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CE6504 HIGHWAY ENGINEERING L T P C
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OBJECTIVES:

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

UNIT I HIGHWAY PLANNING AND ALIGNMENT 8

Significance of highway planning – Modal limitations towards sustainability - History of road development in India – Classification of highways – Locations and functions – Factors influencing highway alignment – Soil suitability analysis - Road ecology - Engineering surveys for alignment, objectives, conventional and modern methods.

UNIT II GEOMETRIC DESIGN OF HIGHWAYS 12

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

UNIT III DESIGN OF FLEXIBLE AND RIGID PAVEMENTS 9

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

UNIT IV HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE 8

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

UNIT V EVALUATION AND MAINTENANCE OF PAVEMENTS 8

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

OUTCOMES: **TOTAL: 45 PERIODS**

- The students completing this course would have acquired knowledge on planning, design, construction and maintenance of highways as per IRC standards and other methods.

TEXT BOOKS:

1. Khanna.S. K., Justo.C.E.G and Veeraragavan A. "Highway Engineering", Nemchand Publishers, 2014.
2. Subramanian K.P., "Highways, Railways, Airport and Harbour Engineering", Scitech Publications (India), Chennai, 2010
3. Indian Road Congress (IRC), Guidelines and Special Publications of Planning and Design.

REFERENCES:

1. Kadiyali.L.R. "Principles and Practice of Highway Engineering", Khanna Technical Publications, 8th edition Delhi, 2013.
2. Yang H. Huang, "Pavement Analysis and Design", Pearson Education Inc, Nineth Impression, South Asia, 2012
3. Ian D. Walsh, "ICE manual of highway design and management", ICE Publishers, Ist Edition, USA, 2011
4. Fred L. Mannering, Scott S. Washburn and Walter P.Kilareski, "Principles of Highway Engineering and Traffic Analysis", Wiley India Pvt. Ltd., New Delhi, 2011
5. Garber and Hoel, "Principles of Traffic and Highway Engineering", CENGAGE Learning, New Delhi, 2010
6. O" Flaherty.C.A "Highways, Butterworth – Heinemann, Oxford, 2006

UNIT I
HIGHWAY PLANNING AND ALIGNMENT

Significance of highway planning – Modal limitations towards sustainability - History of road development in India – Classification of highways – Locations and functions – Factors influencing highway alignment – Soil suitability analysis - Road ecology - Engineering surveys for alignment, objectives, conventional and modern methods.

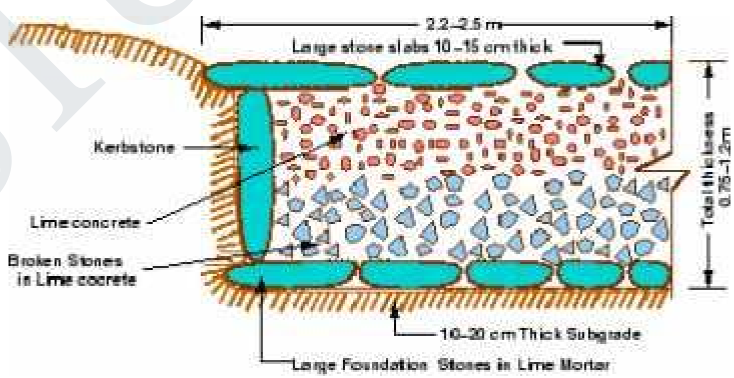
1.1 History of highway engineering

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

1.1.1 Ancient Roads

The first mode of transport was by foot. These human pathways would have been developed for specific purposes leading to camp sites, food, streams for drinking water etc. The next major mode of transport was the use of animals for transporting both men and materials. Since these loaded animals required more horizontal and vertical clearances than the walking man, track ways emerged. The invention of wheel in Mesopotamian civilization led to the development of animal drawn vehicles. Then it became necessary that the road surface should be capable of carrying greater loads. Thus roads with harder surfaces emerged. To provide adequate strength to carry the wheels, the new ways tended to follow the sunny drier side of a path. These have led to the development of foot-paths. After the invention of wheel, animal drawn vehicles were developed and the need for hard surface road emerged. Traces of such hard roads were obtained from various ancient civilization dated as old as 3500 BC. The earliest authentic record of road was found from Assyrian empire constructed about 1900 BC.

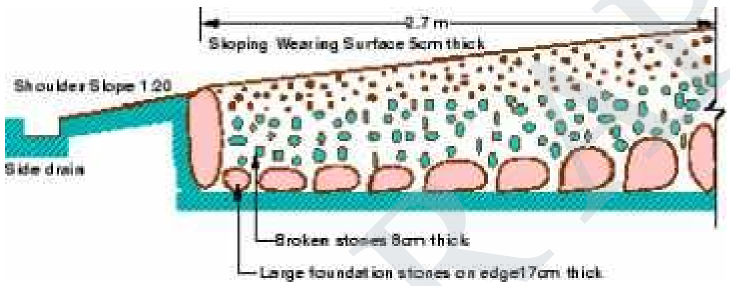
1.1.2 Roman roads



The earliest large scale road construction is attributed to Romans who constructed an extensive system of roads radiating in many directions from Rome. They were a remarkable achievement and provided travel times across Europe, Asia minor, and north Africa. Romans recognized that the fundamentals of good road construction were to provide good drainage, good material and good workmanship. Their roads were very durable, and some are still existing. Roman roads were always constructed on a firm -

formed subgrade strengthened where necessary with wooden piles. The roads were bordered on both sides by longitudinal drains. The next step was the construction of the *agger*. This was a raised formation up to a 1 meter high and 15 m wide and was constructed with materials excavated during the side drain construction. This was then topped with a sand leveling course. The agger contributed greatly to moisture control in the pavement. The pavement structure on the top of the agger varied greatly. In the case of heavy traffic, a surface course of large 250 mm thick hexagonal flag stones were provided. A typical cross section of roman road The main features of the Roman roads are that they were built straight regardless of gradient and used heavy foundation stones at the bottom. They mixed lime and volcanic puzzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

1.1.3 French roads



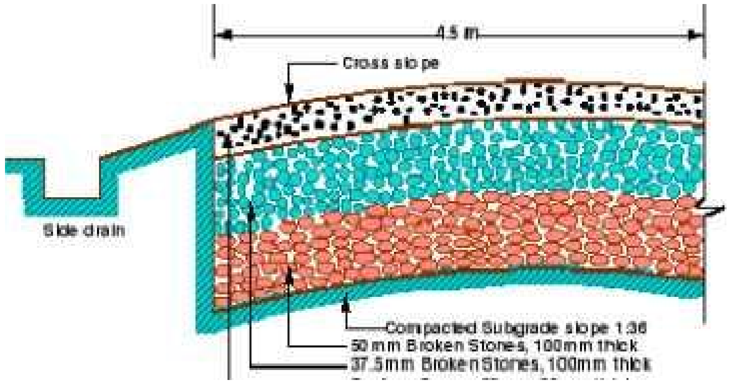
The next major development in the road construction occurred during the regime of Napoleon. The significant contributions were given by Tresaguet in 1764 and a typical cross section of this road. He developed a cheaper method of construction than the lavish and locally unsuccessful revival of Roman practice. The pavement used 200 mm pieces of quarried stone of a more compact form and shaped such that they had at least one flat side which was placed on a compact formation.

Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally the running layer was made with a layer of 25 mm sized broken stone. All this structure was placed in a trench in order to keep the running surface level with the surrounding country side. This created major drainage problems which were counteracted by making the surface as impervious as possible, cambering the surface and providing deep side ditches.

He gave much importance for drainage. He also enunciated the necessity for continuous organized maintenance, instead of intermittent repairs if the roads were to be kept usable all times. For this he divided the roads between villages into sections of such length that an entire road could be covered by maintenance men living nearby.

1.1.4 British roads

The British government also gave importance to road construction. The British engineer John Macadam introduced what can be considered as the first scientific road construction method. Stone size was an important element of Macadam recipe. By empirical observation of many roads



, he came to realize that 250 mm layers of well compacted broken angular stone would provide the same strength and stiffness and a better running surface than an expensive pavement founded on large stone blocks. Thus he introduced an economical method of road construction.

The mechanical interlock between the individual stone pieces provided strength and stiffness to the course. But the inter particle friction abraded the sharp interlocking faces and partly destroy the effectiveness of the course. This effect was overcome by introducing good quality interstitial finer material to produce a well-graded mix. Such mixes also proved less permeable and easier to compact.

1.2 Bombay road congress:

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

- It was the second 20 year road plan (1961-1981)
- The total road length targeted to construct was about 10 lakhs.
- Rural roads were given specific attention. Scientific methods of construction was proposed for the rural roads. The necessary technical advice to the Panchayaths should be given by State PWD's.
- They suggested that the length of the road should be increased so as to give a road density of 32kms/100 sq.km
- The construction of 1600 km of expressways was also then included in the plan.

+ Other District Roads + Village Roads

$$= \left[\frac{A}{4} + \frac{B}{8} + \frac{C}{12} + 48\,K + 24\,M + 11.2\,N + 9.6\,P + 12.8\,Q + 5.9\,R + 1.6\,S + 0.64\,T + 0.2\,V\right] \times \left(\frac{D + 100}{100}\right)$$

where

A = Developed and Agricultural Area, km^2

B = Semideveloped Area, km^2

C = Undeveloped Area, km^2

K = Number of towns with population over 1 lakh

M = Number of towns with population between 50000 to 1 lakh

N = Number of towns with population between 20,000 to 50,000

P = Number of towns with population between 10000 to 20000

Q = Number of towns with population between 5000 to 10000

R = Number of towns with population between 2000 to 5000

S = Number of settlements with population between 1000 to 2000

T = Number of settlements with population between 500 to 1000

V = Number of towns with population less than 500

D = Development allowance generally taken as 5 % for the 20 year draft plan period.

Road Way Length Targets

The road lengths for different categories of roads were fixed in miles since km as a unit was not in vogue in 1959. Converted to km these formulas were

(a) National Highway (km)

$$= \left[\frac{A}{64} + \frac{B}{80} + \frac{C}{96}\right] + 32\,K + 8\,M + D\left[\frac{A}{64} + \frac{B}{80} + \frac{C}{96} + 32\,K + 8\,M\right]$$

(b) National Highways + State Highways (km)

$$= \left[\frac{A}{20} + \frac{B}{24} + \frac{C}{32} + 48\,K + 24\,M + 11.2\,N + 1.6\,P\right] \times \left(\frac{100 + D}{100}\right)$$

(c) National Highways + State Highways + Major District Roads (km)

$$= \left[\frac{A}{8} + \frac{B}{16} + \frac{C}{24} + 48K + 24M + 11.2N + 9.5\,P + 6.4\,Q + 2.4R\right] \times \left(\frac{D + 100}{100}\right)$$

(d) National Highway + State Highways + Major District Roads + Other District Roads (km)

$$= \left[\frac{3A}{16} + \frac{3B}{32} + \frac{C}{16} + 48\,K + 24\,M + 11.2\,N + 9.6\,P + 12.8\,Q + 4\,R + 0.8\,S + 0.32\,T\right] \times \left(\frac{D + 100}{100}\right)$$

(e) National Highways + State Highways + Major District Roads

1.3 Road development Plans.

Road Development Plans : Planning forms the forerunner to any development activity. The Congress has been closely associated with road planning in the country ever since the famous Nagpur Plan formulated in the year 1943 which heralded the advent of systematic planning and development of roads in the country on an all India basis. The IRC also had an active role to play in the finalisation of subsequent 20 Year Road Development Plan (1961-81). The latest Road Development Plan 1981-2001, published by the IRC in 1984 provides the general framework for current long term road development keeping in view the need for connecting all villages with a road by the year 2001 as far as possible. It also covers various measures to conserve energy, to preserve the environment and to improve safety on our highways.

Standards : Adoption of standardised practices in design, construction and maintenance with due regard to variabilities in terrain, soil and climate, is imperative for efficient and economical development of highway facilities. On this front, the Congress has made valuable contributions to the profession in preparing Standards, Specifications, Codes of Practice and Manuals on different aspects of roads, bridges and traffic engineering. These include survey and investigations, design of various components of roads and bridges under different situations, standard construction practices, quality control, landscaping and environmental protection. These standards are widely circulated and invariably adopted by all highway authorities in the country. These are also in demand in a number of countries abroad.

Rural Roads : Ever since its inception in 1934 the Indian Roads Congress has shown active concern for the development of rural roads in India. From the very beginning it realised the importance of rural roads in the socio-economic development of an agrarian based country such as ours. In the first Road Development Plan known as the "Nagpur Plan", subsequent Road Plan for 1961 – 81 and the new Road Development Plan for India (1981-2001) due emphasis was laid on the development and expansion of the rural road network.

In 1958 the IRC set up a Committee which was then called the "Community Project Road Maintenance Committee". The aim of the Committee was to recommend measures for proper and adequate maintenance of roads constructed in rural areas. In 1969, the Council of the IRC decided to change the name and ambit of the Committee. It was renamed as the "Rural Roads Committee", and entrusted with the task of bringing out a comprehensive report dealing with planning, specifications, financing, construction and maintenance of all rural roads. The Committee has done commendable work. On its recommendation and under its guidance, the IRC organised four Workshops on Rural Road Development, the First at Gandhinagar (Gujarat) in February, 1981, the Second at Nainital (Uttar Pradesh) in July, 1981, the Third at Ranchi (Bihar) in May, 1982 and the Fourth at Hyderabad (Andhra Pradesh) in November, 1982. The objectives of the Workshops were to identify problems faced, pool the information on methodologies adopted in various regions and disseminate the information at the national level. As a consequence of the deliberations at these Workshops, a

Special Report No. 26 has been brought out which gives detailed recommendations on (i) Planning and investment criteria and organisational aspects, (ii) Pavement aspects and low cost water crossings, (iii) Construction techniques and (iv) Maintenance of rural roads. For better understanding and easier application of the recommendations, supplementary notes on different aspects have also been published.

The Seventh Five Year Plan (1985-90) envisaged that all villages with a population of 1500 and above and 50 per cent of the villages with population between 1000-1500 would be linked by all-weather roads by 1990. For hilly, tribal, coastal and desert areas, the population sizes of villages to be covered are lower. About 41000 villages would be covered under the Plan. However, one of the difficulties in planning of rural highways is the absence of viable criteria to plan and prioritise rural road networks on the basis of parameters such as population, length of roads, unit cost of construction and economic returns. To fill up this void the Rural Roads Committee of the IRC was requested to deliberate and give its recommendations on the socio-economic aspects of rural road development. In the first phase, an analysis was done of the economic data collected in 1972-73 by the Ministry of Agriculture from 20 blocks spread all over the country. The findings of this study was used as inputs for designing the second phase of the study. Accordingly, detailed studies were carried out in 9 districts in various parts of the country covering both pre-investment and post-investment stages. These studies included, inter-alia, (i) socio-economic effects of roads singly and in combination with other inputs at post-investment stages, (ii) collection of pre-investment data and preparation of road development plan for the district based on the evolved criteria and methodology. The result of these studies threw up many important findings which would go a long way in developing new methodologies for planning of investment in rural roads.

A Panel Discussion was also organised in Bhopal at the time of Annual Session in February, 1986 to review the results from the World Bank Studies on Substitution of Labour. Organising an International Seminar in association with the International Labour Office on 'Rural Transportation' in New Delhi from the 26th to 28th April, 1989, is yet another milestone which also signifies the importance being attached by the IRC to the cause of road development.

Hill Roads : India has a long history of construction of hill roads spanning over a hundred years, but the experience gained has not been well documented. The expansion of road network in hill areas has been receiving increasing attention in recent times for serving the remote villages and for the socio-economic betterment of these areas. However, it is essential to ensure that the construction of these roads does not unduly upset the fragile eco-system of the hills which is already under severe attack due to deforestation, pressure of population and other factors. Keeping in view the importance of the subject, the Indian roads 'Congress organised a Seminar on Construction of Roads in Hill Areas at Nainital in July, 1985. This Seminar evoked very good response. Based on the discussions and recommendations of the Seminar, a comprehensive Manual on design, construction and maintenance of hill roads will soon be brought out.

1.4 Five Year Plans

After independance, we declared ourselves as socialistic sovereign, state with more or less mixed economy. Systematic planning in public sector and directional planning in private sector started and therefore it is worth while to watch the progress in highways planwise.

1.9.1 Pre-plan Period (1943 – 1951)

During the pre plan period of 1943 – 1951, the Nagpur plan was already there as a model for road development. However, due to partition of our country, there was paucity of fund and Nagpur plan expectations could not be fulfilled.

1.9.2 First Five Year Plan Period (1951 – 1956)

In this particular plan period, 6.7 % of the total plan expenditure was incurred on roads and this expenditure was about 30.2 per cent of the expenditure on the transport sector. The salient features of road development in the first five year plan could be summarised below.

National Highways : Through the National Highway Act, the national highways became the central subject and the Central Government statutorily took them over. The missing links on N. H. system to the tune of 2000 km were constructed. About 30 major bridges and improvements to nearly 10,000 km of national highway was taken up. Expenditure to the tune of about Rs. 27 crores was incurred. Some important inter-state roads such as Passi - Badarpur Road in Asam, Assam - Agartala Road connecting Assam with Tripura were taken up. The state sector roads also increased in length. The total road length increased from 399940 km to about 498340 km registering an increase of 25 %.

1.9.3 Second Five Year Plan

About 4.8 % of the total plan expenditure and 20 % of the total transport sector expenditure was incurred on roads. The Central Government sponsored Dhar-Udampur Road and construction of west coast road (Bombay - Kanyakumari Road) which was taken during the first plan was continued. About 40 major bridges were constructed. In line with the activities of the Central Government, the State Governments also formulated different schemes and completed them. As a result, there was an increase in road length from 498340 km to 7012120 km. i.e. about 42 % increase. Thirty three per cent of the roads by this time were surfaced roads.

1.9.4 Third Five Year Plan Period (1961 – 1966)

The Bombay road plan served as a frame work for the third fourth and fifth five year plans. In fact this plan saw tremendous growth in highway construction activity. The significant developments that took place in this plan period.

(1) There was the most important and eye opening event of the epoc that is the Chinese external aggression. As a result of this aggression, Border Road Development Board was created under Transport Ministry to deal with problems concerning these roads. Most of these roads were hill roads or desert roads and as such development of hill roads got a boost.

(2) The system of National Highways was strengthened. Sixty six major bridges were constructed on the national highway system, which included Mahanadi Bridge at Cuttack and Sone Bridge in Bihar.

(3) In this particular period, there was a bottleneck in the coal transportation and the planners realised the shortcoming of railways as a means of communications. Therefore, they started looking towards road work as a means to transport coal, since coal as a source of energy is very important.

(4) In general, there was some shift from labour intensive road construction to somewhat mechanised road construction.

(5) Under the central aided scheme, the lateral road project on the foot - hills of Himalayas from Uttarpradesh to Assam was sanctioned and taken up for construction while the work on West Coast Road already started continued.

(6) In this plan period, Government of India received credit from the World Bank for construction of selected national highway. An expenditure of about Rs. 440 crores was incurred in this plan period which constituted 22 % of the expenditure on transport sector and 6 % of the overall plan expenditure. The total road length registered a rise of 49 % over the length at the end of the second plan.

1.9.5 The Fourth Plan Period (1969 – 1974)

In between 1966 - 1969, there was plan holiday and the actual fourth plan commenced in 1969. The salient achievements of this plan were as follows.

(1) In June, 1971, certain new additions to the highway system were done. These were (a) Highway No. NH 44 - connecting Shillong, Passi, Badarpur and Agartala, (b) NH 21 Highway connecting Bilaspur, Kulu and Mandi with Chandigarh, (c) Highway NH 5A connecting Pardeep port to NH 5 at Haridaspur and (d) NH 4 A connecting Belgaum, Phonda and Panaji.

(2) One important happening in this period was that the Government set up one - man commission with Mr. H. P. Sinha as chairman to study the condition and possible development of rural roads. This happened in 1967 and the report got published in 1968 just before the plan period. The recommendations of the committee were.

(a) High-level rural board should be set up in each state for planning and allocation of funds for the rural roads and these should be a post of chief engineer in the state to look after these roads. This recommendation was not followed.

(b) It also envisaged that at least third of the rural road construction cost should come from the beneficiaries. In fact the committee made the proposal that if the third road cost is deposited by the people concerned, the state should come forward to spend the rest 2/3 and construct the road.

(c) The chairman Mr. Sinha favoured a total length of at least 324000 km of village roads and 230,400 km of other district road. Of course the implication of the findings of the committee were felt in fifth plan period.

near Cochin. (e) NH 15. National Highway connecting Pathankot Bhatinda Ganganagar, Bikaner Jaisalmer, Barmer, and Sama Khiali on NH 8 nea Kandla. (f) NH 8 C National Highway connecting Ghandhinagar in Gujarat with NH 8 and NH 8 A, (g) NH 7 A - National Highway connecting Palayamkottai with Tutikorin and (h) NH 1 B - National Highway connecting Batote with Doda and Kishtwar.

(2) As a part of Minimum Needs Programme (M.N.P.) it was proposed to construct all weather rods so that the villages with a population of more than 1500 are interconnected. This was not totally achieved.

(3) Expenditure in this plan period including the plan period 1979 - 1980 was around 31 % of the total transport sector and the road length increased from 1393930 km to about 1534200 km. This expenditure includes the cost that went for conversion of single lane widths to two lane widths for certain National Highways.

1.9.6 The Fifth Plan Period (1974 – 1979)

The significant achievements of this plan period were

(1) The additions to National Highway network namely (a) NH 48 National Highway connecting Nalmangala near Bangalore with Hasan and Mangalore, (b) NH 23 connecting Chas, Ranchi, Rourkela, Talcher, and terminating on NH 42, (c) NH 17 A connecting MarmuGao Port with NH 17, (d) NH 17. National Highway connecting Panvel on NH 4 to Mahad, Panaji Karwar, Mangalore, Caunanore, Calicut and Edapalli

near Cochin. (e) NH 15. National Highway connecting Pathankot Bhatinda Ganganagar, Bikaner Jaisalmer, Barmer, and Sama Khiali on NH 8 nea Kandla. (f) NH 8 C National Highway connecting Ghandhinagar in Gujarat with NH 8 and NH 8 A, (g) NH 7 A - National Highway connecting Palayamkottai with Tutikorin and (h) NH 1 B - National Highway connecting Batote with Doda and Kishtwar.

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1.9.7 The Sixth Five Year Plan 1980 – 1985

Sixth Five Year Plan is characterised by the following achievements :

(1) Many highways to the tune 2500 km were constructed in the strategic North Eastern Zone.

(2) The minimum needs programme of the sixth plan was reinforced.

(3) In general, this plan could be said to be stock checking plan, the deficiencies in the previous plans were made up, missing links provided, certain inter - state roads of economic importance and border roads were constructed. The sixth plan contained a provision of 3440 crores representing around 29 % of the outlay in the transport sector and around 3.5 % outlay in the total plan.

(4) The system of National Highway was strengthened. The expenditure that is to be in curred on National Highways in this plan as a comparison to other previous plans is indicated in the table 1.2.

(5) For the first time, provision of new generation of roads along high density corridors with divided carriageway facilities were proposed.

(6) The seventh plan makes an outlay of Rs. 892 crores for National Highways and Rs. 128 for other centrally sponsored schemes and Rs. 4180 crores for the state sector roads.

1.9.8 The Seventh Plan (1985 – 1990)

The main objectives and the achievements of this plan are -

(1) Proposal to construct expressways i.e. Ahmedabad - Vadodara and Kolkata - Durgapur. These will be first expressways of the country.

(2) Continued rural road activity so that the minimum needs programme is completed. These rural roads will be constructed if required under Employment Gurantee Scheme or Rural Landless Employment Gurantee Programme (NLEGRP) or National Rural Employment Programme (NREP). Presently out of nearly 6,00,000 villages, about 2,60,000 villages only are connected by all-weather roads. The level of accessibility in respect of villages of 1500 population or above is 86 % and that of 1000 - 1500 is 63%.

(3) No National Highways as such were proposed and most of the expenditure went in consolidating the gains.

(4) The system of National Highway was strengthened. The expenditure that is to be in curred on National Highways in this plan as a comparison to other previous plans is indicated in the table 1.2.

(5) For the first time, provision of new generation of roads along high density corridors with divided carriageway facilities were proposed.

(6) The seventh plan makes an outlay of Rs. 892 crores for National Highways and Rs. 128 for other centrally sponsored schemes and Rs. 4180 crores for the state sector roads.

1.9.9 Eighth Five Year Plan Roads (1990 - 1995)

General

Along with other modes like railways, waterways and air services, roads provide the basic infrastructure for transportation of goods and passengers. Roads cater to all types of traffic; the long distance traffic is served by National highways and State highways, inter district and intra district traffic by major district roads, feeder traffic connecting rural centres of production to market outlets by other district roads and local traffic by village roads and urban roads.

Thrust Areas and Strategy for the Eighth Plan

- The existing deficiencies in national highways (NH) would require construction of missing links, four laning and two laning of various sections, construction of bridges and by-passes etc. The first priority will be given to complete the ongoing works. For systematic development of the NH system, different strategies will need to be adopted for low, medium and high volume traffic density routes. Capacity augmentation of high density traffic corridors carrying more than 15,000 passenger car units traffic per day, through four laning will need to be taken up during the Eighth Plan. For selected high density corridors, it may be necessary to consider expressway facility for rapid and safe movement of fast traffic. Levy of tolls may be considered for highway users. For national highways carrying medium traffic density, traffic upto 15000 PCUs, strengthening of pavement and widening to two-lanes including reconstruction of bridges, wherever necessary, need to be taken up. For low traffic density routes carrying traffic upto 5,000 PCUs, widening to two-lanes may be considered only on a selective basis, depending upon the resource availability. However, weak and narrow bridges have to be replaced.
- As regards additions to the National Highways system, it would be necessary to adopt a very selective approach in view of the resource constraints and the need to give priority to removal of deficiencies on the existing NH-system
- Constraints of resources may not permit removal of all the existing deficiencies in the State highways during the Plan period and a selective approach based on economic cost benefit analysis may have to be adopted. Consolidating the existing network should receive high priority. It would be necessary to widen and strengthen the pavement

structure to minimize vehicle operating costs and maintenance expenditure. A number of bridges would be required to be constructed/ reconstructed. Special attention has to be given to those State Highways which would require to be upgraded to National Highway in the future on the basis of traffic densities and growth It is essential that the State Governments make arrangements to prepare suitable road and bridge inventories covering the existing physical status and structural condition of the main network comprising the State Highways and major district roads and then update them at regular periodic intervals. Regular traffic counts on these roads would be necessary in order to decide on the inter-se priority of development of various sections.

- Rural roads are essential for achieving the objective of integrated rural development. The priority for rural road development in the Eighth Plan would be as under :-
  - (a) Linking of all villages with a population of 1000 and above on the basis of 1981 census.
  - (b) Special efforts to accelerate village connectivity in respect of backward regions and tribal areas.
- It would be appropriate to integrate rural road construction and maintenance under Minimum Needs Programme (MNP) with local area development planning. State Governments may pool the resources, made available under MNP and special employment programmes and undertake rural road construction under the respective local area development plan.

1.9.10 Ninth Five Year Plan (1995 - 2000)

The following goals and objectives have been kept in view while framing the outline of the Ninth Plan :

(a) Phased removal of deficiencies in the existing NH network in the tune with traffic needs for 10-15 years with emphasis on high density corridors for four-laning.

(b) Bring in highway-user oriented project planning in identifying package of projects section-wise rather than isolated stretches.

(c) Greater attention to rehabilitation and reconstruction of weak/dilapidated bridges for the safety of the traffic.

(d) Modernization of road construction technology for speedy execution and quality assurance.

(e) Engineering measures to improve road safety and conservation of energy.

(f) Continued emphasis on research and development

(g) Integrating the development plans with Railways and other modes of transport.

(h) Providing employment opportunities to the labour force in rural areas.

(i) Special attention for development of roads in the North-Eastern Region.

(j) Encouraging private sector participation in development of roads.

1.9.11 Tenth Five Year Plan (2001-05)

The following broad goals and objectives for road sector development have been set for the Tenth Plan :

1. Balanced development of the total road network comprising three functional groups viz. the primary system (National Highways (NH) and expressways), secondary system (State Highways and Major District Roads) and rural roads.
2. Development of roads to be considered an integral part of the total transport system supplementing other modes, integrating the development plans with railways and other modes of transport.
3. Completion of the National Highways Development Project comprising the Golden Quadrilateral and the North-South and East-West corridors.
4. Phased removal of deficiencies in the existing NH network in tune with traffic for the next 10-15 years with emphasis on four-laning of high-density corridors.
5. To plan and take preliminary action for expressways to be built in future in those sections where these can be economically justified.
6. To make long distance travel safer and faster so as to give a boost to the economy.
7. Priority is to be accorded to areas like overloading of trucks, control of encroachments and unplanned ribbon development, energy conservation and environment protection.
8. Greater attention to be paid to rehabilitation and reconstruction of weak/dilapidated bridges for traffic safety.
9. Special attention is to be paid to the development of roads in the North-Eastern region.
10. Particular emphasis needs to be given to the commercialisation of highways particularly the National Highways and State Highways and bringing in the concept of user-charges for sustainable financing of the road sector. Further steps must also be taken to encourage private sector participation in the highway sector. It is necessary to implement the policy of levying toll on all four-lane roads on the National Highway network. States must adopt a similar strategy in respect of State Highways etc.
11. High-density corridors within the network of National and State Highways and Major District Roads should be identified. Such corridors and major inter-state roads should be developed on a priority basis.
12. To improve the quality of life in rural areas and ensure balanced regional development by achieving the PMGSY target of providing connectivity through all-weather roads to all habitations with a population of over 500 persons (as per the 2001 Census).
13. To encourage industry and export by providing sufficiently wide roads leading to industrial centres, ports, mining areas and power plants.
14. To encourage tourism by improving roads leading to centres of tourist importance.
15. To provide wayside amenities along highways.

16. To reduce transportation costs by providing better riding surface and popularising the use of containers and multi-axle vehicles in the haulage of goods.
17. Utmost attention to the proper upkeep and maintenance of the existing road network.
18. To ensure road connectivity where rail link is not available or possible.
19. Integrating the development plan with railways and other modes of transport and to :
    (a) identify feeder roads to important railway routes and undertake needed improvement including periodic maintenance;
    (b) link minor important ports with minimum two-lane NHs/SHs;
    (c) link all Inland Container Depots/container freight stations with minimum two-lane NHs/SHs.
20. Use of modern management techniques for scientific assessment of maintenance strategies/priorities.
21. Development of a road data bank and computerised project monitoring system and promotion of the use of information technology in the highway sector.

1.9.12 An approach to Eleventh Five Year Plan (2007-2012)

1. The Tenth Plan stressed the need for improving mobility and easy accessibility. Accordingly, the National Highway Development Programme (NHDP) consisting of four laning of the Golden Quadrilateral (NHDP I) with a length of 5,846 km and the North-South and East-West Corridor (NHDP II) with a length of 7472 km coupled with Pradhan Mantri Gram Sadak Yojana (PMGSY) for rural roads were taken up. The PMGSY programme has been recently expanded to achieve the Bharat Nigam target of connecting 1000 + habitation (500 + for hilly and tribal areas) by 2008-09 with all-weather roads. This programme will help bring India's villages into the market economy. It will also help us to tackle social sector problems like illiteracy, high IMR and MMR) which are dragging India down because while roads connect villages to markets, they also connect them to schools and hospitals. The "Special Accelerated Development Road Programme for the North Eastern Region (SARDP-NE)", will help in developing and integrating these regions with the rest of the country.

2. The problems of development of our roads network are diverse and future requirements are formidable magnitude. Therefore, the strategy for development of roads would would have to vary keeping in view the nature of problem and the development required. It is proposed to undertake an expanded programme for highway development going beyond NHDP I and II to include NHDP III to VII. This programme will involve substantial resources from public private partnership based on build, operate and transfer (BOT) model which has many advantages over the

traditional contracts (See *Box* on PPPs). All contracts on provision of road services for high density corridors to be taken up under NHDP III onwards would be awarded only on BOT basis, and the traditional construction contracts will be awarded only in specified exceptional cases. A model concession agreement has been developed to facilitate speedy award of contracts. This is a very significant innovation in the areas of public-private partnership. This would leave a substantial part of National Highways network which would also require development during the Eleventh Plan period. These sections are characterised by low density of traffic. Some of these stretches fall in backward and inaccessible areas and others are of strategic importance. The development of these categories of National Highways would be carried out primarily through budgetary resources.

3. The present traffic mix consisting of non-motorised and low-powered vehicles compels low speed Furthermore, most of the National Highways pass through habitations and ribbon development is a perennial problem. It is, therefore, necessary to establish a network of access controlled Expressways across the country for which advance planning would be undertaken during the Eleventh Plan. The actual construction (except for 1000 kms already taken up) would be undertaken during the Twelth Plan period and would be prioritised according to the density of traffic.

4. Vehicular traffic needs more than just the arterial routes to be of world class. Adequate attention has not been given in the past to other roadways, which are the responsibility of the state governments. Priority would be accorded for ensuring integrated development of road networks including State Highways, Major District Roads and Other District Roads. The increased emphasis on rural roads would also continue and a major proportion of the 1.72 lakh unconnected habitations would be connected with all weather roads under the PMGSY.

5. The maintenance of roads has not been given adequate importance by the states mainly due to paucity of resources. This has resulted in poor riding quality of the road network which is highly uneconomic. A rupee spend on maintenance saves two to three rupees in vehicle operating costs, besides improving traffic flow. Therefore, there is a need to accord higher priority to the needs of maintenance by providing more allocation or considering it as a part of Plan. In fact, the 12th Finance Commission has recommended additional grants to the States, to the tune of Rs. 15,000 crore for maintenance of roads and bridges for the four-year period 2006-07 to 2009-10.

6. The National Highway Authority of India (NHAI) has an enormous task before it to implement a road programme. The Authority is being restructured to give it greater professional skills combined with a measure of autonomy and accountability.

7. Indian roads are considered very accident prone and claim a large number of casualties representing an enormous human and economic loss. This problem is compounded by the phenomenal growth in road transport fleet, particularly personalized vehicles and the consequent problems of increase in vehicular pollution and road safety. Steps need to be taken to improve the public transport system and safety of road transport operations.

1.5 Classifications of roads

2.1.1 Classification Based on the Weather Condition

The different types of road are classified into two categories, depending on whether they can be used during different seasons of the year.

1. All-weather roads
2. Fair-weather roads

All-weather roads : All weather roads are those which are negotiable during weather, except at major river crossing where interruption to traffic is permissible upto a certain extent, the road pavement should be negotiable during all weathers.

Fair-weather roads : Roads which are called fair-weather roads on these, the traffic may be interrupted during monsoon season at causeways where stream may overflow across the road.

2.1.2 Classification Based on the Road Pavement

Based on road pavement, roads are classified as paved roads and unpaved roads.

1. Paved road
2. Unpaved road

Pavement roads : If they are provided with a hard pavement course which should be at least water bound macadam (WBM) layer.

Unpaved roads : If they are not provided with a hard pavement course of at least a WBM layer. Thus, earth road and gravel road may be called unpaved roads.

2.1.3 Classification Based on the Pavement Surfacing

Based on the type of pavement surfacing providing, the roads are divided into two categories as :

1. Surfaced road
2. Unsurfaced road

Surfaced Roads : Surface roads which are provided with a bituminous or cement concrete surfacing.

Unsurfaced Roads : Unsurfaced roads which are not provided with bituminous or cement concreting.

2.1.4 Classification Based on the Road Plan

- **Classification of Rural Roads :** (I.R.C-1980)

The road plan classified the roads in India based on location and function into following categories.

1. Expressways
2. National Highways (NH)
3. State Highways (SH)
4. Major District Roads (MDR)
5. Other District Roads (ODR)
6. Village Roads (VR)

Expressways : Expressways are a separate class of highways with superior facilities and design standards and are meant as through routes having very high volume of traffic. The expressways are to be provided with divided carriageways, controlled, grade separations at cross roads and fencing. These highways should permit only fast moving vehicles. Expressways may be owned by Central Government or a State Government, depending on whether the route is a National Highway or State Highway. Example : Mumbai-Pune Expressway.

National Highways (NH) : National highways are highways running through the length and breadth of India, connecting major ports, foreign highways, capital of large states and large industrial and tourist centres including roads required for strategic movements for the defence of India. Example NH-1 Delhi-Ambala-Amritsar, NH-50 Nasik-Pune.

State Highways (SH) : State highways are arterial roads of a state, connecting up with the national highways of the adjacent states, district head quarters and important cities within the state and serving as the main arteries for traffic to and from district roads. The NH and SH have the same design speed and geometric design specifications. Examples :

SH-61 Belha Pabal Shikrapur Astapur Road

SH-70 Mahad-Pandharpur Road.

Major District Roads (MDR) : Major district roads are important roads within a district serving areas of production and markets and connecting those with each other or with the main highways of a district. The MDR has lower speed and geometric design specifications than NH / SH. Example, MDR-2 Kendur Dhamani Hirare Ranjangaon Road.

Other District Roads (ODR) : Other district roads are roads serving rural areas of production and providing them with outlet to market centres, taluka head quarters, block development head quarters or other main roads. These are of lower design specifications than MDR.

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

VR-183-Hiware-Jategaon Road

2.1.5 Classification of Urban Roads (I.R.C. - 1977)

The road systems within urban areas are classified as Urban Roads and will form a separate category of roads to be taken care by the respective urban authorities. They are divided into following types

1. Arterial roads
2. Sub-arterial roads
3. Collector streets and
4. Local streets

Arterial Roads : The city roads which are meant for through traffic usually on a continuous route are called arterial streets. Arterial streets are generally spaced at less than 15 km in developed business centres whereas in less important areas, these may be 8 km apart. Arterial roads are also divided highways with fully or partially controlled access. Parking, loading and unloading activities are carefully regulated. Pedestrians are permitted to cross them at intersections only.

Sub-Arterial roads : The city roads which provide lower level of travel mobility than arterial streets are called as sub-arterial streets. Their spacing may vary from 0.5 km in central business districts to 3 to 5 km in sub-urban areas. Loading and unloading are usually restricted. Pedestrians are allowed to cross these highways at intersections.

Collector Streets : The city roads which are constructed for collecting and distributing the traffic to and from local streets, and also to provide an access to arterial and sub-arterial streets, are also called collector streets. These are located in residential, business and industrial areas. These roads are accessible from the building along them. Parking restrictions are few that too during peak hours.

Local Streets : The city roads which provide an access to residence, business and other building are called local streets. The traffic carried either originates or terminates along the local streets. Depending upon the importance of the adjoining areas, a local street may be residential, commercial or industrial. Along local streets, pedestrians may move freely and parking may be permitted without any restriction.

1.6 Road patterns

The road network can be laid in various patterns. These patterns can vary. The patterns in which the road network is laid could be (1) Rectangular or block pattern, (2) Radial or star and block pattern, (3) Radial or star and circular pattern, (4) Radial or star and grid pattern, (5) Hexagonal pattern, (6) Minimum travel pattern. These patterns are illustrated in the next subarticles. The Nagpur road plan formulae were prepared on the assumption of star and grid pattern. Connaught place in New Delhi has radial and circular pattern, whereas Chandigarh has rectangular or block pattern. If the city is being planned from scratch, some pattern can be given. In most of our cities, some of the pattern is already existing and one has to go with them.

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

The rectangular plots may be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front. The rectangular pattern has been adopted for the city roads of Chandigarh. The construction and maintenance of roads of this pattern is comparatively easier but from traffic point of view, this pattern is not very much convenient because at the intersections, the vehicles face each other.

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

Radial or Star and Circular Pattern : In this system, the main radial roads radiating from the central business area are connected together with concentric roads. In these areas, boundary by adjacent radial roads and corresponding circular roads, the built-up area is planned with a curved block system. An example of this road pattern is the road network of co naught place in New Delhi.

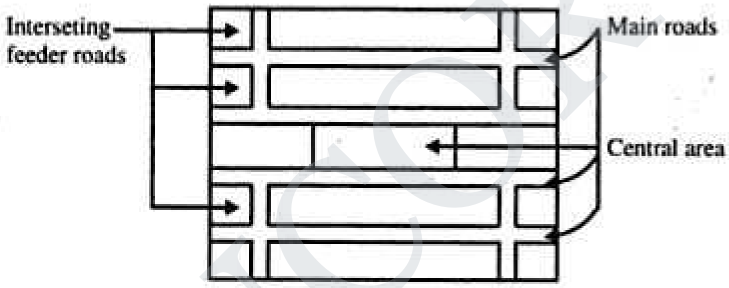


Fig. 2.1 : Rectangular or block pattern

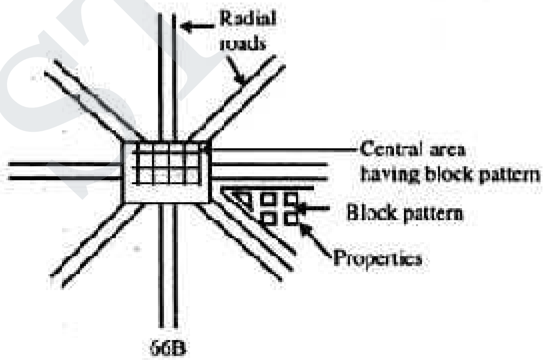


Fig. 2.2 : Radial or star and block pattern

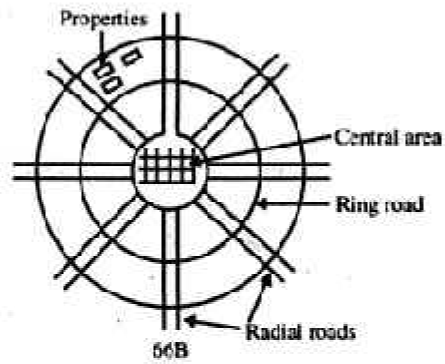
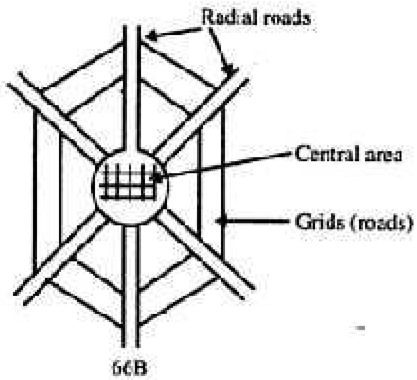


Fig. 2.3 : Radial or star and circular pattern



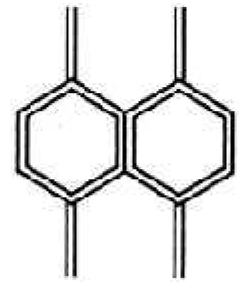
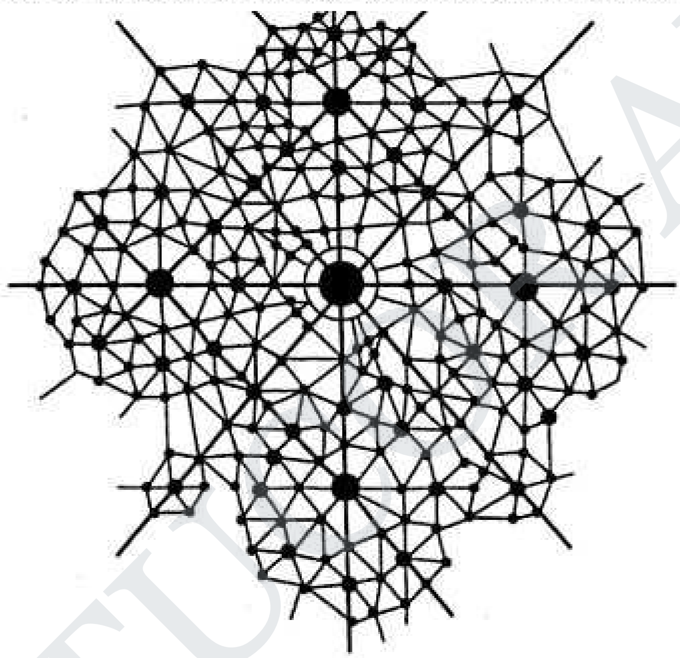


Fig. 2.4 : Radial or star and grid pattern **Fig. 2.5 : Hexagonal pattern**

Hexagonal Pattern : In this pattern, the entire area is provided with a network of roads forming hexagonal figures. At each corner of the hexagon, three roads meet The built-up area bounded by the sides of the hexagons is further divided in suitable sizes.



Minimum Travel Pattern : In this road pattern, city (city centre) is contented by sector centres, suburban centres and neighbourhood centres by the road which required minimum to connect the city centre.

1.7 Camber

Camber or cant is the cross slope provided to raise middle of the road surface in the transverse direction to drain of rain water from road surface. The objectives of providing camber are:

_ Surface protection especially for gravel and bituminous roads
_ Sub-grade protection by proper drainage
_ Quick drying of pavement which in turn increases safety

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

1.7.1 Types of cambers.

The common types of camber are parabolic, straight, or combination of them

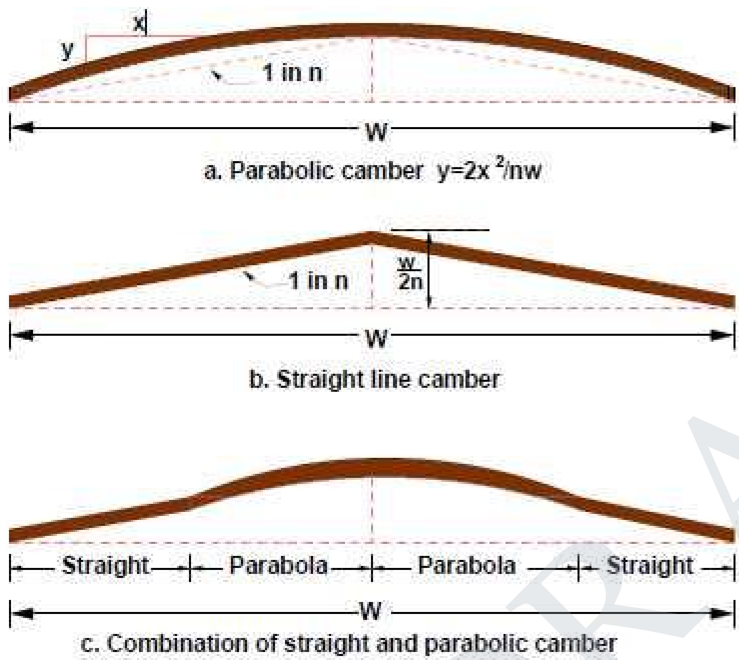


Table 12:1: IRC Values for camber

Surface type	Heavy rain	Light rain
Concrete/Bituminous	2 %	1.7 %
Gravel/WBM	3 %	2.5 %
Earthen	4 %	3.0 %

1.8 Width of carriage way

Width of the carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance. Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.44 and the desirable side clearance for single lane traffic is 0.68 m. This require minimum of lane width of 3.75 m for a single lane road .However, the side clearance required is about 0.53 m, on either side and 1.06 m in the center. Therefore, a two lane road require minimum of 3.5 meter for each lane The desirable carriage way width recommended by IRC is given in Table

Table 12:2: IRC Specification for carriage way width

Single lane	3.75
Two lane, no kerbs	7.0
Two lane, raised kerbs	7.5
Intermediate carriage	5.5
Multi-lane	3.5

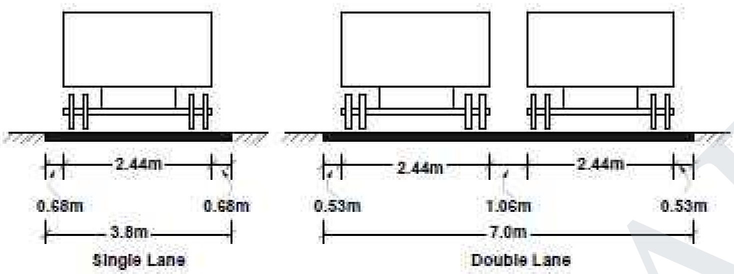


Figure 12:2: Lane width for single and two lane roads

1.9 Importance of Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths.

Different types of kerbs are

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

Semi-barrier type kerbs : When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.

Barrier type kerbs : They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.

Submerged kerbs: They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.

Width of formation:

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders.

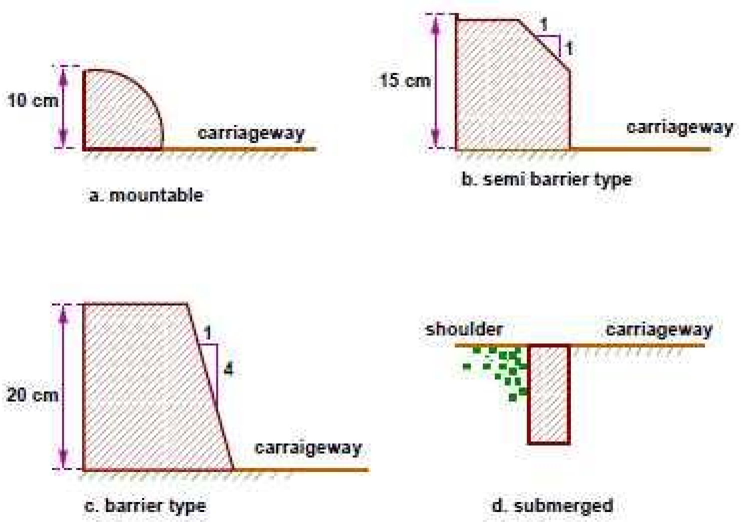


Figure 12:3: Different types of kerbs

Table 12:3: Width of formation for various classed of roads

Road classification	Roadway width in m	
	Plain and rolling terrain	Mountainous and steep terrain
NH/SH	12	6.25-8.8
MDR	9	4.75
ODR	7.5-9.0	4.75
VR	7.5	4.0

1.10 Right of way.

Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development. To prevent ribbon development along highways, control lines and building lines may be provided. Control line is a line which represents the nearest limits of future uncontrolled building activity in relation to a road. Building line represents a line on either side of the road, between which and the road no building activity is permitted at all. The right of way width is governed by:

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

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

Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.

Drainage system and their size which depends on rainfall, topography etc.

Sight distance considerations : On curves etc. there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like building structures etc.

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

Table 12:4: Normal right of way for open areas

Road classification	Roadway width in m	
	Plain and rolling terrain	Mountainous and steep terrain
Open areas		
NH/SH	45	24
MDR	25	18
ODR	15	15
VR	12	9
Built-up areas		
NH/SH	30	20
MDR	20	15
ODR	15	12
VR	10	9

The importance of reserved land is emphasized by the following. Extra width of land is available for the construction of roadside facilities. Land acquisition is not possible later, because the land may be occupied for various other purposes (buildings, business etc.)

The normal ROW requirements for built up and open areas as specified by IRC is given in Table 12:4 A typical cross section of a ROW is given in Figure 12:4.

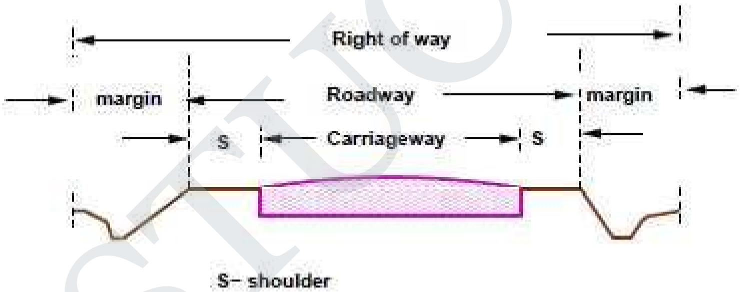


Figure 12:4: A typical Right of way (ROW)

1.11 Alignment

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

Requirements

The requirements of an ideal alignment are

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

Factors controlling alignment

We have seen the requirements of an alignment. But it is not always possible to satisfy all these requirements. Hence we have to make a judicial choice considering all the factors.
The various factors that control the alignment are as follows:

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

- Bridge site: The bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.
- Mountain: While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills. The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.
- Intermediate town: The alignment may be slightly deviated to connect an intermediate town or village nearby.

These were some of the obligatory points through which the alignment should pass. Coming to the second category, that is the points through which the alignment should not pass are:

- Religious places: These have been protected by the law from being acquired for any purpose. Therefore, these points should be avoided while aligning.
- Very costly structures: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.
- Lakes/ponds etc: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.

2. Traffic: The alignment should suit the traffic requirements. Based on the origin- destination data

of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc.

3. Geometric design: Geometric design factors such as gradient, radius of curve, sight distance etc. also govern the alignment of the highway. To keep the radius of curve minimum, it may be required to change the alignment. The alignments should be finalized such that the obstructions to visibility do not restrict the minimum requirements of sight distance. The design standards vary with the class of road and the terrain and accordingly the highway should be aligned.
4. Economy: The alignment finalized should be economical. All the three costs i.e. construction, maintenance, and operating cost should be minimum. The construction cost can be decreased much if it is possible to maintain a balance between cutting and filling. Also try to avoid very high embankments and very deep cuttings as the construction cost will be very higher in these cases.

UNIT II
GEOMETRIC DESIGN OF HIGHWAYS

Typical cross sections of Urban and Rural roads — Cross sectional elements - Sight distances – Horizontal curves, Super elevation, transition curves, widening at curves – Vertical curves - Gradients, Special consideration for hill roads - Hairpin bends – Lateral and vertical clearance at underpasses

2.1 Design Speed

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

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

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

Table : Terrain classification

Terrain classification	Cross slope (%)
Plain	0-10
Rolling	10-25
Mountainous	25-60
Steep	60

The recommended design speed is given in Table .

Table : Design speed in as per IRC (ruling and minimum)

Type	Plain	Rolling	Hilly	Steep
NS&SH	100-80	80-65	50-40	40-30
MDR	80-65	65-50	40-30	30-20
ODR	65-50	50-40	30-25	25-20
VR	50-40	40-35	25-20	25-20

2.1.1 Topography:

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

2.1.2 Other factors :

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

Vehicle: The dimensions, weight of the axle and operating characteristics of a vehicle influence the design aspects such as width of the pavement, radii of the curve, clearances, parking geometrics etc. A design vehicle which has standard weight, dimensions and operating characteristics are used to establish highway design controls to accommodate vehicles of a designated type.

Human: The important human factors that influence geometric design are the physical, mental and psychological characteristics of the driver and pedestrians like the reaction time.

Traffic: It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is determined from the various traffic data collected. The geometric design is thus based on this design volume, capacity etc.

Environmental: Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.

Economy: The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.

Others: Geometric design should be such that the aesthetics of the region is not affected.

2.2 Factors affecting Sight distance

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

The computation of sight distance depends on:

Reaction time of the driver

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

Speed of the vehicle

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

Efficiency of brakes

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

Frictional resistance between the tyre and the road

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

Gradient of the road.

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

2.3 Stopping sight distance

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

There is a term called safe stopping distance and is one of the important measures in tra c engineering. It is the distance a vehicle travels from the point at which a situation is rst perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in highway design, sight distance atleast equal to the safe stopping distance should be provided. The stopping sight distance is the sum of lag distance and the braking distance. Lag distance is the distance the vehicle traveled during the reaction time t and is given by vt, where v is the velocity in m=sec^2. Braking distance is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is F l = f W l where W is the total weight of the vehicle. The kinetic energy at the design speed is

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

where v is the design speed in m=sec^2, t is the reaction time in sec, g is the acceleration due to gravity and f is the coefficient of friction. The coefficient of friction f is given below for various design speed.

When there is an ascending gradient of say +n%, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the braking force is equal to W sin W tan = W n=100. Equating kinetic energy and work done:

Similarly the braking distance can be derived for a descending gradient.

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

2.4 Overtaking sight distance

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

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

The dynamics of the overtaking operation is given in the figure which is a time-space diagram. The x-axis denotes the time and y-axis shows the distance traveled by the vehicles. The trajectory of the slow moving vehicle (B) is shown as a straight line which indicates that it is traveling at a constant speed. A fast moving vehicle (A) is traveling behind the vehicle B. The trajectory of the vehicle is shown initially with a steeper slope. The dotted line indicates the path of the vehicle A if B was absent. The vehicle A slows down to follow the vehicle B as shown in the figure with same slope from t_0 to t_1. Then it overtakes the vehicle B and occupies the left lane at time t_3. The time duration $T = t_3 \;\; t_1$ is the actual duration of the overtaking operation. The snapshots of the road at time t_0 ; t_1, and t_3 are shown on the left side of the figure. From the Figure, the overtaking sight distance consists of three parts.

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

$d_1 = v_b t$

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

$s = 0{:}7v_b + 6$

Let T be the duration of actual overtaking. The distance traveled by B during the overtaking operation is $2s + v_b T$. Also, during this time, vehicle A accelerated from initial velocity v_b and overtaking is completed while

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

where v_b is the velocity of the slow moving vehicle in m=sec^2, t the reaction time of the driver in sec, s is the spacing between the two vehicle in m and a is the overtaking vehicles acceleration in m=sec^2. In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower the design speed.

The acceleration values of the fast vehicle depends on its speed

2.5 Horizontal curve

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

They are the centrifugal force (P) acting outward, weight of the vehicle (W) acting downward, and the reaction of the ground on the wheels (R_A and R_B). The centrifugal force and the weight is assumed to be from the centre of gravity which is at h units above the ground. Let the wheel base be assumed as b units. The centrifugal force P in kg=m^2 is given by

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

where W is the weight of the vehicle in kg, v is the speed of the vehicle in m=sec, g is the acceleration due to gravity in m=sec^2 and R is the radius of the curve in m.

The centrifugal force has two effects: A tendency to overturn the vehicle about the outer wheels and a tendency for transverse skidding. Taking moments of the forces with respect to the outer wheel when the vehicle is just

The second tendency of the vehicle is for transverse skidding. i.e. When the centrifugal force P is greater than the maximum possible transverse skid resistance due to friction between the pavement surface and tyre. The transverse skid resistance (F) is given by:

$$F = F_A + F_B$$
$$= f(R_A + R_B)$$
$$= f W$$

where F_A and F_B is the fractional force at tyre A and B, R_A and R_B is the reaction at tyre A and B, f is the lateral coefficient of friction and W is the weight of the vehicle. This is counteracted by the centrifugal force (P), and equating:

2.6 Analysis of Super-elevation

Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counteracting the effect of centrifugal force. In order to find out how much this raising should be, the following analysis may be done. The forces acting on a vehicle while taking a horizontal curve with superelevation is shown in figure

Forces acting on a vehicle on horizontal curve of radius R m at a speed of v $m=sec^2$ are:

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

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

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

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

where W is the weight of the vehicle, P is the centrifugal force, f is the coefficient of friction, is the transverse slope due to super elevation. Dividing by W cosθ, we get:

By substituting the value of P/W this in equation

2.6.1 Design of super-elevation

While designing the various elements of the road like superelevation, we design it for a particular vehicle called design vehicle which has some standard weight and dimensions. But in the actual case, the road has to cater for mixed traffic. Different vehicles with different dimensions and varying speeds ply on the road. For example, in the case of a heavily loaded truck with high centre of gravity and low speed, superelevation should be less; otherwise chances of toppling are more. Taking into practical considerations of all such situations, IRC has given some guidelines about the maximum and minimum superelevation etc.

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

2.7 Mechanical widening

The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in figure. This phenomenon is called o - tracking, and has the effect of increasing the effective width of a road space required by the vehicle. Therefore, to provide the same clearance between vehicles traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles are using the road. Trailor trucks also need extra carriageway, depending on the type of joint. In addition speeds higher than the design speed causes transverse skidding which requires additional width for safety purpose. The expression for extra width can be derived from the simple geometry of a vehicle at a horizontal curve as shown in figure. Let R_1 is the radius of the outer track line of the rear wheel, R_2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, then the mechanical widening W_m is derived below:

2.8 Psychological widening

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

2.9 Length of transition curve

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

Rate of change of centrifugal acceleration

At the tangent point, radius is infinity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. The rate of change of centrifugal acceleration should be adopted such that the design should not cause discomfort to the drivers. If c is the rate of change of centrifugal acceleration, it is given by an empirical formula suggested by by IRC

2.10 Vertical alignment

The vertical alignment of a road consists of gradients(straight lines in a vertical plane) and vertical curves. The vertical alignment is usually drawn as a pro le, which is a graph with elevation as vertical axis and the horizontal distance along the centre line of the road as the the horizontal axis. Just as a circular curve is used to connect horizontal straight stretches of road, vertical curves connect two gradients. When these two curves meet, they form either convex or concave. The former is called a summit curve, while the latter is called a valley curve.

2.11 Types of gradient

Many studies have shown that gradient upto seven percent can have considerable effect on the speeds of the passenger cars. On the contrary, the speeds of the heavy vehicles are considerably reduced when long gradients as at as two percent is adopted. Although, flatter gradients are desirable, it is evident that the cost of construction will also be very high. Therefore, IRC has specified the desirable gradients for each terrain. However, it may not be economically viable to adopt such gradients in certain locations, steeper gradients are permitted for short duration. Different types of grades are discussed below and the recommended type of gradients for each type of terrain and type of gradient is given in table 17:1.

Ruling gradient, limiting gradient, exceptional gradient and minimum gradient are some types of gradients which are discussed below.

Ruling gradient

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

Limiting gradient

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

Exceptional gradient

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

Critical length of the grade

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

Minimum gradient

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

2.12 Creeper lane

When the uphill climb is extremely long, it may be desirable to introduce an additional lane so as to allow slow ascending vehicles to be removed from the main stream so that the fast moving vehicles are not affected. Such a newly introduced lane is called creeper lane. There are no hard and fast rules as when to introduce a creeper lane. But generally, it can be said that it is desirable to provide a creeper lane when the speed of the vehicle gets reduced to half the design speed. When there is no restrictive sight distance to reduce the speed of the approaching vehicle, the additional lane may be initiated at some distance uphill from the beginning of the slope. But when the restrictions are responsible for the lowering of speeds, obviously the lane should be initiated at a point closer to the bottom of the hill. Also the creeper lane should end at a point well beyond the hill crest, so that the slow moving vehicles can return back to the normal lane without any danger.

In addition, the creeper lane should not end suddenly, but only in a tapered manner for efficient as well as safer transition of vehicles to the normal lane

2.13 Grade compensation

While a vehicle is negotiating a horizontal curve, if there is a gradient also, then there will be increased resistance to traction due to both curve and the gradient. In such cases, the total resistance should not exceed the resistance due to gradient specified. For the design, in some cases this maximum value is limited to the ruling gradient and in some cases as limiting gradient. So if a curve need to be introduced in a portion which has got the maximum permissible gradient, then some compensation should be provided so as to decrease the gradient for overcoming the tractive loss due to curve. Thus grade compensation can be defined as the reduction in gradient at the horizontal curve because of the additional tractive force required due to curve resistance (T cosθ), which is intended to o set the extra tractive force involved at the curve. IRC gave the following specification for the grade compensation.

1. Grade compensation is not required for grades flatter than 4% because the loss of tractive force is negligible.
2. Grade compensation is $\frac{30+R}{}$ %, where R is the radius of the horizontal curve in meters.
3. The maximum grade compensation is limited to $\frac{75}{}R$ %.

2.14 Summit curve

Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illus-trated in figure 17:2 in any of the following four ways:

= when a positive gradient meets another positive gradient

2.14.1 Types of Summit Curve

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

In determining the type and length of the vertical curve, the design considerations are comfort and security of the driver, and the appearance of the pro le alignment. Among these, sight distance requirements for the safety is most important on summit curves. The stopping sight distance or absolute minimum sight distance should be provided on these curves and where overtaking is not prohibited, overtaking sight distance or intermediate sight distance should be provided as far as possible. When a fast moving vehicle travels along a summit curve, there is less discomfort to the passengers. This is because the centrifugal force will be acting upwards while the vehicle negotiates a summit curve which is against the gravity and hence a part of the tyre pressure is relieved. Also if the curve is provided with adequate sight distance, the length would be sufficient to ease the shock due to change in gradient. Circular summit curves are identical since the radius remains same throughout and hence the sight distance. From this point of view, transition curves are not desirable since it has varying radius and so the sight distance will also vary. The deviation angle provided on summit curves for highways are very large, and so

the a simple parabola is almost congruent to a circular arc, between the same tangent points. Parabolic curves is easy for computation and also it had been found out that it provides good riding comfort to the drivers. It is also easy for field implementation. Due to all these reasons, a simple parabolic curve is preferred as summit curve.

Length of the summit curve

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. That is, a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road. Equation of the parabola is given by $y = ax^2$, where N is the deviation angle and L is the length of the In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight distance.

2.14.2 Design considerations for valley curve

There is no restriction to sight distance at valley curves during day time. But visibility is reduced during night. In the absence or inadequacy of street light, the only source for visibility is with the help of headlights. Hence valley curves are designed taking into account of headlight distance. In valley curves, the centrifugal force will be acting downwards along with the weight of the vehicle, and hence impact to the vehicle will be more. This will result in jerking of the vehicle and cause discomfort to the passengers. Thus the most important design factors considered in valley curves are: (1) impact-free movement of vehicles at design speed and (2) availability of stopping sight distance under headlight of vehicles for night driving.

For gradually introducing and increasing the centrifugal force acting downwards, the best shape that could be given for a valley curve is a transition curve. Cubic parabola is generally preferred in vertical valley curves.

During night, under headlight driving condition, sight distance reduces and availability of stopping sight distance under head light is very important. The head light sight distance should be at least equal to the stopping sight distance. There is no problem of overtaking sight distance at night since the other vehicles with headlights could be seen from a considerable distance.

2.14.3 Length of the valley curve

The valley curve is made fully transitional by providing two similar transition curves of equal length The transitional curve is set out by a cubic parabola $y = bx^3$. The length of the valley transition curve is designed based on two criteria:

comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a comfortable level of about $0{:}6m{=}sec^3$.

safety criteria; that is the driver should have adequate headlight sight distance at any part of the country.

Comfort criteria

The length of the valley curve based on the rate of change of centrifugal acceleration that will ensure comfort: Let c is the rate of change of acceleration, R the minimum radius of the curve, v is the design speed and t is

where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as 0:6m=sec^3.

Safety criteria

Length of the valley curve for headlight distance may be determined for two conditions: (1) length of the valley curve greater than stopping sight distance and (2) length of the valley curve less than the stopping sight distance.

UNIT III
DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

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

3.1 Flexible pavements

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure (see Figure 19:1). The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear. The lower layers will experience lesser magnitude of stress and low quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways). Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

3.2 Types of Flexible Pavements

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

Conventional layered flexible pavement,

Full - depth asphalt pavement, and

Contained rock asphalt mat (CRAM).

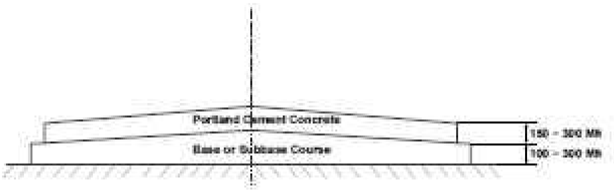
Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

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

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

3.3 Types of Failure in flexible pavements

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of subgrade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low-temperature cracking and thermal fatigue cracking.



Typical Cross section of Rigid pavement

3.4 Rigid pavements

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

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

3.5 Types of Rigid Pavements

Rigid pavements can be classified into four types:

Jointed plain concrete pavement (JPCP),

Jointed reinforced concrete pavement (JRCP),

Continuous reinforced concrete pavement (CRCP), and

Pre-stressed concrete pavement (PCP).

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

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

Continuous Reinforced Concrete Pavement: Complete elimination of joints are achieved by reinforce-ment.

3.6 Material characterization for pavement construction

The following material properties are important for both flexible and rigid pavements.

When pavements are considered as linear elastic, the elastic moduli and poisson ratio of subgrade and each component layer must be specified.

If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.

When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided.

However, many of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which require the modulus of elasticity and poisson ratio only.

3.7 The Environmental factors that affect the pavement materials

Environmental factors affect the performance of the pavement materials and cause various damages. Environ-mental factors that affect pavement are of two types, temperature and precipitation and they are discussed below:

Temperature

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

Precipitation

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

3.8 Factors which affects pavement design

Traffic and Loading

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design.

Fixed traffic: Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design.

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

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

3.9 Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub- grade.

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

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

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

Surface course

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

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

It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,

It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

3.10 Important factor in the pavement design

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

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

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

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

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

Repetition of Loads: The influence of traffic on pavement not only depend on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 kN single axle).

3.11The construction of WBM

Sub-base

Sub-base materials comprise natural sand, gravel, laterite, brick metal, crushed stone or combinations thereof meeting the prescribed grading and physical requirements. The sub-base material should have a minimum CBR of 20 % and 30 % for traffic upto 2 msa and traffic exceeding 2 msa respectively. Sub-base usually consist of granular or WBM and the thickness should not be less than 150 mm for design traffic less than 10 msa and 200 mm for design traffic of 1:0 msa and above.

Base

The recommended designs are for unbounded granular bases which comprise conventional water bound macadam

(WBM) or wet mix macadam (WMM) or equivalent confirming to MOST specifications. The materials should be of good quality with minimum thickness of 225 mm for traffic up to 2 msa an 150 mm for traffic exceeding 2 msa.

Bituminous surfacing

The surfacing consists of a wearing course or a binder course plus wearing course. The most commonly used wearing courses are surface dressing, open graded premix carpet, mix seal surfacing, semi-dense bituminous concrete and bituminous concrete. For binder course, MOST specifies, it is desirable to use bituminous macadam (BM) for traffic upto 5 msa and dense bituminous macadam (DBM) for traffic more than 5 msa.

3.12 Equivalent single wheel load.

To carry maximum load with in the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth. The procedure of finding the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

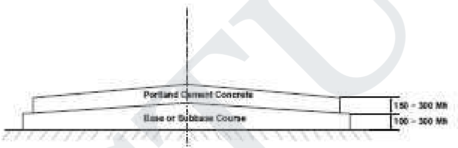
equalancy concept is based on equal

stress; contact area is circular;

influence angle is 45^o; and

soil medium is elastic, homogeneous, and isotropic half space.

The ESWL is given by:



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

3.13 Requirements of Bituminous mixes

Stability

Stability is defined as the resistance of the paving mix to deformation under traffic load. Two examples of failure are (i) shoving - a transverse rigid deformation which occurs at areas subject to severe acceleration and (ii) grooving - longitudinal ridging due to channelization of traffic. Stability depend on the inter-particle friction, primarily of the aggregates and the cohesion offered by the bitumen. Sufficient binder must be available to coat all the particles at the same time should offer enough liquid friction. However, the stability decreases when the binder content is high and when the particles are kept apart.

Durability

Durability is defined as the resistance of the mix against weathering and abrasive actions. Weathering causes hardening due to loss of volatiles in the bitumen. Abrasion is due to wheel loads which causes tensile strains. Typical examples of failure are (i) pot-holes, - deterioration of pavements locally and (ii) stripping, lost of binder from the aggregates and aggregates are exposed. Disintegration is minimized by high binder content since they cause the mix to be air and waterproof and the bitumen lm is more resistant to hardening.

Flexibility

Flexibility is a measure of the level of bending strength needed to counteract traffic load and prevent cracking of surface. Fracture is the cracks formed on the surface (hairline-cracks, alligator cracks), main reasons are shrinkage and brittleness of the binder. Shrinkage cracks are due to volume change in the binder due to aging. Brittleness is due to repeated bending of the surface due to traffic loads. Higher bitumen content will give better flexibility and less fracture.

Skid resistance

It is the resistance of the finished pavement against skidding which depends on the surface texture and bitumen content. It is an important factor in high speed traffic. Normally, an open graded coarse surface texture is desirable.

Workability

Workability is the ease with which the mix can be laid and compacted, and formed to the required condition and shape. This depends on the gradation of aggregates, their shape and texture, bitumen content and its type. Angular, flaky, and elongated aggregates workability. On the other hand, rounded aggregates improve workability.

3.14 Design procedures for flexible pavement

For flexible pavements, structural design is mainly concerned with determining appropriate layer thickness and composition. The main design factors are stresses due to traffic load and temperature variations. Two methods of flexible pavement structural design are common today: Empirical design and mechanistic empirical design.

Empirical design

An empirical approach is one which is based on the results of experimentation or experience. Some of them are either based on physical properties or strength parameters of soil subgrade. An empirical approach is one which is based on the results of experimentation or experience. An empirical analysis of flexible pavement design can be done with or with out a soil strength test. An example of design without soil strength test is by using HRB soil classification system, in which soils are grouped from A-1 to A-7 and a group index is added to differentiate soils within each group. Example with soil strength test uses McLeod, Stabilometer, California Bearing Ratio (CBR) test. CBR test is widely known and will be discussed.

Mechanistic-Empirical Design

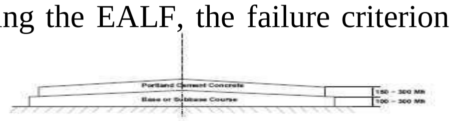
Empirical-Mechanistic method of design is based on the mechanics of materials that relates input, such as wheel load, to an output or pavement response. In pavement design, the responses are the stresses, strains, and deflections within a pavement structure and the physical causes are the loads and material properties of the pavement structure. The relationship between these phenomena and their physical causes are typically described using some mathematical models. Along with this mechanistic approach, empirical elements are used when defining what value of the calculated stresses, strains, and deflections result in pavement failure. The relationship between physical phenomena and pavement failure is described by empirically derived equations that compute the number of loading cycles to failure.

3.15 Equivalent single axle load

Vehicles can have many axles which will distribute the load into different axles, and in turn to the pavement through the wheels. A standard truck has two axles, front axle with two wheels and rear axle with four wheels. But to carry large loads multiple axles are provided. Since the design of flexible pavements is by layered theory, only the wheels on one side needed to be considered. On the other hand, the design of rigid pavement is by plate theory and hence the wheel load on both sides of axle need to be considered. Legal axle load: The maximum allowed axle load on the roads is called legal axle load. For highways the maximum legal axle load in India, specified by IRC, is 10 tonnes. Standard axle load: It is a single axle load with dual wheel carrying 80 KN load and the design of pavement is based on the standard axle load.

Repetition of axle loads: The deformation of pavement due to a single application of axle load may be small but due to repeated application of load there would be accumulation of unrecovered or permanent deformation which results in failure of pavement. If the pavement structure fails with N_1 number of repetition of load W_1 and for the same failure criteria if it requires N_2 number of repetition of load W_2 , then W_1 N_1 and W_2N_2 are considered equivalent. Note that, W_1N_1 and W_2 N_2 equivalency depends on the failure criterion employed.

Equivalent axle load factor: An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the i^{th} type of axle relative to the damage per pass of a standard axle load. While finding the EALF, the failure criterion is important. Two types of failure criterias are commonly



tigue cracking model has the following form:

$$N_f = f_1 (\epsilon_t)^{-f_2} \times (E)^{-f_3} or N_f \propto \epsilon_t{}^{-f_2}$$

where, N_f is the number of load repetition for a certain percentage of cracking, $_t$ is the tensile strain at the bottom of the binder course, E is the modulus of elasticity, and f_1; f_2; f_3 are constants. If we consider fatigue

3.16 Design criteria as per IRC

The flexible pavements has been modeled as a three layer structure and stresses and strains at critical locations have been computed using the linear elastic model. To give proper consideration to the aspects of performance, the following three types of pavement distress resulting from repeated (cyclic) application of traffic loads are considered:

vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.

horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.

pavement deformation within the bituminous layer.

While the permanent deformation within the bituminous layer can be controlled by meeting the mix design requirements, thickness of granular and bituminous layers are selected using the analytical design approach so that strains at the critical points are within the allowable limits. For calculating tensile strains at the bottom of the bituminous layer, the stiffness of dense bituminous macadam (DBM) layer with 60/70 bitumen has been used in the analysis.

Failure Criteria

A and B are the critical locations for tensile strains ($_t$). Maximum value of the strain is adopted for design. C is the critical location for the vertical subgrade strain ($_z$) since the maximum value of the ($_z$) occurs mostly at C.

Fatigue Criteria:

Bituminous surfacings of pavements display flexural fatigue cracking if the tensile strain at the bottom of the bituminous layer is beyond certain limit. The relation between the fatigue life of the pavement and the tensile strain in the bottom of the bituminous layer was obtained as

[illegible]

in which, N_f is the allowable number of load repetitions to control fatigue cracking and E is the Elastic modulus of bituminous layer. The use of equation 28.1 would result in fatigue cracking of 20% of the total area.

Rutting Criteria

The allowable number of load repetitions to control permanent deformation can be expressed as

3.17 Design procedure of IRC for flexible pavement.

Based on the performance of existing designs and using analytical approach, simple design charts and a catalogue of pavement designs are added in the code. The pavement designs are given for subgrade CBR values ranging from 2% to 10% and design traffic ranging from 1 msa to 150 msa for an average annual pavement temperature of 35 C. The later thicknesses obtained from the analysis have been slightly modified to adapt the designs to stage construction. Using the following simple input parameters, appropriate designs could be chosen for the given traffic and soil strength:

Design traffic in terms of cumulative number of standard axles; and CBR value of subgrade.

Design traffic

The method considers traffic in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design life. This requires the following information:

- Initial trafficin terms of CVPD
- Traffic growth rate during the design life
- Design life in number of years
- Vehicle damage factor (VDF)

Distribution of commercial traffic over the carriage way.

Initial traffic

Initial traffic is determined in terms of commercial vehicles per day (CVPD). For the structural design of the pavement only commercial vehicles are considered assuming laden weight of three tonnes or more and their axle loading will be considered. Estimate of the initial daily average traffic flow for any road should normally be based on 7-day 24-hour classified traffic counts (ADT). In case of new roads, traffic estimates can be made on the basis of potential land use and traffic on existing routes in the area.

Traffic growth rate

traffic growth rates can be estimated (i) by studying the past trends of traffic growth, and (ii) by establishing econometric models. If adequate data is not available, it is recommended that an average annual growth rate of 7.5 percent may be adopted.

Design life

For the purpose of the pavement design, the design life is defined in terms of the cumulative number of standard axles that can be carried before strengthening of the pavement is necessary. It is recommended that pavements for arterial roads like NH, SH should be designed for a life of 15 years, EH and urban roads for 20 years and other categories of roads for 10 to 15 years.

Vehicle Damage Factor

The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the axle configuration, axle loading, terrain, type of road, and from region to region. The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions. For these equivalency factors refer IRC:37 2001. The exact VDF values are arrived after extensive field surveys.

Vehicle distribution

A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design. Until reliable data is available, the following distribution may be assumed.

Single lane roads: Traffic tends to be more channelized on single roads than two lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.

Two-lane single carriageway roads: The design should be based on 75 % of the commercial vehicles in both directions.

Four-lane single carriageway roads: The design should be based on 40 % of the total number of commercial vehicles in both directions.

Dual carriageway roads: For the design of dual two-lane carriageway roads should be based on 75 % of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four-lane carriageway the distribution factor will be 60 % and 45 % respectively.

Design the pavement for construction of a new bypass with the following data:

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

vehicle

6. Design CBR of subgrade soil = 4%.

[illegible]

$$= 7200000$$

$$= 7{:}2 \text{ msa}$$

4. Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm

5. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

   (a) Bituminous surfacing = 25 mm SDBC + 70 mm DBM

   (b) Road-base = 250 mm WBM

   (c) sub-base = 315 mm granular material of CBR not less than 30 %

Design the pavement for construction of a new two lane carriageway for design life 15 years using IRC method. The initial traffic in the year of completion in each direction is 150 CVPD and growth rate is 5%. Vehicle damage factor based on axle load survey = 2.5 std axle per commercial vehicle. Design CBR of subgrade soil=4%.

1. Distribution factor = 0.75

2. [illegible]

$$= 4430348{:}837$$

$$= 4{:}4 \text{ msa}$$

4. Total pavement thickness for CBR 4% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm

5. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).

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

   (b) Road-base = 250 mm Granular base

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

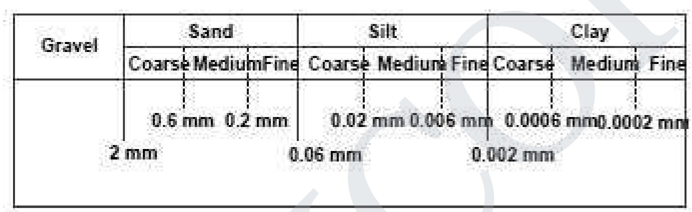
UNIT IV
HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE

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

4.1 Soil Types

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 different soils. A survey of locally available materials and soil types conducted in India revealed wide variety of soil types, gravel, moorum and naturally occurring soft aggregates, which can be used in road construction. Broadly, the soil types can be categorized as Laterite soil,

Moorum / red soil, Desert sands, Alluvial soil, Clay including Black cotton soil.



Indian standard grain size soil classification system

Gravel: These are coarse materials with particle size under 2.36 mm with little or no fines contributing to cohesion of materials.

Moorum: These are products of decomposition and weathering of the pavement rock. Visually these are similar to gravel except presence of higher content of fines.

Silts: These are finer than sand, brighter in color as compared to clay, and exhibit little cohesion. When a lump of silty soil mixed with water, alternately squeezed and tapped a shiny surface makes its appearance, thus dilatancy is a specific property of such soil.

Clays: These are finer than silts. Clayey soils exhibit stickiness, high strength when dry, and show no dilatancy. Black cotton soil and other expansive clays exhibit swelling and shrinkage properties. Paste of clay with water when rubbed in between fingers leaves stain, which is not observed for silts.

4.2 Tests on soil

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The sub grade soil and its properties are important in the design of pavement structure. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests.

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

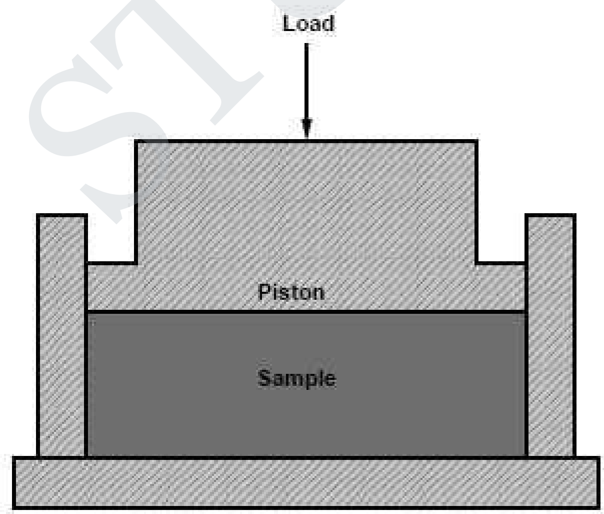
Shear tests Bearing tests Penetration tests

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

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

Penetration tests 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 the size of the loaded area is much greater than the ratios in bearing tests. The penetration tests are carried out in the field or in the laboratory.

4.2.1 Crushing test



One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions (Figure 22:1). Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again. The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (W_2) is expressed as percentage of the weight of the total sample (W_1) which is the aggregate crushing value.

Aggregate crushing value = W1x100

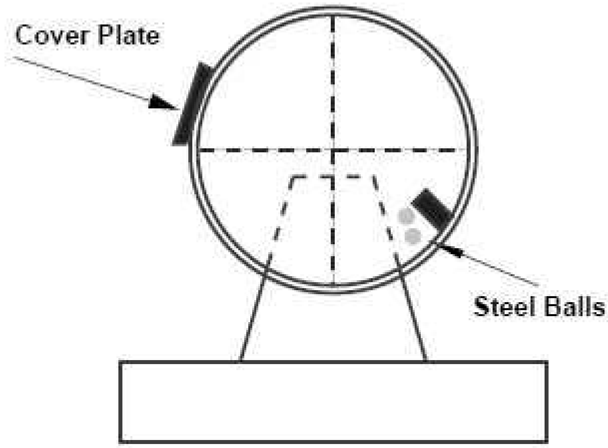
W2

A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.

4.2.2 Abrasion test

Abrasion test is carried out to test the hardness property of aggregates and to decide whether they are suitable for different pavement construction works. Los Angeles abrasion test is a preferred one for carrying out the hardness property and has been standardized in India (IS:2386 part-IV). The principle of Los Angeles abrasion test is to find the percentage wear due to relative rubbing action between the aggregate and steel balls used as abrasive charge.

Los Angeles machine consists of circular drum of internal diameter 700 mm and length 520 mm mounted on horizontal axis enabling it to be rotated (see Figure 22:2). An abrasive charge consisting of cast iron spherical balls of 48 mm diameters and weight 340-445 g is placed in the cylinder along with the aggregates. The number of the abrasive spheres varies according to the grading of the sample. The quantity of aggregates to be used depends upon the gradation and usually ranges from 5-10 kg. The cylinder is then locked and rotated at the speed of 30-33 rpm for a total of 500 -1000 revolutions depending upon the gradation of aggregates.



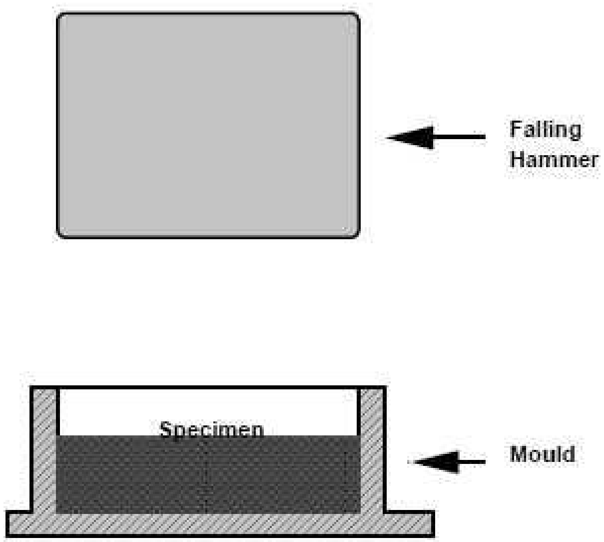
Los Angeles abrasion test setup

After specified revolutions, the material is sieved through 1.7 mm sieve and passed fraction is expressed as percentage total weight of the sample. This value is called Los Angeles abrasion value.

A maximum value of 40 percent is allowed for WBM base course in Indian conditions. For bituminous concrete, a maximum value of 35 is specified.

4.2.3 Impact test

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 number of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as percentage of aggregates passing sieve (W_2) to the total weight of the sample (W_1).



Impact test setup

Aggregate impact value = $\frac{W1}{W2} \times 100$

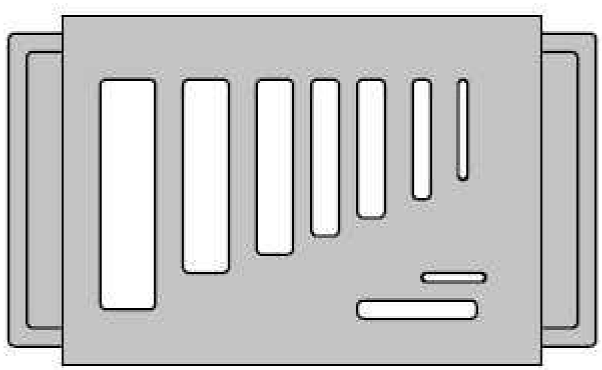
Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent

4.2.4 Soundness test

Soundness test is intended to study the resistance of aggregates to weathering action, by conducting accelerated weathering test cycles. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely. To ascertain the durability of such aggregates, they are subjected to an accelerated soundness test as specified in IS:2386 part-V. Aggregates of specified size are subjected to cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16 - 18 hours and then dried in oven at 105 110^{o}C to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. And the loss in weight should not exceed 12 percent when tested with sodium sulphate and 18 percent with magnesium sulphate solution.

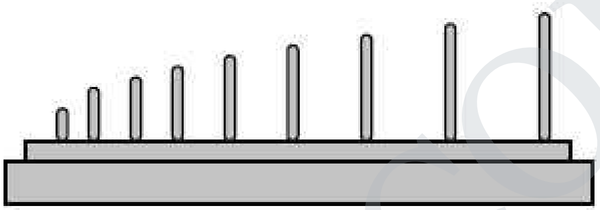
4.3 Shape tests

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes.



Flakiness gauge

The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. Test procedure had been standardized in India (IS:2386 part-I).



Elongation gauge

The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm. This test is also specified in (IS:2386 Part-I). However there are no recognized limits for the elongation index.

4.4 Specific Gravity and water absorption

The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. Because the aggregates may contain water-permeable voids, so two measures of specific gravity of aggregates are used:

apparent specific gravity and bulk specific gravity.

Apparent Specific Gravity, G_{app} , is computed on the basis of the net volume of aggregates i.e the volume excluding water-permeable voids. Thus

$$G_{app} = \frac{M_D/V_N}{W}$$

where, M_D is the dry mass of the aggregate, V_N is the net volume of the aggregates excluding the volume of the absorbed matter, W is the density of water.

Bulk Specific Gravity, G_{bulk} , is computed on the basis of the total volume of aggregates including water permeable voids. Thus

$$G_{bulk} = \frac{M_D/V_B}{W}$$

where, VB is the total volume of the aggregates including the volume of absorbed water.

Water absorption, The difference between the apparent and bulk specific gravities is nothing but the water-permeable voids of the aggregates. We can measure the volume of such voids by weighing the aggregates

dry and in a saturated, surface dry condition, with all permeable voids filled with water. The difference of the above two is M_W . M_W is the weight of dry aggregates minus weight of aggregates saturated surface dry condition. Thus

$$\text{water absorption} = \frac{M_W}{M_D} \times 100$$

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

4.5 Bitumen adhesion test

Bitumen adheres well to all normal types of road aggregates provided they are dry and free from dust. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold. This problem can be dealt with by removing moisture from the aggregate by drying and increasing the mixing temperature. Further, the presence of water causes stripping of binder from the coated aggregates. This problems occur when bitumen mixture is permeable to water. Several laboratory tests are conducted to arbitrarily determine the adhesion of bitumen binder to an aggregate in the presence of water. Static immersion test is one specified by IRC and is quite simple. The principle of the test is by immersing aggregate fully coated with binder in water maintained at 40^0C temperature for 24 hours.

IRC has specified maximum stripping value of aggregates should not exceed 5%.

4.6 California Bearing Ratio Test

California Bearing Ratio (CBR) test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements. CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus. It is a penetration test wherein a standard piston, having an area of 3 in^2 (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the CBR.

In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired. The CBR test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

Test Procedure

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

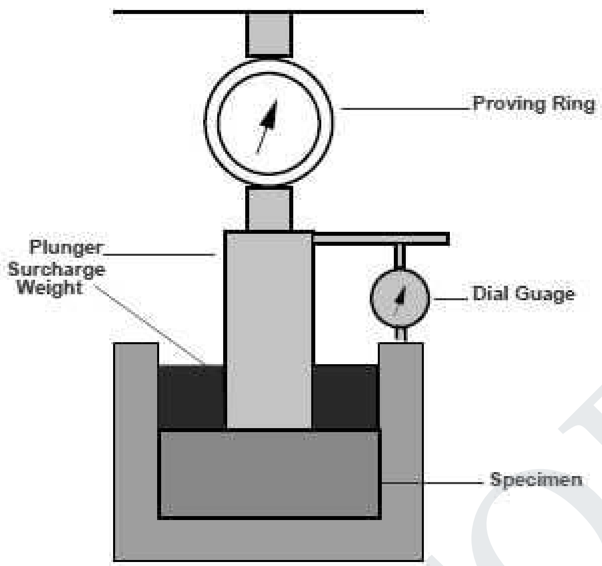
The specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame.

Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min. A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively.

CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore,

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

Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.



4.7 Desirable properties of aggregates

Strength

The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should posses high resistance to crushing, and to withstand the stresses due to traffic wheel load.

Hardness

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

Toughness

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

Shape of aggregates

Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, aky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

Adhesion with bitumen

The aggregates used in bituminous pavements should have less affinity with water when compared with bitu-minous materials, otherwise the bituminous coating on the aggregate will be stripped o in presence of water.

Durability

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

Freedom from deleterious particles

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

4.8 Different forms of bitumen

Cutback bitumen

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

Bitumen Emulsion

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilised by suitable material. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC). Bitumen emulsions are ideal binders for hill road construction. Where heating of bitumen or aggregates are difficult. Rapid setting emulsions are used for surface dressing work. Medium setting emulsions are preferred for premix jobs and patch repairs work. Slow setting emulsions are preferred in rainy season.

Bituminous primers

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

Modified Bitumen

Certain additives or blend of additives called as bitumen modifiers can improve properties of Bitumen and bituminous mixes. Bitumen treated with these modifiers is known as modified bitumen. Polymer modified bitumen (PMB)/ crumb rubber modified bitumen (CRMB) should be used only in wearing course depending upon the requirements of extreme climatic variations. The detailed specifications for modified bitumen have been issued by IRC: SP: 53-1999. It must be noted that the performance of PMB and CRMB is dependent on strict control on temperature during construction. The advantages of using modified bitumen are as follows Lower susceptibility to daily and seasonal temperature variations Higher resistance to deformation at high pavement temperature Better age resistance properties

Higher fatigue life for mixes

Better adhesion between aggregates and binder Prevention of cracking and reflective cracking

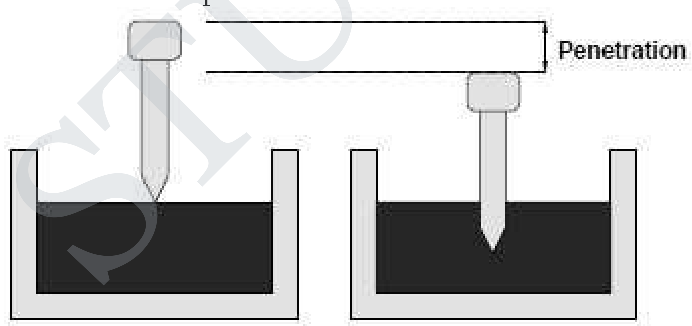
4.9 Tests on bitumen

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

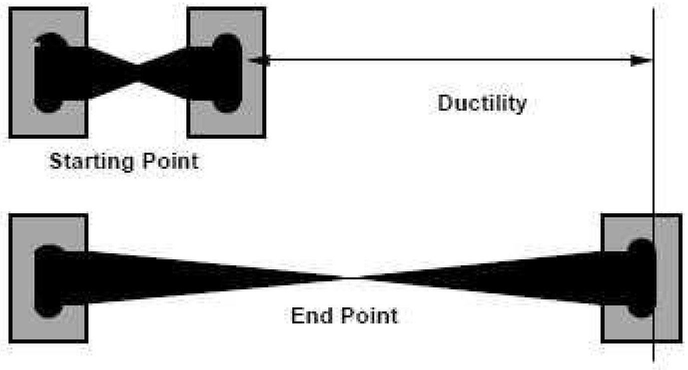
1. Penetration test
2. Ductility test
3. Softening point test
4. Specific gravity test
5. Viscosity test
6. Flash and Fire point test
7. Float test
8. Water content test
9. Loss on heating test

4.9.1 Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardised the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25^{o} C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions.
In hot climates, a lower penetration grade is preferred. The Figure shows a schematic Penetration Test setup.

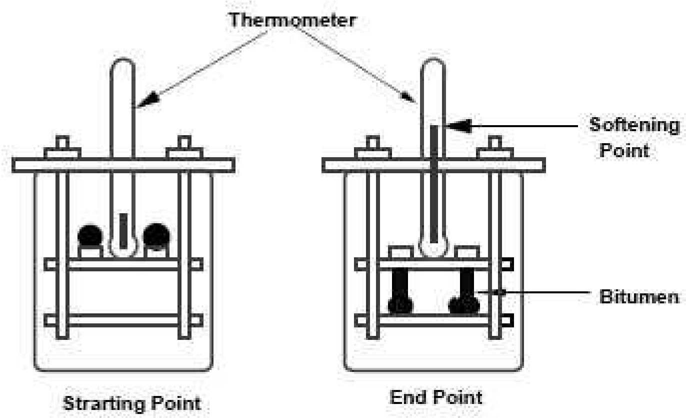


the Ductility test and Softening point test



Ductility is the property of bitumen that permits it to undergo great deformation or elongation. Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking. Dimension of the briquette thus formed is exactly 1 cm square. The bitumen sample is heated and poured in the mould assembly placed on a plate. These samples with moulds are cooled in the air and then in water bath at 27^{o} C temperature. The excess bitumen is cut and the surface is leveled using a hot knife. Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes. The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated. The distance up to the point of breaking of thread is the ductility value which is reported in cm. The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc. A minimum ductility value of 75 cm has been specified by the BIS. Figure 23.4.2 shows ductility moulds to be filled with bitumen.

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. 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 medium is heated at a rate of 5^{o} C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates. Figure shows Softening Point test setup.



4.9.2 Specific gravity test and Viscosity test

Specific gravity test

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

The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27^{o} C. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi solid or solid state. The specific gravity of bitumen varies from 0.97 to 1.02.

Viscosity test

Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing has been observed to result in lower stability values. At high viscosity, it resist the compactive effort and thereby resulting mix is heterogeneous, hence low stability values. And at low viscosity instead of providing a uniform lm over aggregates, it will lubricate the aggregate particles. Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4.0 mm orifice at 25^{o} C or 10 mm orifice at 25 or 40^{o} C.

UNIT V

EVALUATION AND MAINTENANCE OF PAVEMENTS

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

5.1 Surface deformation in detail

Deformation takes place when a road surface undergoes changes from its original constructed profile. It may occur after construction due to trafficking or environmental influences. In some cases, deformation may be built into a new pavement owing to inadequate control during construction. It influences the riding quality of a pavement and may reflect structural inadequacies. It may lead to cracking of the surface layer.

The major types of surface deformation covered in this section are:

i) rutting.
ii) corrugation.
iii) depression.
iv) shoving.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate pavement thickness	strengthening overlay or reconstruction
2.	inadequate compaction of structural layers	reconstruction
3.	unstable bituminous mixes	replace or recycle bituminous surfacing or use stiffer mix/HCM
4.	unstable shoulder materials which do not provide adequate lateral support	shoulder improvement and overlay rutted area with bituminous surfacing
5.	overstressed subgrade which deforms permanently	reconstruction
6.	unstable granular bases or sub-bases	base or sub-base strengthening

Corrugations are regular transverse undulations, closely spaced alternate valleys and crests with wavelengths of less than 2 m. Generally, it will result in a rough ride and will become worse with time.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate stability of bituminous surface	replace bituminous surface
2.	compaction of base in wave form	base reconstruction
3.	faulty paver behaviour with some mixes	replace the faulty mixes and correct the faulty paver behaviour
4.	heavy traffic on steep downgrade or upgrade	mill off corrugated surface and replace with stiffer mix or use HCM
5.	stopping at intersection stop lights or roundabout	mill off corrugated surface and replace with stiffer mix or use HCM
6.	inadequate stability of base course	base reconstruction

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	differential settlement of subgrade or base materials	subgrade or base reconstruction
2.	settlement of services and/or widening trenches	reconstruction of services and/or widening trenches
3.	volume change of subgrade due to environmental influences	improve sub-soil drainage and reconstruct
4.	settlement due to instability of embankment	embankment stabilization

Depressions are localized areas within a pavement with elevations lower than the surrounding area. They may not be confined to wheel paths only but may extend across several wheel paths. Generally, it results from settlement, slope failure, or volume changes due to moisture changes.

Shoving is the bulging of the road surface generally parallel to the direction of traffic and/or horizontal displacement of surfacing materials, mainly in the direction of traffic where braking or acceleration movements occur, caused by traffic pushing against the pavement. Transverse shoving may arise with turning movements.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	low stability mix	mill off and replace the bituminous surfacing
2.	lack of bond between asphalt surface and underlying layer which may be caused by excessive tack coat acting as lubricant	replace bituminous surfacing with lower binder content mix
3.	unstable granular base reflecting through the surface	base reconstruction
4.	stop and start of vehicles at intersections or roundabout	mill off and replace with stiffer mix or use HCM
5.	inadequate pavement thickness	bituminous overlay or reconstruction

5.2 Surface defects in detail.

Surface defects cover loss of surfacing materials, loss of surface micro and macro textures. While they do not usually indicate pavement structural inadequacy, they have a significant influence on the serviceability and safety of a pavement, especially with regard to skid resistance, maneuverability and riding quality. Some defects, if not corrected, may lead to subsequent loss of pavement structural integrity.

The major types of surface defects are:-

i) bleeding.
ii) ravelling.
iii) polishing.
iv) delamination.

Bleeding is the presence of free bitumen binder on the surface resulting from upward migration of the binder, causing low texture depth and inadequate tyre to stone contact. It is most likely to occur in the wheel paths during hot weather.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	excessive application of binder with respect to the stone size. On hot days, the binder expands into air voids; if volume of air voids is too low, continued expansion results in lower stability of the mix with the consequence that traffic will force out excess binder to the surface	apply hot sand to blot up the excess binder
2.	paving over flushed surfaces. The excess bitumen on the old surface may be pumped up through the new paving over a period of time	apply hot sand or aggregate seal coat
3.	paving over excessively primed surfaces	apply hot sand

Ravelling is the progressive disintegration of the pavement surface by loss of binder or aggregates or both.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	insufficient bitumen content	thin bituminous overlay
2.	poor adhesion of bitumen binder to aggregate particles due to wet aggregate	thin bituminous overlay
3.	inadequate compaction or construction during wet weather	thin bituminous overlay
4.	deterioration of binder and/or aggregate	thin bituminous overlay

Polishing is the smoothening and rounding of the upper surface of the roadstone, exposing coarse aggregate which are glossy in appearance and smooth to the touch. It usually occurs in the wheel paths.

Delamination is the loss of a discrete and large (minimum 0.01 square metre) area of the wearing course. Usually there is a clear delineation of the wearing course and the layer below.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate resistance to polishing of surface aggregates, particularly in areas of heavy traffic movements or where high stresses are developed between surface and tyres	thin bituminous overlay or use of stiffer mix or use HCM
2.	use of naturally smooth uncrushed aggregates	thin bituminous overlay

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate cleaning or inadequate tack coat before placement of upper layers	mill off and re-lay upper layers
2.	seepage of water through asphalt, especially in cracks, to break bond between surface and lower layers	replace wearing course or thin bituminous overlay
3.	weak, loose layer immediately underlying seal	reconstruction of weak layers
4.	adhesion of surface binder to vehicle tyres	thin bituminous overlay

5.3 Patches And Potholes

A patch is a repaired section of pavement where a portion of the pavement surface has been removed and replaced (see **FIGURE 4**). It may or may not be associated with either a loss of serviceability (apart from a loss of appearance) or structural capacity. The extent and frequency of patching can be useful indicators of the structural adequacy of the pavement. Defects can occur within a patch or the patch can be a further defect where it is raised or depressed below the level of the pavement surface.

Pothole is bowl shaped cavity in the pavement surface resulting from the loss of wearing course and binder course materials (see **FIGURE 4**). They are produced when traffic breaches small pieces of the pavement surface allowing the entry of water. These spots disintegrate because of the weakening of the base course or poor quality surfacing. Free water collecting in the hole and the underlying base accelerates its development.

	AREA (square metre)		
DEPTH (mm)	< 0.1	0.1 - 0.3	> 0.3
< 25	Low	Low	Moderate
25 - 50	Moderate	Moderate	High
> 50	Moderate	High	High

MEASUREMENTS TO BE TAKEN

a) depth of pothole.
b) area of pothole.
c) number of potholes at each severity level.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	loss of surface course	patching
2.	moisture entry to base course through a cracked pavement surface	cut and patch
3.	load associated disintegration of base	base reconstruction

5.4 Edge Defects In Detail

Edge defects occur along the interface of flexible pavement and the shoulder, and are most significant where the shoulder is unsealed. The detrimental effects of edge defects include:

i) reduction of pavement width.
ii) loss of quality of ride and possible loss of control of vehicle.
iii) channelling of water at the edge of the pavement leading to erosion of shoulder.
iv) entry of water into base.

The defect types covered in this section are:

i) edge break.
ii) edge drop-off.

Edge break occurs when the edge of the bituminous surface are fretted, or broken.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate pavement width	widen the pavement
2.	alignment which encourages drivers to travel on pavement edge	pavement widening and realignment
3.	inadequate edge support	shoulder strengthening
4.	edge drop-off	strengthening and levelling of shoulder with road surface
5.	loss of adhesion to base	cut and patch or bituminous overlay

Edge drop-off is the difference in elevation between the traffic lane and outside shoulder; typically occurs when the outside shoulder settles or erodes. It is not usually considered a defect if the drop-off is less than 25 mm.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate pavement width	widen the pavement
2.	shoulder material with inadequate resistance to erosion and abrasion	replace shoulder material and reconstruct
3.	resurfacing of pavement without resurfacing of shoulder	levelling of shoulder with road surface

5.5 Causes And Remedies Of Shear Cracks

This type of cracks are half moon or crescent shaped cracks, commonly associated with shoving, often occurring in closely spaced parallel group. It is mainly associated with bituminous layer only.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	lack of bond between wearing course and the underlying layers	cut and patch
2.	low modulus base course	reconstruction of base
3.	thin wearing course	bituminous overlay
4.	dragging of paver during laying when bituminous mix temperatures were low	cut and patch
5.	high stresses due to braking and acceleration movements	bituminous overlay with stiffer mix or use high compaction mix (HCM)

UNIT-I
HIGHWAY PLANNING AND ALIGNMENT
PART- A (2 Marks)

1. Define central road fund?

On the recommendation of Jayakar Committee, a "Central Road Fund" came into existence on 1st march 1929, Upon the authority of a resolution adopted by the Indian legislature.

2. Define National Highway Act 1956?

In 1956, National Highway act was passed declaring the National Highways and empowering the central Govt. to declare any other highway to be NH. This act came into force with effect from 15th April 1957.

3. Explain CRRI?

CRRI- The central Road Research Institute Delhi in 1950 It is an organ of the council of scientific and industrial research, and in function include.

4. Write Short notes on Highway Research Board?

This board was set up by I.R.C in 1973 to give proper direction and guidance to road research work in India.

5. What are classified roads in Nagpur plan?

1. National Highways (NH)
2. State Highways (SH)
3. District Roads:
   (1) Major district Roads
   (2) Other district Roads
4. Village roads.

6. Define Express ways?

These roads are of higher, day than National highway. There are Such roads on which only font moving vehicles like car and jeeps are classified.

7. What are the modified classifications of Road system by Third RDP (1981-2001)?

1. Primary System
2. Secondary System
3. Tertiary system

8. What are types of Road patterns?

1. Rectangular (or) Black pattern.
2. Radial (or) Star and black pattern.

9. Write short notes or Nagpur plan (or) its 20-year Road plan.

The first attempt for proper Scientific planning of roads in India, Wan made in chief Engineers conference held at Nagpur in 1943. Nagpur conference finalized at 20 years (1943-1963) road development plan.

10. Write short notes on Second twenty year road plan (1961-81)

A Second road development programmer (1961-81) was finalized by the chief engineers connected with road development, both at centre and Staten in a meeting held at Hyde Chad in 1959.

11. What are the fundamental principles of alignment?

1. Length of road should be shortest
2. The Proposed road should form a most economical line.

3. The alignment should provide corny.

12. What are the function which control the selection of alignment?

1. Volume and type of traffic
2. Obligatory points
3. Canal river (or) railway crossings
4. Geotechnical standard to he adopted

13. Define obligatory point?

Obligatory points are such points which act to control points in highway alignment.

14. What are special considerations for him road alignment?

1. Stability
2. Drainage
3. Geometric standard
4. Deep writing and heavy fillings should he avoided.

15. What are the various types of engineering surveys?

1. Map shady
2. Reconnaissance survey
3. Preliminary survey
4. Detailed Survey

16. What are two type of road project?

1. A new highway Project
2. Re-alignment (or) revenging Highway project

17. What are head involved in Highway Geometric?

1. Cross Section eleventh like camber, Super elevation
2. Sight distance character sight like stopping sight distance, overtaking sight distance etc.
3. Horizontal and vertical alignments

18. Define camber?

Traverse slope given to the road surface in called camber. It is provided mainly to drain off rain water from the road surface.

19. What are the factors deepens on camber?

1. Account of Surface
2. Type ground surface

20. What camber recommended in WBM Road?

Water Bound Macadam road 1 to 33 (3%) 1 in 40 (2.5%).

21. What camber recommended in bihiminour road?

Bihiminour surface 1 in 40 (2.5%) 1 in 50 (2%)

22. What camber recommended in cement concrete Road?

Cement concrete Road 1 in 50 (2%) 1 in 60 (1.7%)

23. What are the different types of camber?

1. Parabolic camber
2. Sloped camber
3. Composite camber

24. Define carriage way width?

Metal led puce strip of road meant for vehicular traffic movement in called carriage way.

25. Define dual carriageways?

Each portion of the carriageway is reserved for traffic moving in opposite direction. Such carriage ways are called dual carriageways.

26. What are the width of carriage way in meteor two lane without raised wert state highways?

State highways 7.0 m

27. Write note on high speed barrier herb?

This herb is 23cm to 45cm to height. This herb is mainly used at initial location such as bridge and hill roads.

28. Define formation width?

Formation width is also called road way. It is the sum of width of carriage way shoulders, and separations it provided

29. Define Right of way:-

Area to the acquired along the road alignment in called right of way.

30. What are the important modifications made in Macadam's method with respect to the other methods?

Following are the important modifications made in Macadam's method.

i) Realizing the importance of subgrade drainage and compaction, the subgrades were prepared with sufficient cross slope.
ii) Heavy foundation stones were replaced with broken stones and with adequate drainage arrangements.
iii) The total thickness is comparatively less and the order of 25 cm.
iv) The size of broken stones used for the layer was based on the stability under animal drawn vehicles.

31. What are the objectives of Central Road Fund?

As per the recommendation of Jayakar Committee, a "Central Road Fund" was created in $1^{st\ march}$ 1929. The Consumers of petrol were then charged an extra levy of 2.64 paisa per liter (i.e., two annas per gallon). Twenty percent of the revenue collected through the fund was retained as Central Reserve and the balance allotted to the various states based on the actual petrol consumptions.

32. State the principles of highway financing.

Highway financing is concerned with the sources and distribution of the money that is obtained for highway purposes. Thus the basic principle in highway financing is that the money spent on the construction and maintenance must be recovered from the roads users.

33. Mention the functions of medians in urban roads.

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

PART – B (16 Marks)

1.Nagpur classification

In Nagpur road classification, all roads were classified into five categories as National highways, State highways, Major district roads, Other district roads and village roads.

National highways

- They are main highways running through the length and breadth of India connecting major ports , foreign highways, capitals of large states and large industrial and tourist centers including roads required for strategic movements.
- It was recommended by Jayakar committee that the National highways should be the frame on which the entire road communication should be based.
- All the national highways are assigned the respective numbers.
- For e.g. the highway connecting Delhi-Ambala-Amritsar is denoted as NH-1 (Delhi-Amritsar), where as a bifurcation of this highway beyond Fullundar to Srinagar and Uri is denoted as NH-1_A.
- They are constructed and maintained by CPWD.
- The total length of National highway in the country is 58,112 Kms, and constitute about 2% of total road networks of India and carry 40% of total traffic.

State highways

- They are the arterial roads of a state, connecting up with the national highways of adjacent states, district head quarters and important cities within the state
- They also serve as main arteries to and from district roads.
- Total length of all SH in the country is 1,37,119 Kms.

Major district roads

- Important roads with in a district serving areas of production and markets , connecting those with each other or with the major highways.
- India has a total of 4,70,000 kms of MDR.

Other district roads

- Roads serving rural areas of production and providing them with outlet to market centers or other important roads like MDR or SH.

Village roads

- They are roads connecting villages or group of villages with each other or to the nearest road of a higher category like ODR or MDR.
- India has 26,50,000 kms of ODR+VR out of the total 33,15,231 kms of all type of roads.

2.Alignment

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

Requirements

The requirements of an ideal alignment are

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

Factors controlling alignment

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

The various factors that control the alignment are as follows:

- Obligatory points: These are the control points governing the highway alignment. These points are classified into two categories. Points through which it should pass and points through which it should not pass. Some of the examples are:
-
    - Bridge site: The bridge can be located only where the river has straight and permanent path and also where the abutment and pier can be strongly founded. The road approach to the bridge should not be curved and skew crossing should be avoided as possible. Thus to locate a bridge the highway alignment may be changed.
    - Mountain: While the alignment passes through a mountain, the various alternatives are to either construct a tunnel or to go round the hills. The suitability of the alternative depends on factors like topography, site conditions and construction and operation cost.

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

These were some of the obligatory points through which the alignment should pass. Coming to the second category, that is the points through which the alignment should not pass are:

- Religious places: These have been protected by the law from being acquired for any purpose. Therefore, these points should be avoided while aligning.
- Very costly structures: Acquiring such structures means heavy compensation which would result in an increase in initial cost. So the alignment may be deviated not to pass through that point.
- Lakes/ponds etc: The presence of a lake or pond on the alignment path would also necessitate deviation of the alignment.

Traffic: The alignment should suit the traffic requirements. Based on the origin-destination data of the area, the desire lines should be drawn. The new alignment should be drawn keeping in view the desire lines, traffic flow pattern etc. Geometric design: Geometric design factors such as gradient, radius of curve, sight distance etc. also govern the alignment of the highway. To keep the radius of curve minimum, it may be required to change the alignment. The alignments should be finalized such that the obstructions to visibility do not restrict the minimum requirements of sight distance. The design standards vary with the class of road and the terrain and accordingly the highway should be aligned. Economy: The alignment finalized should be economical. All the three costs i.e. construction, maintenance, and operating cost should be minimum. The construction cost can be decreased much if it is possible to maintain a balance between cutting and filling. Also try to avoid very high embankments and very deep cuttings as the construction cost will be very higher in these cases.

3. Explain Jayakar committee recommendations.

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

Jayakar Committee

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

- Committee found that the road development of the country has become beyond the capacity of local governments and suggested that Central government should take the proper charge considering it as a matter of national interest.

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- They gave more stress on long term planning programme, for a period of 20 years (hence called twenty year plan) that is to formulate plans and implement those plans with in the next 20 years.
- One of the recommendations was the holding of periodic road conferences to discuss about road construction and development. This paved the way for the establishment of a semi-official technical body called Indian Road Congress (IRC) in 1934
- The committee suggested imposition of additional taxation on motor transport which includes duty on motor spirit, vehicle taxation, license fees for vehicles plying for hire. This led to the introduction of a development fund called Central road fund in 1929. This fund was intended for road development.
- A dedicated research organization should be constituted to carry out research and development work. This resulted in the formation of Central Road Research Institute (CRRI) in 1950.

4. Write about the Lucknow road congress 1984

This plan has been prepared keeping in view the growth pattern envisaged in various fields by the turn of the century. Some of the salient features of this plan are as given below:

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

1. (i) State the construction steps of Macadam method of road formation.
   (ii) Compare with Telford road construction.
2. How urban and rural roads are classified? Explain.
3. State and explain the various types of kerbs.
4. (i) What are the requirements of an ideal highway alignment? Discuss briefly.
   (ii)Compare Conventional methods with modern methods in Highway.
5. (i) Discuss in detail about the obligatory points controlling highway alignment.
   (ii) Explain
   1. GIS 2. GPS 3. Remote sensing 4. Total station

6. Define MORTH. Write the importance of MORTH.
7. (i) Briefly explain the role of MORTH and IRC in highway development.
   (ii) State and explain the economic factors influencing highway alignments.
8. Draw typical cross sections of urban and rural roads.
9. Draw a neat sketch and explain the cross section of an urban arterial.
10. With a neat sketch explain the cross-sectional elements of a 2 lane rural road on embankment.
11. Write the salient features of Nagpur Road plan.
12. Describe the various steps in a highway project.
13. Explain the different components of the National Highway Development Programme (NHDP).
14. Describe the classification of urban roads in India. Give the cross section of urban Arterial Street with all its features.
15. (i) Explain the activities of National Highway Authority of India.
    (ii) Explain the procedure for carrying out road alignment using remote sensing and GIS technique.
16. Compare the three "Twenty year road development plan" in India. Also discuss the merits of each one of them.
17. Explain in detail about second twenty year road plan.
18. Write a brief notes on:
    a. Central Road Fund (CRF). b. Indian Roads Congress (IRC).
    c. Motor vehicle act. d. Central Road Research Institute (CRRI).
    e. Highway Research Board (HRB). f. Nagpur road plan.
    g. National Highway Authority of India (NHAI).

UNIT-II
GEOMETRIC DESIGN OF HIGHWAYS
PART- A (2 Marks)

1. Define sight distance?

Sight distance in the actual length of road over which a driver sitting at a specified height in a vehicle can see objects either moving (or) stationary on the road surface.

2. What are classifications of sight distance depending upon the situation?

1. Stopping sight distance
2. Sate overtaking sight distance
3. Sight distance at intersection

3. Define S.S.D?

Stopping sight distance is the minimum distance required with in which a vehicle moving at designed speed can be stopped without colliding with a stationary object on the road surface.

4. What is the height of driver eye above the road surface?

IRC recommended height of driver eye is 1.22m.

5. Define reaction time:-

It is the time in seconds which a driver can take from the instant the objects visible to him to the instant the brakes are effectively applied.

6. Define perception period?

Perception period is the time taken by an average driver to realize a danger a head before actually trying to apply the breaker.

7. Define overtaking sight distance (OSD)

The distance visible to the driver of a vehicle intending to overtake another slow moving vehicle, without causing any inconvenience (or) possibility of accident to the traffic in the opposite direction in called overtaking sight distance (or) safe passing sight distance.

8. Define design speed?

Design speed can be defined as the speed which is permissible for safe and comfortable driving on a given surface of the highway.

9. What are the two effects of centrifugal force?

1. Tendency to overturn the vehicle.
2. Tendency to skid the vehicle laterally.

10. Define super elevation?

The outer edge of the road in raised above the inner edge called super elevation (or) cant (or) banking.

11. What is the relation between super elevation, continuant of friction and centrifugal force

$$e+f=v^2/9.8R$$

e = super elevation whose value is taken an 40 (or)
1/15 f = Lateral frictional coefficient whose value in
R = Radian of curve in
metros. g = 9.8
V = speed of vehicle in m/sec.

13. Define horizontal curve?

It is a curve in plan to provide change in the direction of the central time by the road surface.

14. What are the factors attesting the design of curve?

1. Design speed of the vehicle
2. Allowable friction
3. Maximum allowable super elevation.
4. Permissible centrifugal ration.

15. Define vertical curve?

It is a curve in the longitudinal section of a highway to provide a easy change of the gradient.

16. What are curve used in a highway.

1. Circular curve
2. Transition curve
3. Parabolic curve

17. What is the value of radian of the simple curve?

R= 1720m app

18. Define compound curve?

A compound curve currish of a serial of hoot (or) more simple curve that run in the same direction and joint at common tangent point.

19. Define Reverse curve?

A reverse curve consist of two simple curve opposite direction that point at the common tangent point. This common point in called the point of reverse curve

20. What are the types of transition curve?

1. True spiral (or clothed.
2. cubic spiral.
3. cubic parabolic.
4. Lemniscate's.

21. What are characteristics of Transition curve?

1. It should meet the straight path tangentially
2. It should meet the circular curve tangentially

22. What is the equation of a spiral transition curve?

Ls = m Ö Q

Where m = Ö2RL = a constant

Q = tangent of deflection angle in radians

23. How many methods to determine the length of transition curve?

(1) By the rate of charge of radial acceleration

(2) By empirical formula

24 . Define gradient?

It is the rate of rise (or) fall of road level along if length

25. What are the factors governs the gradient?

(1) characteristics – of the traffic.

(2) Physical factors of the site such a drainage, safety,

(3) Bridge, approach Road and railway Line intersection etc.

26. What are different types of gradient?

(1). Maximum gradient (2). Puling gradient
(3). Limiting gradient (4). Exceptional gradient

27. What are the driaclvantager of Exceptional gradient?

(1). More fuel consumption (2). More friction losses
(3). Efficiency of engine reducer (4). Early fatigue to animals.

28. What are the hyper of vertical curve?

1. Summit curve 2. Valley curve

29. what is the minimum Radian of vertical curve?

The minimum ration of the curve is given by

$$R = \frac{L}{Q}$$

30. What is the length of valley curve?

L= 0.38 (NV 3) ½
L = Total Length of valley curve
N = Deviation angle
v = Design speed in triumph

PART – B (16 Marks)

1.Types of gradient

Many studies have shown that gradient upto seven percent can have considerable effect on the speeds of the passenger cars. On the contrary, the speeds of the heavy vehicles are considerably reduced when long gradients as flat as two percent is adopted. Although, flatter gradients are desirable, it is evident that the cost of construction will also be very high. Therefore, IRC has specified the desirable gradients for each terrain. However, it may not be economically viable to adopt such gradients in certain locations, steeper gradients are permitted for short duration. Different types of grades are discussed below and the recommended type of gradients for each type of terrain and type of gradient is given in table 1.

Table 1: IRC Specifications for gradients for different roads

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

Ruling gradient, limiting gradient, exceptional gradient and minimum gradient are some types of gradients which are discussed below.

Ruling gradient

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

Limiting gradient

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

Exceptional gradient

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

Critical length of the grade

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

Minimum gradient

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

3. How is super-elevation attained?

Elimination of the crown of the cambered section by:

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

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

Rotation of the pavement cross section to attain full super elevation by: There are two methods of attaining superelevation by rotating the pavement

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

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

4. What are the factors affecting Sight distance?

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

The computation of sight distance depends on:

Reaction time of the driver

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

Speed of the vehicle

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

Efficiency of brakes

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

Frictional resistance between the tyre and the road

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

Gradient of the road.

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

1. What are the objectives of widening of road pavement at horizontal curves? Derive an expression for the extra widening
2. (i) The speed of overtaking and over taken vehicles are70 and 40 kmph, respectively on a two way traffic road. If the acceleration of overtaking vehicle is 0.99m/sec^2
   a. Calculate safe overtaking sight distance
   b. Mention the minimum length of overtaking zone and
   c. Draw a neat-sketch of the overtaking zone and show position of sign posts.

   (ii) What is overtaking sight distance and intermediate sight distance?
3. (i) Derive the formula for the radius of horizontal curve.

   (ii) Why do you provide the extra widening on horizontal curves?
4. Describe the various types of horizontal curves.
5. Under what circumstances summit curves are provided.
6. What are the objectives of providing transition curves in the horizontal alignment of highway curves? Mention the method of designing transition curve length.
7. What are the objectives of widening of road pavement at horizontal curves? Derive an expression for the extra widening.
8. What are the objects of extra widening of pavements at horizontal highway curves? Mention the recommended method of design and introduction in the field.
9. A valley curve is formed by a descending gradient of 1 in 25 meeting an ascending gradient of 1 in 30. Design the length of valley curve to fulfill both comfort condition for a design speed of 80 kmph (c = 0.6 mtr/sec^3) and a head sight distance

of 127 m for this speed.

10. (i) Compute the stopping sight distance on a highway with a design speed of 80 kph, if the highway is on an upgrade of 2%.
    (ii) Outline the design elements of hill roads.
11. (i) What is the need for transition curve? How its length is determined?
    (ii) Explain the procedure for calculating the length of valley curve.
12. (i) Explain the factors influencing the geometric design of hill roads.
    (ii) Calculate the SSD for design speed of 70 kmph for two way traffic and one way traffic road. Take reaction time = 2.5 seconds and coefficient of friction = 0.35.
13. (1) Derive the formula for calculating super elevation on horizontal curve.
    (2) Explain the factors influencing overtaking sight distance
14. Calculate the stopping sight distance required to avoid head on collision of two cars approaching from opposite directions at a speed of 75 kmph and 80 kmph. Assume that the reaction time of divers be 2.5 secs and coefficient between road surface and tyros be 0.4.
15. (i) Distinguish between overtaking sight distance and intermediate sight distance. How will you calculate these?
    (ii) What is the super elevation to be provided on a horizontal curve on a National Highway in plain terrain (Hint: Design speed =100 kph), if the curve has a radius of 310 m?
16. (i) Why is super elevation provided for pavements in curves? Explain the factors influencing it.
    (ii) Why are extra widening of pavements requited in curve?
17. (i) Calculate the stopping sight distance for the design speed of 60 kmph for a two-way traffic road and an one-way traffic road, Take the reaction time of driver as 2.5 seconds and the coefficient of friction as 0.36.
    (ii) Under what circumstances summit curves are provided.
18. (i) Calculate the stopping sight distance to avoid head on collision of two cars approaching from opposite directions at 100k/hr and 80 k/hr. Make suitable assumptions.
    (ii) A highway width 7.5 m of radius 150 m, with a speed of 130 km/hr and the length of wheel base is 7.0 m. Find out the extra widening required.
19. Calculate the stopping sight required to avoid head on collision of two cars approaching from opposite directions at a speed of 75 kmph and 85 kmph. Assume the reaction time of drivers be 2.5 secs. And the coefficient of friction between road surface and tyres is 0.4.
20. Calculate the minimum set back distance required on a two lane highway curve radius 400 m so as to provide an intermediate sight distance 180 m , assuming the length of the curve to be greater than SD (200 m).
21. A valley curve is formed due to two gradients +2.5% and –1.75%. If the design speed of this highway is 80 kmph, determine the stopping sight distance and design the valley curve to fulfill both comfort and head light sight distance conditions.

UNIT-III
FLEXIBLE AND RIGID PAVEMENTS
PART- A (2 Marks)

1. What are the materials required for W.B.M roads?

1. Coarse aggregate.
2. Screenings.
3. Filler materials

2. What are types of bituminous road?

1. Surface dressing
2. Bituminous bound macadam

3. Define seal coat?

Premised snail bitumen (or) surface dressing type seal coat is applied either immediately (or) after a few days.

4. What are methods adopted consummation of cement concrete pavement?

1. Cement grout method
2. Rolled concrete method.
3. Cement connate slab method

5. What types of join provided in cement concrete pavements?

1. Expansion joint
2. Contraction joint
3. Warping joint.

6. What material used as joint Filler?

1. Soft wood
2. Impregnated fiber board
3. Cork (or) cork bound with bitumen
4. Coir fiber

7. What mate rich used a joint sealer?

1. Birdmen
2. Rubén bitumen

8. Write short notes on Hair pin bend?

A hair pin bend should he located on the hill side having the minimum slope and maximum stability It should be sate against land slide and ground water. Hair pin bends with long arms and further spacing should he provided.

9. What are the methods of pavement?

1. Flexible pavement
2. Rigid pavement

10. What are the components of a fallible pavement?

1. Soil sub grade
2. Sub base course
3. Base course
4. Wearing course

11. Define sub grade?

The soil sub grade in a layer of natural soil prepared to receive the other lays of the pavement.

12. What properties posses soil sub grade?

a. strength
b.
Drainage
c. Ease of compaction
d. permanency of compaction etc.

13. What are tests conducted the strength properties of the sub grade?

1. California bearing ratio tests
2. California resistance value test
3. Plate bearing test
4. Trysail shear test

14. Define bone course?

It is the foundation layer, designed for the structural stability. The main function of the bare course in edible pavements is to improve the load supporting capacity by distributing the load through a finite ethicalness.

15. Define leaving course?

It is that component of pavement with which the wheels of vehicular are in archival contain.

16. What are the factors attaching stability of pavement?

a. Traffic factors.
b. Mosher
factors. c.
Climatic factors.
d. Soil factors
e. Stets dissipation factors.

PART – B (16 Marks)

1.Comparison of Flexible and Rigid Pavement

1. Deformation in the sub grade is transferred to the upper layers	1. Deformation in the sub grade is not transferred to subsequent layers
2. Design is based on load distributing characteristics of the component layers	2. Design is based on flexural strength or slab action
3. Have low flexural strength	3. Have high flexural strength
4. Load is transferred by grain to grain contact	4. No such phenomenon of grain to grain load transfer exists
5. Have low completion cost but repairing cost is high	5. Have low repairing cost but completion cost is high
6. Have low life span	6. Life span is more as compare to flexible
7. Surfacing cannot be laid directly on the sub grade but a sub base is needed	7. Surfacing can be directly laid on the sub grade

2.What are the Types of Flexible Pavements?

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

layered flexible pavement,

Full - depth asphalt pavement, and

Contained rock asphalt mat (CRAM).

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

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

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

3.What are the Typical layers of a flexible pavement?

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade.

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

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

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

Surface course

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

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

It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,

It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade

The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

4. What are the different types of road surfaces?

Unsurfaced earthen roads, or cart-track

Unsurfaced earthen roads upgrades with natural soil from borrow pits and attention to drainage, and compaction is by traffic

Dry aggregate and sand-clays mix, in which the the former act as wear resistant and the latter as natural binder

Water-bound macadam, the above constituents, mixed together (pre-mix or in-situ) with water and com-pacted to improve the strength

Oiled roads, introduced to reduce dust by bitumen stabilized soils

Seal coat: the base course is protected from traffic and moisture by sealing the surface with a thin lm of bitumen aggregate mix, which is structurally strong surface for pneumatic-tyred traffic. This is provided on firm and smooth base course after a tack coat using cutback bitumen or bitumen emulsions with a penetration of 5 mm.

Asphaltic concrete: Traffic and the axle configuration are increasing very much which raises demand for the new type of pavement which can meet the above requirements. The asphaltic concrete is one which is the high dense graded premix and it is termed as the highest quality pavement surface course.

Bitumen mix or asphalt mix overlays of minimum 20 - 40 mm to as high as 300 - 500 mm or even more.

5. What are the Design procedures for flexible pavement

For flexible pavements, structural design is mainly concerned with determining appropriate layer thickness and composition. The main design factors are stresses due to traffic load and temperature variations. Two methods of flexible pavement structural design are common today: Empirical design and mechanistic empirical design.

Empirical design

An empirical approach is one which is based on the results of experimentation or experience. Some of them are either based on physical properties or strength parameters of soil subgrade. An empirical approach is one which is based on the results of experimentation or experience. An empirical analysis of flexible pavement design can be done with or with out a soil strength test. An example of design without soil strength test is by using HRB soil classification system, in which soils are grouped from A-1 to A-7 and a group index is added to differentiate soils within each group. Example with soil strength test uses McLeod, Stabilometer, California Bearing Ratio (CBR) test. CBR test is widely known and will be discussed.

Mechanistic-
Empirical Design

Empirical-Mechanistic method of design is based on the mechanics of materials that relates input, such as wheel load, to an output or pavement response. In pavement design, the responses are the stresses, strains, and deflections within a pavement structure and the physical causes are the loads and material properties of the pavement structure. The relationship between these phenomena and their physical causes are typically described using some mathematical models. Along with this mechanistic approach, empirical elements are used when defining what value of the calculated stresses, strains, and deflections result in pavement failure. The relationship between physical phenomena and pavement failure is described by empirically derived equations that compute the number of loading cycles to failure.

1. Briefly give the IRC Recommendations useful in the design of cement concrete pavement.
2. Explain in detail about the IRC method of flexible pavement design. Discuss limitation of this method.
3. Explain the methods of design of Flexible pavement by CBR method.
4. Discuss the advantage and limitations of CBR method of design.
5. Differentiate between Flexible and rigid Pavement (or) Compare Flexible and Rigid Pavement.
6. Explain the design consideration for spacing of expansion and construction Joints.
7. What are the objectives of joints in cement concrete pavement? Sketch the different types of joints used in pavement construction. Indicate the principle of design.
8. Explain mud pumping. What are the causes for mud pumping and how it can be prevented?
9. Define ESWL and Lane distribution factor and explain their significance.
10. Describe the factors influencing the design of pavements.
11. Explain the recommended design procedure for design of rigid pavements by

IRC.

12. List the different stresses induced in cement concrete pavements. Discuss the critical combination of these stresses.
13. How will you calculate the Equivalent Single Wheel Load for a given combination of wheel loads?
14. Explain the IRC method of design of rigid pavements.
15. Explain the factors to be considered in the design of pavements.
16. State how variations in climatic conditions affect the design of pavements.
17. What is equivalent single wheel load? Explain briefly.
18. Design the pavement of a plain cement concrete 7m wide. Use IRC Recommendations where ever applicable. Adopt expansion joint gap 20mm and Maximum variation in temperature between summer and winter is 40˚c.Present Traffic intensity is 1050 veh/day of weight more than 3T. Modulus of reaction of sub base 7 kg/cm³.E for concrete = $3x10^5$ kg/cm², μ = 0.15 and radius of contact area is 15 cm and design wheel load is 4100 kg. Temperature differential slab in the region is 17.3, 19.0 and 20.3 for thickness is of 15, 20 and 25cm respectively.(use design chart if necessary)
19. CBR value of sub grade is 4%. Calculate total thickness of pavement. Also calculated the thickness of sub base, base, wearing layer having CBR value of 15%, 80%, and 90% respectively. Use IRC accepted CBR curve'D'. (Use design chart)
20. Using the following data, design the flexible pavements layers

    CBR of the sub-grade soil = 5%
    CBR of poorly graded gravel sub-base = 15%
    CBR of WBM = 80%
    Design life = 15 years
    Annual rate of increase in the heavy vehicles = 7.5%
    No. of heavy vehicles per day during last count = 200
    No. of years between the year of completion and year of last count = 3 years.

    Assume any other data found required
21. Design the flexible pavement for construction of new Highway with the following data.

    Number of commercial vehicles as per last count = 1000
    Period of construction = 3 years
    Annual traffic growth rate = 8%
    Category of road = NH, two lane single carriageway
    Design life = 10 years.

UNIT – IV
HIGHWAY MATERIALS AND CONSTRUCTION PRACTICE
PART- A (2 Marks)

1. Define contact presume?

$$\text{Contact presume} = \frac{\text{loud on wheel}}{\text{Contact area}}$$

2. Define Rigidity factor?

$$\text{Rigidity factor} = \frac{\text{contact presume}}{\text{Type presume}}$$

3. What is ESUL?

Equivalent Single Used Load

4. What understand by Repetition of load?

The repeated loading may produce permanent and non uniform deformation of sub grade.

5. What are the causes of increase in moisture?

1. Percolation of surface water through Erath in the pavement surface.
2. Entry of water through edger of the pavement
3. Seepage
4. Capillary rise from high water table

6. What is meaning of frost heave?

The terms frost heave return to rising up of the pavement portion.

7. What method is used for strengthening of flexible pavement?

Benkelman Beam Reflection method.

8. What is the basic principle of Benkelman Beam deflection method?

The deflection method is based on the concept that pavement section which have been conditioned by traffic elastically under a load.

9. What are the factors considered deformation under a given load?

1. Sub grade soil type
2. Soil mousier content and its compaction
3. Thickness of pavement layers
4. Drainage conditions.

10. What are factors causing stressor in slab?

1. Used loads
2. Cyclic changer in temperature
3. Changes in moisture
4. Volumetric changer in bare course.

11. Define hand aggregator give example?

Hand aggregator are used to resist crushing effect and adverse weather effect (ex) granite trap

12. What is the user of soft aggregator?

They can also be used in lower layer of good type of roads. Soft aggregator are usable in low cost road.

13. What are the proportions of aggregator?

1. Strength
2. Hardness
3. Toughens
4. Sound ness
5. shape of aggregate
6. Bushmen adhesion properly
7. Cementations

14. What are test for Road aggregator?

1. Abrasion test
2. Lost angler abrasion test

15. Define Elongation index?

This test is also suitable for aggregate of size greater than 6.3mm and is carried our in the same way a how been explained in flakiness index

PART – B (16 Marks)

1. What are the Tests on soil?

Sub grade soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. The sub grade soil and its properties are important in the design of pavement structure. The main function of the sub grade is to give adequate support to the pavement and for this the sub grade should possess sufficient stability under adverse climatic and loading conditions. Therefore, it is very essential to evaluate the sub grade by conducting tests.

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

Shear tests

Bearing tests

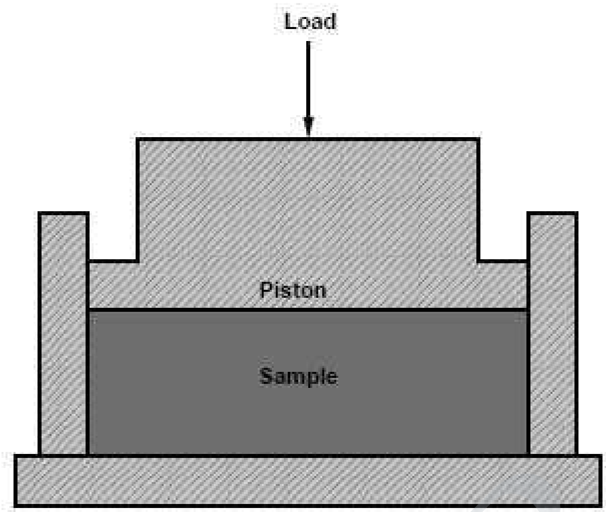
Penetration tests

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

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

Penetration tests 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 the size of the loaded area is much greater than the ratios in bearing tests. The penetration tests are carried out in the field or in the laboratory.

2. Explain the Crushing test



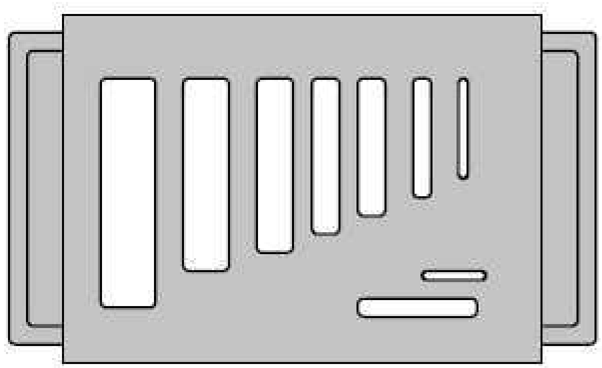
One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions (Figure 22:1). Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again. The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (W_2) is expressed as percentage of the weight of the total sample (W_1) which is the aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W1 \times 100}{W2}$$

A value less than 10 signifies an exceptionally strong aggregate while above 35 would normally be regarded as weak aggregates.

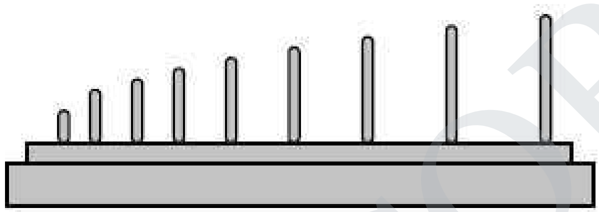
3. What are the Shape tests?

The particle shape of the aggregate mass is determined by the percentage of flaky and elongated particles in it. Aggregates which are flaky or elongated are detrimental to higher workability and stability of mixes.



Flakiness gauge

The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. Test procedure had been standardized in India (IS:2386 part-I).



Elongation gauge

The elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm. This test is also specified in (IS:2386 Part-I). However there are no recognized limits for the elongation index.

4. Explain the California Bearing Ratio Test

California Bearing Ratio (CBR) test was developed by the California Division of Highway as a method of classifying and evaluating soil-sub grade and base course materials for flexible pavements. CBR test, an empirical test, has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus. It is a penetration test wherein a standard piston, having an area of 3 in^2 (or 50 mm diameter), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 12.5 mm and it's ratio to the bearing value of a standard crushed rock is termed as the

CBR.

In most cases, CBR decreases as the penetration increases. The ratio at 2.5 mm penetration is used as the CBR. In some case, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used. The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired. The CBR test may be conducted in re-moulded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

Test Procedure

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

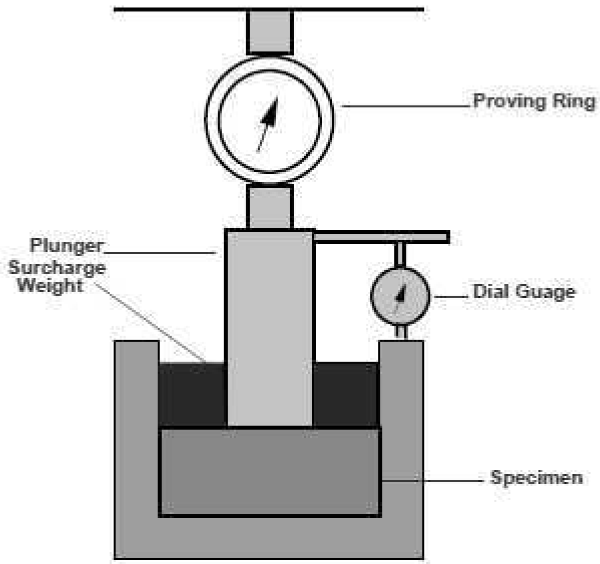
The specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame.

Load is applied on the sample by a standard plunger with dia of 50 mm at the rate of 1.25 mm/min. A load penetration curve is drawn. The load values on standard crushed stones are 1370 kg and 2055 kg at 2.5 mm and 5.0 mm penetrations respectively.

CBR value is expressed as a percentage of the actual load causing the penetrations of 2.5 mm or 5.0 mm to the standard loads mentioned above. Therefore,

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

Two values of CBR will be obtained. If the value of 2.5 mm is greater than that of 5.0 mm penetration, the former is adopted. If the CBR value obtained from test at 5.0 mm penetration is higher than that at 2.5 mm, then the test is to be repeated for checking. If the check test again gives similar results, then higher value obtained at 5.0 mm penetration is reported as the CBR value. The average CBR value of three test specimens is reported as the CBR value of the sample.



5. What are the Desirable properties of aggregates?

Strength

The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should posses high resistance to crushing, and to withstand the stresses due to traffic wheel load.

Hardness

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

Toughness

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

Shape of aggregates

Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, aky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as possible.

Adhesion with bitumen

The aggregates used in bituminous pavements should have less affinity with water when compared with bitu-minous materials, otherwise the bituminous coating on the aggregate will be stripped o in presence of water.

Durability

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

Freedom from deleterious particles

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

1. Write down the construction steps for water bound macadam road. Explain with sketch.
2. Describe the construction steps for surface dressing (or) Bituminous concrete methods of Bituminous construction with sketch.
3. Enumerate the steps in the construction of cement concrete pavement. Explain with sketch.
4. Write short notes on (a) CBR test on soil (b) Field density test on soil.
5. Explain with sketch the following testing methods.
   (a) Penetration test on Bitumen (b) Softening point test on Bitumen
   (or) Briefly explain the penetration test and softening point test on Bitumen.
6. Explain with neat sketch of impact value test on aggregates.
7. Explain with neat sketch of Durability test on Bitumen.
8. Explain with neat sketch of Los angel’s abrasion testing method of Road aggregates.
9. Explain with neat sketches how the subsurface drainage system is provided to lower the water table and control seepage flow.
10. Explain briefly with sketches “Drainage in Hill Roads”

11. Explain briefly "crushing strength" test on Road aggregates with sketches
12. Describe how impact value of aggregate and specific gravity of bitumen are found by experiment in laboratory?
13. Distinguish between impact and abrasion values of aggregate. How are these values measured?
14. What is WBM? Describe the construction procedure of a WBM road.
15. Distinguish between viscosity and softening point of road bitumen. Describe their test procedures.
16. Discuss the importance of surface and sub-surface drainage in highways.
17. What are the desirable properties of road aggregates? Explain briefly.
18. Write a note on aggregate impact test.
19. Write short notes on the following:
    (i) Crushing Test
    (ii) Water Absorption Test
    (iii) Ductility Test
    (iv) Viscosity Test.
20. Describe how impact value of aggregate is found in laboratory.
21. Explain the test procedure for assessing polishing value of aggregate.
22. Explain the construction procedure of dense bituminous macadam road.
23. Describe the procedure recommended by bureau of Indian standards for carrying out the following tests.
    a. Abrasion Test
    b. Flash and Fire point test
24. Specify the design approach for the surface drainage system of highways.
25. Explain the construction procedure for bituminous concrete.
26. Describe how impact value of aggregate and specific gravity of bitumen are found by experiment in laboratory?
27. Explain the construction procedure of the following types of roads.
    (i) Dense Bituminous Macadam.
    (ii) Bituminous Concrete.

UNIT – V
HIGHWAY MAINTENANCE
PART- A (2 Marks)

1. What are the proportions of bihiminour material?
1. Consistency
2. Durability

2. What are test of bitumen?
1. Generation test
2. Ductility test
3. Solubility test

3. What are different grade of bitumen?
30/40, 80/100, 60/70

4. Define emulsion?
Emulsion is a combination of water bitumen and an emulsifying agent.

5. What are test for bitumen emulsion?
1. Sieve test
2. Mining test

6. What are general causers of pavement failure?
1. Faulty material of commotion
2. Faulty construction and improper quality control during construction.

7. What are typical failover of flexible pavement?
1. Shear failure
2. Longitudinal cracks.

8. What is typical failure of cement concrete pavements?
1. Mud pumping
2. Spelling of join

9. What are the classifications of maintenance?
1. Routine maintenance (or) repairs
2. Periodic maintenance
3. Special repairs.

10. What are two methods of pavements evaluation?
1. Structural evaluation of pavement
2. Evaluation of pavement surface conditions.

PART – B (16 Marks)

1. Explain the edge defects in detail.

Edge defects occur along the interface of flexible pavement and the shoulder, and are most significant where the shoulder is unsealed. The detrimental effects of edge defects include:

i) reduction of pavement width.
ii) loss of quality of ride and possible loss of control of vehicle.
iii) channelling of water at the edge of the pavement leading to erosion of shoulder.
iv) entry of water into base.

The defect types covered in this section are:

i) edge break.
ii) edge drop-off.

Edge break occurs when the edge of the bituminous surface are fretted, or broken.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate pavement width	widen the pavement
2.	alignment which encourages drivers to travel on pavement edge	pavement widening and realignment
3.	inadequate edge support	shoulder strengthening
4.	edge drop-off	strengthening and levelling of shoulder with road surface
5.	loss of adhesion to base	cut and patch or bituminous overlay

Edge drop-off is the difference in elevation between the traffic lane and outside shoulder; typically occurs when the outside shoulder settles or erodes. It is not usually considered a defect if the drop-off is less than 25 mm.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	inadequate pavement width	widen the pavement
2.	shoulder material with inadequate resistance to erosion and abrasion	replace shoulder material and reconstruct
3.	resurfacing of pavement without resurfacing of shoulder	levelling of shoulder with road surface

2. Explain the patches and potholes.

Pothole is bowl shaped cavity in the pavement surface resulting from the loss of wearing course and binder course materials (see **FIGURE 4**). They are produced when traffic breaches small pieces of the pavement surface allowing the entry of water. These spots disintegrate because of the weakening of the base course or poor quality surfacing. Free water collecting in the hole and the underlying base accelerates its development.

A patch is a repaired section of pavement where a portion of the pavement surface has been removed and replaced (see **FIGURE 4**). It may or may not be associated with either a loss of serviceability (apart from a loss of appearance) or structural capacity. The extent and frequency of patching can be useful indicators of the structural adequacy of the pavement. Defects can occur within a patch or the patch can be a further defect where it is raised or depressed below the level of the pavement surface.

	AREA (square metre)		
DEPTH (mm)	< 0.1	0.1 - 0.3	> 0.3
< 25	Low	Low	Moderate
25 - 50	Moderate	Moderate	High
> 50	Moderate	High	High

MEASUREMENTS TO BE TAKEN

a) depth of pothole.
b) area of pothole.
c) number of potholes at each severity level.

NO.	POSSIBLE CAUSES	PROBABLE TREATMENTS
1.	loss of surface course	patching
2.	moisture entry to base course through a cracked pavement surface	cut and patch
3.	load associated disintegration of base	base reconstruction

1. Discuss the various types of failure in Flexible pavement? Explain the causes. (or)

Classify the different types of failures in flexible pavement and mention the important causes of each. (or)
Discuss with the help of sketches the different types of failures in flexible pavements.

2. Discuss briefly the different types of failures in rigid pavement.
3. List the causes of failure in cement concrete pavements. What are the effects of different types of failure?
4. Write short notes on the following.
   a) Mud pumping.
   b) Alligator cracks.
   c) Consolidation deformation.
   d) Pavement evaluation.
5. (i) Explain the different types of evaluation of pavement surface condition
   (ii) Explain the causes and remedial measures for surface rut.
6. Describe the symptoms, causes and remedial measures for the different types of failures in flexible pavements.
7. Briefly explain the procedure of overlay design by Benkelman beam method.
8. Explain how resealing of cracks may be carried out in rigid pavements.
9. Explain any two commonly employed methods for the structural evaluation of flexible pavements.
10. Explain briefly the maintenance of bituminous surface.
11. What is meant by rutting? Explain the symptoms, causes and treatment,
12. Explain the procedure for the structural evaluation of pavements.
13. (i) What are the different types of failures in cement concrete pavements?
    (ii) What are flexible overlays? Explain how the Benkelman Beam is used to design the thickness of the overlay.
14. (i) Explain the principle and uses of Benkelman Beam test.
    (ii) Describe the complete procedure of carrying out Benkelman Beam test to evaluate the pavement with model calculation.
15. Write short notes on the following.
    a. Stripping and raveling
    b. Structural cracks and temperature cracks.
    c. Longitudinal cracking and reflection cracking.
    d. Mud jacking and Overlay thickness.
16. Write a critical note on the maintenance of following roads.
    a. Earthen roads
    b. Gravel roads.
       i. C. W.B.M roads
    c. Cement concrete roads.
17. Discuss the following procedure for Flexible pavement evaluation
    (a) Benkelman beam deflection studies.
    (b) (i) Estimation of Unevenness Index.
        (ii) Pavement serviceability Index.
        (iii) Present serviceability Rating.
        (iv) Highway financing