zone with all details. (April/May 2017)

Solution

Given data:

Speed of overtaking vehicle, V = 70 kmph, therefore v = 70/3.6 = 19.4 m/sec

Speed of overtaken vehicle, V_b = 40 kmph, therefore v_b = 40/3.6 = 11.1 m/sec

Average acceleration during overtaking, a = 0.99 m/sec^2

(a) Overtaking sight distance for two way traffic, vide Eq 4.7, OSD

$= (d_1 + d_2 + d_3) = (v_b\,t + v_b\,T + 2s + vT)$ m

Reaction time for overtaking, t = 2 sec

$d_1 = v_b\,t = 11.1 \times 2 = 22.2$ m

$d_2 = v_b\,T + 2\,s$

$s = (0.7\,v_b + 6) = (0.7 \times 11.1 + 6) = 13.8$ m

$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47$ sec

$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5$ m

$d_3 = v\,T = 19.4 \times 7.47 = 144.9$ m

OSD $= d_1 + d_2 + d_3 = 22.2 + 110.5 + 144.9 = 277.6$ m,

say 278 m

(b) Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390

(c) The details of the overtaking zone are shown in Fig. 4.16

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8. (i) List and draw the various vertical curves adopted in highways.
(ii) Explain the controls and guidelines for safe, comfortable travel in highway vertical curves.
(iii) List the various technical guidelines recommended for safety and comfort in case of horizontal curves in highways.

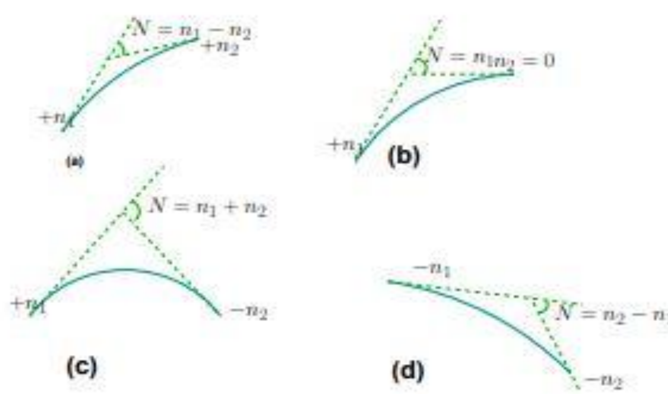
(i) SUMMIT CURVE

Summit curves are vertical curves with gradient upwards.

They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

1. When a positive gradient meets another positive gradient [figure 1a]
2. When positive gradient meets a flat gradient [figure 1b].
3. When an ascending gradient meets a descending gradient [figure 1c]
4. When a descending gradient meets another descending gradient [figure 1d]

Type of Summit Curve Many curve forms can be used with satisfactory results, the common practice has been to use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another. Although a circular curve offers equal sight distance at every point on the curve, for very small deviation angles a circular curve and parabolic curves are almost congruent. Furthermore, the use of parabolic curves were found to give excellent riding comfort.



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(ii) Design Consideration

In determining the type and length of the vertical curve, the design considerations are comfort and security of the driver, and the appearance of the profile alignment. Among these, sight distance requirements for the safety are most important on summit curves.

The stopping sight distance or absolute minimum sight distance should be provided on these curves and where overtaking is not prohibited, overtaking sight distance or intermediate sight distance should be provided as far as possible.

When a fast moving vehicle travels along a summit curve, there is less discomfort to the passengers. This is because the centrifugal force will be acting upwards while the vehicle negotiates a summit curve which is against the gravity and hence a part of the tyre pressure is relieved.

Also if the curve is provided with adequate sight distance, the length would be sufficient to ease the shock due to change in gradient. Circular summit curves are identical since the radius remains same throughout and hence the sight distance.

From this point of view, transition curves are not desirable since it has varying radius and so the sight distance will also vary. The deviation angles provided on summit curves for highways are very large, and so the simple parabola is almost congruent to a circular arc, between the same tangent points.

Parabolic curves are easy for computation and also it had been found out that it provides good riding comfort to the drivers. It is also easy for field implementation. Due to all these reasons, a simple parabolic curve is preferred as summit curve.

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9. **(i) Calculate the super-elevation to be provided for a horizontal curve with a radius of 400 m for a design speed 100 kmph in plain terrain. If super-elevation is restricted to 0.07, calculate the coefficient of lateral friction mobilized.**

   (ii) Calculate the safe stopping distance while travelling at a speed of 100 kmph on a level road.

   (iii) Draw the various components of overtaking sight distance on a straight stretch of a highway and explain each one. (Nov/Dec 2015)

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Solution

Given data:

Speed of overtaking vehicle, V = 70 kmph, therefore v = 70/3.6 = 19.4 m/sec

Speed of overtaken vehicle, V_b = 40 kmph, therefore v_b = 40/3.6 = 11.1 m/sec

Average acceleration during overtaking, a = 0.99 m/sec^2

(a) Overtaking sight distance for two way traffic, vide Eq 4.7, OSD = $(d_1 + d_2 + d_3) = (v_b\,t + v_b\,T + 2s + vT)$ m

Reaction time for overtaking, t = 2 sec

$$d_1 = v_b\,t = 11.1 \times 2 = 22.2 \text{ m}$$

$$d_2 = v_b\,T + 2\,s$$

$$s = (0.7\,v_b + 6) = (0.7 \times 11.1 + 6) = 13.8 \text{ m}$$

$$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 13.8}{0.99}} = 7.47 \text{ sec}$$

$$d_2 = 11.1 \times 7.47 + 2 \times 13.8 = 110.5 \text{ m}$$

$$d_3 = v\,T = 19.4 \times 7.47 = 144.9 \text{ m}$$

$$OSD = d_1 + d_2 + d_3 = 22.2 + 110.5 + 144.9 = 277.6 \text{ m, say } 278 \text{ m}$$

(b) Minimum length of overtaking zone = 3 (OSD) = 3 × 278 = 834 m

Desirable length of overtaking zone = 5 × (OSD) = 5 × 278 = 1390

(c) The details of the overtaking zone are shown in Fig. 4.16

10. Find the rate of super elevation on a horizontal curve having a radius curvature of 90m. The design speed is 50Kmph and assume f= 0.15. (Nov/Dec 2017)

Solution:

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

$$e + 0.15 = \frac{(50)^2}{127(90)}$$

$$e = \frac{2500}{(11430 - 0.15)}$$

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$$e = \frac{2500}{(11429)}$$

$$\boldsymbol{e = 0.218}$$

11. Explain shortly various special considerations to be given in design and construction of Hilly roads in highway design. (Nov/Dec 2018)

(Refer Question no.4 in Part B)

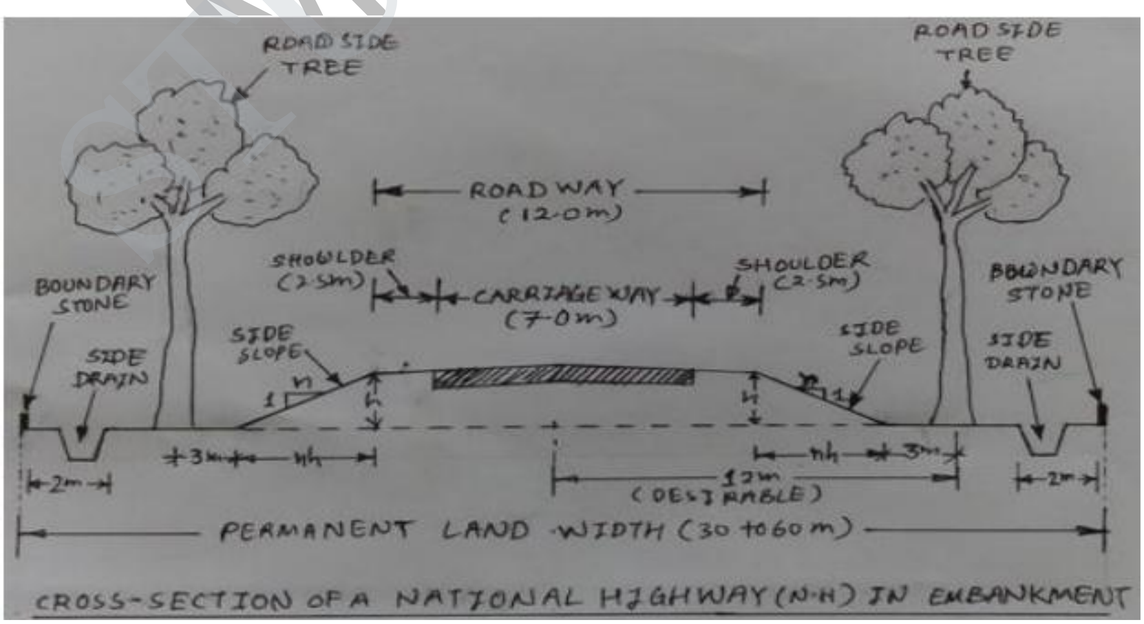
12. Explain in brief the various classifications rural roads with its salient components as per IRC Standards with neat sketches.(Nov/Dec 2018)

The Indian Highways as classified in types of roads are as follows.

(i) National Highways (NH)
(ii) State Highways (SH)
(iii) Major District Roads (MDR)
(iv) Other District Highways (ODR)
(v) Village Roads (VR)

(i) National highways

National highways are the main highways running through the length and breath of India, connecting major parts, highways, capital of large states and industrial and tourist centers 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.



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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.

(ii) 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.

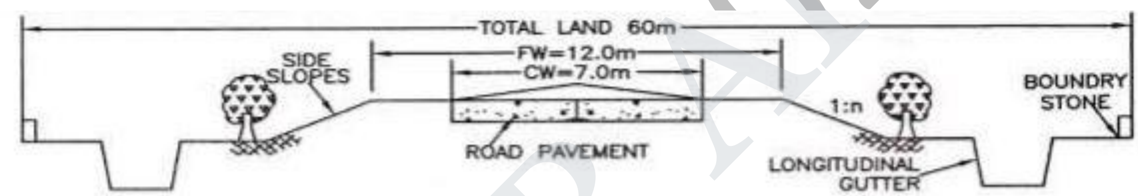


FIG. 3.4 CROSS-SECTION OF NH OR SH IN RURAL AREA IN EMBANKMENT

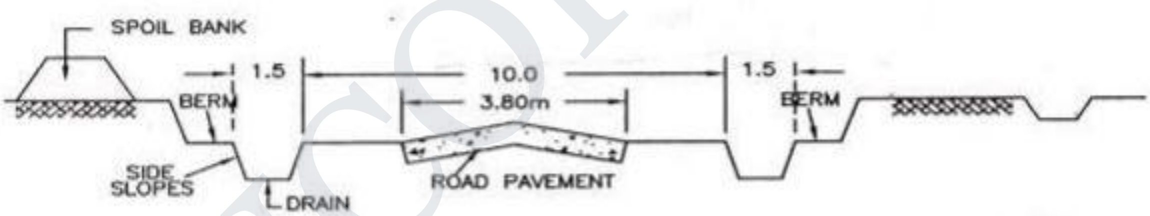


FIG. 3.5 CROSS-SECTION OF MDR IN CUTTING IN RURAL AREA

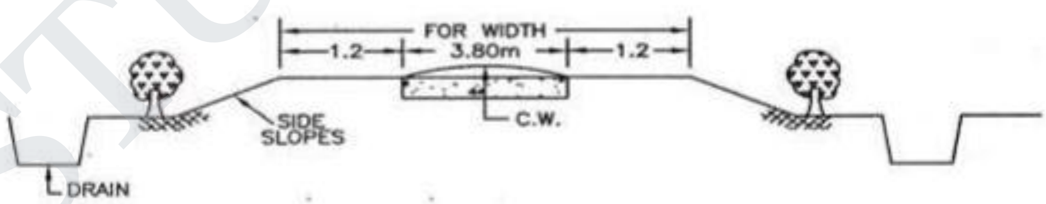
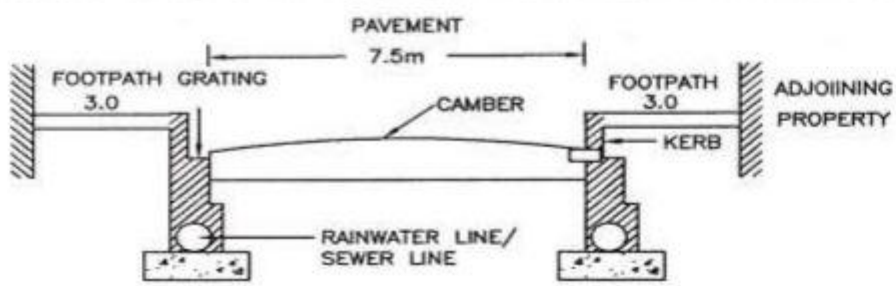


FIG. 3.6 CROSS-SECTION OF VR OR ODR IN EMBANKMENT IN RURAL AREA



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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.

(iii) 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.

(iv) 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.

(v) 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.

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The Each type of roads from Expressway , National Highways (NH), State Highways (SH), Major District Roads (MDR), Other District Highways (ODR), Village Roads (VR , briefly presented its specifications in below the table.

Specifications	Expressway	National Highways	State Highways	Major District Roads	Other District Roads	Village Roads
Right of way	90-100m	45m	45m	25m	15m	12m
Carriage way	11.25m	12m	12m	9m	7.5m	7.5m
Speed	120 km/hr	100 km/hr	80 km/hr	60 km/hr	50 km/hr	40 km/hr
Horizontal curve	700-2600m	360m	360m	230m	155m	90m
Vertical curve (Minimum)	0.5 %	0.6 %	0.8 %	1.0 %	1.2 %	1.5 %
Camber	2.5%	2.5 %	2.5 %	2.5 %	2.5 %	2.5 %
Median	12-15m	4m	2m	1m	0.5m	Nil
Shoulder	2.5-3.0 m	2.5m	1m	0.5m	0.5m	Unpaved
Super elevation	7%	7%	7%	7%	7%	7%

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13. A road has a total width of 7.5 m including extra widening on curve and design speed of 65kmph. Calculate the length of transition curve and its shift on this curve of 200m radius. Allowable super elevation is 1 in 150 and pavement is rotated about centre line. (Nov/Dec 2019), (Nov/Dec 2016)

Solution:

Design speed = 65kmph
Radius of curve = 200 m
Total pavement width = 7.5 m (Including Extra Widening)
Rate of Super elevation = 1 in 150

A) Length of transition curve, (Ls)

Length based allowable rate of centrifugal acceleration, C

$$C = \frac{80}{75+V}$$

$$C = \frac{80}{75+65} = 0.57 \ \ m/sec^3$$

As the value of C is between 0.5 and 0.8, C= 0.57 is accepted

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

$$Ls = \frac{0.0215(65^3)}{0.57x200} = \frac{5904.437}{114} = \mathbf{51.79\ m}$$

Length by allowable rate of introduction of super elevation, E

Super elevation rate $\boldsymbol{e} = \frac{\mathbf{V^2}}{\mathbf{225R}} = \frac{\mathbf{65^2}}{\mathbf{225x200}}$

$$\mathbf{e} = \frac{\mathbf{65^2}}{\mathbf{225x200}} = 0.080$$

As this value is greater than the maximum allowable rate of 0.07, limit the value of e=0.07. Check the safety against traverse skidding by finding the friction co efficient developed, fd for the design speed of 65 kmph.

$$fd = \frac{V^2}{225R} - e$$

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$$fd = \frac{65^2}{225x200} - 0.07$$

$$fd = 0.0938 - 0.07 = 0.023$$

Total width of the pavement at the curve, B=7.5 m

Total raise of outer edge of pavement with respect to the centre line

$$= \frac{E}{2} = \frac{eB}{2} = \frac{0.07x7.5}{2} = 0.26\, m$$

Rate of super elevation, 1 in N=1 in 150

$$Ls = \frac{EN}{2} = 0.26\, x\, 150 = 39\, m$$

Length as per IRC empirical formula

$$= \frac{\mathbf{2.7\,V^2}}{\mathbf{R}} = \frac{\mathbf{2.7\,x\,65^2}}{\mathbf{200}} = \frac{11407.5}{200} = 57.03 \text{ m}$$

Adopt the highest value 57 m as the design length of transition curve

B) <u>Shift of transition curve, (Ls)</u>

$$\boldsymbol{S = \frac{Ls^2}{24R} = \frac{57^2}{24\,x\,200} = \frac{3249}{4800} = 0.67\text{m}}$$

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UNIT-III

DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

1. **What is the Equivalent Wheel load? (NOV/DEC 2019), (April/May 2015)**

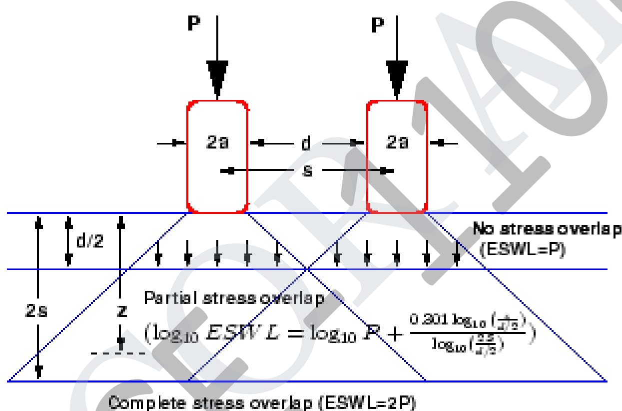
To carry maximum load within the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth.

This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

• Equalancy concept is based on equal stress;

• Contact area is circular;

• Influence angle is 45˚; and Soil medium is elastic, homogeneous, and isotropic half space.



The ESWL is given by:

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

where P is the wheel load, S is the center to center distance between the two wheels, d is the clear distance between two wheels, and z is the desired depth.

2. **What are the requirements of an Ideal Pavement? (Nov/Dec2019), (Nov/Dec2016)**

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the subgrade 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.

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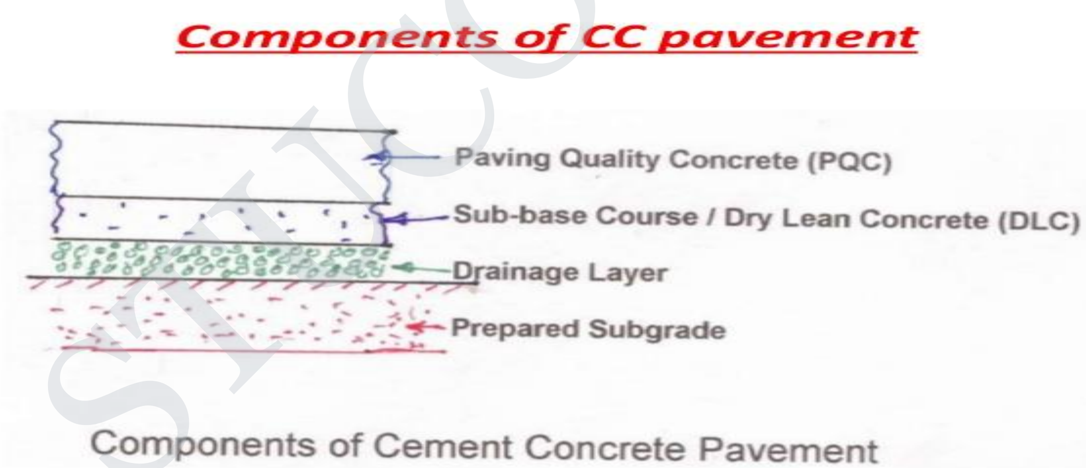
3. Difference between rigid and flexible pavement in pavement design (April/May 2019), (Nov/Dec2018)

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 place	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

4. Draw the typical rigid pavement with its vital components (April/May 2019), (Nov/Dec2018)



5. Define modulus of sub-grade reaction (April/May 2018)

- Modulus of sub-grade reaction is the reaction pressure sustained by the soil sample under a rigid plate of standard diameter per unit settlement measured at a specified pressure or settlement.
- IRC specifies that the K value be measured at 1.25 mm settlement.
- To calculate the Modulus of Subgrade Reaction, Plate Bearing Test is conducted.
- In this a compressive stress is applied to the soil pavement layer through rigid plates of relatively large size and the deflections are measured for various stress values.
- The exact load deflection behavior of the soil or the pavement layer in-situ for static obtained by the plate bearing test.

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6. What are dowel bars? (April/May 2018)

The dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height. The dowel bars are provided in the direction of the traffic (longitudinal). The design considerations are:

- Mild steel rounded bars,
- Bonded on one side and free on other side

7. Differentiate between Tack coat Prime coat and Seal coat (April/May 2017)

Tack coat	Prime coat	Seal coat
Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water.	Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed.	Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.
It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.	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.	

8. What are the types of Rigid Pavements? (April/May 2017)

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)

9. Define: Rigidity Factor (Nov/Dec2017)

The ratio of contact pressure to tyre pressure is defined as Rigidity factor. Thus value of rigidity factor is 1.0 for an average tyre pressure of $7kg/cm^2$. Rigidity factor is higher than unity for lower tyre pressures and less than unity for tyre pressures higher than $7kg/cm^2$

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10. What are the various factors considered for the design of pavements? (Nov/Dec2017), (May/June 2016)

i) Wheel load.

ii) Axle configuration.

iii) Contact pressure.

iv) Vehicle speed.

v) Repetition of loads.

vi) Subgrade type.

vii) Temperature.

viii) Precipitation.

11. What is the radius of resisting section? (Nov/Dec2016)

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. 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

12. Define Critical Load Positions. (May/June 2016)

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

13. What are the effects of Temperature on Rigid Pavements? (Nov/Dec2015)

- Expansion and
- Contraction

14. Explain rigid pavement? (April/May 2015)

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area 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. 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.

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PART-B

1. Design the pavement for construction of a new bypass with the following data: (Nov/Dec 2019), (April/May 2017), (May/June 2016)

1. Two lane carriage way
2. Initial traffic in the year of completion of construction = 400 CVPD (sum of both directions)
3. Traffic growth rate = 7.5 %
4. Design life = 15 years
5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial vehicle
6. Design CBR of sub-grade soil = 4%.

Solution

1. Two lane carriage way
2. Initial traffic in the year of completion of construction = 400 CVPD (sum of both directions)
3. Traffic growth rate = 7.5 %
4. Design life = 15 years
5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial vehicle
6. Design CBR of subgrade soil = 4%.

Solution

1. Distribution factor = 0.75
2.

$$
\begin{aligned}
N &= \frac{365 \times \left[(1+0.075)^{15}-1)\right]}{0.075} \times 400 \times 0.75 \times 2.5 \\
&= 7200000 \\
&= 7.2\ msa
\end{aligned}
$$

3. Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
   (a) Bituminous surfacing = 25 mm SDBC + 70 mm DBM
   (b) Road-base = 250 mm WBM
   (c) sub-base = 315 mm granular material of CBR not less than 30 %

2. Design the pavement for construction of a new two lane carriage way for Design life 15 years using IRC method. The Initial traffic in the year of completion of construction 150 CVPD (sum of both directions), Traffic growth rate = 5 % Vehicle damage factor based on

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axle load survey = 2.5 standard axle per commercial vehicle. Design CBR of sub-grade soil = 4%. (April/May 2019),

Solution

1. Distribution factor = 0.75
2. $$\begin{aligned} N &= \frac{365 \times \left[(1+0.05)^{15} - 1)\right]}{0.05} \times 300 \times 0.75 \times 2.5 \\ &= 4430348.837 \\ &= 4.4\ msa \end{aligned}$$
3. Total pavement thickness for CBR 4% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
   (a) Bituminous surfacing = 20 mm PC + 50 mm BM
   (b) Road-base = 250 mm Granular base
   (c) sub-base = 280 mm granular material.

3. Explain the California Bearing Ratio (CBR) Method (April/May 2018)

California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.porter.

One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including subgrade, subbase and base course.

Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.

A higher load needs a thicker pavement layer to protect the sub-grade. Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.

It is possible to extend the CBR design curves for various loading conditions, using the expression:

$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]$$

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$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{\frac{1}{2}}$$

$$t = \left[\frac{1.75p}{CBR} - \frac{A}{\pi}\right]^{\frac{1}{2}}$$

Hence,

t= pavement thickness, cm

p=Wheel load, kg

CBR= California bearing ratio, percent

P=tyre pressure, kg/cm^2

A= area of contact.cm^2

IRC Recommendations:

a) The CBR tests should be performed on remoulded soils in the laboratory. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction.

b) For the design of new roads, the sub grade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment.

c) The CBR test samples may be soaked in water for four days period before testing .the annual rainfall is less than 50 cm and the water table is too deep to affect the sub grade and imperable surfacing is provided to carrying out CBR test.

d) If the maximum variations in CBR value of the three specimens exceed the specified limits, the design CBR should be average of at least six samples.

e) The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.

f) An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.

g) The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G.The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500 kg.

h) When subbase course materials contain substantial proportion of aggregates of size above 20mm, the CBR value of these materials would not be valid for the design of

ove t hem.

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The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

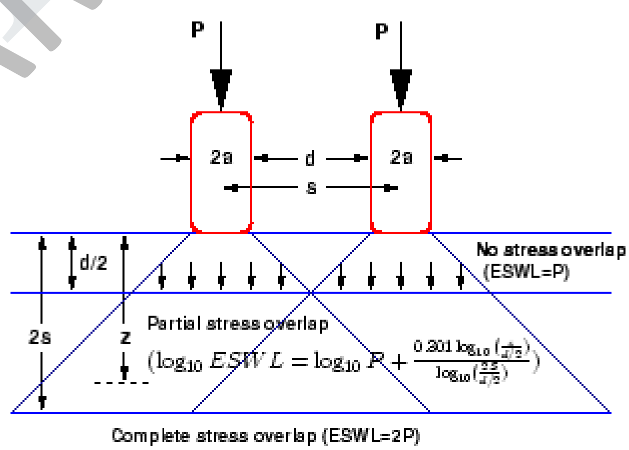
4. Compare the flexible and Rigid pavements (April/May 2018)

Difference between Flexible Pavements and Rigid Pavements:

	Flexible Pavement	Rigid Pavement
1.	It consists of a series of layers with the highest quality materials at or near the surface of pavement.	It consists of one layer Portland cement concrete slab or relatively high flexural strength.
2.	It reflects the deformations of subgrade and subsequent layers on the surface.	It is able to bridge over localized failures and area of inadequate support.
3.	Its stability depends upon the aggregate interlock, particle friction and cohesion.	Its structural strength is provided by the pavement slab itself by its beam action.
4.	Pavement design is greatly influenced by the subgrade strength.	Flexural strength of concrete is a major factor for design.
5.	It functions by a way of load distribution through the component layers	It distributes load over a wide area of subgrade because of its rigidity and high modulus of elasticity.
6.	Temperature variations due to change in atmospheric conditions do not produce stresses in flexible pavements.	Temperature changes induce heavy stresses in rigid pavements.
7.	Flexible pavements have self healing properties due to heavier wheel loads are recoverable due to some extent.	Any excessive deformations occurring due to heavier wheel loads are not recoverable, i.e. settlements are permanent

5. Describe about Equivalent single wheel load (April/May 2018)

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 are in between a single wheel load and double the load carried by any one wheel. Stress overlap is presented in fig below



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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.

A 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.

6. **Calculate the stresses at interior, edge and corner regions of a cement concrete pavement using Westergaards stress equations. Use the following data.(Nov/Dec 2017)**

Wheel load, P = 5200 Kg

Modulus of elasticity of cement concrete, E = 3.0 x 10^5 kg/cm^2

Pavement thickness, h = 18 cm

Poisson's ratio of concrete, μ = 0.15

Modulus of subgrade reaction, K = 6.0 kg/cm^3

Radius of contact area, a = 15cm

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Solution:

Radius of relative stiffness (l) is given by

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}} = \left[\frac{3.0x10^5 x18^3}{12x6(1-0.15^2)}\right]^{\frac{1}{4}} = 70.6cm$$

The equivalent of resisting section is given by:

a/h = 15/8=0.833 <1.74

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

$$= \sqrt{1.6x15^2 + 18^2} - 0.675x18 = 14.0cm$$

Stress at the interior,(S_i)

$$S_i = \frac{0.316P}{h^2}\left[4\log 10^{\frac{l}{b}} + 1.069\right]$$

$$= \frac{0.316x5100}{18^2}\left[4\log 10\left(\frac{70.6}{14.0}\right) + 1.069\right] = 19.3kg/cm^2$$

Stress at the edge,(S_e)

$$S_e = \frac{0.572p}{h^2}\left[4\log 10^{\frac{l}{b}} + 0.359\right]$$

$$= \frac{0.572x5100}{18^2}\left[4x0.7027 + 0.359\right] = 28.54kg/cm^2$$

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Stress at the corner (S_c)

$$S_c = \frac{3p}{h^2}\left[2-\left(a\frac{\sqrt{2}}{l}\right)^{0.6}\right]$$

$$= \frac{3x5100}{18^2}\left[1-\left(\frac{15\sqrt{2}}{70.6}\right)^{0.6}\right] = 24.27kg/cm^2$$

7. **Explain any two methods of flexible pavement design (Nov/Dec 2017)**

The flexible pavement is built with number of layers. In the design process it is to be ensured that under the application of load none of the layers is overstressed.

The maximum intensity of stresses occurs in the top layer of the pavement .The magnitude of load stresses reduces at lower layers.

In the design of flexible pavements, it has yet not been possible to have a rational design method wherein design process and service behavior of the pavement can be expressed by mathematical laws.

Flexible pavement design methods are accordingly either empirical or semi empirical. In these methods, the knowledge and experience gained on the behavior of the pavements in the past are usefully utilized.

Various approaches of flexible pavement design may be thus classified into three groups:

i) Empirical method
ii) Semi-empirical or Semi theoretical method
iii) Theoretical method

Empirical methods are either based on physical properties or strength parameters of soil sub grade. When the design is based on stress strain function and modified base on experience it may be called semi-empirical or semi-theoretical. There are design methods based on theoretical analysis and mathematical computations.

Out of the flexible pavement design method available is

i) Group index method
ii) California bearing ratio method
iii) California R value (or) Stabiliometer method
iv) Triaxial test method
v) McLeod method
vi) Burmister method

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Group index method:

Group index value is an arbitrary index assigned to the soil type in numerical equations base on the percent fines liquid limit and plasticity index.

The design chart for group index method for determining the pavement thickness. The traffic volume in this method is divided in three groups.

Traffic volume	No of vehicles per day
Light	Less than 50
Medium	50 to 300
Heavy	Over 300

The design of the pavement thickness by this method, first the G1 value of the soil is found the anticipated traffic is estimated and is designated as light, medium or heavy as indicated

The G1 method of pavement design is essentially an empirical method based on physical properties of the subgrade soil. This method does not consider the strength characteristics of the subgrade soil and therefore is open to question regarding the reliability of the design based on the index properties of the soil only.

California Bearing Ratio (CBR) Method:

California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.porter.

One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including subgrade, subbase and base course.

Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.

A higher load needs a thicker pavement layer to protect the subgrade.Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.

It is possible to extend the CBR design curves for various loading conditions,using the expression:

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$$t=\sqrt{p}\left[\frac{1.75}{CBR}-\frac{1}{p\pi}\right]^{\frac{1}{2}}$$

$$t=\left[\frac{1.75p}{CBR}-\frac{A}{\pi}\right]^{\frac{1}{2}}$$

Hence,

t= pavement thickness, cm

p=Wheel load, kg

CBR= California bearing ratio, percent

P=tyre pressure, kg/cm^2

A= area of contact.cm^2

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IRC Recommendations:

a) The CBR tests should be performed on remoulded soils in the laboratory. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction.

b) For the design of new roads, the sub grade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment.

c) The CBR test samples may be soaked in water for four days period before testing .the annual rainfall is less than 50 cm and the water table is too deep to affect the sub grade and imperable surfacing is provided to carrying out CBR test.

d) If the maximum variations in CBR value of the three specimens exceed the specified limits, the design CBR should be average of at least six samples.

e) The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.

f) An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.

g) The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G.The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500 kg.

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h) When subbase course materials contain substantial proportion of aggregates of size above 20mm, the CBR value of these materials would not be valid for the design of subsequent layers above them.

The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

California Resistance Value Method:

In this design method based on stabliometer R-value and cohesiometer C-value .Based on performance data it was established by pavement thickness varies directly with R value and algorithm of load repetitions. It varies inversely with fifth root of c value.The expression for pavement thickness is given by the empirical equation:

$$T = \frac{K(T_1)(90 - R)}{C^{\frac{1}{5}}}$$

Hence,

T=total thickness of pavement, cm

K=Numerical constant 0.166

T_1=traffic index

R= stabiliometer resistance value

C=Cohesiometer value

In the design of flexible pavements based on California resistance value method for the following data are needed:

R-value of soil subgrade

T_1 value

Equivalent C-value

R value of soil subgrade is obtained from the test using stabliometer.The computation of T_1 value has been explained.

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Equivalent C-value:

The cohesiometer value c is obtained for each layer of pavement material separately from tests. However the composite or equivalent C-value of the pavement may be estimated if the thickness of each component layer and the c-value of the material of the layer are known. while designing a pavement as the thickness of the pavement is not known, it is easier if the pavement is first assumed to consist of any one material like gravel base course with known C-value. Subsequently the individual thickness of each layer is converted in terms of gravel equivalent by using relationship:

$$\frac{t1}{t2} = \left(\frac{C_2}{C_1}\right)^{\frac{1}{5}}$$

t1 and t2 are the thickness values of any two pavement layers.c1 and c2 are their corresponding cohesiometer values.

8. **Calculate the stresses at interior, edge and corner regions of a rigid pavement using Westergaard's method. (April/May 2018)**

   Wheel load P=4100Kg;

   E=3X10⁵kg/cm²,

   h=slab thickness 20cm,

   μ=Poisson's ratio for concrete =0.15,

   k= Modulus of sub grade reaction 4.0kg/cm²

   a=Radius of wheel load distribution 15cm.

Solution:

Stresses in interior

$$S = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{\ell}{b}\right) + 1.069\right]$$

$$l = \left[\frac{Eh^3}{12K1-\mu_2}\right]^{\frac{1}{4}} = \left[\frac{3\times10^5\times20^3}{12\times4.01-0.15^2}\right]^{\frac{1}{4}} = 84.56\text{cm}$$

$$b = \sqrt{1.6a^2+h^2} - 0.675 = h\sqrt{1.6\times15^2+20^2} - 0.675x = 20\ 14.06\text{cm}$$

$$S = \frac{0.316\times4100}{20^2}\left[4\log_{10}\left(\frac{84.56}{14.06}\right) + 1.069\right] = 13.55\,\text{kg/cm}^2$$

Stress in edge

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$$S = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{\ell}{b}\right) + 0.359\right]$$

$$= \frac{0.572 \times 4100}{20^2}\left[4\log_{10}\left(\frac{84.56}{14.06}\right) + 0.359\right]$$

$$= 20.37\,\text{kg/cm}^2$$

Stress in corner

$$S = \frac{3P}{h^2}\left[L\left(\frac{a\sqrt{2}}{\ell}\right)\right]$$

$$= \frac{3 \times 4100}{20^2}\left[1 - \left(\frac{15\sqrt{2}}{84.56}\right)\right] = 23.03\,\text{kg/cm}^2$$

Result

Stress at interior=13.55kg/cm^2

Stress at edge=20.37kg/cm^2

Stress at corner=23.03kg/cm^2

9. Explain the design procedure for the design of rigid pavements.

(April/May17)(Nov/Dec 16)

(i) 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.

(ii) 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.

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Traffic Classification	Design traffic intensity, A_d (number of vehicles of ωt > 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

(iii) 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.

(iv) 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.

(v) 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 ^{o}C for design purpose.

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(vi) 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.

(vii)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.

(viii) Joint spacing

For all slab thicknesses with rough foundation the maximum spacings recommended for 25mm wide expansion joint ios 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/cm^2 and 14m spacing for 20cm thick slabs with steel reinforcement of 3.8kg/cm^2.

(ix) 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.

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(x) 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.

(xi) 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.

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10. Explain the functions of the components of flexible pavements.(Nov/Dec 2015)

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 subgrade.

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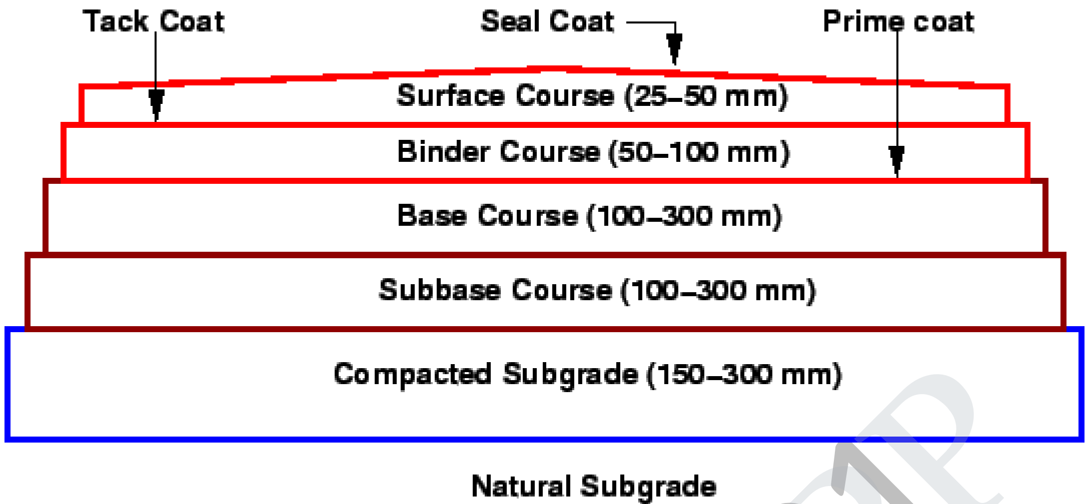

Seal Coat:

Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat:

Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat:

Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete(AC).

The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade

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- 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 of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by a sub-base course. In such situations, subbase 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.

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11. Explain the Design of Joints (May/June 2016)

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. The design considerations are:

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- Provided along the longitudinal direction, design involves finding the joint spacing for a given expansion joint thickness (say 2.5 cm specified by IRC) subjected to some maximum spacing (say 140 as per IRC)

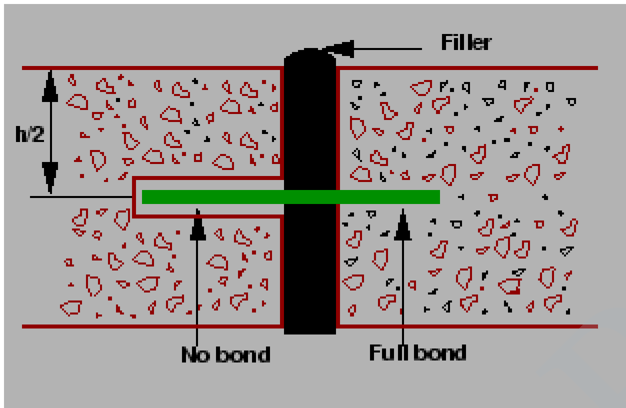

Figure: Expansion joint

Contraction joints

The purpose of the contraction joint is to allow the contraction of the slab due to fall in slab temperature below the construction temperature. The design considerations are:

- The movement is restricted by the sub-grade friction
- Design involves the length of the slab given by:

$$L_c = \frac{2 \times 10^4 S_c}{W.f}$$

- where, S_c is the allowable stress in tension in cement concrete and is taken as 0.8 kg/cm^2, **W** is the unit weight of the concrete which can be taken as 2400 kg/cm^3 and *f* is the coefficient of sub-grade friction which can be taken as 1.5.
- Steel reinforcements can be use, however with a maximum spacing of 4.5 m as per IRC.

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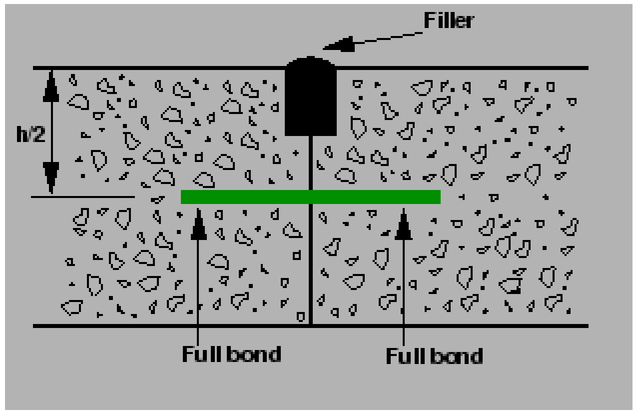

Figure: Contraction joint

12. Explain the following the following (i) Exceptional gradient (ii) Minimum gradient (iii) summit curve (iv) Valley curve (April/May 2015)

(i) Exceptional gradient

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

(ii) Minimum gradient

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

(iii) Summit curve

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. That is, a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road.

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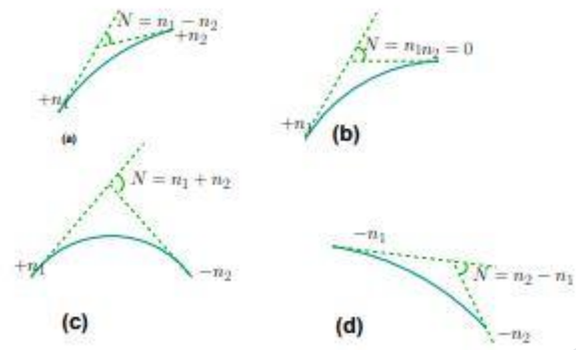

Equation of the parabola is given by $y = ax^2$, where $a = N/2L$, where N is the deviation angle and L is the length of the In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight distance.

(iv) **Valley curve**

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet as illustrated in figure 1 in any of the following four ways:

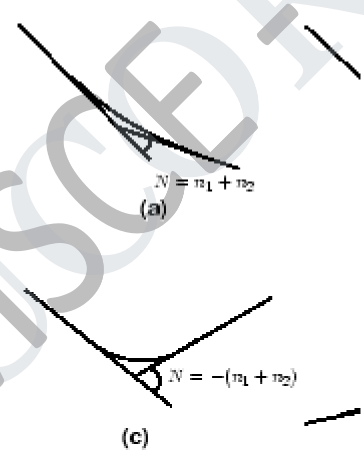

Figure 1: Types of valley curve

13. List the various factors influencing the design of Rigid Pavements and describe the design procedures as per IRC 58 (Nov/Dec 2015)

(Refer Part B- Question no.9)

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14. (i) A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design. (Nov/Dec 2015)

(ii) For the above data, determine the total pavement thickness based on the IRC method and the thickness of the different layers forming the total composition.

(iii) What is PMB? How it improves the quality of pavement?

(i) A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design.

1. Two lane carriage way

2. Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)

3. Traffic growth rate = 7.5 %

4. Design life = 15 years

5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial

(ii) Distribution factor = 0.75

(ii) For the above data, determine the total pavement thickness based on the IRC method and the thickness of the different layers forming the total composition.

Total pavement thickness

Total pavement thickness for CBR 6% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

(a) Bituminous surfacing = 20 mm PC + 50 mm BM

(b) Road-base = 250 mm Granular base

(c) sub-base = 280 mm granular material.

(iii) (What is PMB? How it improves the quality of pavement?

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.

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It must be noted that the performance of PMB and CRMB is dependent on strict control on temperature during construction. The advantages of using modified bitumen are as follows Lower susceptibility to daily and seasonal temperature variations

- Higher resistance to deformation at high pavement temperature Better age resistance
- Properties Higher fatigue life for mixes
- Better adhesion between aggregates and binder Prevention of cracking and reflective
- Cracking

15. What are the most important factor in the pavement design? (April/May 2017)

(i) Temperature

The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature affects the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed. While in flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition.

(ii) Precipitation

The precipitation from rain and snow affects the quantity of surface water in filtrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

(iii) Traffic and Loading

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design. Fixed traffic: Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design.

(iv) Fixed vehicle:

In the fixed vehicle procedure, the thickness is governed by the number of repetitions of a standard axle load. If the axle load is not a standard one, then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor.

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(v) Variable traffic and vehicle:

In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided into a number of groups and the stresses, strains, and deflections under each load group can be determined separately; and used for design purposes. The traffic and loading factors to be considered include axle loads, load repetitions, and tyre contact area.

(vi) Contact pressure:

The tyre pressure is an important factor, as it determine 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.

(vii) 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 pavemnet. 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.

(viii) Axle configuration:

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

16. Explain in sequence the steps followed in design of cement concrete pavement. (Nov/Dec 2019)

(Refer the question no.9 in Part B)

17. Explain the IRC design procedure for rigid pavement (April/May 2019)

(Refer the question no.9 in Part B)

18. Explain in details the various design practices normally adopted in rigid pavement design as per IRC Standards (Nov/Dec 2018)

(Refer the question no.9 in Part B)

19. Explain in brief various design principles to be adopted in flexible pavement design (Nov/Dec 2018)

(Refer the question no.7 in Part B)

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PART C

1. **A cement concrete pavement has a thickness of 18cm and has two lanes of 7.2 m with a longitudinal joint along the centre. Design the dimension and spacing of tie bar using the following details. (Nov/Dec 2017)**

Given data:

Allowable working stress in tension = 1400kg/cm²

Unit weight of concrete =2400 kg/m³

Coefficient of friction =1.5

Allowable bending stress in deformed bars in concrete =2.5 kg/cm²

Thickness =18 cm, Lanes =2, Width =7.2m

S_s=1400kg/cm², w= 2400 kg/m³

Co efficient of friction =1.5, S_b =2.5 kg/cm²

Solution :

Area of steel required per meter of longitudinal joint is given as

$$As = \frac{bfhw}{dx100Ss}$$

$$As = \frac{\left[\frac{7.2}{2}\right] x1.5x\ 18x2400}{100\ x\ 1400}$$

$$As = 1.66\text{cm}^2/m$$

Tie bars of 1cm diameter may be used.
Area of cross section of each bar **a_a =0.785 cm²**

$$\text{Spacing of tie bars} = \frac{100 \text{ x } 0.785}{1.66}$$

$$\text{Spacing of tie bars} = 47.28 \text{ cm}$$

$$\text{Length of the bar Lt} = \frac{ds}{2Sb}$$

$$\text{Spacing of tie bars} = \frac{1 \text{ x } 1400}{2 \text{ x } 2.5}$$

$$\text{Spacing of tie bars} = 280 \text{ cm}$$

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Length of tie bar of 280 cm at 45 to 50 cm c/c may be considered

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UNIT-IV

HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE

1. **Differentiate between "Geo textile and Geo-Membrane" in Highway construction (NOV/DEC 2019), (NOV/DEC 2018),**

Geo textile:
Geotextile; material that can pass water from wicker (woven) or non-woven (non-woven) from the threads or synthetic fibers used in ground work, the synthesis of thin sheets, flexible, permeable used for soil stabilization and improvement.

Geomembrane:
Geomembrane; material that serves as a waterproof, made of HDPE (Hight Density Polyethylene) or LDPE (Low Density polyethylen). Geomembrane is made of waterproof material, resistant to corrosion, oil, acid and high heat, which are the current trends in the world of civil engineering.

2. **Write short note on Highway Drainage. (NOV/DEC 2019)**
   - Surface drainage deals with arrangements for quickly and effectively leading away the water that collects on the surface of pavements, shoulders, and other adjoining areas.
   - Rain water from road surface is left off to the sides by cross slope or camber. Based on the rainfall of the area the rate of cross slope is provided

3. **How Geo textiles improve safety and stability of highway embankments? (April/May 2019), (Nov/Dec2015),**

These are flexible textile fabrics of controlled permeability used to provide filtration, separation or reinforcement in soil, rock and waste material. Load on the soil produces expansion. Thus, under load at the interface between the soil and reinforcement (assuming no slippage occurs, i.e. there is sufficient shear strength at the soil/fabric interface).

These two materials must experience the same extension, producing a tensile load in each of the reinforcing elements that in turn is redistributed in the soil as an internal confining stress. Thus the reinforcement acts to prevent lateral movement because of the lateral shear stress developed. Hence, there is an inbuilt additional lateral confining stress that prevents displacement. This method of reinforcing the soil can be extended to slopes and embankment stabilization

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4. **How adding up the waste plastics help in the improvement of bituminous pavements? (April/May 2019), (Nov/Dec2015),**

   Use of plastic waste in the construction of flexible pavement is gaining importance because of the several reasons. The polymer modified bitumen show better properties for road construction & plastics waste, otherwise considered to be a pollution menace, can find its use in this process and this can help solving the problem of pollution because most of the plastic waste is polymers.

5. **Define flakiness index. (Nov/Dec 2017),(April/May 2017), (May/June 2016)**
   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.

6. **Define Elongation index. (April/May 2018), (Nov/Dec 2016)**
   Elongation index (I E) The percentage by weight of particles whose long dimension is greater than 1.8 times the mean dimension measured with a standard gauge. The elongation, n, is length divided by breadth and the elongation ratio is 1/n.

7. **Differentiate between cut-back bitumen and bitumen emulsions (April/May 2018)**

   Cutback Bitumen

   Normal practice is to heat bitumen to reduce its viscosity. In some situations preference is given to use liquid binders such as cutback bitumen. In cutback bitumen suitable solvent is used to lower the viscosity of the bitumen. From the environmental point of view also cutback bitumen is preferred. The solvent from the bituminous material will evaporate and the bitumen will bind the aggregate. Cutback bitumen is used for cold weather bituminous road construction and maintenance. The distillates used for preparation of cutback bitumen are naphtha, kerosene, diesel oil, and furnace oil. There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC). RC is recommended for surface dressing and patchwork. MC is recommended for premix with less quantity of fine aggregates. SC is used for premix with appreciable quantity of fine aggregates.

   Bitumen Emulsion :

   Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. 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

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construction. Where heating of bitumen or aggregates are difficult. Rapid setting emulsions are used for surface dressing work. Medium setting emulsions are preferred for premix jobs and patch repairs work. Slow setting emulsions are preferred in rainy season.

8. List out the major construction machineries normally used at present in Highway Construction. (NOV/DEC 2018),

i. Dozer
ii. Grading
iii. Wheel Loader
iv. Hydraulic Excavator
v. Scrapper
vi. Batching plant
vii. Paver finisher
viii. Mixers
ix. Hot mix plant
x. Bitumen mixer
xi. Bitumen sprayer
xii. Bitumen storage equipment

9. What is the purpose of conducting abrasion test? (April/May 2017)

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works.

10. What are the desirable properties of soil highway materials?(Nov/Dec 2017)

a. Strength
b. Drainage
c. Ease of compaction
d. permanency of compaction

11. What is the significance of CBR test? (NOV/DEC 2016)

The california bearing ratio test is penetration test meant for the evaluation of sub-grade 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.

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12. What is the significance of static immersion test? (May/June 2016)

Bitumen and tar adhere well to all normal types of aggregates provided they are dry and are not exceptionally dusty. This problem of stripping is experienced only with bituminous mixtures, which are permeable to water. This test gives the procedure for determination of the stripping value of aggregates by static immersion method, when bitumen and tar binders are used.

13. What is California bearing ratio? (April/May 2015)

CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus.

14. Define Softening point (April/May 2015)

Softening point is the temperature at which the substance attains a particular degree of softening under specified conditions of test.

PART-B

1. **Discuss the following test procedures for testing procedures for the testing the quality of aggregate and Bitumen.(Nov/Dec 2019), (Nov/Dec 2015), (Nov/Dec 2017), (May/June 2016), (April/May 2018)**

Test on Aggregate

- **i) Aggregate Impact Test**
- **ii) Crushing Test**
- **iii) Los angles abrasion test**
- **iv) Flakiness Index Test**
- **v) Soundness test**

Test on Bitumen

- **i) Softening Point Test on Bitumen**
- **ii) Penetration test on Bitumen**
- **iii) Ductility test on Bitumen**
- **iv) Viscosity test**

(i) Aggregate Impact Test

A test designed to evaluate the toughness of stone or the resistance of the aggregates to fracture under repeated impacts is called impact test. The aggregate impact test is commonly carried out to evaluate the resistance to impact of aggregate and has been standardized by ISI.

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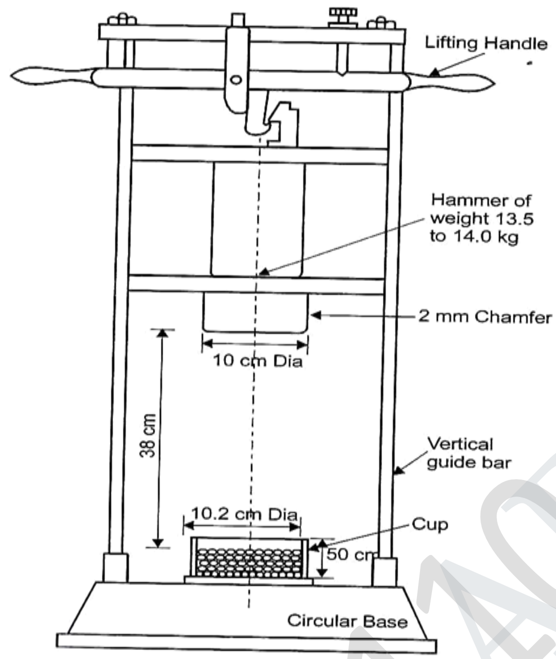

The aggregate impact value indicates a relative measure of resistance of aggregates to impact, which has a different effect then the resistance to gradually increasing compressive stress. The aggregate impact testing machine consists of a metal base and a cylindrical steel cup of internal diameter 10.2cm and depth 5cm in which the aggregate specimen is placed. A metal hammer of weight of 13.5-14.0 kg having a free fall from a height 38cm is arranged to drop through vertical guides.

Aggregate specimen passing 12.5mm sieve and retained on 10mm sieve is filled in cylinder measure in 3 layers by tamping each layer by 25 blows. The sample is transferred from the measure to the cup of the aggregates impact testing machine and compacted by tamping 25 times.

The hammer is raised to a height of 38cm above the upper surface of the aggregate in the cup and is allowed to fall freely on the specimen. After subjecting the test specimen to 15 blows, the crushed aggregate is sieved on 2.36mm sieve. The aggregate impact value is expressed as the percentage of the fine formed in terms of the total weight of the sample.

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

(ii) **Crushing strength test**

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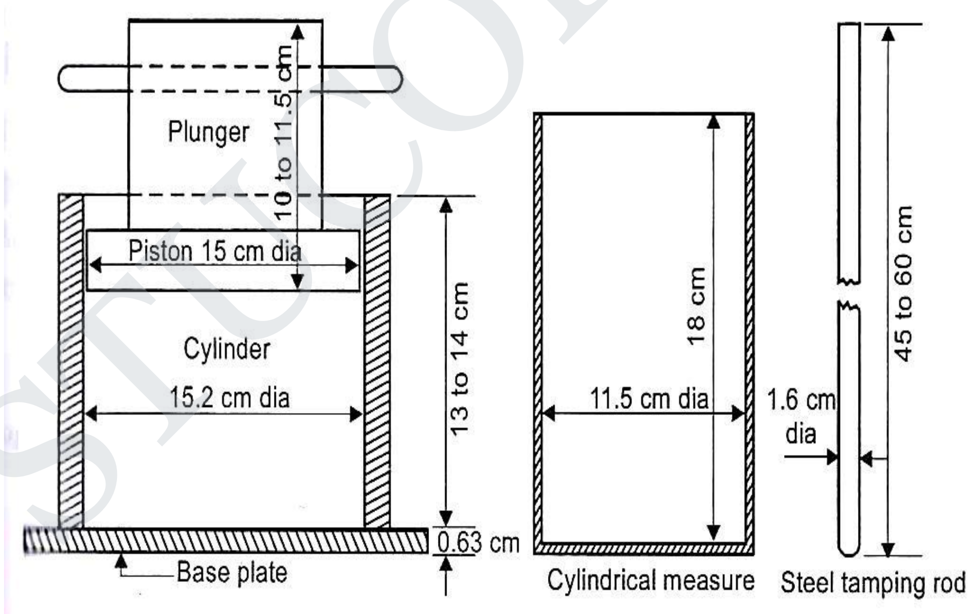
The strength of course aggregate may be assessed by aggregate crushing strength test. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied compressive load. To achieve a high quality of pavement aggregates possessing high resistance to crushing or low aggregate crushing value are preferred.

The apparatus for standard test consists of a steel cylinder 15.2cm diameter with a base plate and plunger, compression testing machine, cylindrical measure of diameter 11.5cm and height 18cm, tamping rod and sieves.

Dry aggregates passing 12.5mm IS sieve and retained on 10mm sieve is filled in the cylinder measure in three equal layers, each layer being ramped 25 times by the tamper. The test sample is weighed (equal to w_1g) and placed in the test cylinder in compression machine.

The plunger is placed on the top of specimen and a load of 40 tones is applied at a rate of 4 tones per minute by the compression machine. The crushed aggregate is removed and sieved on 2.36mm IS sieve. The crushed material which passes this sieve is weighed equal to w_2g.the aggregate crushing value is the percentage of the crushed material passing 2.36mm sieve in terms of original weight of the specimen.

Aggregate crushing value=$100w_2/w_1$



Aggregate crushing test apparatus

(iii) **Los angles abrasion test**

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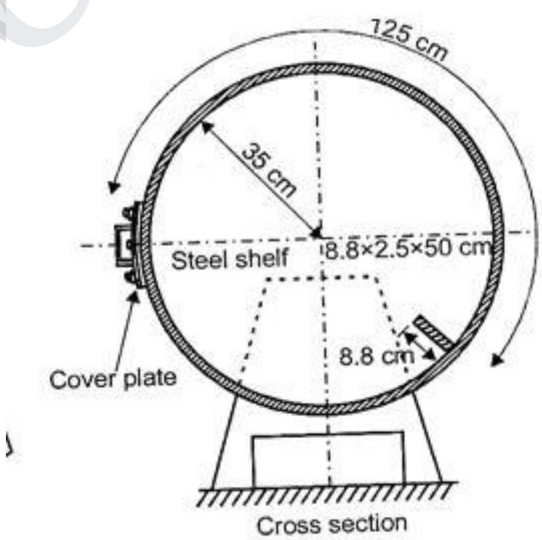
The principle of los angles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregate and steel balls used as abrasive charge. Pounding action of these balls also exists during the test and hence the resistance to wear and impact is evaluated in this test. The los angles consists of a hollow cylinder closed at both ends, having inside diameter 70cm and length 50cm and mounted so as to rotate about its horizontal axis.

The abrasive charge consists of cast iron spheres of approximately diameter 4.8cm and each of weight 390-445 g. the number of spheres to be used as abrasive charge and their total weight have been specified based on grading of the aggregate sample.

The specified weight of aggregate specimen, (5 to 10 kg) is placed in the machine along with the abrasive charge. The machine is rotated at a speed of 30-33rpm for the specified number of revolutions(500-1000).the abraded aggregate is then sieved on 1.7mm IS sieve and the weight of powdered aggregate passing this sieve is found.

The result of the abrasion test expressed as the percentage wear or the percentage of passing 1.7mm sieve expressed in terms of the original weight of the sample. The los angles abrasion value of good aggregate acceceptable for cement concrete bituminous concrete and other high quality pavement materials should be less than 30 percent.

Values up to 50 percent are allowed in base course like water bound and bituminous macadam road. This test is more dependable than other abrasion tests as rubbing and pounding action in the test simulate the field conditions better. Also correlation of los angles abrasion value with field performance and specifications of the test values have been established.



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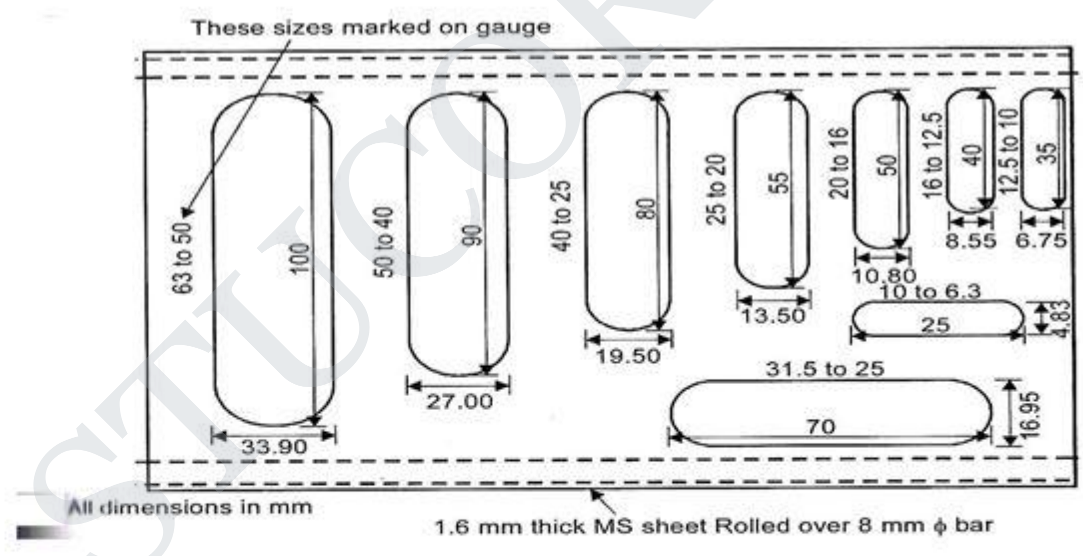
(IV) Flakiness Index Test

The flakiness index of aggregate is the percentage by weight of aggregate particles whose least dimensions /thickness is less than three fifths or 0.6 of their mean dimension. The test applicable to sizes larger than 6.3mm.standard thickness gauge is used to cause the thickness of the sample.

The sample of aggregates to be tested is sieved through a set of sieves and separated into specified size ranges. Now to separate the flaky material the aggregate which passes through the appropriate slot would be 0.6 of the average of the size range. If the size range of aggregate in a group is 16-20mm,the width of the slot too be selected in thickness gauge would be 18x0.6=10.8mm.

The flaky material passing the appropriate slot from each size r5ange of test aggregates are added up and let this weigh be w. If the total weight of sample taken from the different sizes ranges is W. flaky index is given by 100w/W percent, or in other words it is the percentage of flaky materials the width of which are less than 0.6 of the mean dimentions.it is desirable that the flakiness index of aggregates used in road construction is less than the 15 percent and normally does not exceed 25 percent.



(V) Soundness test

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely.

To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V. Aggregates of specified size are subjected to

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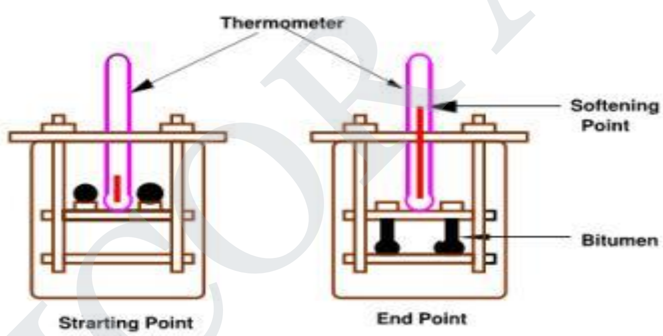
cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105 110oC to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the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

TEST ON BITUMEN

(i) Softening Point Test

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. The softening point of bitumen is usually determined by ring and ball test.

Generally higher softening point indicates lower temperature susceptibility and is preferred in warm climates brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature steel ball is placed upon the bitumen sample and the liquid medium is then **heated at a rate of 5^0C per minute.**



The temperature at which the softened bitumen touches the metal placed at a specified distance below the ring is recorded as the softening point of bitumen. Hard grade bitumen posses higher softening point than soft grade bitumen's. The softening point of various bitumen grades used in **paving jobs very between 35^0 to 70^0C.**

(ii) **Penetration test**

The penetration test determines the hardness and softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in five seconds. The sample is maintained at a temperature of 25^0C.

The penetrometer consists of a needle assembly with a total weight OF 100g and device for releasing and locking any position. There is a graduated dial to read penetration values to $1/10^{th}$ of a millimeter.

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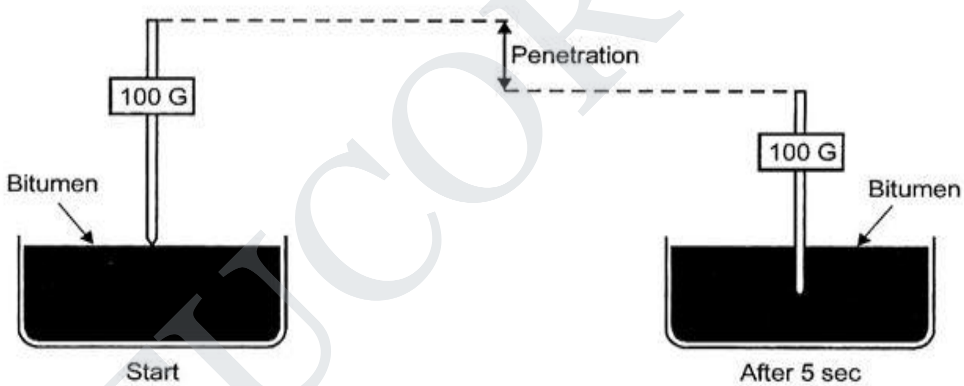
The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers to a depth at least 15mm in excess of the expected penetration. The sample containers are then placed in a temperature controlled water bath at temperature of 25°C for one hour. The sample with container is taken out and the needle is arranged to contact with the surface of the sample. The dial is set to zero or the initial reading is taken and the needle is released for 54 seconds. The final reading is taken on dial gauge. At least three penetration tests are made on this sample by testing at distances of at least 10mm apart. After each test the needle is disengaged and wiped with benzene and dried. The depth of penetration is reported in one tenth millimeter unit. The mean value of three measurements is reported as a penetration value. It may be noted that the penetration value is largely influenced by any inaccuracy as regards pouring temperature, size of needle weight placed on the needle and the test temperature.

The bitumen grade is specified in terms of penetration value 80-100 or 80/100 grade bitumen mean as that the penetration value of the bitumen is in the range 80 to 100 at standard test conditions.



Penetration test concept

(iii) Ductility test on Bitumen

Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square.

The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27o C temperature. The excess bitumen is cut and the surface is leveled using a hot knife.

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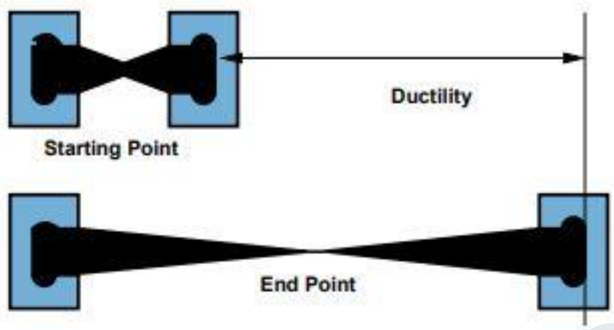
Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated.



The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc.

A minimum ductility value of 75 cm has been specified by the BIS. Figure 23.4.2 shows ductility moulds to be filled with bitumen.

(iv) 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 resist the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles.

Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions.

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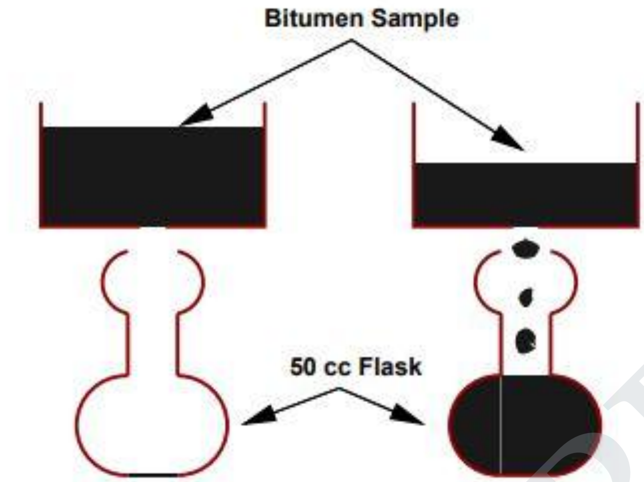


The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25o C or 10 mm orifice at 25 or 40o C.

2. Explain the method of construction of cement concrete road (April/May 2015)

There are two methods of construction of cement concrete road slabs:

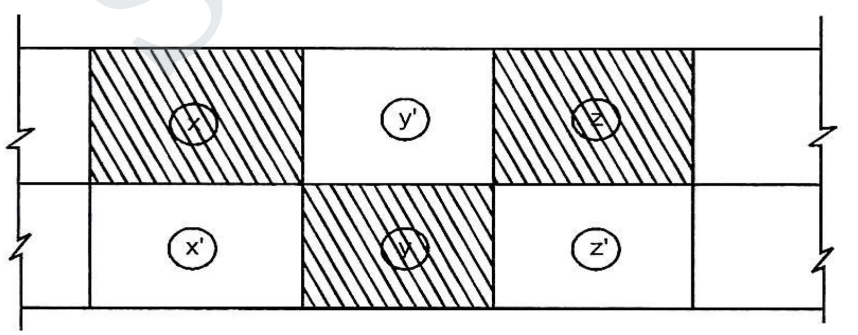
Alternate bay method

Continuous bay method

Alternate bay method

In this method, constructing a bay or one slab in alternate succession leaving the next or intermediate bay. The next construction is done after time gap of one week or so.

For example the alternate bays X, Y and Z are constructed at one stretch. Others, viz., X^1, Y^1 and Z^1 are constructed after one week. This technique provides additional working convenience during the laying of slabs. Provision of construction joints is easier.



Modes of construction of cement concrete road

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This mode of construction has the following setbacks:

- More number of transverse joints have to be provided and thereby increasing the cost. Possibility of collection of surface water on the base or sub grade and thereby disturbing the base or sub grade.
- Diversion of traffic is needed as the construction is done on alternate bays covering the entire width.

Continuous bay method

In the continuous bay method X, Y, Z, etc are done at a stretch in sequence. Construction joints are however provided at the end of the day's job.

In general the second method is preferred as constructed while the other half is being used by traffic.

Construction procedure of pavement slab

- Preparation of sub grade and base
- Placing of forms
- Installation of joints
- Batching of aggregates and cement
- Mixing and placing concrete
- Consolidation and finishing concrete
- Curing of concrete

Preparation of sub grade and base

- The sub grade and base should be prepared complying with the following conditions:
- No soft spots are present in the sub grade or base
- Sub grade or base should be uniformly compacted and extended about 30 cm on either side of the width of pavement to be concreted.
  Sub grade or base should be adequately drained
- Plate load test conducted on the sub grade should yield a minimum modulus of sub grade reaction of 5.5 kg/cm^3.

Placing of forms

- Wooden or steel forms are used.
- Wooden forms have minimum base width 10 cm for 20 cm slab thickness and of 15 cm for slabs over 20 cm thicknesses.
- Forms are jointed nearly and are set with exact grade and alignment.
- Forms are rigidly fixed such that during the entire operation of concreting they should not deviate more than 3mm from straight edge of 3m length.
- Steel forms commonly used are straight 3m sections.
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They are aligned vertically and horizontally by slip joints and held in position by three or more steel stakes.

Installation of joints

- Extreme care should be taken in all operations connected with joints.
- Face of transverse joints should be straight, perpendicular to the centre line of pavement and also perpendicular to the surface of the finished slab.
- Load transfer devices like dowel bars used in expansion joint should be aligned and placed accurately.
- There should be free movement of slab ends in longitudinal direction.

Batching of aggregate and cement

- Based on the design concrete mix, the proportion of ingredients like course aggregate and fine aggregate are proportioned by weight in a weigh batching plant. These are placed in the hopper of the mixer along with the necessary quantity of cement.
- Cement is measured by the bag which measures 50kg.thus all batching of material is done on the basis of one or more whole bags of cement taking the unit weight of cement is taken as 1440kg/m^2.
- Mixing and placing concrete
- The ingredients are mixed in required quantity for immediate use and are deposited on the sub grade or base.
- Deposited concrete should be to the correct depth and width of pavement section within the formwork.
- The operation of placing concrete should be continuous.

Consolidation and finishing

- Concrete is spread uniformly by shovels with redistribution wherever needed, Needle vibrator is used for compaction.
- Surface of the pavement is compacted either using a power driven finishing machine or using a vibrating hard screed.

Curing of concrete

It is very important to ensure proper curing of the finished concrete. Following are the methods usually adopted:

- Bonding or each cover kept wet, Hay or straw cover kept wet.
- Cover of wet felt mats cotton mats.
- Saw dust kept wet.

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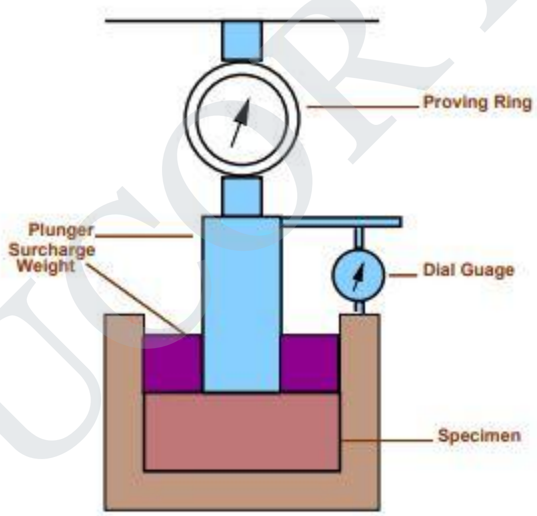
3. **California Bearing Ratio Test (April/May 2019), (April/May 2017), (Nov/Dec 2016), (Nov/Dec 2015)**

California Bearing Ratio (CBR) 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. CBR test, an empirical test, has been used to determine the material properties for pavement design.

Empirical tests measure the strength of the material and are not a true representation of the resilient modulus. It is a penetration test wherein a standard piston, having an area of 3 in2 (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the CBR.



In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used.

The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired.

The CBR test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

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Test Procedure The laboratory CBR apparatus consists of a mould 150 mm diameter with a base plate and a collar, a loading frame and dial gauges for measuring the penetration values and the expansion on soaking.

The specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame. Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min.

A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively. CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore,

$$CBR = \frac{\text{load carries by specimen}}{\text{load carries by standard specimen}} \times 100$$

Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted.

If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking.

If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.

The average CBR value of three test specimens is reported as the CBR value of the sample.

4. **What is the modern construction materials used for the construction of pavements? Explain their characteristics and usage in detail.(April/May 2019), (April/May 2017),**

(i)Polymer Modified Bitumen

(ii) Geo- Textile

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Polymer modified bitumen is emerging as one of the important construction materials for flexible pavements. Use of plastic waste in the construction of flexible pavement is gaining importance because of the several reasons.

The polymer modified bitumen show better properties for road construction & plastics waste, otherwise considered to be a pollution menace, can find its use in this process and this can help solving the problem of pollution because most of the plastic waste is polymers.

In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate.

It also helps to improve the strength of the road. But its resistance towards water is poor. Antistripping agents are being used. A common method to improve the quality of bitumen is by modifying the rheological properties of bitumen by blending with organic synthetic polymers like rubber and plastics.

Geo- Textile

Geo- textile is any permeable textile material used with foundation, soil, rock, earth, etc. that is an integral part of a constructed project, structure or system.

It may be made of synthetic or natural fibers. In contrast; a geo-membrane is a continuous membrane-type liner or barrier. It must have sufficiently low permeability to control migration of fluid in a constructed project, structure or system.

A geo-textile is designed to be permeable to allow the flow of fluids through it or in it, and a geomembrane is designed to restrict the fluid flow.

Some importance applications of geotextile are described below:

Separation

In this function, the geo-textile serves to separate two dissimilar materials, eg, two different soils, landfill material and the native soil, stone material and sub-grade soil, old and new pavement, foundation soils and various types of walls, or one of many other similar situations. In some instances, it is difficult to distinguish between the separation and stabilization functions because in both situations the geo-textile is serving as a separator. However, in stabilization some additional phenomena occur.

Stabilization

In this application, the natural soil on which the geo-textile is placed is usually a wet, soft, compressible material, exhibiting very little strength. By acting as a separator, the geo-

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textile allows water from the soft natural soil to pass from this soil into a free-draining construction soil, which in turn allows consolidation of the natural soil to take place. As a result of the consolidation process, there is a strength gain in the natural soil, which then provides an adequate foundation for construction to take place.

Reinforcement

The key difference between stabilization and reinforcement is that stabilization is accomplished by providing for drainage of water from the unstable soil, while in reinforcement the strength characteristics (stress–strain) of the geo-textile provide added strength to the whole system. Another difference is that in stabilization the geo-textile is placed on or around the area being stabilized and thereby also acts as a separator, whereas in the reinforcement application the geotextile is placed within the material being reinforced. This is in line with reinforcement concepts in concrete and other materials.

Filtration

The prime function is to retain soil or other fine materials, while allowing water to pass through. Again, it is seen that more than one function is being performed. If there were no drainage of water taking place, movement, and therefore retention of the soil, would not be of concern. Part of the mechanism by which filtration occurs is through the development of a soil filter behind the geo-textile. As the water passes through, soil is filtered out and collects behind the geo-textile. As buildup takes place, a natural soil filter is developed.

Drainage

In the previous sections, drainage was discussed as taking place in a direction perpendicular to the plane of the geo-textile. Here, drainage parallel to the plane of the geo-textile is described. The property called transmissivity is defined as flow parallel to the plane of the geotextile. This type of flow can occur to some extent in all geo-textiles, but is best achieved in needle-punched nonwoven materials. This class of geo-textiles can be manufactured in a range of thicknesses such that this characteristic is optimized.

Moisture Barrier

When impregnated with an asphaltic emulsion, geo-textiles become impermeable and can then be used as moisture barriers. The primary application for this type of geo-textile is in pavement rehabilitation.

5. **Explain the different forms of bitumen.(Nov/Dec 2016)**

   The bitumen can be classified into the following grade types:

   i) **Penetration Grade Bitumen**
   ii) **Oxidized Bitumen Grades**

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iii) **Cut Back Bitumen**

iv) **Bitumen Emulsion**

v) **Polymer Modified Bitumen**

(i) Penetration Grade Bitumen

The penetration grade bitumen is refinery bitumen that is manufactured at different viscosities. The penetration test is carried out to characterize the bitumen, based on the hardness. Thus, it has the name penetration bitumen. The penetration bitumen grades range from 15 to 450 for road bitumen. But the most commonly used range is 25 to 200. This is acquired by controlling the test carried out i.e. the distillation process. The partial control of fluxing the residual bitumen with the oils can help in bringing the required hardness.

(ii) Oxidized Bitumen

The refinery bitumen is further treated by the introduction of processed air. This will give us oxidized bitumen. By maintaining a controlled temperature, the air is introduced under pressure into soft bitumen. Compounds of higher molecular weight are formed by the reaction of this introduced oxygen and bitumen components. Thus, the Asphaltenes and the Maltenes content increases resulting in a harder mix. This harder mix has a lower ductility and temperature susceptibility. The oxidized bitumen is used in industrial applications such as roofing and coating for pipes. By this method of processing, the bitumen that has a lower penetration can be manufactured, which can be employed for paving roads.

(iii) Cutback Bitumen

These are a grade of bitumen that comes under penetration grade bitumen. This type of bitumen has a temporarily reduced viscosity by the introduction of a volatile oil. Once after the application, the volatile material is evaporated and bitumen gain its original viscosity. The penetration grade bitumen is a thermoplastic material. It shows the different value of viscosity for different temperature.

In areas of road construction, it is necessary for the material to be fluid in nature at the time of laying i.e. during surface dressing. It is also essential for the material to regain back to its original hardness and property after setting. This is ensured by cutback bitumen. The fluidity is obtained for any bitumen by raising the temperature. But when it is necessary to have fluidity at lower temperatures during surface dressing, cutback bitumen is employed. The time for curing and the viscosity of cutback bitumen can be varied and controlled by the

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1. Dilution of volatile oil, and
2. The volatility of the oil added.

(iv) Bitumen Emulsion

The type of bitumen forms a two-phase system with two immiscible liquids. One of them is dispersed as fine globules within the other liquid. When discrete globules of bitumen are dispersed in a continuous form of water, bitumen emulsion is formed. This is a form of penetration grade bitumen that is mixed and used for laying purposes. An emulsifier having a long hydrocarbon chain with either a cationic or anionic ending is used for dispersing the bitumen globules. This emulsifier provides an electrochemical environment. The ionic part of the chain has an affinity towards water and the bitumen is attracted by hydrocarbon part.

6. What are the desirable properties of aggregates (May/June 2016), (April/May 2015)

Desirable Properties of Road Aggregates

1. Strength
2. Hardness
3. Toughness
4. Durability
5. Shape of aggregates
6. Adhesion with bitumen

1. Strength

The aggregates to be used in road construction, particularly the aggregates used in the wearing course of the pavement should be sufficiently strong/ resistant to crushing to withstand the high stresses induced due to heavy traffic wheel loads.

2. Hardness

The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. Abrasive action may be increased due to the presence of abrasing material like sand between the tyres of vehicle and the aggregates exposed to the top surface. Thus, they should be hard enough to resist the wear due to abrasive action of traffic.

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3. Toughness

Aggregates in the pavement are also subjected to impact due to moving wheel loads. The magnitude of impact increase with roughness of road and speed of vehicle. Severe impact is common when heavily loaded steel tyred vehicles move on WBM. The resistance to impact or toughness is thus another desirable property of aggregates.

4. Durability

The aggregates are subjected to physical and chemical actions of rains and ground water, the impurities in them and that of atmosphere. Thus it is desirable that the road stones used in the construction should be sound enough to withstand the weathering action. The property of aggregates to withstand the adverse actions of weather may be called soundness.

7. Discuss the requirements of good drainage system (April/May2018)

Surface drainage deals with arrangements for quickly and effectively leading away the water that collects on the surface of pavements, shoulders, and other adjoining areas.

Surface drainage consists of two operations:

1. Collection of surface water
2. Disposal of collected surface water

Rain water from road surface is left off to the sides by cross slope or camber. Based on the rainfall of the area the rate of cross slope is provided.

In rural plain area, the disposal of water depends on whether the road is in embankment or in cutting or on ground line.

Side drains of suitable size and adequate longitudinal slope are constructed along both the sides of the road at some distance from the foot of embankment. The side drains are trapezoidal in shape.

In cuttings, drains are provided along both the sides of the road just next to the shoulders. If there is a restriction of space covered drains or drainage trenches are provided with layers of coarse sand and gravel.

In case of urban roads, underground drainage facilities are provided to drain off surface water. Urban drains are provided because of presence of foot path and other developments. Water drained from the pavement surface can be drained longitudinally and may be collected in catch pits and carried forward through underground drainage pipes. A typical

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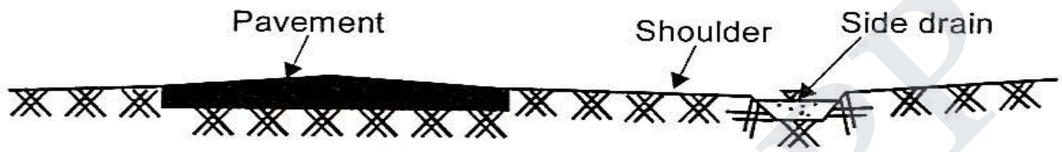
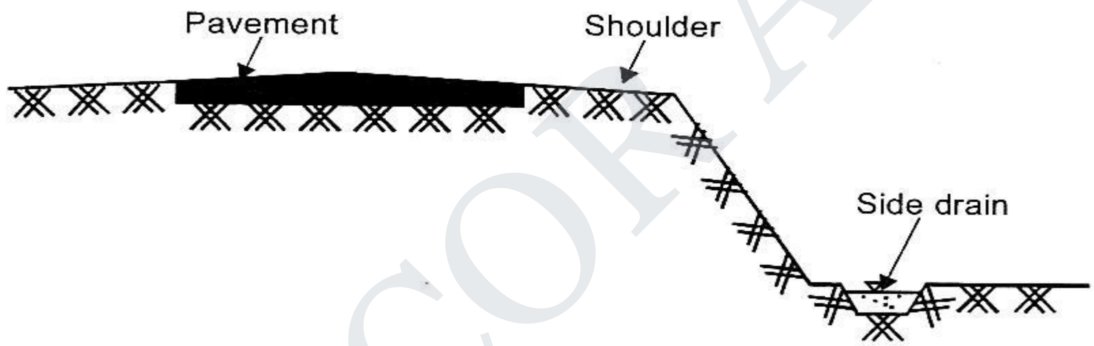
catch pit with grating to pavement the entry of rubbish into the drainage system is shown in fig.

Highway drainage is of much more important in hill road formation, it is essential to divert and dispose off the water flowing down the hill slope across the road and efficient it will result in complex maintenance problems. Hence drainage arrangements in hill road should be made to work efficiently.



(a) Side-drain in ground line



(b) Side-drain in filling ground (embankment)

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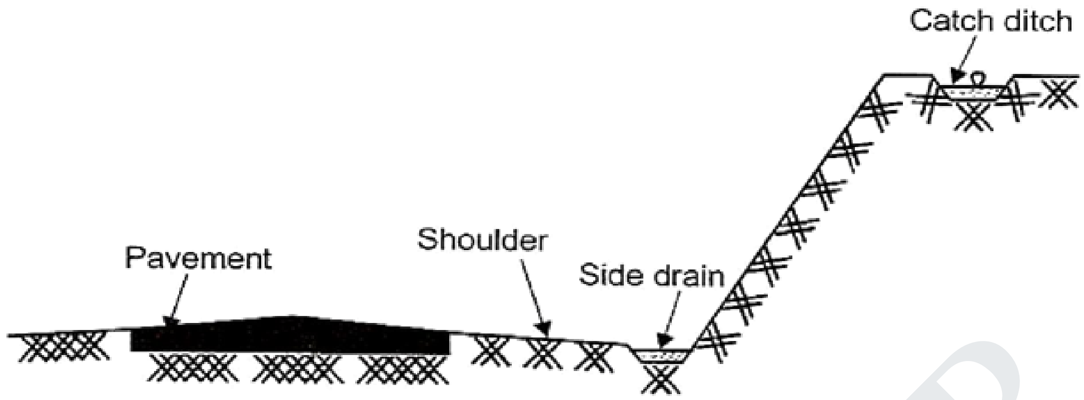
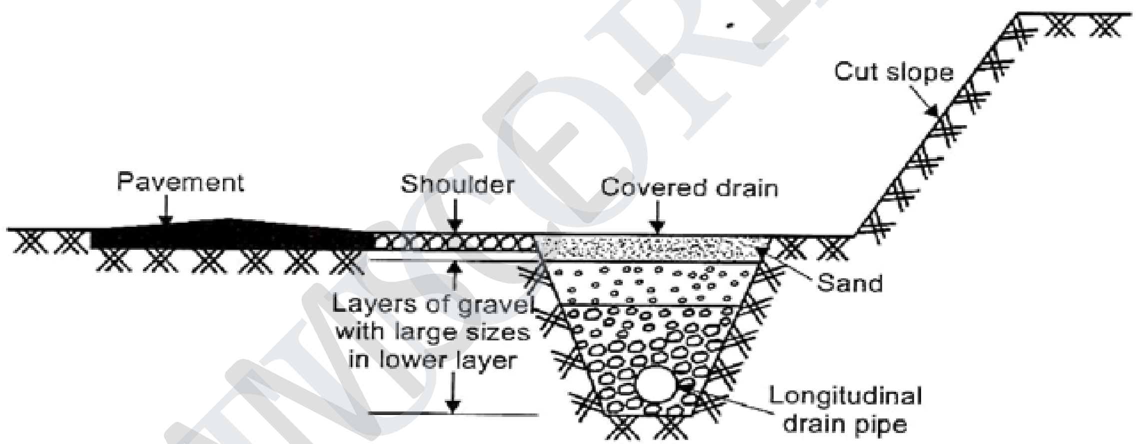
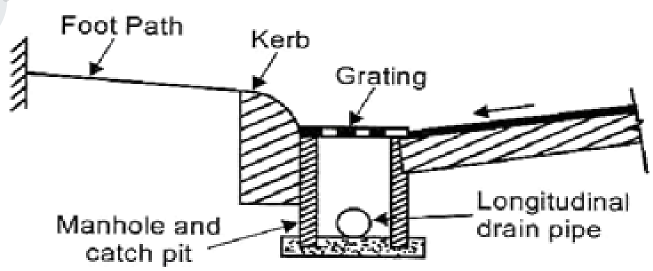


(c) Side-drain in cutting

Arrangement of side-drains



Trench filled with gravel and sand



Surface Drainage system in urban roads

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8. What is geo textiles? Describe the functions of geotextiles in road construction (April/May 2018)

Geo textile:

Geotextile; material that can pass water from wicker (woven) or non-woven (non-woven) from the threads or synthetic fibers used in ground work, the synthesis of thin sheets, flexible, permeable used for soil stabilization and improvement.

Woven Geotextiles

i. Load carrying filaments, fibres and yarns in woven geotextiles are aligned in specific directions
ii. This is usually along the longitudinal direction or warp direction and transverse direction or weft direction
iii. They provide separation as well as filtration functions

Non –Woven Geotextiles

i. The filaments are entangles and bonded together
ii. There is no specific direction to the fibres and hence they elongate longer when
iii. compared to woven geotextiles
iv. They are mostly used as separators

Knitted Geotextiles

i. Knitted geotextiles are similar to non-wovens but bundles of load carrying
ii. Filaments can be made to be aligned in a given direction and this type of product is called as directionally structured fabric or DSF
iii. They provide an alternative to woven geotextiles

Geotextiles:

i. One of the two largest groups in geosynthetics
ii. They are textiles in the traditional sense, but they consist of synthetic fibers rather than natural ones such as cotton, wool, or silk
iii. These synthetic fibers are made into flexible, porous fabrics by standard
iv. Weaving machinery or are matted together in a random nonwoven manner or knitted. The major point is that geotextiles are porous to liquid flow across their manufactured plane and also within their thickness, but to a widely varying degree

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The fabric always performs at least one of four discrete functions:

- Separation,
- Reinforcement,
- Filtration, and/Or Drainage

Geogrids

They represent a rapidly growing segment in geosynthetics Geogrids are polymers formed into a very open, gridlike configuration, i.e., they have large apertures between individual ribs in the transverse and longitudinal directions They are made by either Stretching in one or two directions On weaving or knitting machinery

(i) By bonding straps or rods
(ii) There are many specific application areas,

Geo-membranes

- They represent the other largest group in geosynthetics
- They are relatively thin, impervious sheets of polymeric material used primarily for linings and covers of liquids or solid-storage facilities
- This includes all types of landfills, reservoirs, canals, and other containment facilities
- Thus the primary function is always containment as a liquid or vapor barrier or both.

Geonets

- Geonets, also called geospacers, constitute another specialized segment within the geosynthetics area
- They are formed by a continuous extrusion of parallel sets of polymeric ribs at acute angles to one another
- When the ribs are opened, relatively large apertures are formed into a netlike configuration
- Two types are most common, either biplanar or triplanar
- Their design function is completely within the drainage area where they are used to convey liquids of all types

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Geomats

- A three-dimensional water permeable mat made from extruded and bi-oriented polyethylene grids.
- The underside of the mat is made flat to provide even contact with the prepared soil surface
- The upper surface is made cuspated to provide excellent soil retention
- Geomats are applied to create stable vegetation along river, pond banks and slopes to prevent erosion processes of surfaces.
- Geomats are used in combination with geotextiles to reinforce foundations and increase bearing resistance.

Geosynthetic Clay Liners

They are rolls of factory fabricated thin layers of bentonite clay sandwiched between two geotextiles or bonded to a geo-membrane Structural integrity of the subsequent composite is obtained by needle-punching, stitching or physical bonding GCLs are used as a composite component beneath a geo-membrane or by themselves in geo-environmental and containment applications.

Geofoams

Geofoam is a product created by a polymeric expansion process resulting in a "foam" consisting of many closed, but gas-filled, cells. The resulting product is generally in the form of large, but extremely light, blocks which are stacked side-by-side providing lightweight fill in numerous applications . The primary function is dictated by the application; however separation is always a consideration

Geocells

- Geocells (also known as Cellular Confinement Systems) are three-Dimensional honeycombed Cellular structures that form a confinement system when in-filled with compacted soil.
- The cellular confinement reduces the lateral movement of soil particles, thereby maintaining Compaction and forms a stiffened mattress that distributes loads over a wider area.
- Traditionally used in slope protection and earth retention applications, geocells made from Advanced polymers are being increasingly adopted for long-term road and rail load support Much larger geocells are also made

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from stiff geotextiles sewn into similar, but larger, unit cells that are used for protection bunkers and walls

9. **Discuss the construction practice adopted for flexible pavement (Nov/Dec 2019)**

The existing surface is reconditioned to proper cross section and the surface is cleaned. On the prepared and cleaned surface a thin layer of binder (prime and teak coat) is applied on a 10 sq.m surface and 4.0 to 7.5 kg of binder is to be used for black top surface or 7.5 to 10 kg for untreated WBM surfaces.

Aggregates of proper gradation and binder are separately heated at about 120^0c and then mixed in a mixture. This mixture so prepared is placed on the already prepared surface and uniformly spread for the required thickness with rakes. The cross section is again checked. Rolling is done as early as possible after placing premixed material with a 8 to 10 tonne roller.

The rolling is started from the edges and processed towards the centre with uniform overlapping. The wheels of the roller should be kept wet while rolling so as to avoid sticking of mixed material on the wheels.

Bituminous concrete

- The existing base course is reconditioned as explained in earlier cases at least one week before laying the binder course.
- Then the bitumen course layer will be laid.
- This is also a hot mix process. The hot mix is collected and spread over the prepared surface. The camber and thickness of bitumen layer is checked.
- The placed concrete is rolled by a roller at a speed not more than 5km/hour.
- The number of passes required to attain the final desired thickness depends on the thickness.
- The initial rolling is done using a 8 to 12 tonne roller followed by fixed wheel pneumatic roller of 15 to 30 tonnes. The wheels are kept damp with water or wet gunny.

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10. Discuss in brief the construction practice with modern material and methods to adopted for high type of bituminous pavement as per IRC standards (Nov/Dec 2018).

(Refer Part-B, Question No. 4 & 5)

11. Write in details the different types of test to be conducted to check the suitability of Aggregate Material in highway materials.(Nov/Dec 2018)

(Refer Part-B, Question No. 1 & 6)

12. Describe the construction procedure of a flexible pavement. Explain the equipment required for various layers while constructing the flexible pavement (Nov/Dec 2015).

Preparation of Sub-Grade

Layer Prepare the sub-grade layer, it is done after placing the drainage system, piping and electric cable. The sub-grade surface will be compacted levelled and be cut to make camber as in plan. If the material of the soil did not have a good quality, it will be changed with suitable material.

Base formation covers with 50-75mm sand layer or quarry dust and will be ***compacted with 8-10 tone compactors.***

This job must be done to prevent the clay from absorbing into the stone layer of sub-base and reduce the shear strength of the pavement.

Construction And Compacting The Sub-Base

After the sub-base has been prepared with list materials, it will be placed and constructed into two layers if the thickness is more then150mm. Every layer will be compacted according to the plan.

Sub-baselayer must be compacted carefully with compactor machine.

Compactors with rubber roller can compact 120mm layer in 12 times.

Compacting should start from the side of the road hen slowly towards the middle of the road in horizontal way.

In super-elevated bends compaction machine will start at the lowest part and slowly towards the higher level. The finished part should not be more than 20mm from the plan.

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Construction of Road Base

Before road base is constructed, sub-grade surface and sub-base must be formed perfectly and compacted enough.

The lowest layer and sub-base must be prepared ***at least distance of 200m from the base construction.***

This material is place and compacted to on the surface of the road. The road base must be constructed in two layers of same thickness. ***Each layer should not exceed 150mm.***

Construction of Road Surface

The road surface is constructed with bitumen materials, such as concrete asphalt, macadam bitumen and so on. The constructed should be free from dust and waterproof.

To construct the surface layer, the base course must be prepared first. Prime coat is poured onto the road base surface to be a binder between the road bases and the base course.

To pour the prime coat, the temperature must be according to the specifications stipulated.

Base course is built on one layer only with a pavers' machine. After this layer is constructed, it is placed before it is compacted.

The surface is checked and corrected if there are any differences. The compacting must be done immediately. It should be compacted from the side towards the middle of the road. It there is a super elevated bend, then it should be compacted from lower part to higher part. The type of compactors must be according to the specifications.

Finally wearing course is prepared. Like always, base course should be cleaned before tack coat is poured. The compacting job is done the same way as the base course.

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PART C

1. Explain in detail about the crushing test, Abrasion test, Impact test and Soundness test on the aggregates used for highway road construction. (April/May 2018)

(Refer Part-B, Question No. 1)

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2.Explain the application of Geotextiles and Geomembrance in Road Construction(Nov/Dec 2017)

(Refer Part-B, Question No. 8)

3. Write in detail the present status of highway drainage in Chennai city roads and list out the measures to be taken for effective removal of water from the pavement(April/May 2019), (April/May 2018)

(Refer Part-B, Question No. 7)

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UNIT-V

EVALUATION AND MAINTENANCE OF PAVEMENTS

1. **List any 4 types of failures observed in flexible pavement (NOV/DEC 2019)**

   The failures are

   1) Failures in sub-grade
   2) Failures in sub-base
   3) Failure in wearing course
   4) Failure in Cracking, Potholes , Rutting and Ravelling

2. **What are the causes of cracks in Pavement? (NOV/DEC 2019),(April/May 2019)**

   Over loading

   Sub -Grade weak

   Improper compaction

3. **Differentiable delamination and depression (April/May 2019), (May/June 2016)**

Delamination	Depression
Loss of a discrete and large (Minimum $0.01m^2$) area of the top bituminous layer	Localized area within a pavement with elevations lower than the surrounding area

4. **Differentiate between Spalling and Traverse crack (April/May 2018)**

Spalling	Traverse crack
Breaking or cutting off small pieces from the pavement surface	Perpendicular to the centre line of the pavement

5. **What is meant by mud pumping? (April/May 2018), (Nov/Dec 2017)**

   It is recognized when the soil slurry ejects out through the joints and cracks of cement concrete pavement caused during the downward movement of slab under the heavy wheel loads. It is called as mud pumping.

6. **Write down the works under routine repairs (Nov/Dec 2017)**

   Routine road maintenance works are usually non-structural in nature and are meant to extend the life of the pavement, to enhance the performance and to reduce user delays in road use.

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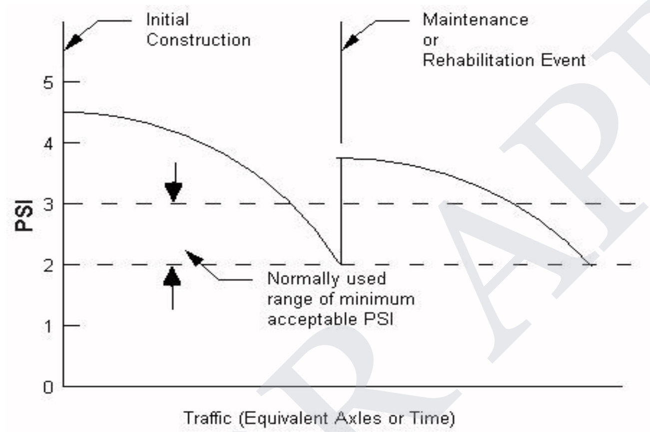
7. Define Bleeding (Nov/Dec 2016)

It is identified by a film of bituminous material on the pavement surface that creates a shiny, glass like, reflective surface.

8. Define the terms Present Serviceability Index with its importance (Nov/Dec 2018)

The present serviceability index (PSI) is based on the original AASHO Road Test PSR. Basically, the PSR was a ride quality rating that required a panel of observers to actually ride in an automobile over the pavement.



9. What do you mean by the term Highway Project Formulation (Nov/Dec 2018)

i) Taking a first look carefully and critically at the project idea
ii) Carefully weighing its various components
iii) Analysing with the assistance of specialists or consultants
iv) Assessment of the various aspects of an investment proposition
v) It is an important stage in the pre-investment phase

10. What are the parameters that should be observed for evaluating a rigid pavement? (April/May 2017)

i) Scaling
ii) Faulting
iii) Roughness
iv) Skid resistance
v) Cracking

11. What are the causes of cracks? (April/May 2017), (May/June 2016)

A common defect in bituminous pavements is formation of cracks. The crack pattern can, in many cases indicate the causes of the defect, As soon as the cracks are observed, it is necessary to study the pattern in detail. Cracks are very serious defects be it is vulnerable for ingress of water through the cracks.

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Causes of cracks

Over loading

Sub -Grade weak

Improper compaction

12. Differentiate Pumping and Ravelling (Nov/ Dec 2016)

Pumping	Ravelling
The ejection of water and fine materials under pressure through cracks under moving loads	The weather away of the pavement surface causes by the loss of binder or the dislodging of aggregate particles of both.

13. What is alligator Crack? (Nov/Dec 2015)

The general pattern of alligator or map cracking of the bituminous surfacing. This is the most common type of failure and occurs due to the relative movement of pavement layer materials.

14. What is FWD and state its use? (Nov/Dec 2015)

A falling weight deflectometer (FWD) is a testing device used to evaluate the physical properties of pavement. FWD is used in highways, airport pavements, harbor areas and railway track.

15. List the types of pavements (April/May 2015)

(i) Flexible pavement

(ii) Rigid pavement

(iii) Semi rigid pavement

16. Brief the Pavement Evaluation (April/May 2015)

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.

PART-B

1. **Explain in detail the possible causes and remedial measures of rigid pavement failure (Nov/Dec 2019), (April/May 2018), (Nov/Dec 2017)**

   Common failures of Rigid Pavements

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i) Spalling joint
ii) Faulting Joint
iii) Shrinkage Cracking
iv) Longitudinal cracks
v) Slab cracking

(i) Spalling Joint

- Cracking, breaking or chipping of joint/crack edges. Usually occurs within about 0.6 m (2 ft.) of joint/crack edge.
- Loose debris on the pavement, roughness, generally an indicator of advanced joint/crack deterioration.
- Excessive stresses at the joint/crack caused by infiltration of incompressible materials and subsequent expansion (can also cause blowups).

(ii) Faulting Joint

- A difference in elevation across a joint or crack usually associated with undoweled JPCP. Usually the approach slab is higher than the leave slab due to pumping, the most common faulting mechanism.
- Faulting is noticeable when the average faulting in the pavement section reaches about 2.5 mm (0.1 inch). When the average faulting reaches 4 mm (0.15 in), diamond grinding or other rehabilitation measures should be considered.

(iii) Longitudinal cracks

Longitudinal cracks not associated with corner breaks or blowups that extend across the entire slab. Typically, these cracks divide an individual slab into two to four pieces. often referred to as "panel cracking".

iv) Shrinkage Cracking

Hairline cracks formed during PCC setting and curing that are not located at joints. Usually, they do not extend through the entire depth of the slab. Shrinkage cracks are considered a distress if they occur in an uncontrolled manner (e.g., at locations outside of contraction joints in JPCP or too close together in CRCP).

Possible causes-

- Contraction joints sawed too late.
- Poor reinforcing steel design.
- Improper curing technique.
- High early strength PCC.

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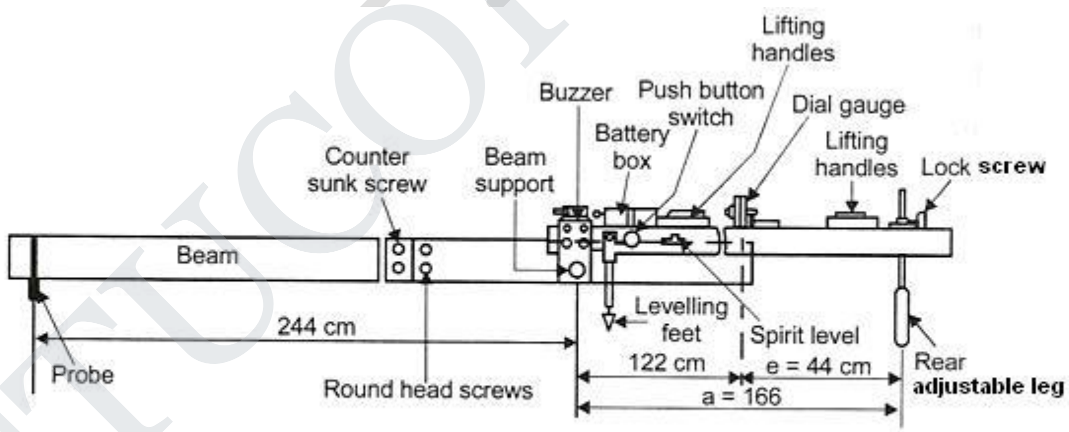
2. Explain the methods employed for evaluation of pavements and explain the evaluation of pavement by BENKELMAN Beam method and deflection measurement. (Nov/Dec 2019), (April/May 2017), (April/May 2015)

Benkelman beam is a device which can be conveniently used to measure the rebound deflection of a pavement due to a dual wheel load assembly or the design wheel load. The equipment consists of a slender beam of length 3.66m which is pivoted to a datum frame at a distance 2.44m from the probe end. The datum frame rests on a pair of front leveling leg with adjustable height. The probe end of the beam is inserted between the dual rear wheels of truck and rests on the pavement surface at the center of the loading area of the dual wheel load assembly. a dial gauge is fixed on the datum frame with its spindle in contact with the other end of the beam in such a way that the distance between the probe end and the fulcrum of the beam is twice the distance between the fulcrum and the dial gauge spindle. Thus the rebound deflection reading measured at the dial gauge is to be multiplied by two to get the actual movement of the probe end due to the rebound deflection of the pavement surface when the dial wheel load is moved forward. a loaded truck with rear axle load of 8170kg is used for the deflection study. The design wheel load is a dual wheel load assembly of gross weight 4085kg/cm^2.



Benkelman Beam

Procedure

The stretch of road length to be evaluated is first surveyed to assess the general condition of the pavement with respect to the ruts, cracks and undulations. Based on the above pavement condition survey, the pavement stretches are classified and grouped into different classes such as good, fair and poor for the purpose of Benkelman beam deflection studies. The loading points on the pavement for deflection measurements are located along the wheel paths, on a line 0.9 m from the pavement edge in the case of pavements of total width more than 3.5m, the distance from the edge is reduced to 0.6m on narrower pavements. The number of loading points in a stretch and the spacing between them for the

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deflection measurements are to be decided depending on the objective of the project and the precision desired. A minimum of 10 deflection observations may be taken on each of the selected stretch of pavement.

The deflection observation points may also be staggered if necessary and taken along the wheel path on both the edges of the pavement. After marking the deflection observation points, the study is carried out in the following steps:

- The truck is driven slowly parallel to the edge and stopped such that the left side rear dual wheel is centrally placed over the first point for deflection measurement.
  The probe end of the Benkelman beam is inserted between the gaps of the dual wheel and is placed exactly over the deflection observation point.
  When the dial gauge reading is stationary or when the rate of change of pavement deflection is less than 0.025mm per minute, the initial dial gauge reading D_0 is noted. Both the readings of the large and small needles of the dial gauge may be noted. The large needle may also be set to zero if necessary at this stage.
- The truck is moved forward slowly through a distance of 2.7m from the point and stopped. The intermediate dial gauge reading D_i is noted. When the rate of recovery of the pavement is less than 0.025mm per minute. The truck is then driven forward through a further distance of 9.0m and final dial gauge reading D_f is recovered as before.
- The three deflection dial reading D_0, D_i and D_f from a set of readings at one deflection point under consideration. Similarly the truck is moved forward to the next deflection point, the probe of the Benkelman beam inserted and the procedure of noting the set of three deflection observations is repeated. The deflection observations are continued at all the desired points.

The temperatures of the pavement surface are recorded at intervals of one hour during the study. The tyre pressure is checked and adjusted if necessary, at intervals of about three hours during the deflection study. The moisture content in the sub grade soil is also to be determined at suitable intervals.

The rebound deflection value D at any point is given by one of the following two conditions:

i) If $D_i - D_f \leq 2.5$ divisions of the dial gauge or 0.025mm, $D=2(D_0 - D_f)$ divisions of 0.01mm units $=0.02(D_0 - D_f)$ mm.

ii) If $D_i - D_f \geq 2.5$ division, this indicates that correction is needed for the vertical movement of the front legs. Therefore,
$D=2(D_0 - D_f)+2K(D_i - D_f)$ divisions.

The value of K is to be determined for every make of the Benkelman beam and is given by the relation:

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$$K = \frac{3d - 2e}{f}$$

Where

d=distance between the bearing of the beam and the rear adjusting leg. e=the distance between the dial gauge and rear adjusting leg f=distance between the front and rear legs.

The value of K of Benkelman beam generally available in India is found to be 2.91.therefore, the deflection value D in case (ii) with leg correction is given by:

$D=0.02(D_O- D_f) +0.0582(D_i- D_f)$ mm.

3.Explain the details the possible causes and remedial measures for Joint failures (April/May 2017)

Refer Part-B, Question .1

4. Explain any three non-destructive testing methods of pavement deflection (Nov/Dec 2017)

i. **The IDOT road rater**
ii. **The falling weight deflect meter**
iii. **Accelerometer measurements**

i) The IDOT road rater

The road rater was the main testing device used in the program. The road rater is an electro hydraulic vibrator with the capability of generating harmonic loads of up to 8kips at driving frequencies between 6 and 60 Hz. When the vibrator is set over the testing point a static preload of 5kips is applied through the 12 inch diameter circular loading plate.

The desired peak to peak load is then generated at the preselected driving frequency, and peak to peak deflections are recorded with velocity transducers. The IDOT road rater has four deflection sensors located at the centre of the loading plate, and 1, 2, and 3 feet away from the centre. The following procedure for road rater deflection measurements were used in the program:

Road rater was operated at an 8kips peak to peak load and 15 Hz driving frequency. This type of testing was performed in the first 12 sections in table 1between four and six times during the program. The same 20points, 10 in each traffic lane, 10 feet, in a 100 feet stretch of pavement were tested on every occasion. FST (frequency sweep test) selected stations were subjected to a frequency sweep test. The road rater peak to peak load was kept constant at 8 kips and driving frequency was varied in increments of 2 Hz from 6 to 30 Hz.

LFST (load frequency sweep test)the road rater was operated at peak to peak loads of 1, 2, 4, 6, and 8 kips, and the driving frequency was incremented at 2 Hz intervals from 6 to 30 Hz.

ii) The falling weight deflectometer

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The falling weight deflectometer is an deflection testing device operating on the impulse loading principle. A mass is dropped from a preselected height onto a footpath that is connected to a base plate by a set of springs. The base plate is placed in contact with the pavement surface over the testing point. By varying the drop height, the impulse load can be varied from 2 to 11 kips. The duration of the impulse loading is essentially constant ranging from 30 to 40 msec.

The falling weight deflectometer are measured with velocity transducers. One of these sensors is located at the center of the loading plate. Two additional sensors are movable and can be placed at any desired distance away from the center of the plate. During this testing program the falling weight deflectometer sensors were placed at 1, 2, and 3 feet away from the center of loading plate, the same spacing used for the road rater. Four to six load magnitudes between 2 to 11 kips were used.

iii) Accelerometer measurements

An accelerometer was implanted in the surface of selected test road section to measure deflections under moving trucks, and under the falling weight deflectometer loading plate. The accelerometer was placed in a 2 inch diameter by 2 inch depth hole in the outer wheel path. The single wire coming off the accelerometer was buried in a slot to the direction of travel.
The following trucks were used in the testing

Truck	Rear axle weight(lb)
Light	5100
Medium	9000
Heavy	18000

4. Describe the objectives of Pavement Evaluation (April/May 2018)

There are various approaches and methods of pavement evaluation. The various methods may be broadly classified into two groups:

i) Structural evaluation of pavement
ii) Evaluation of pavement surface condition

i) **Structural evaluation of pavement**

The structural evaluation of both flexible and rigid pavement may be carried out by plate bearing test. The structural capacity of the pavement may be assessed by the load carried at a specified deflection of the plate or by the amount of deflection at a specified load on the plate.

Field investigations and test carried out in various countries have shown that the performance of a flexible pavement is closely related to be elastic deflection under loads or its rebound deflection. Measurement of transient deflection of pavement under design wheel loads serves as an index of the pavement to carry traffic loads under the prevailing conditions. Assessment of flexible pavement overlay thickness requirements by Benkelman beam method. There are number of other non destructive testing techniques for assessing the load carrying capacity of pavements.

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ii) **Evaluation of pavement surface condition**

The surface condition of flexible pavement may be evaluated by the unevenness, ruts, patches and caracks.the surface condition of rigid pavement may be assessed by the cracks developed and by faulty affecting the riding quality of the pavement. The pavement unevenness may be using unevenness indicator, profilograph, profilometer or roughness cumulative scale and that gives the unevenness index of the surface in cm/km length of the road may be rough meter. Equipment capable of integrating the unevenness of pavement surface bump integrator or unevenness integrator. The pavement serviceability concept was introduced at the AASHO Road test for comparing relative performance of various test section during periods. The present serviceability of a pavement is related to a pre determined scale by a panel of judges sensitive to the wishes of motor vehicle users by actually riding over the pavement. The present serviceability rating is the mean opinion of the members of the rating panel and this is corrected with the physical measurements such as longitudinal and transverse profile of the pavement, degree of cracking and patching etc… affecting pavement serviceability. Mathematical models are evolved for determining serviceability rating of pavements based on the physical measurements made on the pavement surface.

5. Explain in details the possible causes and remedial measures for joint failure (May/June 2016)

(Refer Part-B, Question No. 1)

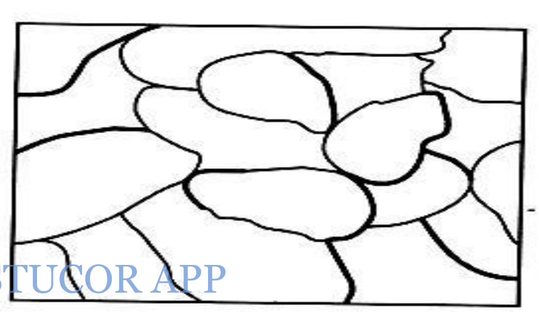
7. Explain the different types of failures in flexible pavement (April/May 2019), (April/May 2018), (Nov/Dec 2018), (Nov/Dec 2016), (Nov/Dec 2015),(April/May 2015),

Following are the some of the flexible pavement failures:

i) Alligator (map) cracking
ii) Consolidation of pavement layers
iii) Shear failure
iv) Longitudinal cracking
v) Frost heaving
vi) Lack of binding to the lower course
vii) Reflection cracking
viii) 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.



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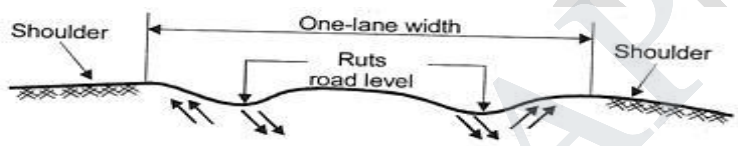
Consolidation of pavement layers

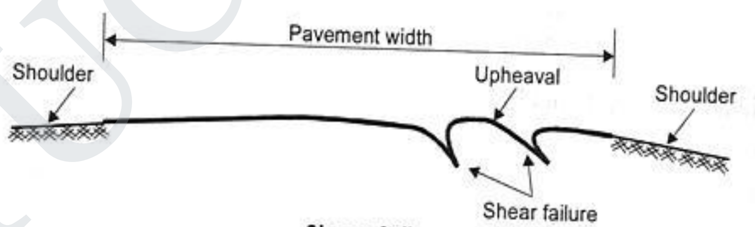
Formations of ruts are mainly attributed to the consolidation of one or more layers of pavement. The repeated application of loads along the same wheel path cause cumulative deformation resulting in consolidation deformation or longitudinal ruts. Shallow ruts on the surfacing course can also be due to 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

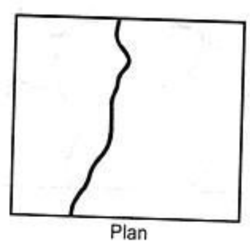
Shear failures are associated with the inherent weakness of pavement mixtures, the shearing resistance being low due to inadequate stability or excessively heavy loading. The shear failure causes upheaval of pavement materials by forming a fracture or cracking.



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

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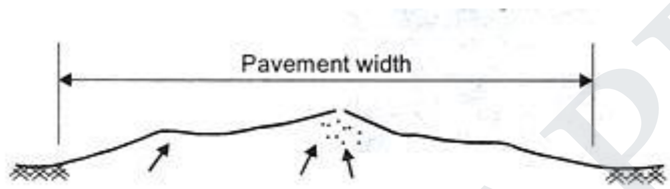
Frost heaving

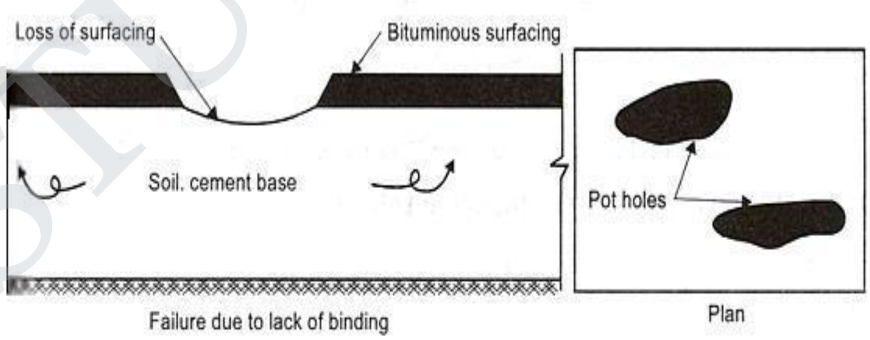
Frost heaving is often misunderstood for shear or other types of failure. In shear failure, the upheaval of portion of pavement is followed with a depression. In the case of frost heaving, there is mostly a localized heaving up pavement portion depending upon the ground water and climate conditions.



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

8. Define overlay and the procedure for design and construction of overlays (Nov/Dec 2015), (April/May 2019).

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Define overlay

It means the additional thickness of the pavement of adequate thickness in one or more layers over the existing pavement which is called overlay.

Types of overlay

The overlay combination is divided into four categories based on the type of existing pavement and the overlay.

i) **Flexible overlay over flexible pavements**
ii) **Cement concrete or rigid overlay over flexible pavement**
iii) **Flexible overlays over cement concrete or rigid pavement**
iv) **Cement concrete or rigid overlay over rigid pavement.**

(i) Flexible overlay over flexible pavement

The total thickness requirement is designed for the design traffic and the existing conditions of sub grade. Any one of the design methods is chosen for the design and appropriate strength test is carried out in the soil collected from the sub grade.

The existing thickness of the pavement is found from test pits dug along the wheel path on the pavement. The overlay thickness required is given by the relation:

$h_0 = h_d - h_c$

Where,
h_0 =overlay thickness required, cm

h_d = total design thickness required, presently determined, cm h_c = Total thickness of the existing pavement, cm

(ii) Rigid overlay over rigid pavement

When a rigid or CC is constructed over and existing rigid or CC pavement. The interface between the old and new concrete cannot have perfect n\bond such that the two slabs could act as a monolithic one.

Two typical types of interface are possible;

a. Providing maximum possible interface bond by making the old surface rough

b. Separating the two slabs at the interface by thin layer of bituminous material

To obtain the overlay thickness the following relationship may be used:

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$h_o = (ha^d - Xh_c^b)^n$

Here,

h_0= rigid pavement thickness

h_d = design thickness

h_e = existing pavement thickness.

(iii) **Flexible overlay over rigid pavement:**

A flexible overlay when provided over a rigid pavement, the wheel load is distributed through larger area by the overlay, thus slightly reducing the wheel load stress in the old rigid pavement. For calculating the thickness of flexible overlay over rigid pavement the following relationship is employed:

$h_f = 2.5\ (Fh_d - h_e)$

Here,

h_f = flexible overlay thickness

h_e=existing rigid pavement thickness

h_d= design thickness of rigid pavement

F= factor which depends upon modulus of existing pavement.

(iv) **Rigid overlay over flexible pavement:**

The thickness of rigid overlay is calculated by using the design criteria for rigid pavement as laid down, the plate bearing test is conducted on the existing flexible pavement and K value is thus obtained. The design is made for this K value and the design wheel load.

8. Explain in details the possible causes and remedial measures for joint spalling (May/June 2016)

(Refer Part-B, Question No. 1)

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9. Briefly explain the procedure of overlay design by Benkelman beam method. (April/May 2015),

The overlay thickness required h_0 may be determined after deciding the allowable Deflection D_a in the pavement under the design load. According to Ruiz's equation, overlay thickness h_0 in cm is given by:

$$h_0 = \frac{R}{0.434} \log_{10} \frac{D_c}{D_a} \text{ cm}$$

Where

h_0=thickness of bituminous overlay in cm

R=deflection reduction factor depending on the overlay material (usual values for Bituminous overlays range from 10 to 15, the average value that may be generally taken being 12)

D_a=allowable deflection which depends upon the pavement type and the desired design life, values ranging from 0.75 to 1.25mm are generally used in flexible pavements for overlay design.

The Indian road congress suggests the following formula for the design of overlay thickness equivalent to granular material of WBM layer. When superior materials are used in the overlay layer; the thickness value has to be suitably decreased taking equivalency factor of the material into consideration.

$$h_0 = 550 \log_{10} \frac{D_c}{D_a} \text{ mm}$$

Where

h_0=thickness of granular or WBM overlay in mm

D_c=(D+ρ), after applying the corrections for pavement temperature and sub grade moisture.

D_a=1.00, 1.25 and 1.5mm, if the projected design traffic A is 1500 to 4500, 450 to 1500 and 150 to 450 respectively. Here

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

When bituminous concrete or bituminous macadam with bituminous surface course is provided as the overlay, an equivalently factor o0f 2.0 is suggested by the IRC to decide the actual overlay thickness required. Thus the thickness of bituminous concrete overlay in mm will be $h_0/2$ when the value of h_0 is determined.

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10. Explain the detail about any four methods of strengthening damaged pavements (Nov/Dec 2016)

Refer Part-B, Question No. 6

11. Explain in details the pavement management system (PMS) with its effectiveness in pavement maintenance? (Nov/Dec 2018)

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

- Defects in the quality of materials used.
- Defects in construction method and quality control during construction
- Inadequate surface or subsurface drainage in the locality resulting in the stagnation of water in the sub grade or in any of the pavement layers.
- Increase in the magnitude of wheel loads and the number of load repetitions due to increase in traffic volume.
- Settlement of foundation of embankment of the fill material itself.
- Environmental factors including heavy rainfall, spil erosion, high water table, snow fall, frost action etc.
- The various items of highway maintenance works may be broadly classified under three heads:

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.

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

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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, sings.etc.

Maintenance Management System

The type and extent of maintenance requirement for a road depend on the serviceability standard laid down, the maintenance needs funds available and the priorities for the maintenance operarions.As several interlinked factors are involved in the maintenance works of road net work consisting of different categories of road, a system approach is appropriate for the road maintenance management.
The various factors to be included in the maintenance management system are:

- Minimum acceptable serviceability standards for the maintenance of different categories of roads.
- Field surveys for the evaluation of maintenance requirements.
- Various factors influencing the maintenance needs such as sub grade soil, drainage, climate, traffic, environmental conditions.
- Estimation of rate of deterioration of the pavement under the prevailing set of conditions. Type and extent of maintenance requirements and various possible alternatives and their economic evaluation.
- Availability of funds.
- Maintenance cost, availability of materials, man power and equipment.

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12. Describe about Mud Jacking.(April/May 2018)

Mud jacking is a process of lifting concrete slabs that have settled by drilling holes through the slab and pumping a sand or cement mixture under the slabs. Mud jacking allows the slab to be maneuvered back to it's original location.

Fill Voids
Frequently, foundation problems in the Metroplex are the result of the perimeter of the foundation settling. When the concrete piers are installed under the perimeter grade beam and the foundation is returned to its original position (raised), a void is

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created under the slab. In some instances, it may be necessary to fill this void to properly support the foundation. Mud jacking to fill this type of void is accomplished from the outside of your home by drilling 2″ holes through the perimeter grade beam and pumping a mixture of soil/cement grout into the void. This type of mud jacking uses a fluid mix of soil/cement grout and is not intended to raise the foundation.

Raise Interior Floors

In some situations, the interior portion of the slab foundation may have settled. Mud jacking may be used to return interior floors which have settled to their original position. Mud jacking to raise interior floors is accomplished from the inside of your home by drilling 2″ holes through the slab in the areas that have settled and pumping a mixture of soil/cement grout under the foundation. This type of mud jacking uses a stiff mix of soil/cement grout and is often associated with more complicated foundation problems. As a result, it is important to deal with experienced professionals and with a reputable company. Power Jack Foundation Repair personnel have extensive experience with the mud jacking process and monitor the work carefully while in progress. Power Jack Foundation Repair has an excellent reputation and stands behind its work.

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