CE2255- HIGHWAY ENGINEERING

(FOR IV – SEMESTER)

UNIT – I

HIGHWAY PLANNING AND ALIGNEMNT

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UNIT-I

HIGHWAY PLANNING AND ALIGNMENT

History of Road Construction, Highway Development in India - Jayakar Committee Recommendations and Realisations, Twenty-year Road Development Plans, Concepts of Ongoing Highway Development Programmes at National Level, Institutions for Highway Development at National level - Indian Roads Congress, Highway Research Board, National Highway Authority of India, Ministry of Road Transport and Highways (MORTH) and Central Road Research Institute. Requirements of Ideal Alignment, Factors Controlling Highway Alignment Engineering Surveys for Alignment - Conventional Methods and Modern Methods (Remote Sensing, GIS and GPS techniques) Classification and Cross Section of Urban and Rural Roads (IRC), Highway Cross Sectional Elements – Right of Way, Carriage Way, Camber, Kerbs, Shoulders and Footpaths [IRC Standards], Cross sections of different Class of Roads - Principles of Highway Financing

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TWO MARKS QUESTIONS AND ANSWERS

1. Define highway and highway engineering.

The term road or roadway thus constructed is therefore termed 'highway' and the science and technology dealing with road engineering is generally called 'Highway Engineering'.

2. Explain scope of highway engineering?

Scope of highway Engineering

PHASES		DETAILS
Development, planning and locations	----------	Basis for planning, engineering Surveys and highway alignment
Highway design, Geometrics & structures	----------	Road construction and their design Design of drainage system.
Traffic performance and its control	----------	Traffic studies analysis.
Materials, construction & Maintenance	----------	Maintenance of pavements and Drainage System.
Economics, finance and administration	----------	Road user cost and economic analysis of highway projects.

3) What is the usage of road statistics? And what basis it is presented?

The road statistics give an idea of the stage of road development of a country. The road statistics may be presented on the basis of area of the country or the population. The road network of this country has to be considerably increased during the development plans.

4) Give some reasons for the poor state of road development in India?

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

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

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

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

5) What are the main features in roman roads?

The main features of the roman roads are:

- They were built straight regardless of gradients.
- They were built after the soft soil was removed and a hard statum was reached the total thickness of the construction was as high as 0.75 to 1.2 meters at some places, even though the magnitude of wheel loads of animal drawn vehicles was very low.

6) What are the advantages of road transportation?

The advantages of transportation are:

- Transportation is for advancement community
- Transportation is essential for the economic and general development of the country.

7) Give the various characteristics of roadways.

- Roads are used by various types of road vehicles like passengers, cars, buses; trucks, two or three-wheeled automobiles.etc.But railway tracks are used only by rail locomotives. Waterways are used by only ships.
- Construction & maintenance of roads is cheaper than others.
- Flexibility
- For short distance travel road transport saves time.
- Road transport is the only means of transport that offers itself to the whole community alive.

8) What is mean by tresaguet construction?

Pierre Tresaguet (1716-1796) developed an improved method of construction in France by the year 1964.Tresaguet developed several methods of construction which were considered to be quite meritorious. The main feature of his proposal was that the thickness of construction need be only in the order of 30 cm.

9) What are the steps allowed in Macadam construction?

The construction steps are:

- Sub grade is compacted and prepared with a cross slope of 1 in 36 up to a desired width.
- Broken stones of a strong variety, all passing through 5 cm size sieve were compacted to a uniform thickness of 10 cm.
- The second layer of strong broken stones of size 3.75cm was compacted to thickness of 10 cm.
- The top layer consisted of stones of size less than 2cm compacted to a thickness of about 5 cm and finished so that the cross slopes of pavement surface was also 1 in 36.

10) What are the two important principles of good road construction given by John Macadam construction?

The principles of good road construction are:

- It is the native soil that supports the traffic load ultimately, and when the soil is maintained in a dry state it can carry heavy loads without settlement.
- Stones which are broken to small angulr pieces and compacted can interlock with each other and form a hard surface.

11) Comparison between Macadam & Telford construction?

The two methods have been compared here:

Macadam method	Telford method
i) The subgrade was given a cross slope of 1 in 36 to facilitate subgrade drainage.	The subgrade was kept horizontal and hence subgrade drainage was not proper.
ii) The bottom layer of pavement or the subbase course consisted of broken stones of less than 5 cm.	Heavy foundation stones of varying sizes, about 17 cm towards the edges and 22 cm towards the centre were hand packed and prepared to serve as sub base course.
iii) Base and surface courses consisted of broken stones of smaller sizes to compacted thickness of 10 and 5 cm respectively.	Two layers of broken stones were compacted over the foundation stones before laying the wearing course.
iv) The total thickness of pavement construction was kept uniform from edge t centre to a minimum value of only 25cm.	The total thickness of construction varied from about 35 cm at the edge to about 41 cm at the centre.

12) Define CRF.

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 litre 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.

13) What are the various committees and sub committees in IRC?

IRC has many committees and sub committees:

Committee:

- Bituminous committee
- Cement concrete committee
- Road Transport Development committee
- Research organization committee
- Transport operation cost committee
- Specification standard committee

Sub Committee:

- Cement road concrete surfacing
- Education of road engineers
- Soil research
- Traffic engineering

14) Define the objectives of Twenty year Road development plan.

The broad objectives are:
i) Provision of good communication in the rural areas is essential to check increasing urbanization.
ii) The future road system should besides serving the highly developed and agricultural areas, also take into account the needs of the semi-developed and undeveloped areas.
iii) The road length should be increased as to give a road density of 32 km per 100 sq.km

15) How do you calculate the total length of metalled road & NH & SH & MDR?

The formulas are:

$$\text{NH + SH + MDR (km)} = \left[\frac{A}{8} + \frac{B}{32} + 1.6N + 8T\right] + \text{D} - \text{R}$$

Where,

A = Agricultural area, km2
B = Non-Agricultural area
N = Number of towns and villages with population range 2001 -5000
T= Number of towns and villages with population over 5000
D = Development allowance of 15 percent of road length.
R = Existing length of railway track, km

16) What are the recommendations made by the jayakar committee?

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 fro the road users to develop a road development fund called central road fund.

17) What is mean by Bombay Road Plan?

The Second Twenty Year road development pan for the period 1961-81 was initiated by the IRC and was finalized in 1959 at the meeting of the chief engineers and the same was forwarded to the central government. This road development plan is also known as Bombay road plan.

18) Define IRC.

Instance of Central government a semi official technical body known as Indian Roads Congress (IRC). The IRC was constituted to provide a forum fro regular pooling of experience and ideas on all matters affecting the planning construction and maintenance of roads in India.

19) What are the objectives of Highway Research Board?

The objectives are IRC highway research Board is:

i) To ascertain the nature and extent of research required.
ii) To correlate research information from various organizations in India and abroad.
iii) To co-ordinate and conduct correlation services.
iv) To collect and disseminate results on research.
v) To channelize consultative services.

20) Define the main objectives of CRRI.

The main objectives are:

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.

21) Define alignment and types of alignment.

The position (or) the layout of the centerline of the highway on the ground is called the alignment.

Types:

1) Horizontal alignment
2) Vertical alignment

22) What are the requirements of ideal alignment?

The basic requirements of ideal alignment between two terminal stations are that it should be:

a) Short
b) Easy
c) Safe
d) Economical

23) What are the factors controlling highway alignment?

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

a) Obligatory points
b) Traffic
c) Geometric design
d) Economics
e) Other considerations

In hill roads additional care has to be given for

a) Stability
b) Drainage
c) Geometric Standards
d) Resisting Length

24) What are the stages in engineering surveys?

The stages of engineering surveys are:

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

25) What are the classifications of urban roads?

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

- Arterial roads
- Sub-arterial roads
- Collector roads
- Local roads

26) Define landwidth.

Right of Way is the area of land acquired for the road, along its alignment. The width of this required land is known as landwidth.

27) What is mean by Traffic lane?

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.

28) Define camber (or) cross slope.

Cross slope (or) camber is the slope provided to the road surface in the transverse direction to drain off the rainwater from the road surface.

29) Define kerbs and types of kerbs.

Kerbs indicate the boundary between the pavement and shoulder (or) sometimes islands or foot path or kerbs parking space. Kerbs may be divided into three groups:

i) Low (or) mountable types kerbs
ii) Semi-barrier types kerbs
iii) Barrier type kerbs.

30) What are the urban applications of remote sensing & GIS?

The urban application of remote Sensing and GIS are:

- In creating construction material Inventions
- Engineering soil mapping
- Slope stability studies
- Highway planning and highway engineering
- Power line location
- Pipe line location
- Site surveys for town planning

31) What are the objectives of NHAI?

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.

32) What are the classifications of non-urban roads in India?

The classifications are:

- National highways (NH)
- State highways (SH)
- District highways (DH)
- Major district roads
- Other district roads
- Village roads (VR)

33) Give the various steps in new project work.

The Various steps are:

- Map study
- Reconnaissance survey
- Preliminary survey
- Location of final alignment
- Detailed survey
- Materials survey
- Design
- Earth work
- Pavement construction
- Construction controls

34) Define Perception.

Perception is the process of perceiving the sensations received through the sensory organs, such as the eyes, ears, skin, nose and the brain. It is recognition of the sensations and becoming aware of the information transmitted.

35) Comparison between First and second 20 year road plans.

The comparison is:

First 20 year plan	Second 20 year plan
1) It divides the area into two categories namely,1) agricultural 2) Non agricultural	It divides the area into three categories namely 1) Developed and agricultural 2) Semi developed 3) Undeveloped
2) The towns have been divided into six population ranges with Max as 5000 & above.	The towns have been been divided into nine population ranges with Max as 100000 above.
3) It allowed deduction for the length of railway track	It did not allowed deduction for the length of railway track.
4) The development allowance was taken as 15 % of road length	The development allowance was taken as 5 % of road length.

16 Marks Questions and Answers

1) Briefly explain about advantages and disadvantages of road transport?

Wide Geographical Coverage provided by roads:

Roads can be constructed to penetrate the interior of any region and to connect remote villages. The advantage becomes particularly evident when planning the communication system in hilly regions and sparsely populated areas.

Low Capital investment:

Roads can be constructed at comparatively lower initial cost than railways. The cost of roads varies with specifications, but even the best road is cheaper than a railway line.

Quick and assured deliveries:

Time is great value for a wide range of articles; including both perishables and high value is manufactured products. Road transport by its quick deliveries reduces the need for larger inventories and locking up of working capital a great cost.

Flexibility:

Road transport offers a flexible service, free from fixed schedules. Any number of trucks or buses can be pressed into service quickly to meet sudden demand or withdrawn .Such a flexibility is absent in railways, which operate generally according to fixed schedules.

Door-to-door services:

Road transport offers door-to-door service, free from transshipments from origin to destination. Railways on the other hand have to depend upon road transport for picking up loads and making deliveries.

Simpler packaging:

Road transport permits simpler packaging and crating for the protection of goods against breakage.

Personalized service:

A personal touch is generally present in road transport. The customer is given in individualized attention in various matters.

Employment potential:

Road transport has a high employment potential. This is an important factor in a country with a large and employment problem.

Personalized travel:

Travel by private car or motorized two wheeler or even a cycle, satisfies personal pleasures.
This is one of the main reasons for the popularity of personalized travel mode in the developed countries.

Short hauls:

For short hauls transport is there only economical means if a major project is to be constructed and is the construction materials have to be transported through short distances one turns only to road transport.

Safety:

One of the serious advantages of road transport is its poor record of safety. Road accidents have become a serious menace, claiming enormous economic loss to the nation.

Environmental pollution:

Road transport has been one of the major causes for environmental pollution, noise fumes, vibration, loss of aesthetics, ribbon development these are the some ill effects.

Parking problem:

Road transport has caused parking problem of serious proportions in city streets.

Long hauls:

It has been found that most commodity movements are cheaper by road for short hauls up to 300-350 kms, but beyond this range, the cost advantage lies with the railways.

Energy:

Road transport consumes greater energy per passenger km and tonne km than railways.

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

Tresaguet construction:

*) Pierre Tresaguet (1716-1796) developed an improved method of construction in France by the year 1964.The main feature of his proposal was that the thickness of construction need be only in the order of 30 cm.

*) Tresaguet was the inspector General of roads in France from 1775 to 1785.So his method of construction was implemented in that country in 1775.

*) The typical cross section of tresaguets road construction is given in fig. and the construction steps may be enumerated as below.

i) The sub grade was prepared and layers of large foundation stones were laid on edge by hand. At the two edges of the pavement large stones were embedded edge wise to serve as submerged kerbs stones.
ii) The corners of the heavy foundation stones were hammered and then the interstices filled with smaller stones.
iii) The top-wearing course was made of smaller stones and compacted to a thickness of about 5 cm at the edges and gradually increased towards the center.
iv) The shoulders were also provides cross slope to drain the surface water to the side drain.

Macadam Construction

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

i) The importance of sub grade drainage and compaction were recognized and the sub grade was compacted and was prepared with a cross slope of 1 in 36.
ii) Macadam was the first person to suggest the heavy foundation stones are not at all necessary to be placed at the bottom layer of construction.
iii) Though the total thickness of construction was less than previous methods. This technique could serve the purpose in a better way.
iv) The size of broken stones for the top layer was decided based on the stability under animal drawn vehicles.

Macadam's method is the first method based on scientific thinking
The construction steps are:

i) Sub grade is compacted and prepared with a cross slope of 1 in 36 up to a desired width.
ii) Broken stones of a strong variety, all passing through 5 cm size sieve were compacted to a uniform thickness of 10cm.
iii) The second layer of strong broken stones of size 3.75 cm was compacted to thickness of 10 cm.
iv) The top layer consisted of stones of size less than 2 cm compacted to a thickness of about 5 cm. The cross slope of pavement surface was also 1 in 36.

3) Explain the sketches the various factors controlling the alignment of roads.

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.

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.

*) 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.

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) Does the roads in India perform the role in achieving speedy economic development?

Roads in India perform a variety of roles in achieving speedy economic development. Some of the important aspects are discussed below:

Connection to villages:

India is a country having 590,000 villages, scattered into small habitations and often located in the extreme interior. Thus social uplift, health and education of the village population is aided by roads.

Communications in hilly terrain:

For the hill states located along the Himalayan range, communication facility is possible only by roads because of the steep terrain involved.

Strategic importance:

The defence of the northern, north-eastern and western borders of the country is dependent to a large extent on the road system.

Helps agricultural development:

Roads have fostered quicker agricultural development facilitating movement of modern inputs such as fertilizers and high yielding seeds.

Helps dairy development:

Since the cattle wealth of the nation is concentrated in innumerable villages and small habitations, the collection and processing of surplus milk only because of roads.

Forestry development:

The forest wealth of the country is being exploited mainly because of the roads which penetrate in to the thick jungles.

Fisheries Development:

The Development of the fisheries along the coast line has been rendered possible because of the construction of link roads leading to the coast.

Tourism Development:

Some of the ancient monuments, religious places, natural parks and sanctuaries are accessible only roads. Tourism, both domestic and international, has been greatly aided by roads serving such as places of interest.

Employment:

As already stated, roads and road transport provide employment to a large number of people in the country. Since road construction involves labour intensive techniques in India, the large unemployed labour force gets gainful employment.

Famine and flood relief:

Roads have helped operations pertaining to flood and famine relief. The affected people are frequently employed on road construction to build durable assets.

Administrative convenience:

Roads have helped the effective administration of this large country. Maintenance of law and order and dispensation of justice have been aided by roads. National integration and cohesion have been brought about by roads which traverse the length and breath of the country and which link people from different parts together.

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

The stages of the engineering surveys are:

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

Map study: -

*) In the topographic map, to suggest the likely routes of roads. In India topographic maps are available from the survey of India with 15 or 30-meter contour intervals.

*) The main feature like rivers, hills, and valleys etc. The probable alignment can be located on the map from the following details available on the map.

- 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.

- 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.

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.

Preliminary survey: -

The main objectives of the preliminary surveys are:

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

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

*) **Primary survey: -**

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

*) **Topographical features: -**

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

*) **Leveling work: -**

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

*) **Drainage studies: -**

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

*) **Soil survey: -**

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

*) **Material survey: -**

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

*) **Traffic survey: -**

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

Final location and detailed survey: -

The alignment finalized at the design office after the preliminary survey is to be first located on the field by establishing the centerline. The detailed survey should be carried out for collecting the information technology for the preparation of plans and construction details.

Location: -

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

Detailed survey: -

*) Levels along his final centerline should be taken at all staked points. 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.

6) Discuss the Twenty-year road plan and its features?

The first attempt for proper planning of the highway development programme in India .On a long term basis was made at the Nagpur conference in 1943.The second twenty year plan was drawn for the period 1961-81.The third twenty year road development plan for the period 1981-2001 was approved only by the year 1984.

Nagpur road plan (or) First 20-year road plan: -

The conference of civil engineer held at nagpur in 1943 finalized the first twenty year road development plan for India called Nagpur plan the period 1943-63.The road network in the country was classified into five categories.

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

Two-plan formulas were finalized at the Nagpur conference for deciding two categories of road length for the country as a whole as well as for individual areas. The two plan formula assumed the star and Grid pattern of road network.

The total length of the first category or metalled roads for national and state Highways and major District Roads in lm is given by the formula:

$$NH+SH+MDR\ (km) = \left[\frac{A}{8} + \frac{B}{32} + 1.6N + 8T\right] + D\text{-}R \qquad (2.1)$$

Where

A=Agricultural area, km2
B = Non-agricultural are, km2
N=Number of towns and villages with population range 2001-5000
T= Number of towns and villages with population over 5000
D= Development allowance of 15 percent of road length calculated to be provided for agricultural and industrial development during the next 20 years.
R= Existing length of railway track, km.

The total length of second category roads for other District road and village Roads in km is given by the formula:

$$ODR + VR\ (km) = [0.32\ V + O.8\ Q + 1.6\ P + 3.2\ S] + D \qquad (2.2)$$

Where,

V = Number of villages with population 500 or less
Q = Number of villages with population range 501-1000
P = Number of villages with population range 1001-2000
S = Number of villages with population range 2001-5000
D = Development allowance of 15 % for next 20 years.

From the above two formulae. It may be seen that in addition to the road length based on agricultural and non-agricultural areas, specific road length were allocated for towns and villages of different population ranges.

Salient Features of Nagpur Road Plan:

1) The responsibility of construction and maintenance of national highways was assigned to the central government.
2) It was a 20-year plan intended for the period 1943-63 aiming to provide for about two-lakh km of surfaced roads and remaining unsurfaced roads.
3) The formulae were based on star and grid pattern of road network. But the existing irregular pattern of roads and obligatory points not fitting in the geometric pattern were to be given due consideration.
4) The second category roads are meant to provide internal road system linking small villages with first category roads.
5) An allowance for agricultural and industrial development during the next 20 years was estimated as 15 percent and this allowance was to be provided while calculating the road length for both the categories of roads.

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 sub committee and this was approved by the Chief Engineers. The Second Twenty Year Road Development plan 1961-81 is also Called Bombay Road Plan.

Five different formulae were framed to calculate the lengths of NH, SH, MDR, ODR, VR.

These five formulae are given below:

a) National highway (km)

$$\left[\frac{A}{64} + \frac{B}{80} + \frac{C}{96}\right] + [32\,k + 8\,M] + D \qquad (2.3)$$

b) National Highways + State Highways (km)

$$\left[\frac{A}{20} + \frac{B}{24} + \frac{C}{32}\right] + [48\,k + 24\,M + 11.2\,N + 1.6\,P] + D \qquad (2.4)$$

c) National Highways + State Highways + Major district roads (km)

$$\left[\frac{A}{8} + \frac{B}{16} + \frac{C}{24}\right] + [48\,k + 24\,M + 11.2\,N + 9.6\,P + 6.4\,Q + 2.4\,R] + D$$

d) National Highways + State Highways + Major district roads + Other District roads (km)

$$\left[\frac{3A}{16} + \frac{3B}{32} + \frac{C}{16}\right] + [48\,k + 24\,M + 11.2\,N + 9.6\,P + 12.8\,Q + 4\,R + 0.8\,S + 0.32\,T] \quad (2.6)$$

e) National Highways + State Highways + Major district roads + Other District roads +Village roads

$$\left[\frac{A}{4} + \frac{B}{8} + \frac{C}{12}\right] + [48\,k + 24\,M + 11.2\,N + 9.6\,P + 12.8\,Q + 5.9\,R + 1.6\,S + 0.64\,T \quad 0.2\,V] + D$$

Where

A= Developed and agricultural areas; km2
B = Semi-Developed area, km2
C = Undeveloped area, km2
K = Number of towns with population over 1,00,000
M = Number of towns with population range 1,00,000-50,000
N = Number of towns with population range 50,000-20,000
P = Number of towns with population range 20,000-10,000
Q = Number of towns with population range 10,000-5,000
R= Number of towns with population range 5,000-2000
S = Number of towns with population range 2,000-1,000
T = Number of towns with population range 1000-500
V = Number of towns with range below 500
D = Development allowance of 5 percent of road length calculated for further development and other unforeseen factors.

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.

Third Twenty-Year Road Development Plan 1981-2001: -

Policies and objectives:

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

a) Thefeatureroaddevelopment should be based on the revised classification of road system consisting of primary, secondary and tertiary road systems.
b) The road network should be developed so as to preserve the rural oriented economy and to develop small towns with all the essential facilities.
c) The overall road density in the country should be increased to 82 km per 100-sq.km areas by the year 2001.
d) The national highway network should be expanded to form square grids of 100 km sides so that no part of the country is more than 50 km away from a NH.
e) The lengths of SH and MDR required in a state or region should be decided based on both areas and number of towns with population above 5,000 in the state or region.
f) Expressways should be constructed along major traffic corridors to provide fast travel.
g) Roads should also be built in less industrialized areas to attract the growth of industries.
h) There should be improvements in environmental quality and road safety.

7) Compare the Nagpur road plan and the second twenty-year road plan discuss the merits of each: -

Nagpur plan	Twenty year road plan
It gives the two formulae, one is to find the length of first category roads consisting of NH, SH, Major District roads. Second is to find the length of secondary category roads are consisting of other district roads and village roads.	In the Second 20 year Road plan five different formulae have been given from which the length of each class of road (i.e.) NH, SH, MDR, ODR and VR.
Nagpur road plan divides the area into two parts. i) Agricultural area ii) Non Agricultural area	In Bombay road plan, the area is divided into three parts. a) Developed and agricultural area b) Semi-developed area c) Undeveloped and uncultivated area
It has double the Nagpur plan target.	It has a target road length of 32 km per 100-sq.km areas.
This formula does not take into account the towns with very large population	In this plan, towns have been divided into nine different population ranges from less than 500 for the smallest town (or) villages to above 1, 00, 000 for largest towns.
Nagpur road plan allowed deduction of the length of railways track in the area while calculating the length of first category roads.	In the Bombay road plan the length of railway track is not deducted.
Allowance for development of agriculture and industry during the next 20 years was made in nagpur plan by allowing 15 percent.	The allowance for development due to unforeseen factors according to the second plan is only 5 percent.

*) The length of various categories of roads as per the targets of Bombay road plan of 1961-81 and the road lengths achieved by the year 1981.
*) The length of NH, SH and MDR achieved by the year 1981 fell short of the plan targets.
*) The length of ODR and VR achieved were however much higher.

8) Write short notes on:

i) Right of way
ii) Carriage way
iii) Camber
iv) Kerbs

Right of way:

***)** Right of way is the area of land acquired for the road along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development.

*) A minimum land width has been prescribed for each category of road. The land width is governed by the following factor:

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

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

iii) Side slopes of embankment (or) cutting which depend on the height of the slope. Drainage system and their size. Which depends on the rainfall, topography and runoff.

Carriage way (or) Width of pavement:

*) 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 0f 3.5m per lane is considered sufficient.

*) The maximum width of vehicle as per IRC specification is 2.44m.If a single carriageway of width 3.8m is provided, a side clearance of 0.68m would be obtained in fig.

*) In the case of two lane pavement of width 0.7m a minimum clearance between two lanes of traffic would be 1.06m for the widest vehicles on the road. The number of lanes required in a highway depends on the predicted traffic volume and the design traffic volume of each lane.

Camber:

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

i) To prevent the entry of surface water into the sub grade soil through pavement.

ii) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping.

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

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

*) The required camber of a pavement depends on:

i) The type of pavement surface

ii) The amount of rainfall

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

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

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

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

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

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

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

Kerbs:

*) Kerbs indicate the boundary between the pavement and shoulder (or) sometimes island or foot path or kerb parking space.

*) There are variety of kerb designs; kerbs may be mainly divided in to three groups based on their functions.

i) Low (or) mountable type kerbs which though encourage traffic to remain in the through traffic lanes, yet allow the driver to enter the shoulder area with little difficulty. This type of kerb is provided at medians and channelization schemes and is also useful for longitudinal drainage system.

ii) Semi-barrier type kerb is provided on the periphery of roadway where the pedestrian traffic is high.

This type of kerb has a height of about 15cm above the pavement edge with a batter of 1:1 on the top 7.5 cm.This kerb prevents encroachment of parking vehicles. But at acute emergency it is possible to drive over this kerb with some difficulty.

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

PART-C

ASSIGNMENT QUESTIONS

1) Describe any three factors controlling alignment of roads? (**Dec 2007, June 2007, June 2009)**

2) What are the objectives of the four stages of engineering surveys**? (Dec 2007, June 2009)**

3) Explain any one ongoing road development programmes in India**? (Dec 2009, May 2008)**

CE2255- HIGHWAY ENGINEERING

(FOR IV – SEMESTER)

UNIT-II

GEOMETRIC DESIGN OF HIGHWAYS

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UNIT II

GEOMETRIC DESIGN OF HIGHWAYS

Design of horizontal alignments-super elevation widening of pavements on horizontal curves and transition curves [derivation of formulae and problems] Design of vertical alignment rolling, limiting, exceptional and minimum gradients, and summit and valley curves. Sight distance-Factors affecting sight distance-PIEV theory, stopping sight distance(SSD),overtaking sight distance(OSD) sight distance at ntersctions,intermediate sight distance and Illumination sight distance. Geometric Design of hill roads.

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PART C
ASSIGNMENT QUESTIONS

1) What are the various design factors controlling the vertical alignment on highways? (Dec 2007)

2) Explain the factors to be considered in deciding the stopping sight distance at intersections.(Dec 2007)

3) State factors on which the overtaking sight distance depends. Explain briefly. (Jun 2006)

4) Explain the procedure for calculating the length of valley curve for rider comfort and stopping sight distance? ((Dec 2009), (June 2006)

5) Describe the factors affecting the sight distance in hill roads. (June 2007)

Two Marks Questions and Answers

1) What is mean by geometric design?

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

2) What are the elements in geometric design?

Geometric design of highways deals with:

i) Cross section elements
ii) Sight distance considerations
iii) Horizontal alignment details
iv) Vertical alignment details
v) Intersection elements.

3) What are the design factors are allowed in geometric design?

The important of these factors which control the geometric elements are:

a) Design speed
b) Topography
c) Traffic factors
d) Design hourly volume and capacity
e) Environmental and other factors

4) Define design speed.

The design speed is the most important factors controlling the geometric design elements of highways. The design speed is decided taking into account the overall requirements of the highway. The design speed standards are modified depending upon the terrain or topography. Design of almost every geometric design element of a road is dependent on the design speed.

5) What are the factors considered in horizontal alignment?

There are various design factors to be considered in the horizontal alignment are design speed, radius of circular curves, type and length of transition curves,superelevation and widening of pavement on curves.

6) Define the formula for centrifugal force?

$$P=Wv^2/gr$$

P= Centrifugal force

W=Weight of the vehicle

R=radius of circular curve

V=speed of vehicle

g= Acceleration due to gravity.

7) What is meant by centrifugal ratio, and effects of ratio?

The ratio of the centrifugal force to the weight of the vehicle, p/w is known as the centrifugal ratio (or) the impact factor. The centrifugal ratio is thus equal to V^2/gr.The effects are:

i) Tendency to overturn the vehicle outwards about the outer wheels.

ii) Tendency to skid the vehicle laterally.

8) Define superelevation?

The effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as superelevation.

9) Explain the analysis of superelevation?

The forces acting on the vehicle while moving on a circular curve of radius R meters, at speed of Vm/sec.

i) The centrifugal force $P=Wv^2/gr$ acting horizontally outwards through the center of gravity,CG

ii) The weight W of the vehicle acting vertically downwards through the CG.

iii) The frictional force developed between the wheels and the pavement counteractions, transversly along the pavement surface towards the center of the curve.

10) Define the two parts of attainment of superelevation?

The attainment of superelevation may be split up into two parts.

a) Elimination of crown of the cambered section.

b) Rotation of pavement to attain full superelevation.

11) Define the formula for Mechanical widening?

The widening required to account for the off tracking due to the rigidity of wheel based is called Mechanical widening (Wm) and may be calculated as given below:

R_1= Radius of the path traversed by the outer rear wheel, m

R_2= Radius of the path traverse by the outer front wheel, m

W_m= off tracking (or) the mechanical widening

L= length of wheel base, m

$W_m = OC - OA = OB - OA = R_2 - R_1$

From

OAB, $OA^2 = OB^2 - BA^2$

$R_1^2 = R_2 - Wm$

$(R_2 - Wm^2) = R_2^2 - l^2$

(ie) $R_2^2 - 2 R_2 Wm + Wm^2 = R_2^2 - l^2$

$l^2 = Wm (2 R_2 - Wm)$

$Wm = L^3 / 2R_2 - Wm$

$= L^2/2r$

12) What are the functions allowed in horizontal transition curve?

The functions are:

a) To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve.
b) To enable the driver turn the steering gradually for his own comfort and security.
c) To enable gradual introduction of the designed superelevation and extra widening of pavement.
d) To improve the aesthetic appearance of the road.

13) What are the different types of transition curves?

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

i) spiral(also called clothoid)
ii) lemniscate.
iii) Cubic parabola.

14) Define gradient.

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

15) What are the categories allowed in gradients?

Gradients are divided into following categories.

i) Ruling gradient

ii) Limiting gradient

iii) Exceptional gradient

iv) Minimum gradient

16) Define vertical curves and categories of vertical curves?

The vertical alignment of highway it is necessary to introduce vertical curve at the intersections of different grads to smoothen out the vertical profile and thus ease off the changes in gradients for the fast moving vehicles.

Categories: a) Summit curves (or) crests curves with convexity upwards.

b) Valley (or) sag curves with concavity upwards.

17) What is mean by sight distance?

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

In otherwords sight distance is the length of road visible ahead to the driver at ay distance.

18) Define SSD.

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

19) What is mean by OSD?

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

20) What are the four parts of PIEV theory?

The parts are:

i) Perception

ii) Intellection

iii) Emotion

iv) Volition

16 Marks Questions and Answers

1) Briefly explain the design of horizontal alignment?

Various design factors to be considered in the horizontal alignment are design speed, radius of circular curves, type and length of transition curves, superelevation and widening of pavement on curves.

Design speed:

*) The design speed is the main factor on which geometric design elements depends. The sight distance, radius of horizontal curve, superelevation extra widening of pavement, length of horizontal transition curves and the length of summit and valley curve are all dependent on design speed.

*) The design speed of roads depends upon

i) Class of the road ii) terrain

*) The speed standards of a particular class of road thus depends on the classification of the terrain.

*) The terrains have been classified as plain,rolling,mountainous and steep, depending on the cross slope of the country.

Horizontal curves:

*) A horizontal highway curve is a curve in plan to provide change in direction to the central line of a road.

*) When a vehicle traverses a horizontal curve, the centrifugal force acts horizontally outwards through the centre of gravity of vehicle.

*) The centrifugal force P is given by:

$$\mathbf{P=Wv^2/gr}$$

P= Centrifugal force

W=Weight of the vehicle

R=radius of circular curve

V=speed of vehicle

g= Acceleration due to gravity.

*) The ratio of the centrifugal force to the weight of the vehicle/w is known as centrifugal ratio.It is equal to v^2/gr.The horizontal curve has two effects:

i) Overturn the effects

ii) Transverse skidding effect.

Radius of Horizontal curve:

***)** The centrifugal force is dependent on the radius of the horizontal curve. The centrifugal force which is counteracted by the superelevation and lateral friction is given per eq; g=127

$$e + f = V^2/gr = v^2/ 127r$$

*) In this equation the maximum allowable superelevation rate has been fixed as 7 percent or 0.07 and the design coefficient of lateral friction 'f' is taken as 0.15.

$$e + f = 0.07 + 0.15 = 0.22$$

*) Thus the ruling minimum radius of the curve for ruling design speed Vm/sec (or) V/kmph is given by:

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

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

*) The absolute minimum radius of horizontal curve R_{min} is given by:

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

Horizontal transition curves:

***)** A transition curve has a radius which decreases from infinity at the tangent point to a designed radius of the circular curve. The rate of change of the radius of the transition curve will depend on the equation of the curve or its slope.

*) Thus the functions of transition curves in the horizontal alignment of highway may be summed up into the following points.

a) To introduce gradually, the centrifugal force between the tangent point and the circular curve.

b) To enable the driver turn the steering gradually for his own comfort and security.

c) To improve the aesthetic appearance of the road.

Different types of transition curves:

i) Spiral

ii) Lemniscate

iii) Cublic parabola.

2) Derive an expression for finding length of transition curve on horizontal alignment of highways?

The length of transition curve is designed to fulfill three conditions.

i) Rate of change of centrifugal acceleration to be developed gradually.

ii) Rate of introduction of the designed superelevation to be at a reasonable rate.

iii) Minimum length by IRC formula.

Rate of change of centrifugal acceleration:

***)** At the tangent point the centrifugal acceleration (v^2/r) is zero at the radius R is infinity. At the end of transition radius R.

*) Hence the centrifugal acceleration is distributed over a length Ls of the transition curve. Let the length of transition curve be Ls meter. If't' is the time taken in seconds to transverse the transition length at uniform design speed of Vm/sec, t=Ls/v.

The rate of change of centrifugal acceleration 'c' is given by

$C= V^2/r.t=V^2/RLs/v$

$C=V^2/Ls.r$ (m/sec^3) ---------- (1)

The IRC has recommended the following equation for finding the value of C for the design speed Vkmph.

$C = 80/(75+v)$ (m/sec^3)---------- (2)

Once the value of C is decided based on the design speed as given above the length of the transition curve Ls, can be calculated from eq.1

$Ls=V^3/CR$ ---------- (3)

If the design speed is Vkmph,

$Ls=V^3/(36)^3CR$

$Ls=V^3/46.5\ R=0.0215V^3/CR$ ---------- (4)

Hence,

L=length of transition curve

C=Allowable rate of change of centrifugal acceleration,m/sec^3

R=radius of the circular curve

Rate of introduction of superelevation:

If a high value of superelevation is to be introduced, it is not desirable to raise the outer edge of a pavement at a larger rate than 1 in 150 relative to the grade of the center line.

Let E be the rate of superelevation designed and normal pavement width W.Let We be the extra widening provided at the circular curve so that the total width of B pavement =(W +We)

Hence allowing a rate of change of superelevation of 1 in N,the length of transition curve Ls given by:

Ls=EN/2=EN/2 (W+We)

Empirical formula:

The length of horizontal transition curve Ls should not be less than the value given by the following equations for the terrain classification.

a) <u>For plain and rolling terrain</u>

$Ls=2.7V^2/R$ ---------- (1)

b) <u>Mountainous terrain</u>

$Ls=V^2/R$ ---------- (2)

The design steps are the transition curve:

a) Find the length of transition curve based on allowable rate of change of the centrifugal acceleration.
b) Find the length of transition curve based on rate of change of superelevation
c) Check for the minimum required value of Ls.
d) Adopt h highest value of Ls given by the transition curve.

The length of transition curve Ls required on a horizontal highway curve depends the following factors.

i) Radius of circular curve,R,
ii) Design speed V
iii) Allowable rate of change of centrifugal acceleration
iv) Maximum amount of superelevation
v) Allowable rate of introduction of superelevation, which depends on the terrain.

3) i) Explain superelevation?

ii) Explain maximum and minimum superelevation?

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

$$E=NL/ML=\tan\theta$$

Hence $e=\tan\theta \approx \sin\theta=E/B$ which is measured as the ratio of the relative elevation of the outer edge, E to width of pavement, B.

Analysis of superelevation:

The forces acting on the vehicle while moving on a circular curve of radius R meters at speed of Vm/sec are,

i) The centrifugal force $P=Wv^2/gr$ acting horizontally outwards through the center of gravity,CG

ii) The weight W of the vehicle acting vertically downwards through the CG.

iii) The frictional force developed between the wheels and the pavement counteractions.

In the fig. considering the equilibrium of the components of forces acting parallel to the plane (p cos ɵ), the component of centrifugal force is opposed by (w sinɵ), the component of gravity and the frictional forces Fa and Fb.

For equilibrium condition

$$P \cos\theta = W \sin\theta + Fa + Fb$$

The limiting equilibrium is reached when the full values of the frictional forces are developed and the values Fa and Fb each their maximum value of F x R_b and F x R_a respectively, where 'f' is the coefficient of lateral friction and R_a and R_b are the normal reactions at wheels A and B.

$$P \cos\theta = w \sin\theta + f (R_a + R_b)$$

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

(ie) $P (\cos\theta - f \sin\theta) = w \sin\theta + f w \cos\theta$

Dividing by W cosɵ

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

$$P/w = \frac{\tan\theta + f}{1 - f \tan\theta}$$

The value of (1- f tan ɵ) in the above equation is equal to 0.99 and may be approximated

$$P/w \approx \tan\theta + f = e + f$$

$$P/w = V^2/gr$$

$$e + f = V^2/gr$$

Where

E= rate of superelevation

F=design value of lateral friction

V= speed of the vehicle

G=Acceleration due to gravity

ii) Minimum Superelevation

*) The minimum superelevation to be provided on horizontal curve may be limited to the camber of the surface.

*) In the camber is maintained from outer to inner edge of pavement at the circular curve. In very flat curves with large radius the centrifugal force developed will be very small

*) Though this practice will cause a negative superelevation on the outer half of the pavement due to normal camber.

*) The centrifugal force together with this negative superelevation would be considerably less than the allowable friction coefficient on such curves.

*) The IRC recommendation giving the radius of horizontal curves beyond which normal cambered section may be maintained and no superelevation is required for curves.

Maximum superelevation:

***)** The value of superelevation needed increases with in speed and with decrease in radius of the curve for a constant value of coefficient of lateral friction 'f'.

*) In the case of heavily bullock carts and trucks carrying less dense materials like straw or cotton, the center of gravity of the loaded vehicle will be relatively high.

*) Hence to avoid the danger to toppling of such loaded slow moving vehicles, it is essential to limit the value of maximum allowable superelevation.

*) However, on hill roads not found by snow a maximum superelevation upto 10 percent has been recommended. On urban road stretches with frequent intersections, it may be necessary to limit the maximum superelevation to 4.0 % keeping in view the convenience in construction and that of turning movements of vehicles.

4) Explain sight distance and the significance of stopping and overtaking sight distance?

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

Sight distance required by drivers applies to both geometric design of highways and for traffic control. The sight distance situations are considered in the design.

i) Stopping or absolute minimum sight distance

ii) Safe overtaking or passing sight distance

iii) Safe sight distance for entering into uncontrolled intersections.

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

Intermediate sight distance:

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

Head light sight distance:

This is the distance visible to a driver during night driving under the illumination of the vehicle head lights.

Stopping sight distance:

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

The absolute minimum sight distance is therefore equal to the stopping sight distance which is also sometimes called nonpassing sight distance. The sight distance available on a road to a driver at any instance depends on,

i) Features of the road

ii) Height of the drivers eye above the road surface

iii) Height of the object above the road surface.

The distance within which a motor vehicle can be stopped depends upon the factors listed below,

a) Total reactions time of the driver

b) Speed of vehicle

c) Efficiency of breaks

d) Frictional resistance between the road and tyres.

e) Gradient of the road.

Total reaction time:

***)** Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied.

*) The total reaction time may be split up into two parts.

i) Perception time

ii) Brake reaction time.

PIEV theory:

According to this theory the total reaction time of the driver is split into four parts:

i) Perception

ii) Intellection

iii) Emotion

iv) Volition

Speed of Vehicle:

The stopping distance depends very much on the speed of the vehicle; first during the total reaction time of the driver the distance moved by the vehicle will depend on the speed.

Efficiency of brakes:

The braking efficiency is said to be 100 percent if the wheels are fully licked preventing them from rotating on application of the brakes. This will result in 100 percent skidding which is normally undesirable except in utmost emergency.

Frictional resistance between road and tyres:

The frictional resistance developed between road and tyres or the skid resistance depends on the type and condition of the road surface and the tyres. IRC has specified a design friction coefficient of 0.35 to 0.4 depending upon the speed to be used for finding the braking distance in the calculation of stopping sight distance.

Analysis of stopping distance:

i) The distance traveled by the vehicle during the total reaction time known as lag distance.

ii) The distance traveled by the vehicle after the application of the brakes is known as braking distance.

Overtaking sight distance:

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

The overtaking sight distance is the distance measured along the center of the road which a driver with his eye level 1.2m above the road surface can see the top of an object 1.2m above the road surface.

Some of the important factors on which the minimum overtaking sight distance required.

a) Speed of

i) overtaking vehicle

ii) overtaken vehicle

iii)The vehicle coming from opposite direction

b) Distance between the overtaking and overtaken vehicles; the minimum spacing depends on the steeds.

c) Skill and reaction time of the driver.

d) Rate of acceleration of overtaking vehicle

e) Gradient of the road.

Criteria for sight distance requirements on highway:

*) The absolute minimum sight distance required throughout the length of the road is the SSD which should invariably be provided at all places.

*) On horizontal curves the obstruction on the inner side of the curves should be cleared to provide the required set back distance and absolute minimum sight distance.

*) On vertical summit curves the sight distance requirement may be fulfilled by proper design of the vertical alignment.

5) While aligning a highway in built up area it was necessary to provide a horizontal circular curve of radius 325 metre, Design the following geometric features.

a) Superelevation

b) Extra widening of pavement

c) Length of transition curve

Data available are:

Design speed = 65Kmph

Length of wheel base of largest truck = 6m

Pavement width = 10.5 m

Solution:

i) superelevation

Here radius R=325 m

$E=V^2/225r = 65^2/225 \times 325 = 0.058$

As this value is less than 0.07, it is safe for the design speed.

Hence provide superelevation rate=0.058

ii) Extra widening of pavement

$We=nl^2/2r + V/9.5\sqrt{r}$

N=3 as the pavement width is 10.5m

Wheel base=6m

$We=3 \times 6^2/2 \times 325 + 65 / 9.5\sqrt{325}$

=0.016 +0.380= 0.546 say 0.05m

iii) Length of transition curve, Ls

a) By rate of change of centrifugal acceleration

Allowable rate of change of centrifugal acceleration C is

$C=10/75 + v = 80 / 76 +65=0.57$ m/sec^3

$Ls=0.0215\ V^3 / CR= 0.0215 \times 65^3/0.57 \times 325=31.9$ m

b)By rate of introduction of superelevation E

Total superelevation E= B x E

Total pavement width including extra widening on curve

B = W + We=10.5 + 0.55=11.05 m

E=0.058

E= 11.05 x 0.058=0.64 m

C) IRC formula, the minimum length

$Ls=2.7V^2/r = 2.7 \times 65^2 /325=35.1$ m.

CE2255- HIGHWAY ENGINEERING

(FOR IV – SEMESTER)

UNIT – III

DESIGN OF RIGID AND FLEXIBLE PAVEMENTS

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UNIT-III

DESIGN OF RIGID AND FLEXIBLE PAVEMENTS

Rigid and Flexible Pavements – Components and their Functions Design Principles of Flexible and Rigid Pavements, Factors affecting the Design of Pavements – ESWL, Climate, Sub-grade soil and Traffic. Design Practice for Flexible Pavements [CBR method, IRC method and Recommendations- Problems] Design Practice for Rigid Pavements [IRC Recommendations- Problems] – Joints

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Two Marks Questions and Answers

1) Define Pavement?

The Pavement consisting of a few layers of Pavement material is constructed over a prepared soil sub grade to serve as a carriageway.

One of the objectives of a designed Pavement is to keep this elastic deformation of the Pavement within the Permissible limits.

2) What are the types of Pavement Structure?

Based on the structural behaviour, Pavements are generally classified in to two categories.

i) Flexible Pavements.

ii) Rigid Pavements.

3) What is mean by Flexible Pavements?

Flexible Pavements are those, which on the whole have low or negligible flextural strength and are rather flexible in their structural action under the loads. The Flexible Pavements layers reflect the deformation of the lower layers on to the surface of the layer.

4) What are the components in Flexible Pavements?

A typical flexile pavement consists of four components

i) Soil sub grade

ii) Sub base course

iii) Base course

iv) Surface course

5) Define rigid pavement.

Rigid pavements are those, which possess note worthy flexural strength or flexural rigidity. The stresses are not transferred from grain to the lower layers as in the ease of flexible pavement layers. The rigid pavements are made of Portland cement concrete either plan, reinforced or prestressed concrete.

6) What are the functions are in pavement components?

The functions are:

1) Soil subgrade are its evaluation
    a. California bearing ratio test
    b. California resistance value test
    c. Triaxial compression test
    d. Plate bearing test.
2) Sub base and base courses and their evaluation
3) Wearing course and its evaluation

7) Define the two parts of pavement design?

Pavement design consists of two parts:

i) Mix design of materials to be used in each pavement component layer

ii) Thickness design of he pavement and the component layer.

8) What are the factors considered in design of pavements?

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

i) Design wheel load

ii) Sub grade soil

iii) Climatic factors

iv) Pavement component materials

v) Environmental factors

vi) Special factors in the design of different types of pavements.

9) Give the equation for Boussineq's theory?

The equation for vertical stress computations under a uniformly distributed circular load based on Boussineq's theory is given by:

$$\sigma_{2=} P \left[1-- \frac{Z^3}{(a^2 + z^2)^{3/2}} \right]$$

Here,

σ_2 = Vertical stress at depth Z

P=Surface pressure

Z= depth at which σ_2 is computed

a= Radius of loaded area.

10) Define the three types of pressure?

The types of pressure are:

A) Tyre pressure B) Inflation pressure C) Contact pressure

11) How to measure the contact pressure?

Contact pressure can be measured by relationship:

$$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area (or) area of imprint}}$$

12) Calculate ESWL of a dual wheel assembly carrying 2004 kg each for pavement thickness of 15,20 and 25 cm. Centre to center tyre spacing 27cm and distance between the walls of the tyres=11 cm.

Solution:

Here=2044 kg 2P= 4088kg D= 11cm S=27cm

X and Y points are plotted on a log graph between ESWL and pavement thickness

X has coordinates (P, d/2) = (2044, 5.5)
Y has coordinates (2P, 2S) = (4088, 54)

13) Define modulii.

Depending upon the design methods the elastic modulii of different pavement materials is evaluated. Mainly plate bearing test is employed for this purpose.

The elastic modulii values of the following are determined by plate bearing tests:

i) Sub grade modulus
ii) Elastic modulii of base course and sub base course materials.

14) What are the major effects in climatic variations?

The climatic variations cause following major effects:

i) Variation in moisture condition
ii) Frost action
iii) Variation in temperature.

15) What is mean by semi-empirical?

When the design is based on stress strain function and modified n\based on experience it may be called semi-empirical (or) Semi theoretical.

16) What are the design methods available in flexible pavement?

The following methods are:

i) Group index method
ii) California bearing ratio method
iii) Stabilometer method
iv) Triaxial test method
v) McLeod method
vi) Burmister method

17) Which formula is used for estimating the design traffic?

The formula is:

$$A = P\,[1 + r]^{(n + 10)}$$

Where,

A= number of heavy vehicles per day for design
P=number of heavy vehicles per day at least count
r= annual rate of increase of heavy vehicles
n= number of years between the last count and the year of completion of construction

18) Define critical load positions.

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.

19) What are the types of loading?

Interior loading --- When load is applied in the interior of the slab surface
Edge loading ----- When load is applied in an edge of the slab.
Corner loading ---- When the center of the load application is located on the bisector of the corner angle formed by two intersecting edges of the slab.

20) Define Wheel load stresses?

A.T.Goldbeck indicated that many concrete slabs failed at the corners. He derived a corner load formula due to a point load at the corner of the slab. It is given by:

$$S_c = \frac{3P}{H^2}$$

S_c = Stress due to corner load, kg/cm^2
P=Corner load assumed as a concentrated point load, kg
H=Thickness of the slab, cm

16 Marks questions and Answers

1) Briefly explain the comparison of rigid and flexible pavements?

The comparisons are:

i) Design precision

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

ii) Life

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

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

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

iii) Maintenance:

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

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

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

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

iv) Initial cost:

***)** The argument so far used against a cement concrete slab is that it is much more costly than a flexible pavement.

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

v) Stage construction:

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

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

vi) Availability of materials:

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

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

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

vii) Surface characterstics:

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

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

viii) Utility location:

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

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

ix) Glame and night visibility:

*) Concrete pavements have a gray color which can cause glam under sunlight. Colored cement can reduce the grave.

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

x) Traffic dislocation during construction:

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

xi) Environmental considerations during construction:

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

xii) Overall economy on a life cycle basis:

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

*) The comparative economy of a flexible pavement and a rigid pavement have proved that on overall economic considerations.

2) Briefly explain about types of pavement structure?

Based on the structural behavior, pavements are generally classified into three categories:

i) Flexible pavements
ii) Rigid pavements
iii) Semi rigid pavements

Flexible pavements:

***)** Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads.The flexible pavement layers reflect the deformation of the lower layers on to the surface of the layer.

*) A flexible pavement consists of four components(i) Soil subgrade (ii) sub base course (iii) base course (iv) Surface course.

*) The flexible pavement layers transmit the vertical or compressive stresses to the lower layers by grain to grain transfer through the points of contact in the granular structure. A well compacted granular structure consisting of strong added aggregate can transfer the compressive stresses.
*) The load spreading ability of this layer therefore depends on the type of the materials and mix design factors. Bituminous concrete is one of the best flexible pavements layer materials. Other materials which fall under the group are all granular materials with or without bituminous binder, granular base and sub base course materials.
*) The vertical compressive stress is maximum on the pavement surface directly under the wheel and is equal to the contact pressure under the wheel. The flexible pavement may be constructed in a number of layers and the top layer has to be strongest as the highest compressive stresses.
*) Flexible pavements are commonly designed using empirical design charts or equations taking into account some of the design factors, there are also semi empirical and theoretical design methods.

Rigid pavements:

*) Rigid pavements are those which possess note flexural strength or flexural rigidity. The stresses are not transferred from grain to grain to the lower layers as in the ease of flexible pavements layers.

*) The rigid pavements are made of Portland cement concrete plain, reinforced or prestressed concrete. The plain cement concrete slabs are expected to take up about 40 kg/cm^2 flexural stress.

*) The rigid pavement has the slab action and is capable of transmitting the wheel load stresses through a wider area below. The main point of difference in the structural behavior of rigid pavement as compared to the flexible pavement is that the critical condition of stress in the rigid pavement is the maximum flexural stress occurring in the slab due to wheel load and the temperature changes whereas in the flexible pavement .

*) As the rigid pavement slab has tensile strength, tensile stresses are developed due to the bending of the slab under wheel load and temperature variations. Thus the types of stresses developed and their distribution within the cement concrete slab are quirt different.

*) The cement concrete pavement slab can very well serve as a wearing surface as well an effective base course. The rigid pavement structure consists of a cement concrete slab, below which a granular base or sub base course may be provided.

*) Though the cement concrete slab can also be laid directly over the soil subgrade, consists of fine grained soil.

*) the rigid pavements are usually designed and the stresses are analyzed using the elastic theory, assuming the pavements as a n elastic plate resting over an elastic or a viscous foundation.

Semi rigid pavements:

*) when bonded materials like the pozzolanic concrete, lean cement concrete or soil cement are used in the base course or sub base course layer the pavement layer has considerably higher flexural strength than the common flexible pavement layers.

*) when this intermediate class of materials are used in the base or sub base course layer of the pavements, they are called semi rigid pavements.

*) This third category of semi rigid pavement are either designed as flexible pavements with some correction factors to find the thickness requirements based on experience or by using a new design approach.

*) The semi rigid pavement materials have low resistance to impact and abrasion and therefore are usually provided with flexible pavement surface course.

3) Describe the various functions of pavement components?

The functions are:

Soil sub grade and its evaluation:

*) The soil sub grade is a layer of natural soil prepared to receive the layers of pavement materials placed over it. It is essential that at no time the soil sub grade is overstressed, it means that the pressure transmitted on the top of the sub grade is within the allowable limit.

*) Many tests are known for measuring the strength properties of the sub grades. Some of the tests have been standardized for the use. The common strength test for the evaluation of soil subgrade is:

i) California bearing ratio test.
ii) California resistance value test.
iii) Triaxial compression test
iv) Plate bearing test.

California bearing ratio (CBR) test:

It is evolved for the empirical method of flexible pavement design. The CBR test is carried out either in the laboratory on prepared specimens or in the field by taking in situ measurements.

California resistance value:

It is found by using hveem stabliometer.This test is used in an empirical method of flexible pavement design based on soil strength.

Triaxial test:

It is the most important soil strength, but still the test is not very commonly used in structural design of pavements.

Plate bearing test:

It is carried out using a relatively large diameter plate to evaluate the load supporting capacity of supporting power of the pavement layers. The results are plate bearing tests are used in flexible pavement design method like McLeod method on based on layer system analysis by brumister.

Sub base and base courses and their evaluation:

*) There layers are made of broken stones, bound or unbound aggreagate,some times in sub base course a layer of stabilized soil.(or) Selected granular soil is also used.

*) however at the sub base course it is desirable to use smaller size graded aggregates. When the sub grade consists of fine grained soil and when the pavement carries heavy wheel loads.

*) Sub base course primarily has the similar function as of the base course and is provided with inferior materials than of base course. Base courses are used, under rigid pavement for

i) Preventing pumping

ii) Protecting the sub grade against frost action.

*) Thus the fundamental purpose of abase course and sub base course is to provide a stress transmitting medium to spread the surface wheel loads in such manner.

*) The sub base and base course layers may be evaluated by suitable strength or stability test like plate bearing CBR test.

Wearing course and its evaluation:

*) The purpose of the wearing course is to give a smooth riding surface that is dense. It resists pressure exerted by tyres and takes up wear and tear due to the traffic.

*) Wearing course also offers a water tight layer against the surface water infiltration. The flexible pavement normally a bituminous surfacing is used as a wearing course.

*) In rigid pavements, the cement concrete acts like a base course as well as wearing course. Most popular test in use is marshal stability test where in the optimum content of bitumen binder is worked out based on the stability density.

*) Plate bearing test and Bankelman beam test are also sometimes made use of for evaluating the wearing course and the pavement as a whole.

4) Explain the various factors to be considered in pavement design? Discuss the significance in each.

Pavement design consists of two parts:

i) Mix design of materials to be used in each pavement component layer. Thickness design of the pavement and the component layers.

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

i) Design wheel load
ii) Sub grade soil
iii) Climatic factors

iv) Pavement component layers.
v) Environmental factors
vi) Special factors in the design of different types of pavements.

Design wheel load:

The various wheel load factors to be considered in pavement design are:

i) Maximum wheel load
ii) Contact pressure
iii) Dual or multiple wheel loads
iv) Repetition of loads.

Maximum wheel load:

The wheel load configurations are important to know the way in which the loads of a given vehicle are applied on the pavement surface. Typical wheel load configurations of a tractor trailer unit of a heavy duty vehicle are shown in fig.

*) For highways the maximum legal axle load as specified by Indian road congress is 8170 kg with a maximum equivalent single wheel load of 4085 kg.

*) The evaluation for vertical stress computations under a uniformly distribute of circular load based on Boussineq's theory is given by:

$$\sigma_z = p\left[1 - \frac{z^3}{\left(a^2 + z^2\right)^{\frac{3}{2}}}\right]$$

σ_z = vertical stress at depth z
P= surface pressure

Z=depth at which σ_z computed.
A=radius of loaded area.

Contact pressure:

Generally the wheel load is assumed to be distributed over a circular area. But by measurement of the imprints of tyers with different load and inflation pressures. Three terms in use with reference to tyre pressure are:

- Tyre pressure
- Inflation pressure
- Contact pressure

Tyre pressure and inflation pressure mean exactly the same .the contact pressure is found to be more than tyre pressure when the tyre pressure is less than 7 kg/m^2 and it is vice versa when the tyre pressure exceeds this value.

Contact pressure can be measured by the relationship

$$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area or area of imprint}}$$

The general variation between the tyre pressure and measured contact pressure is shown in this fig.

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

Equivalent single wheel load (ESWL):

***)** The maximum wheel load within the specified limit and to carry greater load it is necessary to provide dual wheel assembly to the rear axles of the roads vehicles.

*) In other words the pressure at a certain depth below the pavement surface cannot be obtained by numerically adding the pressure caused by any one wheel.

*) The effect is in between the single load and two times load carried by one wheel. The load dispersion is assumed to be at an angle of 45^0.In the dual wheel load assembly let d be the clear gap between the two wheels ,S be the spacing between the centers of the wheels and a be the radius of the circular contact area of each wheel. Then S = (d + 2a).

***)** ESWL may be determined based on either equivalent deflection or equivalent stress criterian.Multiple wheel loads are convert to ESWL and this value is used in pavement design. The ESWL is usually determined by the equivalent stress criterion using a simple graphical method.

*) A straight line relationship is assumed between ESWL and depth on log scales. For determining ESWL the plot is made as shown in fig.

*) Two points A and B are plotted on the log-log graph with coordinates of A (P,d/2) and B(2p,2s),line AB is a plot which is the focus of points where any single wheel load is equivalent to a certain set of dual wheels.

*) To Calculate the ESWL for a dual assembly it is essential to estimate a design thickness of the pavement. If the design thickness so obtained is equal to the estimated thickness then the ESWL calculations could be considered as correct. Otherwise trials are made.

*) In heavy trucks and trailers the load on each wheel may be further reduced by multiple wheels and tandem axles.

Repetition of loads:

*) The deformation of load pavement (or) sub grade due to a single application of wheel load may be small. It required carrying out traffic surveys for accounting the factor of repetitions for wheel loads in the design of pavement.

*) Data collected are converted to some constant equivalent wheel loads. Equivalent wheel load is a single load equivalent to the repeated applications of any particular wheel load on a pavement which requires the same thickness and strength of pavements.

*) McLeod has given a procedure for evolving equivalent load factors for designing flexible pavements.

5) Write short notes on

i) Characteristic of pavement materials

ii) Climatic variation

Characteristic of pavement materials:

For design purpose it is required that the various pavement materials are assigned strength suitable to the design method employed for the purpose. The general strength values evaluated are:

i) California Bearing ratio value

ii) Elastic modulii

California bearing ratio:

The strength values so obtained for the materials tested are of relative significance and do not provide as absolute measure. There is design methods which employ the CBR strength value of materials used in different pavement layers.

Elastic modulii:

Depending upon the design methods the elastic modulii of different pavement materials is evaluated. Mainly plate bearing test is employed for this purpose. The elastic modulii values of the following are determined by plate bearing tests:

i) Sub grade modulus

ii) Elastic Modulii of base course and sub base course materials.

Sub grade modulus:

It is computed from the plate bearing test data.Boussinesq's settlement equation for maximum vertical deflection at the surface and the centre of a flexible plate is given by:

$$\Delta = \frac{1.5pa}{E_s} \qquad \text{---------- (1)}$$

P is the uniform pressure on the flexible loaded plate of radius a.
Es is the modulus of elasticity of the soil.

If the load is applied by means of a rigid circular plate instead of flexible one, the pressure on the surface is not uniformly distributed and so the theoretical value of maximum deflection at the surface in this case is given by

$$\Delta = \frac{1.18pa}{E_s} \qquad \text{---------- (2)}$$

If the level of design deflection is defined, then from the plate bearing test carried out on a given soil subgrade with the plate of diameter = 2a, the pressure p can be recorded from the test plots.

Subgrade modulus Es = $1.18\ \frac{pa}{\Delta}$

For computing elastic modulii of pavement materials, Brumisters elastic layered system analysis is employed. It consisting of a pavement layer of thickness h with the elastic modulus E_p laid over the subgrade is given by:

$$\Delta = 1.5\frac{Pa}{E_s}.F_2 \text{ (For flexible plate)} \qquad \text{---------- (3)}$$

$$\Delta = 1.18\frac{pa}{E_s}.F_2 \text{ (For Rigid plate)} \qquad \text{---------- (4)}$$

With known values of design deflections, yielded pressure P, subgrade modulus Es and radius of loaded area a, the value of displacement factor F_2 is obtained.

Climatic variations:

The climatic variations cause following major effects:

i) Variation in moisture condition
ii) Frost action
iii) Variation in temperature

Variation in moisture content:

***)** Considerable variations in moisture condition of sub grade soil are likely during the year depending on climatic condition soil type groundwater level and its variations drainage conditions type of pavement and shoulders.

*) The stability of the sub grade soils are decreased under adverse moisture conditions. As the moisture content of sub grade below the center is often different from that at the pavement edges, there can be differential rise or fall of the pavement edges with respect to the centre.

*)

*) These effects are likely to cause considerable damages to the pavements and will also be progressive and cumulative.

Frost action:

*) It refers to the adverse effective due to frost heave ,frost melting or thaw and the alternate cycles of freezing and throwing. The frost action in general includes all effects associated with freezing temperature on pavement performance.

*) The freezing and thawing which occur alternately due to the variation in weather causes undulations and considerable damages to the pavement. Hence the overall effects due to frost heave, frost melting and alternate freeze thaw cycles are called the frost action.

*) The various factors on which frost action depends may be broadly classified as:

i) Frost susceptible soil
ii) Depressed temperature below freezing point
iii) Supply of water
iv) Cover.

*) One of the most effective and practical methods to decrease the damaging effects due to water and frost action is to install proper surface and subsurface drainage system.

*) Another effective method is by providing a suitable capillary cut-off. It is also possible to reduce the adverse effects of frost action on pavements by soil stabilization.

*) Salts like calcium chloride (or) Sodium chloride when mixed with sub grade soil lowers the freezing temperature of the soil water and hence temporarily decreases the intensity of frost action.

Variation in temperature:

*) Variation temperature due to climatic changes my cause damaging effects in some pavements.

Temperature stresses of high magnitude are induced in cement concrete pavements consequent warping of the pavement. Bituminous pavement becomes soft in hot weather sand brittle in very cold weather.

6) Enumerate the various methods of flexible pavement design? Briefly indicate the basis of design in any three cases:

***)** 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

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 is given in fig.

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 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. The design curves are shown in this fig.

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

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

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

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 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.

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.

7) Briefly explain the type of stresses?

*) H.M.Westergaard is considered the pioneer in providing the rational treatment to the problem of rigid pavement analysis.

Wheel load stresses:

*) A.T.Goldbeck indicated that many concrete slabs failed at the corners. He derived a corner load formula due to point load at the corner of the slab.Goldbeck's formula is given by:

$$Sc = \frac{3p}{h^2}$$

Sc= stress due to corner load
P=corner load assumed as a concreted point.
H= Thickness of slab.

Westergaards stress equation for wheel loads:

The cement concrete slab is assumed to be a homogenous, thin elastic plate with subgrade reaction being vertical and proportional to the deflection. He considered three typical regions of the cement concrete pavement slab for the analysis of stresses as the interior, edge and the corner regions. The critical stresses S_i, S_e, and S_c at the typical locations.i.e. Interior, edge and corner are given in this equation:

Interior loading

$$S_i = \frac{0.316p}{h^2}\left[4\log10^{\left(\frac{l}{b}\right)} + 1.069\right]$$

Edge Loading

$$S_e = \frac{0.572p}{h^2}\left[4\log10^{\left(\frac{l}{b}\right)}\right] + 0.359$$

Corner loading

$$S_c = \frac{3p}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{1}\right)\right]$$

Here,

S_i, S_e, S_c = Maximum stress at interior, edge and corner loading respectively, kg/cm^2
h= Slab thickness, cm
p= wheel load, kg
a= radius of wheel load distribution, cm
l= radius of relative stiffness, cm
b= radius of resisting section, cm

Charts for stress computation:

***)** if the slab thickness h is to found for the allowable values of maximum stresses Si,Se and Sc trials are required for assumed values of h.

In the general formula

$$S=P/h^2\ Q$$

Evaluation of wheel load stresses for design:

The Indian roads congress recommends the following two formulas for the analysis of load stresses at the edge and corner regions and for the design of rigid pavements.

*) Westergaards edge load stress formula, modified by teller and Sutherland for finding the load stress S_c in the critical edge region,

$$S_c = 0.529\ \frac{P}{h^2}(1+0.54\mu)x\left(4\log10^{\frac{l}{b}} + \log10^{b} - 0.4048\right)$$

*) Westergaards corner load stress analysis modified by Kelley for finding the load stress S_c at the critical corner region,

$$S_c = \frac{3p}{h^2}\left[1-\frac{\left(a\sqrt{2}\right)^{\frac{1}{2}}}{l}\right]$$

Where,

S_c = load stress at the edge region, kg/cm^2
S_c= load stress at the corner region, kg/cm^2
P= design wheel load, kg
h= thickness of CC pavement slab, cm
μ =poisons ratio of the CC slab
E = modulus of elasticity of the CC, kg/cm^2

Temperature stresses:

***)** It is developed in cement concrete pavement due to variation in slab temperature. The variation in temperature across the depth of the slab is caused by daily variation whereas an overall increase (or) decrease in slab temperature.

*) The maximum difference in temperature between the top and bottom of the pavement slab may occur at some period after the mid-noon. During summer season as the mean temperature of the slab increases the concrete pavement expands towards the expansion joints.

*) During the summer season as the mean temperature of the slab increases, the concrete pavement expands towards the expansion joints. Due to the frictional resistance at the interface, compressive stress is developed at the bottom of the slab as it tends to expand.

*) Temperature thus tends to produce two types of stresses in a concrete pavement. These are:

i) Warping stresses
ii) Frictional stresses

Warping stresses:

*) Whenever the top and bottom surface of a concrete pavement simultaneously posses different temperature, the slab tends to wrap downward or upward inducing warping stresses.

*) Now, introducing the effect of poison's ratio the stresses at the interior region in longitudinal and transverse directions as given by Bradbury and expressed by the equations.

$$St_{(t)} = \frac{Eet}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

Hence,

$St_{(t)}$ = Warping stress at interior
E = Modulus of elasticity of concrete
E = Thermal coefficient of concrete
T = temperature between top & bottom of slab.
Cx = Coefficient base on Lx/L in desired direction
μ = Poisson's ratio
Cy = Coefficient based on Ly/L in right angle.

Frictional stresses:

***)** The temperature rise and fall in the cement concrete slab, there is an overall expansion and contraction of the slab.

*) Since the slab in contact with soil,subgrade or the subbase,slab movements due to the friction between the bottom layer of the pavement and the soil layer.

*) Stresses in slabs resulting due to this phenomenon vary with slab length.Equating total force developed in the cross section of concrete pavement due to movement an frictional resistance in half the length of the slab.

$$S_f \text{ x h x B x } 100 = \text{B x } \frac{L}{2} x \frac{h}{100} xWxf$$

$$S_f = \frac{WLf}{2x10^4}$$

Here,

Sf=Unit stresses developed in cement pavement
W= unit weight of concrete.
f= Coefficient of subgrade restraint
L= Slab length
B= Slab width.

8) Calculate the stresses at interior, edge and corner regions of a cement concrete pavement using Westergaards stress equations. Use the following data.

Wheel load, P = 5100 Kg
Modulus of elasticity of cement concrete, E = 3.0×10^5 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

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)

$$S_i = \frac{0.316P}{h^2}\left[4\log10^{\frac{l}{b}} + 1.069\right]$$

$$= \frac{0.316x5100}{18^2}\left[4\log10\left(\frac{70.6}{14.0}\right) + 1.069\right] = 19.3kg/cm^2$$

Stress at the edge,(S_e)

$$S_e = \frac{0.572p}{h^2}\left[4\log10^{\frac{l}{b}} + 0.359\right]$$

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

Stress at the corner (S_c)

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

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

PART-C

ASSIGNMENT QUESTIONS

1) Discuss the merits and demerits of CBR method of flexible pavement design?

(Nov 2007,Jun 2006,Dec 2009)

2) Explain the functions of components of rigid and flexible pavements. (Jun 2007)

3) Explain the necessity for providing joints in rigid pavement? (Jun 2007)

4) Discuss the factors to be considerd in the design of pavements?(Dec 2009)

5) List the typical failure of rigid pavement and explain briefly about any two.(June 2009)

CE2255- HIGHWAY ENGINEERING

(FOR IV – SEMESTER)

UNIT - IV

HIGHWAY MATERIALS AND CONSTRUCTION PRACTICE

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UNIT IV

HIGHWAY MATERIALS AND CONSTRUCTION PRACTICE

Desirable properties and testing of highway materials-[tests have to be demonstrated in highway engineering laboratory]. Soil- California Bearing ratio test, Field density test Aggregate-crushing, Abrasion, Impact tests, water absorption, flakiness and elongation indices and stone polishing value test. Bitumen –penetration, Ductility, Viscosity, Binder content and softening point tests Construction practice-water Bound Macadam road, Bituminous Road and Cement concrete road [as per IRC and MORTH specifications] Highway Drainage [IRC Recommendations]

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PART-C

ASSIGNEMENT QUESTIONS

1) Briefly explain the following tests done on Bitumen, Penetration test, specific gravity test, viscosity test, and softening point test.(Dec 2009,May 2008,June 2009)

2) Write down the construction procedure of water bound macadam road.(Dec 2009),

3) Explain how drainage in hill orads is provided. (Dec 2007)

4) Write down the importance and requirement of highway drainage system? (Dec 2009)

TWO MARKS QUESTIONS AND ANSWERS

1) Define the characteristic s of soil?

Soil consists mainly of mineral malter formed by the disintegration of rocks, by the action of water, frost, temperature, pressure or by plant or animal life. The characteristic of soil grains depend on size, shape, surface temperature, chemical composition and electrical surface changes.

2) What are the desirable properties allowed in highway materials?

The desirable properties in highway materials are:

i) Stability
ii) Incompressibility
iii) Permanency of strength
iv) Minimum changes in volume and stability
v) Good drainage
vi) Ease of Compaction

3) What are the Index properties available in soil?

The properties are:

i) Grain size analysis
ii) Consistency limits and indices
iii) Plastic limit
iv) Plasticity index
v) Shrinkage limit
vi) Field moisture equivalent

4) Define Textural classification?

The textural classification system is based on grain size distribution of the soil and is helpful in classifying a soil which contains different soil component such as sand silt and clay.

5) Define the Various soil classification systems in highway engineering?

The systems are:

i) Burmister descriptive classification
ii) Casagrande soil classification
iii) Unified soil classification
iv) U.S.Public roads Administration
v) Highway research board
vi) Federal aviation agency
vii) Civil aeronautic administration
viii) Compaction classification

6) What is mean by unified soil classification system?

The casagrande classification system which was developed in 1942 to classify soils was later revised, modified and adopted by both U.S.Crops of engineers and the U.S. Bureau unified soil classification systems.

7) What are the seven groups in soil?

Soils are divided into seven groups.A-1 to A-7.A-1, A-2, A-3 soils are granular soils. Percentage fines passing 0.074mm sieve being less than 35.A-4, A-5, A-6 and A-7.soils are fine grained or silt clay soils passing 0.074m sieve being greater than 35 percent.

8) What is the equation for group index of soil?

Group index is function of percentage material passing 200 mesh sieve (0.074mm) liquid limit and plasticity index of soil and is given by the equation.

$G_1 = 0.2\ a + 0.005ac + 0.01\ bd$

9) What are the factors allowed in subgrade soil strength?

The factors are:

i) Soil type
ii) Moisture content
iii) Dry density
iv) Internal structural of the soil
v) Type and made of stress application

10) Define the three groups of evaluation of soil strength?

The three groups are:

a) Shear test
b) Bearing test
c) Penetration test

11) What is the use of plate bearing test?

The plate bearing test is used to evaluate the supporting power of subgrade for use in pavement design by using relatively large diameter plates. The plate bearing test was originally devised to find the modulus of subgrade reaction in the westergaards analysis for wheel load stress in cement concrete pavements.

12) How to calculate the CBR value in highway materials?

The CBR value is calculated using the relation:

$$CBR = \frac{\text{[Load (or) pressure sustained by the specimen at 2.5 or 5.0 min penetration]}}{\text{Load (or) pressure sustained by standard aggregate at the corresponding level}}$$

13) Define the types of tests?

The tests are:

i) Crushing test
ii) Abrasion test
iii) Impact test
iv) Soundness
v) Shape
vi) Specific gravity and water absorption test
vii) Bitumen adhesion test.

14) What are the three types of abrasion test?

The abrasion test on aggregate may be carried out using anyone of the following three tests.

i) Los angles abrasion test
ii) Deval abrasion test
iii) Dorry abrasion test

15) What is mean by 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.

16) What is mean by penetration test?

It may be considered as small scale bearing tests in which the size of the loaded area is relatively much smaller and ratio of the penetration to size of loaded area is much greater than the ratios on bearing test. The California Bearing ratio test and cone penetration tests are commonly known as Penetration test.

17) What are the factors affect the strength test?

The factors are:

i) Factors which are primarily associated with the actual tests such as size and shape of the specimen, method of loading, rate of loading and drainage conditions.

ii) Factors which are associated with the soil such as soil type dry density, moisture content, permeability structure and other properties of the soil.

18) What are the types affect the strength test?

The types are:

i) Static immersion test

ii) Dynamic immersion test

iii) Chemical immersion test

iv) Immersion mechanical test

v) Immersion trafficking test

vi) Coating test

19) What are the problems occur in paving mixes?

The problems are:

i) mixing

ii) Attainment of desired stability of the mix

iii) To maintain the stability under adverse weather conditions

iv) To maintain sufficient flexibility and thus avoid cracking of bituminous surface.

v) To have sufficient adhesion with the aggregates in the mix in presence of water.

20) Describe the various types of tests in bituminous material?

The various tests on bituminous material:

a) Penetration test
b) Ductility test
c) Viscosity test
d) Float test
e) Specific gravity test
f) Softening point test
g) Flash and fire point test
h) Solubility test
i) Spot test
j) Loss on heating test
k) Water content test

16 Marks Questions and Answers

1) Explain briefly about desirable and index properties of soil?

Soil consists mainly of mineral matter formed by the disintegration of rocks, by the action of water, frost, temperature, pressure or by plant or animal life.

Desirable properties:

The desirable properties of soil as a highway material are:

i) Stability
ii) Incompressibility
iii) Permanency of strength
iv) Minimum changes in volume and stability under adverse conditions of weather and groundwater.
v) Good drainage
vi) Ease of compaction

Index properties of soil:

The wide range of soil types available as highway construction materials have made it obligatory on the part of the highway engineer to identify and classify the different soils. The soil properties on which their identification and classification are based are known as index properties.

Grain size analysis:

***)** The grain size distribution is found by mechanical analysis. The components of soils which are coarse grained may be analyzed by sieve analysis and the soil fines by sedimentation analysis.

*) The grain size analysis or the mechanical; analysis is hence carried out to determine the percentage of individual grain size present in a soil sample. The sieve analysis is a simple test consisting of sieving a measured quantity of the material through successively smaller sieves.

*) The sedimentation principle, that the larger grains in a suspension settle faster is used for finding the grain size distribution of fine soil fraction passing 75 micron sieve. Two methods of test can be used; Hydrometer method and pipette method is used base on sedimentation principle.

Consistency Limits and Indices:

*) The physical properties of fine grained soils, especially of clays differ very much at different water contents. a clay may be almost in a liquid state, it may show plastic behavior may be stiff depending on the moisture content.

*) A clay may be almost in a liquid state, or it may show plastic behavior or may be stiff depending on the moisture content. Plasticity is property of outstanding importance of clayey soils, which may be explained as ability to under go changes off shape without rupture.

*) Atterberg in 19911 proposed series of tests, mostly empirical; for the determination on of consistency and plastic properties of fine soils. These are known as atterberg limits and indices.

Liquid limit:

***)** It may be defined as minimum water content at which the soil will flow under the application of very small shearing force. The liquid limit is usually determined the laboratory using a mechanical device.

Plastic limit:

*) It may be defined in general terms, as the minimum moisture content at which the soil remains in a plastic state. The lower limit is arbitrary defined and determined in ht laboratory by a prescribed test procedure.

Plasticity index:

*) It is defined as the numerical difference between the liquid limit and plastic limits. Plasticity index thus indicates the range of moisture content over which the soil is in plastic condition.

Shrinkage limit:

*) It is the minimum moisture content at which further reduction in water content does not cause reduction in volume. It is the lowest water content that can occur in clayey soil sample which is completely saturated.

*) Consistency limits and the plastic index vary for different soil types and therefore these properties are generally used in the identification and classification of soils. Generally soils having high values of liquid limit and plastic index are poor as engineering materials. Both liquid limit and plastic limit depend on the type and amount of clay in soils. The plasticity index generally depends only on that amount of clay present: giving an indication of clay content in soil. In soil having same values of liquid limit, but with different values of plasticity

Index:

*) It is generally found that rate of volume change and dry strength increases and permeality decreases with increases in plasticity index. In soils having same values of plasticity liquid limit, it is seen that compressibility and permeability increase and dry strength decreases with increases in liquid limit. Thus the values of liquid limit and plasticity index help in classification the cohesive soils.

*) In addition to the above tests certain other properties have also been time used in identifying and classifying soils. These include shrinkage limit, field moisture equivalent, cettifege moisture equivalent, and compaction characteristic of the soils.

Field moisture equivalent of a soil is the moisture content at which the demands for absorbed water are fully satisfied.

*) The centrifuge moisture equivalent of a soil is the moisture content retained against a force 1000 times' gravity for one hour. These tests are seldom carried out now-a-days. In most of the soil classification systems that are commonly in use, the classification are based on the grain size distribution, liquid limit and plasticity index of the soils.

2) What are the various soil classification systems and explain the HRB classification system?

Soil classification system:

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

i) Burmister descriptive classification
ii) Casagrande soil classification
iii) Unified soil classification
iv) U.S.Public roads Administration classification
v) Highway Research Board(HRB)
vi) Federal Aviation Agency
vii) Civil Aeronautic administration classification.

Highway research Board (HRB) classification of soils:

*) This is also called American Association of state highway officials (AASHO) classification of revised public roads administration (PRA) soil classification system.

*) The original classification system was developed by bureau of public roads in 1928.In fact by these modifications were made and the HRB classification system was developed. Thus enabling classification of soils by three simple laboratory tests namely, sieve analysis liquid limit and plastic limit.

*) Soils are divided into seven groups.A-1 to A-7.A-1 ,A-2 and A-3 soils are granularsoils,percentage fines passing 0.074 mm sieve being less than 35.A-4,A-5,A-6 and A-7 soils are fine grained or silt clay soils passing 0.074 mm sieve being grater than 35 percent.

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

*) A-2 group of soils include a wide range of granular soils ranging from A-1 to A-3 groups consisting of granular soils up to 35 % fines ofA-4.A-5.A-6 or A-7 groups.

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

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

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

*) A-6 group of soils are plastic clays having high values of plasticity index exceeding 10% and low values of liquid limit below40 % they have high volume change properties with variation in moisture content.

*) A-7 soils are also clayey soils as A-6 soils but with high values of both liquid limit and plasticity index. These soils have low permeability and high volume change properties with moisture content.

Group index of soil:

***)** Fine grained soils of each classification group exhibit a wide range of properties as sub grade material.

*) Soil are thus assigned arbitrary numerical numbers known as group index.(G1).Group index is a function of percentage material passing 200 mesh sieve, liquid limit and plasticity index of the soil and is give by the equation:

$$G1 = 0.2\ a + 0.005\ a\ c + 0.01\ bd$$

Here,

a= that portion of material passing 0074m sieve, greater than 35 and not exceeding 75 percent

b= That portion of material passing 0074 mm sieve greater than 15 and not exceeding 35b percent

c= That Value of liquid limit in excess of 40 and less than 60

d= That Value f plasticity index exceeding 10 and not more than 30.

3) Write short notes on:

a) Sub grade soil strength

b) Evaluation of soil strength

Sub grade soil strength:

The factors on which the strength characteristics of soil depend are:

i) Soil type

ii) Moisture content

iii) Dry density

iv) Internal structural of the soil

v) The type and mode of stress application

*) The problem of predicting the stress strain relationship of soil is difficult, because of the diversity in the soil types and the non-homogenous nature of the soil under the foundations.

*) The highway engineer is interested in the stability or the resistance to deformation of the soil under the stress applications.

*) In the soil mass the deformation is largely due to slippage between soil particles. Hence the shearing resistance in soil represents the strength. The sliding mechanism in soils is complicated as the shear deformation case reorientation of particles resulting in changes in volume, valence bond between particles, thickness and other properties of adsorbed layer of water.

*) Mohr's theory is the most useful one for soils. The basis of his theory is that material fails when the shearing stress on the failure plane is definite function of the normal stress acting on that plane and that failure occurs by slippage only.

*) For these soils the shearing resistance on any plane is given by Coulomb's empirical law:

$$S_r = C + \sigma \tan\phi$$

Here

C= cohesion per unit area

σ = normal stress

ϕ = angle of internal friction

Evaluation of soil strength:

The tests used to evaluate the strength properties of soils may be broadly divided into three groups.

i) shear test

ii) Bearing test

iii) Penetration test

There are number of test methods in each group;

Shear test:

***)** It is usually carried out on the relatively small soil samples in the langboratory, inorder to find the strength properties of a soil, number of representative samples from different locations arte testes.Some of the commonly known shear tests are direct shear test,triaxial compression test and unconfined compression test. Vance shear tests may be carried out either on a soil sample or in-situ soil in the field.

Bearing test:

It is loading tests are carried out on sub grade soils in situ with a load bearing area. The results of the bearing tests are influenced by the variations in the soil properties within the stresses soil mass underneath and hence the overall stability of the part of the soil mass stresses could be studied.

Penetration test:

It may be considered as small scale bearing tests in which the size of the loaded area is relatively much smaller and ratio of the penetration to size of loaded area is much greater than the ratios in bearing test. The penetration tests are carried out in the field or in the laboratory. There are number of factors which affect the results of the strength tests as mentioned below:

*) Factors which are primarily associated width the actual tests such as size and shape of the specimen, method of loading, rate of loading and drainage conditions.

*) Factors which are associated with the soil such as soil type dry density, moisture content,permeablility structure and other properties of the soil.

4) Discuss the principles, applications and limitations of direct shear, triaxial and unconfined compression test?

Direct shear test:

*) This is one of the oldest of shear tests. The direct shear apparatus consists essentially of a box divided horizontally into two halves. One half is kept fixed and the other half is free to move horizontally.

*) The vertical and horizontal movements are measured by dial gauges and the horizontal force is noted from the proving ring dial. The maximum horizontal force is measured for different values of normal load.

*) There are a number of limitations if this test. The failure plane being predetermined horizontal plane, need not necessarily represent the imminent plan be of failure.

*) The area of cross section of specimen decreases with displacement. The flow of water to ore from the soil specimen can not be easily controlled or measured. It is also not practicable to measure pore water pressure during the test.

Triaxial compression test:

***)** The object of triaxial compression test is to determine the shear strength of soil under lateral confinement.

*) Cylindrical specimen of height to diameter ratio 2 is inserted in a thin membaerne, placed in a triaxial cell and the required lateral pressure is applied.

*) The normal load is applied through vertical piston by means of a strain controlled machine and the maximum vertical load at failure is recorded. The specimens are usually subjected to a contrast strain rate of 1.25 mm per minute.

*) Usually the lateral pressure is maintained constant strain rate of 1.25mm per minute. The tests are carried out at different lateral pressures preferably with at least three lateral pressures.

*) For the pavement design, lateral pressure of 0, 0.75 and 1,5kg/cm^2 are considerable desirable. The values are confining pressure and total vertical pressure at failure is plotted and semicircles passing through these points are drawn in this fig

Correction for area of cross section:

In is necessary to correct the stress value for the increased area of cross section due to loading. The corrected value of deviator stress is found of with the assumption that the volume of the specimen remains constant and the area of cross section of the specimen is uniformly increased from the original value of A_0 and A_1 due to load P_1.

Volume $A_0 l_0 = A_1 l_1 = A_1 \left(l_{o-\Delta}\right)$

In that case the deviator stress σ_d is given by:

$$\sigma_d = \frac{p_1}{A_1} = \frac{p_1}{A_1}\frac{l_1}{A_0} = \frac{P_1}{A_0} = \left(\frac{l_1 - \Delta}{l_0}\right)$$

$$\sigma_d = \frac{p_1}{A_0}\left(1-\delta\right)$$

ie

Here,

$\Delta =$ Total deformation of the specimen

δ = Unit strain

A_0= Original area of cross section

P_1 = applied load

σd = Deviator stress

Unconfined compression test:

*) The unconfined compression test may be considered as a special case of triaxial compression test when the confining pressure is zero and the axial compressive straee only is applied to the cylindrical specimen.

*) The area of cross section of the specimen for various strains may be assuming that the volume of the specimen remains constant and that the specimen retains cylindrical cross sectional areas as explained under triaxial test.

*) The Mohr circle of the rupture for an unconfined compression test passes through the origin. It s not possible to draw the Mohr rupture envelope from a single circle, and so the values of C and ϕ cannot be determined as such.

The failure plane of an unconfined compression or triaxial specimen (when a defined failure plans exists) makes an angle θf with major principal plane the value of C also can be calculated from the geometrical relationship of the Mohr diagram.

5) Write short notes on

I penetration test

2 ductility test

3 viscosity test

4 softening point test

*) The penetration test determines the hardness or softness of bitumen by measuring the depth of a millimeter to which a standard loaded needle will penetrate vertically in five seconds. The sample is maintained at temperature of 25^0c. for one hour. The dial is set to zero or the initial reading is taken and the needle is released for 5 seconds. The final reading is taken on dial gauge on dial gauge.

*) After each test the needle is designed and wiped with benzene and dired.the depth of penetration is repeated in one tenth millimeter units. The value is 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. The penetration test is applied almost exclusively to bitumen. As road tars are soft, the penetration test cannot be carried out on these materials.

*) The penetration values of various types of bitumen used in pavement construction in this country range between 20 and 2254,30/40 and 80/1000 grade bitumen are more commonly used, depending on construction type and climatic conditions.

Ductility test:

***)** In the flexible pavement constructions where bitumen binders are used, it is important that the binders form ductile thin films around the aggregates.

*) This serves as a satisfactory binder in improving the physical interlocking of the aggregate bitumen mixes. Under traffic loads the bituminous pavement layer is subjected to repeated deformation and recoveries.

*) Ductility test is carried out on bitumen to test this property of the binder. The test is believed to measure the adhesive property of bitumen and its ability to stretch.

*) Bitumen paving engineer would however want that both test requirements are Satisfied in the field jobs.Penertration and ductility test cannot in nay case replace each other.

*) The ductility test is expressed as the distance in centimeters to which standard briquette bitumen can be stretched before the thread breaks. The test is conducted at 27^0c and at a rate of pull of 50 mm per minute.

*) The ductility machine functions as a constant temperature water bath with a pulling device at a pre calibered rate. The ductility values of bitumen vary from 5 to over 100 for different bitumen grades.

Viscosity test:

*) viscosity is defined as inverse of fluidity. Viscosity thus defines the fluid property of bituminous material. Viscosity is the general term for consistency and it is measure of resistance to flow. Many researchers believe that grading of bitumen should be by absolute viscosity units of the conventional penetration units.

*) The degree of fluidity of the binder at the application temperature greatly influences the strength characteristics of the resulting paving mixes.

*) The bituminous binder simply lubricates the aggregate particles instead of providing a uniform film for binding action.similiarly high viscosity also resists the comp active effort and the resulting mix is heterogeneous in character exhibiting low stability values.

*) The viscosity of tar is determined as the time taken in seconds for 50 ml of the sample to flow through 10mm orifice of the standard tar viscometer at the specified temperature of 35,40,45 or 55^0c.

*) The viscosity of cutback bitumen is determined as the time taken in seconds for 50 ml of the sample to flow through either 4.0mm orifice at 25^0c or 10mm orifice at 25 or 40^0c.

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 .A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature.

*) A steel ball is placed upon the bitumen sample and the liquid, edium 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 a point of bitumen.

CE2255- HIGHWAY ENGINEERING

(FOR IV – SEMESTER)

UNIT – V

HIGHWAY MAINTNANCE

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UNIT V
HIGHWAY MAINTENANCE

Types of defects in flexible pavement-surface defects, cracks, deformation, disintegration-symptoms, causes and treatments.-Types of rigid pavement, failure in rigid pavement-scalling, shrinkage, warping, structural cracks spalling of joints and Mud pumping and special repairs. Pavement evaluation-pavement surface conditions and structural evaluation, evaluation of pavement failure and strengthening-Overlay design by Benkelman beam method-highway drainage-

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5	Explain indetail about the overlay design by Benkleman beam method. (Dec 2009)	---

Two marks questions and Answers

1) What are the operations involve in rod construction?

The operations are:

1) Assessment of road construction
2) Diagnosis of the problem

2) Define the various general causes in pavement failures?

The general causes are:

a) Defects in the quality of materials used
b) Effects in construction method and quality control
c) Inadequate surface (or) Sub surface drainage
d) Increase in the magnitude of wheel loads
e) Settlement of foundation of embankment
f) Environmental factors.

3) What is mean by special repair?

Special repair means strengthening of pavement structure or overlay construction, reconstruction of pavement, widening of roads repairs of damages caused by floods etc.

4) Give any two factors in maintenance management system?

The factors are:

- Field surveys for the evaluation of maintenance requirements.
- Estimation of rate of deterioration of the pavement under the prevailing set of conditions.
- Availability of funds.

5) What are the failures in flexible pavement?

The failures are

1) Failures in subgrade
2) Failures in subbase
3) Failure in wearing course

6) Mention the various types of failure in subbase?

Inadequate stability or strength

- Loss of binding action
- Loss of base course materials
- Inadequate wearing course
- Use of inferior materials and base course materials

7) What are the failures in wearing course?

*) Failures of wearing course are observed due to lack of proper mix design. Improper gradiation of aggregate, binder content and inferior types of binder result in a poor bituminous surfacing.

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

8) Give some typical flexible pavement failures?

Following are some of the typical flexible pavement failures:

i) Alligator cracking
ii) Consolidation of pavement layers
iii) Shear failure
iv) Longitudinal cracking
v) Frost heaving
vi) Lack of binding
vii) Reflection cracking
viii) Formation of waves and corrugation.

9) Define 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 climatic conditions.

10) What are the main factors in cement concrete pavements?

The factors are:
a) Deficiency of pavement materials
b) Structural inadequacy of the pavement system.

11) Give the various defects in cement concrete pavement?

The various defects in that creep in due to the above are:

i) Disintegration of cement concrete
ii) Formation of cracking
iii) Spalling of joints
iv) Poor riding surface
v) Slippery surface
vi) Formation of shrinkage cracks
vii) Ingress of surface water and further progressive failures

12) What are the failures in rigid pavement?

The failures are:

i) Scalling of cement concrete
ii) Shrinkage cracks
iii) Spalling of joints
iv) Warping cracks
v) Mud pumping
vi) Structural cracks

13) What is mean by shrinkage cracks?

The operation of cement concrete pavements immediately after the construction. The shrinkage cracks normally develop. The placement of cracks is in longitudinal as well as in transverse direction.

14) Define mud pumping.

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.

15) What are the factors considered to be mud pumping?

The factors are:

i) Extent of slab deflection
ii) Type of sub grade soil
iii) Amount of free water

16) Define patch repairs.

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

17) Give the various types of routine maintenance?

i) Upkeep of carriageway
ii) Maintenance of shoulders and subgarde
iii) Maintenance o side drains and other ancillary works
iv) Patch repair of pot holes and localized failures.

18) What are the two methods in pavement evaluation?

The various methods may be broadly classified into two groups:

1) Structural evaluation of pavements
2) Evaluation of pavement surface condition

19) 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.

20) Give the various 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.

16 marks questions and answers

1) a) what are the general causes of pavement failures?

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

a) Defects in the quality of materials used.

b) Defects in construction method and quality control during construction

c) Inadequate surface or subsurface drainage in the locality resulting in the stagnation of water in the subgrade or in any of the pavement layers.

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

e) Settlement of foundation of embankment of the fill material itself.

f) 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.

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.

b) Write short notes on 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 wok 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 subgrade 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

2) What are the various types of General failures in flexible pavement? Explain the causes?

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

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

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

*) The cement concrete pavement may develop cracks and deteriorate due to repeated loads and fatigue effects. A rigid pavement failure is observed by the development of structural crack of break resulting in progressive subsidence of some portions of pavement.

*) Pavements are therefore capable of withstanding slight variations in the underlying support and they bridge the localized gaps moderately.

*) It is the combination of many factors that induce the failure conditions in the rigid pavement. Due to the temperature effects, the newly constructed cement concrete pavement may also crack even if no vehicle moves on them.

Failures in flexible pavements:

*) The localized settlement of any one component layer of the flexible pavement structure could be enough to cause pavement failure. This demands that each one of the layers should be carefully designed and laid.

*) thus to maintain the stability of the pavement structure as a whole, each layer should be stable within itself and thereby make the total pavement mainta9n its stability.

*) In this fig shows the failures in soil subgrade, base course and the surface wearing course. It may see that ultimately there is surface deformation when failure takes place either in sub grade or base or surface.

Failures in sub grade:

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

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

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

i) Inadequate stability
ii) Excessive pavement thickness

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

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

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

*) The applied stress is excessive with respect to the stability and plastic flow takes place as in the case of we t clay soil, this deformation is called plastic deformation.

The type of damage in flexible pavement than can be caused by traffic due to sub grade failure r due to inadequate and improper compaction of sub grade and other pavement layers.

Failures in sub base or base course:

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

i) Inadequate stability or strength
ii) Loss of binding action.
iii) Loss of base course materials
iv) Inadequate wearing course
v) Use of inferior materials and crushing of base course materials
vi) Lack of lateral confinement for the granular bass course.

Failures of wearing course:

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

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

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

3) Explain the typical failures in flexible pavement?

Following are some of the typical flexible pavement failures:

i) Alligator cracking
ii) Consolidation of pavement layers
iii) Shear failure
iv) Longitudinal cracking
v) Frost heaving
vi) Lack of binding
vii) Reflection cracking

viii) Formation of waves and corrugation.

Alligator cracking:

*) In this fig shows 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.

*) This may be caused by the repeated application of heavy wheel loads resulting in fatigue failure or due to the moisture variations resulting in swelling and shrinkage of sibgrade and other pavement materials.

Consolidation of pavement layers:

***)** Formation of ruts is 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 ca also are 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.

Shear Failure & cracking:

***)** Shear failures are associated with the inherent weakness of the 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.

Longitudinal cracking:

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

Frost heaving:

*) Frost heaving is often misunderstood for shear or other types of failures. 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 groundwater and climatic condition.

Lack of binding with lower layer:

*) slipping occurs when the surface course is not keyed bound the underlying base. This results in opening up and loss of pavement materials forming patches or pot holes.

*) Such conditions are more frequent in base when the bituminous surfacing is provided over the existing cement concrete base course or soil cement base course.

*) This condition is more pronounced when the prime coat in between two layers is lacking.

Reflection cracking:

*) This type of cracking is observed in bituminous overlays provided over existing cement concrete pavements. The crack pattern as existing in cement concrete pavements are mostly reflected on bituminous surfacing in the same pattern.

*) Structural action of the total pavement section is not much influenced by the presence of reflection Cracks but the cracks appear at the surface .These allows surface water to steep through and cause damage to the soil subgrade or result in mud pumping.

4) Explain how the maintenance of the following pavements are carried out?

a) Earth roads
b) Bituminous surfaces
c) Cement concrete pavements

Earth roads:

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

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

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

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

*) Application of calcium chloride retain some water due to the hygroscopic nature of mix.oiled earth roads are also common these days.

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

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

Maintenance of bituminous surfaces:

Mainly the maintenance works of bituminous surfacing consists of:

i) Patch repairs
ii) Surface treatments
iii) Resurfacing

Patch repairs:

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

*) Inadequate or defective binding materials causes removal of aggregates during monsoons. Patching may be done on affected localized area or sections using a cold premix.

Pot holes and repairs:

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

*) The excavated patches are cleaned and painted with bituminous binder. A premixed material is then placed in the sections. Generally, cutback or emulsion is used as binder.

*) Bituminous emulsions could be used even when the pavement surface and the aggregates are wet during monsoons.

*) The materials so places in the pot hole, is well compacted by ramming to avoid any raveling. The materials in out holes are places in layers of thickness of 6 cm.

*) it is however necessary to replace the base course materials with similar new materials if the failure has been detected in the base curse layer. The finished level of the patched is kept slightly above original level to allow for subsequent compaction under traffic.

Surface treatment:

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

Resurfacing:

*) In the event when the pavement surface is totally worn out and develops a poor riding surface ,it may be more economical to provide an additional surface coarse on the existing surface.

*) In case of the pavement is of inadequate thickness due to increase in traffic loads and strengthening is necessary, than an overlay of adequate thickness should be designed and constructed.

Maintenance of cement concrete roads:

Various types of cracking have been explained:

Treatment of cracks:

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

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

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

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

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

*) therefore before the se cracks get wide enough to permit infiltration of water, they should be sealed off to prevent rapid deteriorations

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

Maintenance of joints:

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

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

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

5) Explain the principle and uses of Benkelman beam test?

Principle:

A well compacted pavement section or one which has been well conditioned by traffic deforms elastically under each wheel load a application such that when the load moves away, there is an elastic recovery or rebound deflection of the deformed pavement surface. This is the basic principle pf deflection method pavement evaluation or overlay design.

The maximum deflection under a design wheel load depends on several factors such as sub grade soil properties, moisture in the subgrade, pavement thickness and its composition, temperature of the pavement, loading particulars.

Benkelman beam:

*) Benkelman beam is a device which can be conveniently used to ensure the rebound defection of a pavement due to a dual wheel load assembly or the design wheel load. The equipment consists of a slender beam of length 3.66 m which is provided to as datum frame at distance 2.44m from the probe end.

*) The datum frame rests on a pair of front leveling leg and a rear 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 loaded 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 in twice the distance between the fulcrum and the dial gauge spindle.

*) A loaded truck with rear axle load of 8170 kg is used for the deflection study. The design wheel load is a dual wheel load assembly of gross weight 4085kg with as inflation pressure of 5.6kg/cm^2.

Procedure:

*) The stretch of road length to be evaluated is first surveyed t 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 class.

*) The loading points on the pavement for deflection measurements are locates along the wheel paths on a line 0.9 m from the pavement edge in the case of pavements of total width more than 3.5 m the distance from the edge is reduced to 0.6 m on narrower pavements.

*) A minimum of 10 deflection observations may be taken on each of the selected stretch of pavement. The deflection observation points may also be staged if necessary and taken along the wheel paths on both the edges of the pavement. The various steps are allowed:

a) The truck is driven slowly parallel to the edge an stopped such that the left side rear wheel is centrally placed over the first point for deflection measurement.

b) The probe end of the Benkelman beam is inserted between the gap of the dual wheel and is placed exactly over the deflection observation point.

c) The truck is moved forward slowly through a distance of 2.7m from the point and stopped. The intermediate dial gauge reading D_1 is notes when the rate of recovery of the pavement is less than 0.025 mm per minutes.

d) The truck is then driven forward through a further distance of 9.0m and the final dial gauge reading D_f is recovered as before.

e) The rebound deflection value D at any point is given by one of the following two conditions:

a) If $D_i - D_f < 2.5$ 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

b) If $D_i - D_f > 2.5$ division this indicate that correction is needed for the vertical movement of the front legs.

$$D = 2\,(D_0 - D_f) + 2\,K\,(D_i - D_f) \text{ divisions}$$

The value of K is to be determined for every make the Benkelman beam and is give by the relation:

$$K = \frac{3d - 2e}{f}$$

Where,

d= Distance between the bearing of the beam and the rear adjusting leg

e= Distance between the dial gauge and rear adjusting leg

f= Distance between the front and rear leg.

6) Explain the necessity of design approach and method of strengthening of existing pavements for the following cases:

i) Flexible overlay over flexible pavement
ii) Flexible overlay over rigid pavement
iii) Rigid overlay over flexible pavement
iv) Rigid overlay over rigid pavement.

Flexible overlay over flexible pavement:

*) The total thickness requirement is designed for the design traffic and the existing conditions of subgrade.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

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;
i) Providing maximum possible interface bond by making the old surface rough
ii) Separating the two slabs at the interface by thin layer of bituminous material

To obtain the overlay thickness the following relationship may be used:

$$h_o = (ha^d - Xh_c^b)^n$$

Here,

h_0= rigid pavement thickness

h_d = design thickness

h_e = existing pavement thickness.

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.

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.