U23CET45-HIGHWAY ENGINEERING

SYLLABUS

UNIT I HIGHWAY PLANNING AND ALIGNMENT 9

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

UNIT II GEOMETRIC DESIGN OF HIGHWAYS 9

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

UNIT III DESIGN OF FLEXIBLE AND RIGID PAVEMENTS 9

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

UNIT IV HIGHWAY CONSTRUCTION MATERIALS AND PRACTICE 9

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

UNIT V EVALUATION AND MAINTENANCE OF PAVEMENTS 9

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

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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.

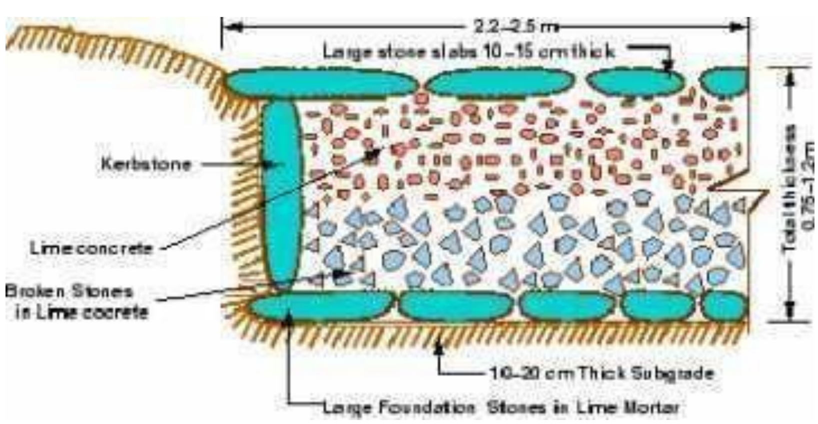
History of highway engineering

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

Ancient Roads

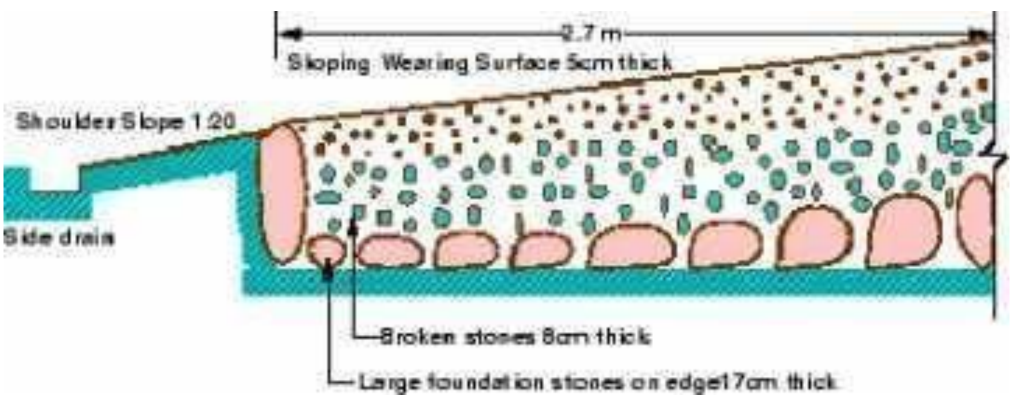
The first mode of transport was by foot. These human pathways would have been developed for specific purposes leading to camp sites, food, streams for drinking water etc. The next major mode of transport was the use of animals for transporting both men and materials. Since these loaded animals required 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.

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 pozzolana to make mortar and they added gravel to this mortar to make concrete. Thus concrete was a major Roman road making innovation.

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.

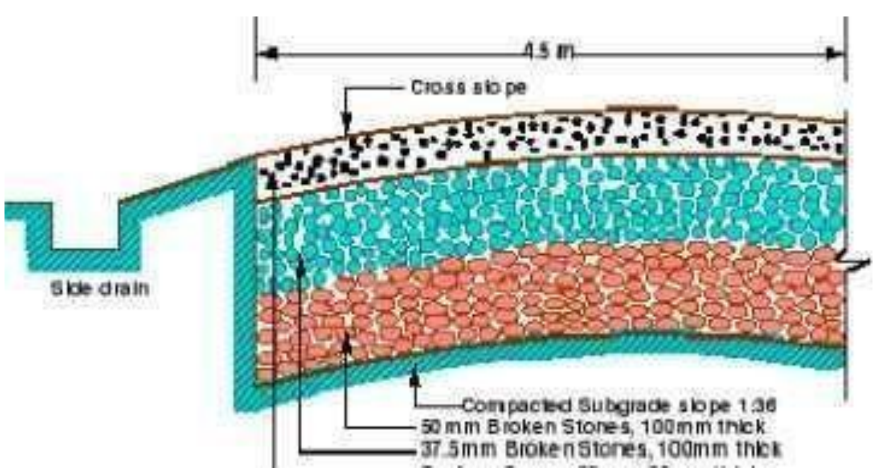
Smaller pieces of broken stones were then compacted into the spaces between larger stones to provide a level surface. Finally the running layer was made with a layer of 25 mm sized broken stone. All this structure was placed in a trench in order to keep the running surface level with the surrounding 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.

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.



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 Panchayats 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.

Classification of Roads Highways

Road classification system groups roads a limited number of clearly defined types.

Purpose of Road Classification

A road network is composed of various types of roads, each of which performs a particular service in facilitating vehicular travel between points of trip origin and destination, and in providing access to property. Road classification is the orderly grouping of roads into systems according to the type and degree of service they provide to the public.

Consideration for classification - Factors affecting classification of roads

Many different classification systems have been introduced and used for particular purpose. The basis for some of these classifications is:

1. Legal control
2. Surface type
3. Function
4. Geometric elements
5. Location

6. Traffic volume

Seldom do these classification system differentiate between roads on basis of service which is essential for road designer.

Design classification system

This system separates roads;

- On the basis of differences in ***traffic service*** and ***land services***.
- On the basis of ***geometric design features***.

The eight primary divisions in this system are:

Rural	Urban
Local	Local
Collector	Collector
Arterial	Arterial
Freeway	Freeway

1. Rural and urban:

It refers to predominant characteristic of the adjacent land use and not only to jurisdictions boundaries or features of typical cross-section.

2. Geometric design:

For geometric design purposes it is essential to divide each of these divisions. For a given road geometric design elements are affected by traffic volume. However it is significant for classification only in determining the number of lanes and whether road should be divided or undivided.

3. Other variables

Affecting geometric design are;

1. The type of terrain road passes through
2. financial
3. Population density

Development characteristics of the land surrounding, the road and the travel habits of the local population.

4. Design speed is the measure of quality and is therefore the final sub division.

Road Classification

	Designspeed Km/h	**Local**	**Collector**	**Arterial**	**Freeway**
RURAL	50::130	RLU*50			
		RLU60	RCU60		
				RAU80	
		RLU100	RCU100		
					RFD100
				RAD130	
URBAN	30	ULU*30			
		ULU50	UCU50	UAU50	
			UCU80		UFD80
					UFD100
					UFD120

*** UAD100:-** Urban, Arterial, Divided, 100km/h (design speed)

Freeway is preferred because it is more descriptive of the type of the traffic movement.

Factors affecting highway classification

To identify the classification to which any road belongs, the following factors should be considered.

I. **SERVICE FUNTION**: - Most roads provide service to traffic, access to land or both. Following road type provide the service function given as;

Freeways and Arterials ==> provide the movement of through traffic.

Local roads ==> are used almost exclusively for land access.

Collectors ==> provide a combined service.

1. **TRAFFIC VOLUME**: - The low and high traffic volumes are carried by different roads. However, the volume rage for each classification is wide and overlaps that of other classification.

   Freeway and arterials ==> carries high volume

   Local and Collectors ==> carries low volume
2. **FLOW CHARACTERSTICS**:- The desire characteristics of traffic flow determine the classification of road, e.g.

   Freeways and Rural Arterials ==> serve primarily uninterrupted traffic flow characteristics.

   Locals Roads ==> provide full land service which is restricted by traffic crossings, entering and leaving road by parked vehicles and in urban areas by pedestrians.
3. **RUNNING SPEED**:- in an ideal road system, local connect with collectors, collectors connect with arterials and arterials with freeways. It is preferable to minimize the interconnection of locals with arterials and collectors with freeways as it can cause inconvenienced to the drivers and may increase in accidents.

I) The particulars of organization, functions and duties

Creation of National Highways Authority of India

National Highways Authority of India (NHAI) was constituted by an Act. of Parliament, namely the National Highways Authority of India Act, 1988, to develop, maintain and manage the National Highways vested or entrusted to it by the Central Government. It became operational in February, 1995.

Organizational Set up

The Authority consists of Chairman and not more than five full time Members [One Member (Admn.), One Member (Finance) and three Members (Technical)] and four part time Members [namely Secretary Department of Road Transport & Highways, Director General (Road Development), Secretary Planning and Secretary Expenditure].

The Authority has Technical, Finance and Administrative wings at Headquarters. At present the Authority has 76 Project Implementation / Corridor Management Units headed by a Project Director and supported by technical and finance officers / staff. The organizational chart of the Authority is enclosed as Annex. I.

Functions of the Authority

The Authority is mandated to develop, maintain and manage the national highways and any other highways vested in, or entrusted to, it by the Government.

The Authority may, for the discharge of its functions:

- survey, develop, maintain and manage highways vested in , or entrusted to it;
- construct offices, or workshops and establish and maintain hotels, motels, restaurants and rest rooms at or near the highways vested in , or entrusted to, it;
- construct residential buildings and townships for its employees;
- regulate and control the plying of vehicles on the highways vested in, or entrusted to, it for the proper management thereof;
- develop and provide consultancy and construction services in India and abroad and carry on research activities in relation to the development, maintenance and management of highways or any facilities thereat;
- provide such facilities and amenities for the users of the highways vested in, or entrusted to, it as are, in the opinion of the Authority, necessary for the smooth flow of traffic on such highways;
- form one or more companies under the Companies Act, 1956 (1 of 1956) to further the efficient discharge of the functions imposed on it by this Act;

- engage, or entrust any of its functions to, any person on such terms and conditions as may be prescribed;
- advise the Central Government on matters relating to highways;
- assist, on such terms and conditions as may be mutually agreed upon, any State Government in the formulation and implementation of schemes for highway development;
- collect fees on behalf of the Central Government for services or benefits rendered under section 7 of the National Highways Act, 1956 (48 of 1956) , as amended from time to time, and such other fees on behalf of the State Governments on such terms and conditions as may be specified by such State Government; and take all such steps as may be necessary or convenient for, or may be incidental to, the exercise of any power or the discharge of any function conferred or imposed on it by this Act.

II) Power and duties of its officers and employees,

The Government / Authority have made Rules and Regulations under the National Highways Authority of India Act, 1988 for smooth functioning of the Authority. A comprehensive delegation of powers to various levels in the Authority is enclosed as Annex. II.

III) The procedure followed in the decision making process, including channels of supervision and accountability

The Authority has been modeled as a lean and thin officer oriented organization. The officers and staff are appointed as per the provisions of National Highways Authority of India (Recruitment, Seniority and Promotion) Regulations, 1996. The recruitment are done by Administrative Division of the Authority headed by Member (Admn) supported by General Manager (Admn.), Dy. General Manager (Admn.), Manager (Admn.) and Asstt. Manager (Admn.)

The Authority generally outsources its services for supervision and administration of the civil contracts in FIDIC format. The procurement of Supervision Consultant / Engineer is done through rigorous international competitive bidding. The civil work contracts also are procured through international competitive bidding following internationally accepted procedure. The NHAI functions as ‘Employer' of the contract whereas the supervision consultant acts as the ‘Engineer' for day to day contract management including quality assurance. The Project Director at field level acts as employer's representative for administration of the projects. The monitoring of the projects are done at Headquarters by Technical Divisions headed by a Member supported by CGM(Tech), GM(Tech), DGM(Tech) and Manager (Tech). The Financial decisions generally taken with the consultation of Finance Division headed by Member (Finance) supported by GM (F&A), DGM (F&A) and Manager (F&A).

The Vigilance Division of the Authority headed by a Chief Vigilance Officer appointed by the Central Government with the consultation of Central Vigilance Commission supported by DGM(Vig.) and Manager (Vig.). The division received and investigates complaints and submits periodic reports / returns to the Commission as per the Vigilance Manual.

IV) Norms set by it for the discharge of its functions

For discharge of functions of the Authority, Rules and Regulations have been framed by the Central Government / Authority as per the provisions of the National Highways Authority of India Act, 1988.

For technical guidance / specifications, the Authority follows the norms set up by the Government / Indian Road Congress / various international & national codal provisions.

V) Rules, Regulations, instructions, manuals and records, held by it or under its control or used by its employees for discharging its functions.

The following categories of rules / regulations / instructions / manuals and records are held by the Authority. The Act, Rules and Regulations are enclosed as Annex. III. Records: Technical Records:

- Gazette Notification relating to entrustment of National Highways to the Authority by the Central Government.
- Records relating to Land Acquisition for highways
- Feasibility study, Detailed Project Report of the contract packages / projects.
- Bidding documents
- Contract agreements including contract with supervision consultants
- Processing records for procurement of tenders and contract administration
- Record relating to dispute resolution process etc.

Financial Records

- Record relating to processing of bills
- Record relating to Financial Management
- Records relating to payment to employees etc.
- Administrative Records
- Records relating to recruitment of officers / employees
- Records relating to management of personnel / posts etc.
- Records relating to User Fee (Toll)
- Records relating User Fee Notification

Management of User Fee (Toll) etc.

VI) Statement of the categories of documents that are held by it or under its control

The following category of records are held by the Authority as per details given in preceding paragraph

- Acts
- Rules & Regulations
- Technical Records
- Financial Records
- Administrative Records

Records relating to user fee

VII) The particulars of any arrangement that exists for consultation with, or representation by, the members of the public in relation of the formulation of its policy or implementation thereof;

An Advisory Group of External Stake Holders was set up with the approval of the Authority. The terms of reference of the Group are as under:

- The group would provide a forum for discussion / advice on sectoral issues, in particular NHDP
- It shall review the overall programme and strategy being implemented by NHAI
- It shall also help to broaden the approach horizon by its multi-disciplinary character and facilitate larger participation as it were, in NHDP

- It shall meet at least twice each year and send its recommendations to NHAI Board for consideration and to government where matters of policy require address.

The group consists of Chief Secretaries of Govt. of Andhra Pradesh and Bihar, Chairman, Infrastructure Development Finance Co. Ltd, President, All India Motor Transport Congress, Chairman Consultancy Development Centre, President, Kum. Rajshree Parmar Memorial Foundation, President, Federation of Indian Automobile Associations, Chairman, All India Confederation of Goods Vehicle Owner's Association and Director General, Confederation of Indian Industries (CII).

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 headquarters 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.

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:

o 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.

o 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.

o 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.

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.

a. 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.

b. 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

c. 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.

d. 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.

UNIT I

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:

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

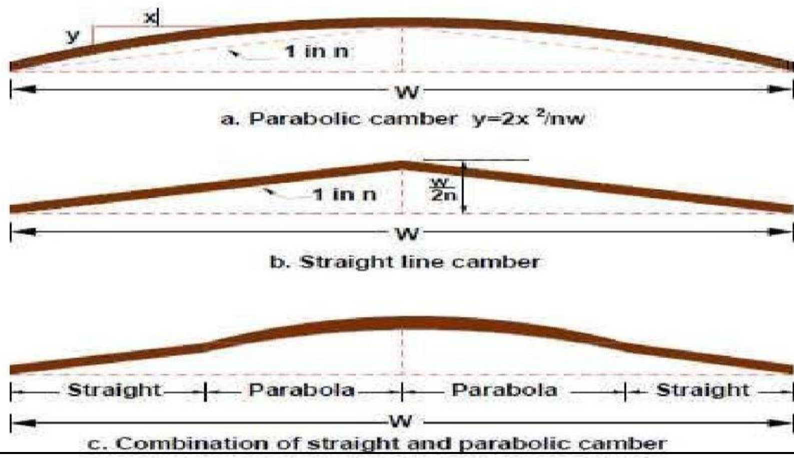
Camber

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.

Types of cambers.

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



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

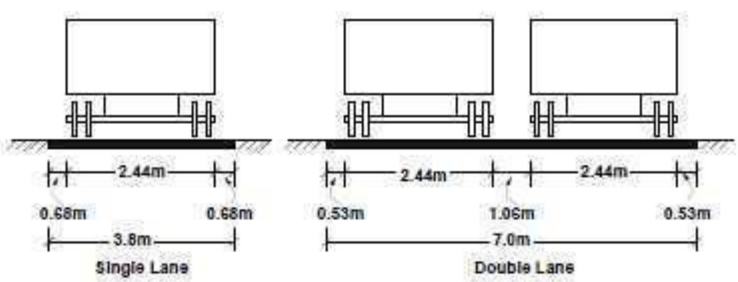


Figure 12:2: Lane width for single and two lane roads

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.

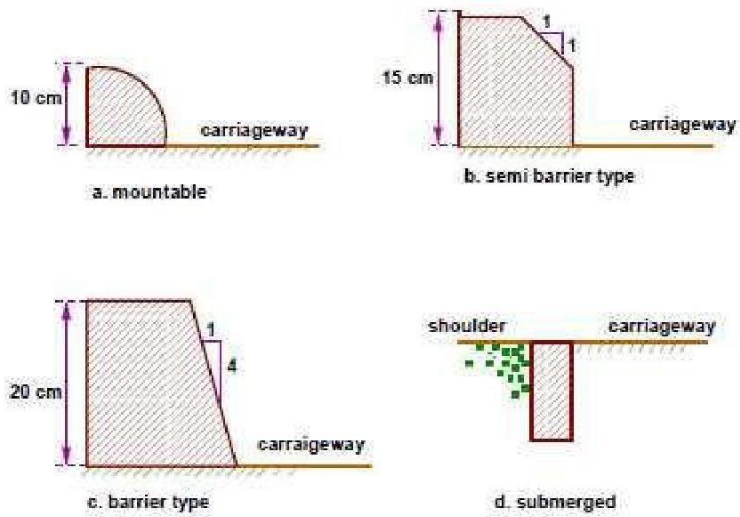


Figure 12:3: Different types of kerbs

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

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.

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.)

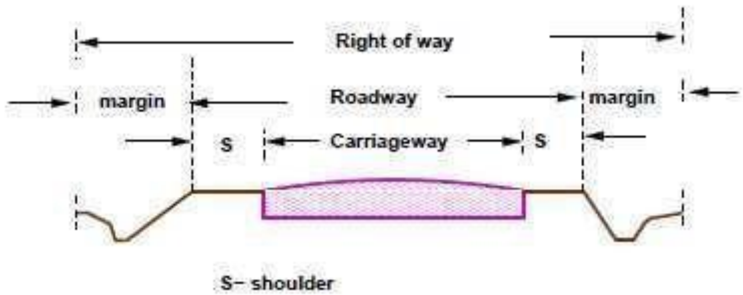


Figure 12:4: A typical Right of way (ROW)

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:

o 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.

Institutions for Highway planning, design and construction at different levels:

Central Road Fund

On the recommendation of Jay existence on 1st march 1929, upon the authority legislature. As per the recommendation of Jayakar Committee, a "Central Road Fund" was created in 1st march 1929. The Consumers of petrol were then charged an extra levy of 2.64 paise per litre (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.

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.

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.

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 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.

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.

ROAD CLASSIFICATION

The roads can be classified in many ways. The classification based on speed and accessibility is the most generic one. Note that as the accessibility of road increases, the speed reduces. Accordingly, the roads can classified as follows in the order of increased accessibility and reduced speeds.

Freeways: Freeways are access controlled divided highways. Most freeways are four lanes, two lanes each direction, but many freeways widen to incorporate more lanes as they enter urban areas. Access is controlled through the use of interchanges, and the type of interchange depends upon the kind of intersecting road way (rural roads, another freeway etc.)

• **Expressways**: They are superior type of highways and are designed for high speeds (120 km/hr is common), high traffic volume and safety. They are generally provided with grade separations at intersections. Parking, loading and unloading of goods and pedestrian traffic is not allowed on expressways.

• **Highways:** They represent the superior type of roads in the country. Highways are of two types - rural highways and urban highways. Rural highways are those passing through rural areas (villages) and urban highways are those passing through large cities and towns, i.e. Urban areas.

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

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

• **Collectors streets:** These are streets intended for collecting and distributing traffic to and from local streets and also for providing access to arterial streets.

Normally full access is provided on these streets. There are few parking restrictions except during peak hours. 11.3.1 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.

State highways:

They are the arterial roads of a state, connecting up with the national highways of adjacent states, district headquarters 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, 37,119Kms.

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, 70,000kms 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, 50,000kms of ODR+VR out of the total 33, 15,231 kms of all type of roads.

THE VARIOUS FACTORS CONTROLLING THE ALIGNMENT OF ROADS.

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

- Obligatory points
- Traffic
- Geometric design
- Economics
- Other considerations
- In hill roads additional care has to be given for Stability
- Drainage
- Geometric standards of hill roads
- Resisting length

.Obligatory Points: - These control points may be divided in to two categories

(i) Points through which the alignment is to pass

(ii) Points through which the alignment should not pass.

(i) Points through which the alignment is to pass:

Obligatory points through which the road alignment has to pass may cause the alignment to often deviate from the shortest (or) easiest path. The straight alignment AB is deviated along the hillside pass, thus avoiding a tunnel (or) heavy cutting. that the straight alignment between stations A and B which passes across the river band is to be deviated along the path shown in order to cross the river at a proper bridge location.

(ii) Obligatory points through which the road should not pass also may make it necessary to deviate from the proposed shortest alignment. The obligatory points, which should be avoided while aligning a road, include religious places, very costly structures. However if there is no alternative and the alignment has to be taken across such an area, the construction and maintenance costs are likely to be very high.

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

Geometric design: - Geometric design factors such as gradient, radius of curve and sight distance also would govern the final alignment of the highway. The absolute minimum sight distance, which should invariably be available in every section of the road, is the safe stopping distance for the fast moving vehicles.

Economy: - The alignment finalized based on the above factors should also be economical. The initial coast of construction can be decreased if high embankments and deep cuttings are avoided and the alignment is choosing in a manner to balance the cutting and filling. Various other factors, which may govern the alignment, are drainage considerations, hydrological factors, political considerations and monotony. The vertical alignment is often guided by drainage considerations. In a flat terrain it is possible to have a very long stretch of road, absolutely straight without horizontal curves.

Special considerations: -

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

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

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

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

The Engineering Surveys Needed For Locating A New Highway

The stages of the engineering surveys are:

a) Map study.

b) Reconnaissance.

c) Preliminary surveys.

d) Final location and detailed surveys.

Map study: - In the topographic map, to suggest the likely routes of roads. In India topographic maps are available from the survey of India with 15 or 30-meter contour intervals. The main feature like rivers, hills, and valleys etc. The probable alignment can be located on the map from the following details available on the map. Alignment avoiding valleys, ponds or lakes when the road has to cross a row of hills, possibility crossing through a mountain pass. Approximate location of bridge site for crossing rivers, avoiding bend of the river. When a road is to be connected between two stations one of the top and the other on the foot of the hill then alternate routes can be suggested keeping in view the permissible alignment. Suppose the scale of the contour map is known, and then the contour intervals it is possible to decide the length of road required between two consecutive contours keeping the gradient within allowable limits. In the fig. Let A and B be two stations to be connected by road. AB is the shortest route (Straight line) APQB is a steep route in which the gradient positively exceeds 1 in 20 as the distance between the contour intervals is only about 200 meter. APLMNB is a route with an approximate slope of 1 in 20 whereas APEFGB is an alternate• alignment with the same gradient. Thus the map study also is possible to drop a certain route in view of any unavoidable obstructions (or) undesirable ground enroute.

Reconnaissance: - The second stage of surveys for highway location is the reconnaissance to examine the general character of the area for deciding the most feasible routes for detailed studies. Some of the details to be collected during reconnaissance are given below: Valleys, ponds, lakes, marshy, land, ridge, hills, permanent structures and other obstructions along the route, which are not available in the map. Approximate values of gradient, length of gradients and radius of curves of alternate alignments. Number and types of cross drainage structures maximum flood level and natural groundwater level along the probable routes. Soil type along the routes from field identification tests and observation of geological features. Sources of construction materials water and location of stone quarries. When the road passes through hilly or mountainous terrain, additional data regarding the geological formation types of rocks, dip of strata, seepage flow etc.

Preliminary survey: - The main objectives of the preliminary surveys are: To survey the various alternate alignments proposed after the reconnaissance and to collect all the necessary physical information and details of topography, drainage and soil. To compare the different proposals in view of the requirements of a good alignment. To estimate quantity of earthwork materials and other construction aspects and to work out the cost of alternate proposals. To finalize the best alignment from all considerations. The procedure of the conventional methods of preliminary survey the given steps:

*) Primary survey: - For alternate alignments either secondary traverses (or) independent primary traverses may be necessary.

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

*) Levelling work: - Levelling work is also carried out side by side to give the centreline profiles and typical cross sections. The levelling work in the preliminary survey is kept to a minimum just sufficient to obtain the approximate earthwork in the alternate alignments.

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

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

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

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

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

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

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

ROAD ECOLOGY:

Road ecology is a relatively new sub discipline of ecology that focuses on understanding the interactions between road systems and the natural environment. Road ecology is an applied science, and much of the work within this field endeavors to find ways to minimize the detrimental effects that road systems can have on plant and animal populations, air and water quality, and human communities. The body of knowledge generated by studies of the ecological and societal effects of road systems also inform many of the current visions of sustainable development. Other highly visible outputs of road ecology include advances in the management of storm water runoff, transportation and land-use planning, and the development of crossing structures that allow animals safe passage across busy roads.

Elements of road ecology:

The science of road ecology is concerned with understanding how roads affect ecological processes, often with the goal of developing strategies for mitigating any negative effects that roads may have on the environment. Although potentially extremely broad in scope, road ecology at present is focused primarily on documenting and predicting the effects of roads on plants and animals and in understanding how roads affect the movement of water and sediments.

- 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
GEO METRIC 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 an d vertical clearance at underpasses

Design Speed

The design speed, as noted earlier, is the single most important f actor 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 de pends on the type of terrain. A plain terrain can afford to have any geometry, but for the same standard in a hilly terrain requires s u b s antial 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 terrai ns 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 1: 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 1.

Table : Design speed in		as per IRC (ruling and minimum)		
Type	Plain	Rolling	Hilly	Steep
NS&SH	100-8 0	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

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.

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.

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 dending 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.

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. 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 landing 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.

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

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

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 t0 to t1. Then it overtakes the vehicle B and occupies the left lane at time t3. The time duration T = t3 t1 is the actual duration of the overtaking operation. The snapshots of the road at time t0 ; t1, and t3 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 vb , the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d1 is given by:

$$d1 = vb\ t$$

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:

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

Let T be the duration of actual overtaking. The distance traveled by B during the overtaking operation is 2s + vb T . Also, during this time, vehicle A accelerated from initial velocity vb and overtaking is completed. The distance traveled by the vehicle C moving at design speed v m=sec during overtaking operation is given by:

where vb 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

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 (RA and RB). 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:

$$F = FA + FB$$
$$= f\,(RA + RB)$$
$$= f\,W$$

where FA and FB is the fractional force at tyre A and B, RA and RB is the reaction at tyre A and B, f is the lateral coefficient of friction and W is the weight of the vehicle.

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 super elevation is shown in figure
Forces acting on a vehicle on horizontal curve of radius R m at a speed of v m=sec^{2}. Analysis of super-elevation P the centrifugal force acting horizontally out-wards through the center of gravity, W the weight of the vehicle acting down-wards through the center of gravity, and 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,

$$P \cos = W \sin\theta + FA + FB$$
$$= W \sin\theta + f\,(RA + RB)$$
$$= W \sin\theta + f\,(W \cos\theta + P \sin\theta)$$

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:

Design of super-elevation

While designing the various elements of the road like super elevation, 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, super elevation 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 super elevation etc.

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

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 R1 is the radius of the outer track line of the rear wheel, R2 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.

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

Length of transition curve

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

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

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.

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.

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%.

The maximum length of the 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..

Creeper lane

When the uphill climb is extremely long, it may be desirable to introduce an additional lane so as to allow slow landing 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

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 ($T \cos\theta$), which is intended to o set the extra tractive force involved at the curve. IRC gave the following specification for the grade compensation.

Summit curve

Summit curves are vertical curves with gradient upwards.

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 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.

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.

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 $0{:}6 m{=}sec^3$. **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 time , 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 $0{:}6 m{=}sec^3$

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.

Culverts Types, Design, Installation and Materials

Culvert pipe, plastic culvert pipe, culvert landscape design ideas, corrugated steel culvert, concrete culverts

Definition

An opening through an embankment for the conveyance of water by mean of pipe or an enclosed channel. **OR** It is a transverse and totally enclosed drain under a road or railway.

Type of Culverts

Pipe Single or Multiple

Pipe Arch Single or Multiple

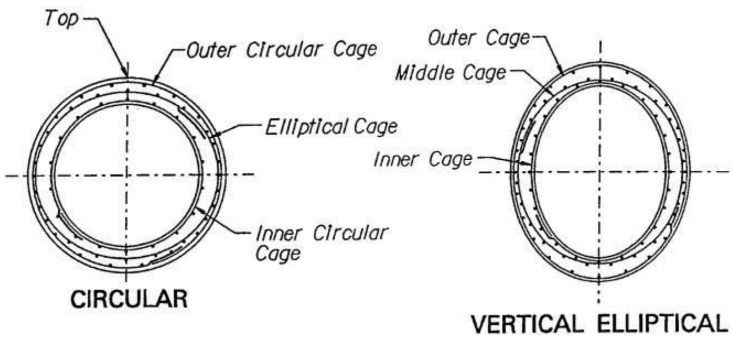
Box Culvert Single or Multiple

Bridge Culvert

Arch Culvert

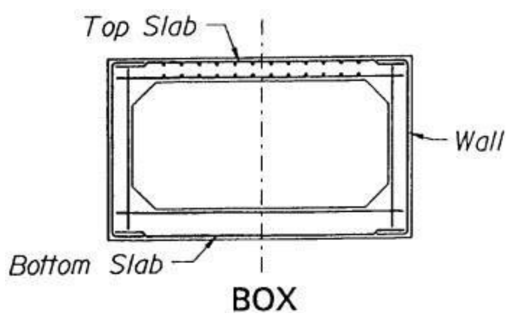
Pipe culverts are made of smooth steel, corrugated metal, or concrete material. Their primary purpose is to convey water under roads, although a variety of wildlife uses them as passageways. Pipe culverts typically range from 1- 6 feet in diameter and are the least expensive type of culvert. Round culverts are best suited to medium and high stream banks.

Pipe Arch Single or Multiple



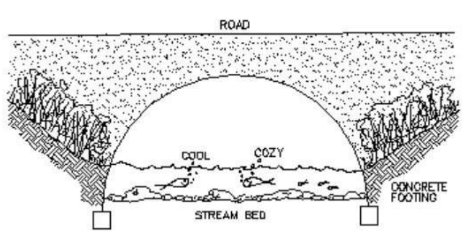
Pipe-arch culverts provide low clearance, openings suitable for large waterways, and are more aesthetic. They may also provide a greater hydraulic advantage to fishes at low flows and require less road fill.

Box Culvert Single or Multiple



Box culverts are used to transmit water during brief runoff periods. These are usually used by wildlife because they remain dry most of the year. They can have an artificial floor such as concrete. Box culverts generally provide MORE for wildlife passage than large pipe culverts. Box culverts are usually made up of Reinforced Concrete (RCC)

Arch Culvert



A pipe arch culvert is a round culvert reshaped to allow a lower profile while maintaining flow characteristics. It is good for installations with shallow cover.

Materials used for arch culverts are RCC, Corrugated Metal or Stone Masonry.

Design of Reinforced Concrete Culverts

Location

Ideally, the axis of a culvert should coincide with that of the natural streamed and the structure should be straight and short. This may require modification of the culvert alignment and grade. Often it is more practical to construct the culvert at right angles to the roadway. However, the cost of any change in stream channel location required to accomplish this should be balanced against the cost of a skewed alignment of the culvert, and changes in channel hydraulics should be considered.

Grade and camber

The culvert invert gradient should be the same as the natural streambed to minimize erosion and silting problems. Foundation settlement should be countered by cambering the culvert to ensure positive drainage.

Entrance and outlet conditions

It is often necessary to enlarge the natural channel a considerable distance downstream of the culvert to prevent backwater from entering the culvert. Also, enlargement of the culvert entrance may be required to prevent pending above the culvert entrance. The entrance and outlet conditions of the culvert structure directly impact its hydraulic capacity. Rounding or beveling the entrance corners increases the hydraulic capacity, especially for short culverts of small cross section. Scour problems can occur when abrupt changes are made to the streamed flow line at the entrance or outlet of the culvert.

Materials used

Foundation material

Materials to be used for the culvert pipe foundation should be indicated on the drawings. Refer to the geotechnical foundation report for the project.

Bedding materials

Bedding class and materials for culverts should be indicated on the drawings. When designing the bedding for a box culvert, assume the bedding material to be slightly yielding, and that a uniform support pressure develops under the box section.

Purpose and Use

Culverts are used in roads, bridges, and berm construction to prevent flooding and washing out of roads.
They also minimize erosion, build-up of standing water, and provide pathways for run-off.

Geometric design of highways

Learning Objectives

understand the considerations and quantifiable aspects of geometric design consider

1. **Locational Design**
2. **Current land use**
3. **Geology**
4. **Future land use**
5. **Existing infrastructure**

Controls and Criteria

Design Vehicles

- Passenger cars, buses, trucks, RVs
- Physical characteristics: weight, dimensions
- Establish intersection radius, pavement markings

Vehicle Performance

- Operating characteristics: accel/decel
- Impacts air quality, noise, land use.

Horizontal Alignment

Basic controlling expression

e=rate of super elevation

u = side friction factor (dep. on pavement, speed,

V = vehicle speed

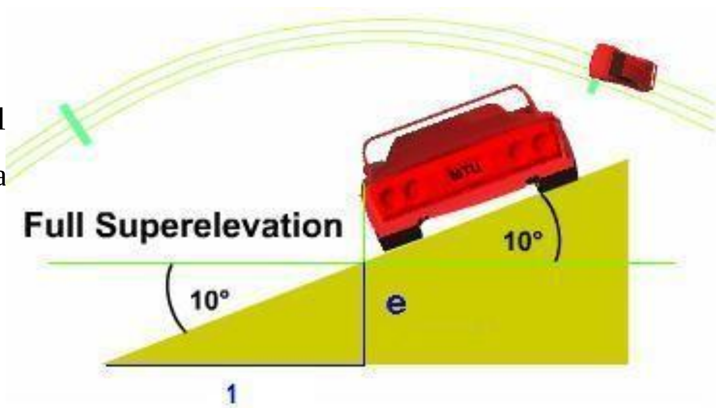
R = radius of curve V = vehicle speed

Overall Design Procedure

Overall design procedure

- Determine a reasonable maximum super elevation rate.
- Decide upon a maximum side-friction factor.
- Calculate the minimum radius.
- Iterate and test several different radii until you are satisfied with your design.
- Make sure that the stopping sight distance is provided.
- Adjust your design if necessary.
- Design the transition segments.

Super Elevation of roads



- Tilting the roadway to help offset centripetal forces developed as the vehicle goes around a curve

General Practice

- **Highways, no ice/snow**
  emax = 0.10
- **Highways snow/ice**
  emax = 0.06
- **Traffic congestion or roadside development, limit speeds**
  emax = 0.04 ~ 0.06

Side Friction

Design based on point where centrifugal force creates feeling of discomfort for driver

Speed	u max	u design
20	0.50	0.17
30	0.35	0.16
40	0.32	0.15
50	0.30	0.14
60	0.29	0.12
70	0.28	0.10

Driver

- **Information handling**
- **Reaction time**
- Time to perceive + react to a hazard in vehicle's path
- Expected/unexpected
- **Speed**
- **Driver errors**
- **Traffic**
- **Composition and volume**
- Average daily traffic (ADT) is not adequate
- Design hourly volume (DHV)
- 30th-highest hourly volume (30HV) in one year
- K-factor (% of ADT; 8~12% urban, 12~18% rural)
- **Speed** of the vehicles
- Operating Speed (typically the 85th percentile speed)
- Free-flow Speed (close to zero density)
- Running Speed (actual speed)
- Design Speed (as high as practical)
- **Capacity**

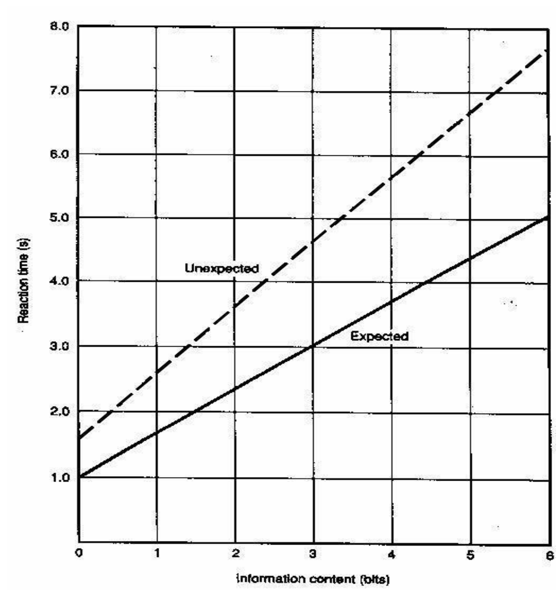
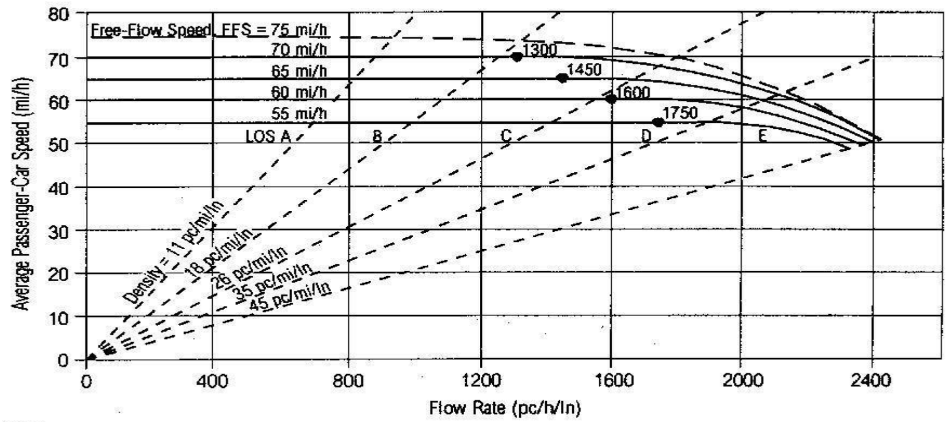


Figure 2.3.2 Eighty-fifth percentile driver reaction time to expected and unexpected information. (From American Association of State and Highway Officials, "A Policy on Geometric Design of Highways and Streets" [2.2], (Fig. 11-19, p. 48). Copyright 1990. Used with permission.)

- Maximum hourly flow rate (per lane) under prevailing conditions
- Determines adequacy of existing roadways
- Helps select roadway type
- Helps define needs Design level of service (LOS)
-

EXHIBIT 23-3. SPEED-FLOW CURVES AND LOS FOR BASIC FREEWAY SEGMENTS



- Note:
Capacity varies by free-flow speed. Capacity is 2400, 2350, 2300, and 2250 pc/h/ln at free-flow speeds of 70 and greater, 65, 60, and 55 mi/h, respectively.

Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are (Figure 1):

- 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.

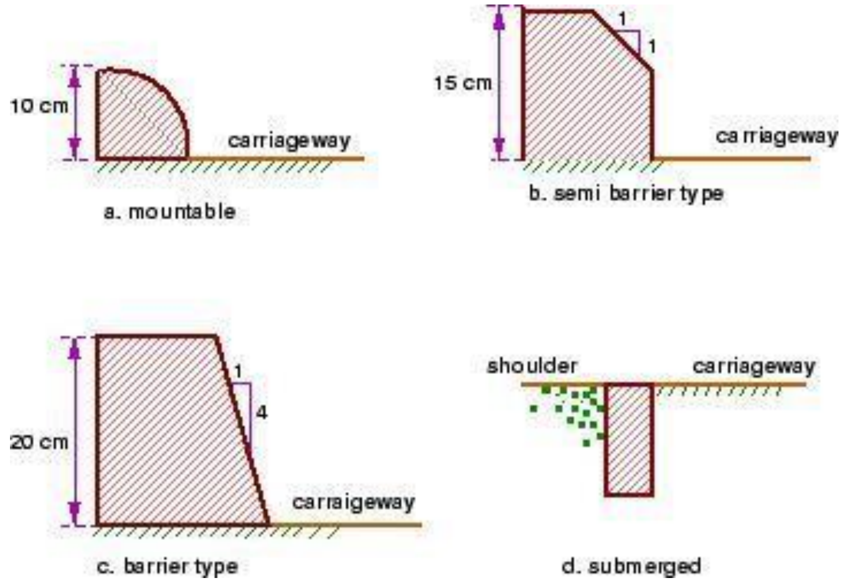


Figure 1: Different types of kerbs

Shoulders

Shoulders are provided along the road edge and are intended for accommodation of stopped vehicles, serve as an emergency lane for vehicles and provide lateral support for base and surface courses. The shoulder should be strong enough to bear the weight of a fully loaded truck even in wet conditions. The shoulder width should be adequate for giving working space around a stopped vehicle. It is desirable to have a width of 4.6 m for the shoulders. A minimum width of 2.5 m is recommended for 2-lane rural highways in India.

Parking lanes

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving on the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking.

Bus-bays

Bus bays are provided by recessing the kerbs for bus stops. They are provided so that they do not obstruct the movement of vehicles in the carriage way. They should be at least 75 meters away from the intersection so that the traffic near the intersections is not affected by the bus- bay.

Service roads

Service roads or frontage roads give access to access controlled highways like freeways and expressways. They run parallel to the highway and will be usually isolated by a separator and access to the highway will be provided only at selected points. These roads are provided to avoid congestion in the expressways and also the speed of the traffic in those lanes is not reduced.

Drainage

The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

Footpath

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

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 1: 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

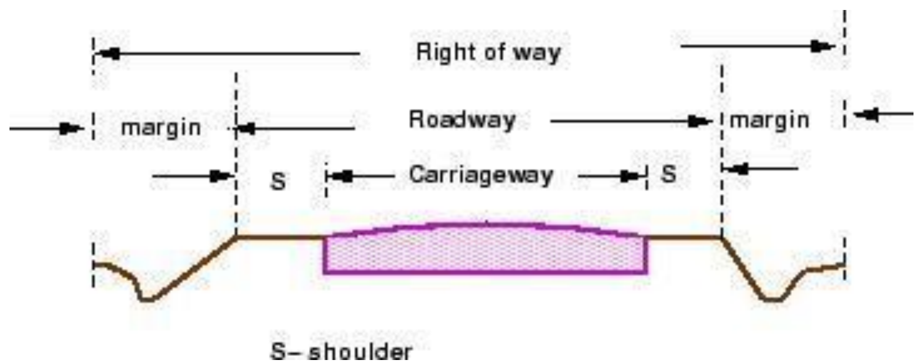


Figure 1: A typical Right of way (ROW)

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 1 A typical cross section of a ROW is given in Figure 1.

Overview

Horizontal alignment is one of the most important features influencing the efficiency and safety of a highway. A poor design will result in lower speeds and resultant reduction in highway performance in terms of safety and comfort. In addition, it may increase the cost of vehicle operations and lower the highway capacity. Horizontal alignment design involves the understanding on the design aspects such as design speed and the effect of horizontal curve on the vehicles. The horizontal curve design elements include design of super elevation, extra widening at horizontal curves, design of transition curve, and set back distance. These will be discussed in this chapter and the following two chapters.

UNIT II

UNIT II

UNIT III

DESIGN OF FLEXIBLE AND RIGID PAVEMENTS

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

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.

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).

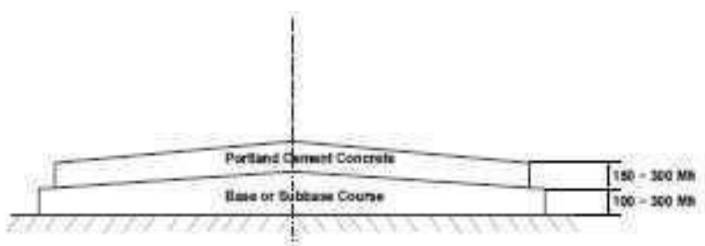
Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

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.

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

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.

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. Reinforcement's help to keep the slab together even after cracks.

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

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.

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.

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.

Typical layers of a flexible pavement:

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

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

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

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

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

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder course

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

Base course

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

Sub-Base course

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion 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.

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 pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

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

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

Repetition of Loads: The influence of traffic on pavement not only 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).

The 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 msaan 150 mm for traffic exceeding 2 msa.

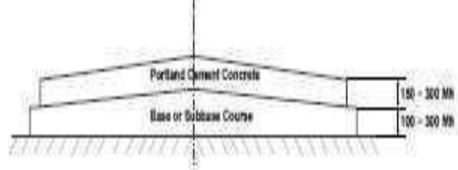
Bituminous surfacing

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.

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.



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.

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.

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 without 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

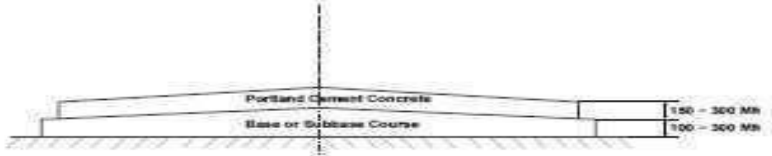
Empirical-Mechanistic method of design is based on the mechanics of materials that relates input, such as wheel load, to an output or pavement response. In pavement design, the responses are the stresses, strains, and deflections within a pavement structure and the physical causes are the loads and material 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.

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 criteria are commonly 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

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.

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 surfacing 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 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:

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 trafficking 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%.

= 7200000

= 7:2 msa

7. Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
8. 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. = 4430348:837

   =4:4 msa

3. Total pavement thickness for CBR 4% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC: 37 2001).
   (a) Bituminous surfacing = 20 mm PC + 50 mm BM
   (b) Road-base = 250 mm Granular base
   (c) Sub-base = 280 mm granular material.

FACTORS AFFECTING PAVEMENT DESIGN

Overview

In the previous chapter we had discussed about the types of pavements and their failure criteria. There are many factors that affect pavement design which can be classified into four categories as traffic and loading, structural models, material characterization, environment. They will be discussed in detail in this chapter.

Traffic and loading

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

Contact pressure

The 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 pavement. Many commercial vehicles have dual rear wheels which ensure that the contact pressure is within the limits. The normal practice is to convert dual wheel into an equivalent single wheel load so that the analysis is made simpler.

Axle configuration

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

Moving loads

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

Repetition of Loads

The influence of traffic on pavement not only 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).

Structural models

The structural models are various analysis approaches to determine the pavement responses (stresses, strains, and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are layered elastic model and visco-elastic models.

Layered elastic model

A layered elastic model can compute stresses, strains, and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic. In other words, the material properties are same at every point in a given layer and the layer will rebound to its original form once the load is removed. The layered elastic approach works with relatively simple mathematical models that relates stress, strain, and deformation with wheel loading and material properties like modulus of elasticity and Poisson's ratio.

Material characterization

The following material properties should be specified 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.

Environmental factors

Environmental factors affect the performance of the pavement materials and cause various damages. Environmental factors that affect pavement are of two types, temperature and precipitation 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. The 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 infiltrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

Summary

Several factors affecting pavement design were discussed, the most important being wheel load. Since pavements are designed to take moving loads, slow moving loads and static loads can be detrimental to the pavement. Temperature also influences pavement design especially the frost action which is very important in cold countries.

Problems

Factor that least affect the pavement is

1. Speed of vehicles
2. Wheel load
3. Axle configuration
4. Load repetition
5. Standard axle load is
    a. 40kN
    b. 60kN
    c. 80kN
    d. 10kN

FLEXIBLE PAVEMENT DESIGN

Overview

Flexible pavements are so named because the total pavement structure deflects, or flexes, under loading. A flexible pavement structure is typically composed of several layers of materials. Each layer receives loads from the above layer, spreads them out, and passes on these loads to the next layer below. Thus the stresses will be reduced, which are maximum at the top layer and minimum on the top of subgrade. In order to take maximum advantage of this property, layers are usually arranged in the order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) on the bottom.

Design procedures

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 is 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.

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 in to 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.

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:

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}\left(\frac{z}{d/2}\right)}{\log_{10}\left(\frac{2S}{d/2}\right)} \quad (1)$$

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.

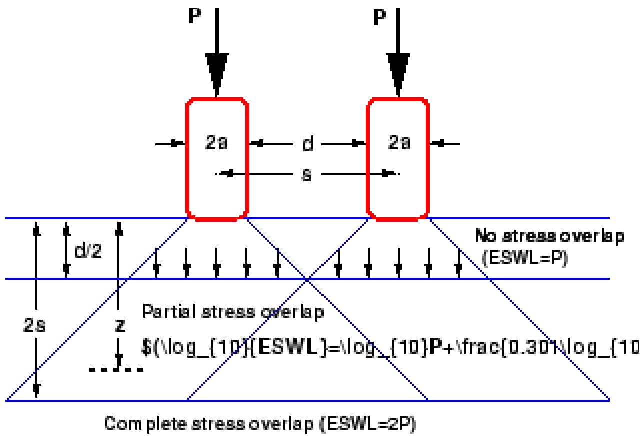


Figure 1: ESWL-Equal stress concept

Example 1

Find ESWL at depths of 5cm, 20cm and 40cm for a dual wheel carrying 2044 kg each. The center to center tyre spacing is 20cm and distance between the walls of the two tyres is 10cm.

Solution

For desired depth z=40cm, which is twice the tyre spacing, ESWL = 2P=2 $\times$ 2044 = 4088 kN. For z=5cm, which is half the distance between the walls of the tyre, ESWL = P = 2044kN. For z=20cm,

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}(\frac{z}{d/2})}{\log_{10}(\frac{2S}{d/2})} = \log_{10} ESWL = \log_{10} 2044 + \frac{0.301 \log_{10}(\frac{20}{10/2})}{\log_{10}(\frac{2\times 20}{10/2})} = 3.511.$$

Therefore, ESWL = antilog(3.511)= 3244.49 kN

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_1number 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 $W_1N_1$and $W_2N_2$are considered equivalent. Note that, $W_1N_1$and W_2N_2equivalency 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 adopted: fatigue cracking and ruttings. The fatigue cracking model has the following form:

$$N_f = f_1 \left(\epsilon_t\right)^{-f_2} \times (E)^{-f_3} \, or N_f \propto {\epsilon_t}^{-f_2} \quad (1)$$

where, N_f is the number of load repetition for a certain percentage of cracking, ϵ_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 cracking as failure criteria, and a typical value of 4 for f_2, then:

$$EALF = \left(\frac{\epsilon_i}{\epsilon_{std}}\right)^4 \quad (2)$$

where, i indicate i^{th} vehicle, and std indicate the standard axle. Now if we assume that the strain is proportional to the wheel load,

$$EALF = \left(\frac{W_i}{W_{std}}\right)^4 \quad (3)$$

Similar results can be obtained if rutting model is used, which is:

$$N_d = f_4 \left(\epsilon_c\right)^{-f_5} \quad (4)$$

where N_d is the permissible design rut depth (say 20mm), ϵ_c is the compressive strain at the top of the subgrade, and $f_4, \ f_5$ are constants. Once we have the EALF, then we can get the ESAL as given below.

$$\text{Equivalent single axle load, ESAL} = \sum_{i=1}^{m} F_i n_i \qquad (5)$$

where, m is the number of axle load groups, F_i is the $EALF$ for i^{th} axle load group, and n_i is the number of passes of i^{th} axle load group during the design period.

Example

Let number of load repetition expected by 80 KN standard axle is 1000, 160 KN is 100 and 40 KN is 10000. Find the equivalent axle load. Solution:

Table 1: Example Solution

	Axle	No.of Load	EALF	
	Load	Repetition		
i	(KN)	(n_i)	(F_i)	$F_i n_i$
1	40	10000	$(40/80)^4$ = 0.0625	625
2	80	1000	$(80/80)^4$ = 1	1000
3	160	100	$(160/80)^4$ = 16	1600

ESAL= $\sum F_i n_i = 3225\ kN$

Example2

Let the number of load repetition expected by 120 kN axle is 1000, 160 kN is 100, and 40 kN is 10,000. Find the equivalent standard axle load if the equivalence criteria is rutting. Assume 80 kN as standard axle load and the rutting model is $N_r = f_4 \epsilon_c^{-f_5}$ where f_4 =4.2 and f_5 =4.5.

Solution

Table 1: Example Solution

	Axle	No.of Load	EALF	
	Load	Repetition		

i	(KN)	n_i ( )	F_i ( )	$F_i n_i$
1	120	1000	$(120/80)^4$ = 6.200	6200
2	160	100	$(160/80)^4$ = 22.63	2263
3	40	10000	$(40/80)^4$ = 0.04419	441.9

ESAL= $\sum F_i n_i = 8904.94\ kN$

Example

Let number of load repetition expected by 60kN standard axle is 1000, 120kN is 200 and 40 kN is 10000. Find the equivalent axle load using fatigue cracking as failure criteria according to IRC.

Hint: $N_f = 2.21 \times 10^{-4} (\epsilon_t)^{-3.89} (E)^0.854$

Solution

Table 1: Example Solution				
	Axle	No.of Load	EALF	
	Load	Repetition		
i	(KN)	n_i ( )	F_i ( )	$F_i n_i$
1	40	10000	$(40/60)^3.89$ = 0.2065	2065
2	60	1000	$(60/60)^3.89$ = 1	1000
3	120	200	$(120/60)^3.89$ = 14.825	2965.081

ESAL= $\sum F_i n_i = 6030.81\ kN$

Material characterization

It is well known that the pavement materials are not perfectly elastic but experiences some permanent deformation after each load repetitions. It is well known that most paving materials are not elastic but experience some permanent deformation after each load application.

However, if the load is small compared to the strength of the material and is repeated for a large number of times, the deformation under each load repetition is nearly completely recoverable and proportional to the load and can be considered as elastic.

The Figure 1 shows straining of a specimen under a repeated load test. At the initial stage of load applications, there is considerable permanent deformation as indicated by the plastic strain in the Figure 1. As the number of repetition increases, the plastic strain due to each load repetition decreases. After 100 to 200 repetitions, the strain is practically all-recoverable, as indicated by ϵ_r in the figure.

Recoverable strain under repeated loads

Example2

Let the number of load repetition expected by 120 kN axle is 1000, 160 kN is 100, and 40 kN is 10,000. Find the equivalent standard axle load if the equivalence criteria is rutting. Assume 80 kN as standard axle load and the rutting model is $N_r = f_4 \epsilon_c^{-f_5}$ where f_4 =4.2 and f_5 =4.5.

Solution

Table 1: Example Solution

i	Axle Load (KN)	No.of Load Repetition (n_i)	EALF (F_i)	$F_i n_i$
1	120	1000	$(120/80)^4$ = 6.200	6200
2	160	100	$(160/80)^4$ = 22.63	2263
3	40	10000	$(40/80)^4$ = 0.04419	441.9

ESAL= $\sum F_i n_i = 8904.94\ kN$

Resilient modulus of soil

The elastic modulus based on the recoverable strain under repeated loads is called the resilient modulus M_R, defined as $M_R = \frac{\sigma_d}{\epsilon_r}$. In which σ_d is the deviator stress, which is the axial stress in an unconfined compression test or the axial stress in excess of the confining pressure in a triaxial compression test.

In pavements the load applied are mostly transient and the type and duration of loading used in the repeated load test should simulate that actually occurring in the field. When a load is at a considerable distance from a given point, the stress at that point is maximum. It is therefore reasonable to assume the stress pulse to be a haversine or triangular loading, and the duration of loading depends on the vehicle speed and the depth of the point below the pavement surface. Resilient modulus test can be conducted on all types of pavement materials ranging from cohesive to stabilized materials. The test is conducted in a triaxial device equipped for repetitive load conditions.

Dynamic complex modulus

When the loading wave form is sinusoidal and if there is no rest period, then, the modulus obtained is called dynamic complex modulus. This is one of the way of explaining the stress-strain relationship of visco-elastic materials. This modulus is a complex quantity and the absolute value of the complex modulus is called the dynamic modulus. This complex modulus test is usually conducted on cylindrical specimens subjected to a compressive haversine loading. The test setup is similar to resilient modulus. The dynamic modulus varies with the loading frequency. Therefore, a frequency that most closely simulates the actual traffic load should be selected for the test.

Correlations with other tests

Determination of resilient modulus is often cumbersome. Therefore, various empirical tests have been used to determine the material properties for pavement design. Most of these test measure the strength of the material and are not a true representation of the resilient modulus. Accordingly, various studies has related empirical tests like CBR test, Tri-axial test etc are correlated to resilient modulus.

Mechanistic-empirical analysis

Mechanics is the science of motion and action of forces on bodies. In pavement design these phenomena are stresses, strains, and deflections within a pavement structure and the physical causes are loads and material properties of the pavements structure.

The relationship between these phenomena and their physical causes is described by a mathematical model. The most common of them is layered elastic model.

Advantages

The basic advantages of the Mechanistic-Empirical pavement design method over a purely empirical one are:

1. It can be used for both existing pavement rehabilitation and new pavement construction
2. It can accommodate changing load types
3. It can better characterize materials allowing for
    - better utilization of available materials
    - accommodation of new materials
    - improved definition of existing layer proportion
4. It uses material proportion that relates better with actual pavement performance
5. It provides more reliable performance predictions
6. It defines role of construction in a better way
7. It accommodates environment and aging effect of materials in the pavement

Mechanistic model

Mechanistic models are used to mathematically model pavement physics. There are a number of different types of models available today (e.g., layered elastic, dynamic, viscoelastic) but this section will present the layered elastic model.

Layered elastic model

A layered elastic model can compute stresses, strains and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic. In other words, it is the same everywhere and will rebound to its original form once the load is removed. This section covers the basic assumptions, inputs and outputs from a typical layered elastic model.

Assumptions in layered elastic model

The layered elastic approach works with relatively simple mathematical models and thus requires following assumptions

- Pavement layer extends infinitely in the horizontal direction
- The bottom layer (usually the subgrade) extends infinitely downwards
- Materials are not stressed beyond their elastic ranges

Inputs

A layered elastic model requires a minimum number of inputs to adequately characterize a pavement structure and its response to loading. These inputs are:

- Material properties of each layer, like modulus of elasticity (E), Poisson's ratio (ν),
- Pavement layer thicknesses, and
- Loading conditions which include the total wheel load (P) and load repetitions.

Output

The outputs of the layered elastic model are the stresses, strains and deflections in the pavements.

- **Stress**. The intensity of internally distributed forces experienced within the pavement structure at various points. Stress has units of force per unit area (pa)
- **Strain**. The unit displacement due to stress, usually expressed as a ratio of change in dimension to the original dimension (mm/mm)
- **Deflection**. The linear change in dimension. Deflection is expressed in units of length (mm)

Failure criteria

The main empirical portions of the mechanistic-empirical design process are the equations used to compute the number of loading cycles to failure. These equations are derived by observing the performance of pavements and relating the type and extent of observed failure to an initial strain under various loads. Currently, two types of failure criteria are widely recognized, one relating to fatigue cracking and the other to rutting initiating in the subgrade.

Summary

Basic concepts of flexible pavement design were discussed. There are two main design procedures- empirical and mechanistic empirical design. For design purposes, equivalent single wheel load and equivalent single axle load concepts are used.

Problems

1. A set of dual tyres has a total load of 4090 kg, a contact radius a of 11.4 cm and a center to center tyre spacing of 34.3 cm. Find the ESWL by Boyd & Foster method for a depth of 34.3 cm. [Ans: 3369.3 kg]
2. Calculate ESWL by equal stress criteria for a dual wheel assembly carrying 2044 kg each for a pavement thickness of 5, 15, 20, 25 and 30 cms. The distance between walls of the tyre is 11 cm. Use either graphical or functional methods. (Hint: P=2044kg, d=11cm, s=27cm). [Ans: 2044, 2760, 3000, 3230 and 4088]

3. Let number of load repetition expected by 60kN standard axle is 1000, 120kN is 200 and 40 kN is 10000. Find the equivalent axle load using fatigue cracking as failure criteria according to IRC. Hint: $N_f = 2.21 \times 10^{-4} (\epsilon_t)^{-3.89} (E)^{0.854}$

(IRC 37:2001) Design of flexible pavements

The Pavement designs given in the previous edition IRC:37-1984 were applicable to design traffic upto only 30 million standard axles (msa). The earlier code is empirical in nature which has limitations regarding applicability and extrapolation. This guidelines follows analytical designs and developed new set of designs up to 150 msa.

Scope

These guidelines will apply to design of flexible pavements for Expressway, National Highways, State Highways, Major District Roads, and other categories of roads. Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub- base courses conforming to IRC/ MOST standards. These guidelines apply to new pavements.

Design criteria

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:

1. Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
2. Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
3. 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

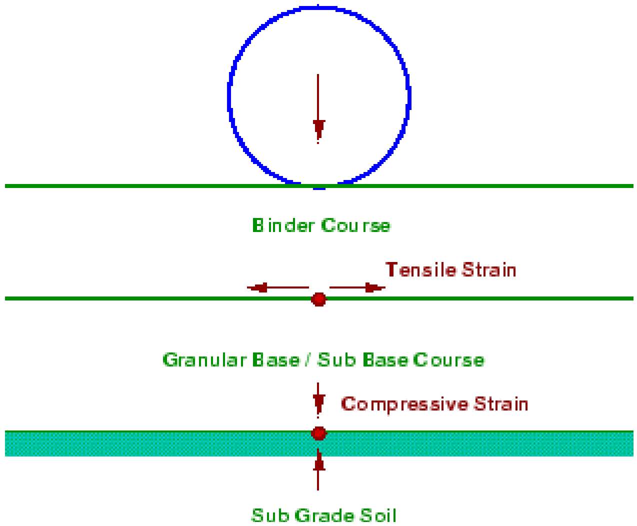


Figure: Critical Locations in Pavement

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

Fatigue Criteria:

Bituminous surfacing 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

$$N_f = 2.21 \times 10^{-4} \times \left(\frac{1}{\epsilon_t}\right)^{3.89} \times \left(\frac{1}{E}\right)^{0.854} \quad (1)$$

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 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

$$N_r = 4.1656 \times 10^{-8} \times \left(\frac{1}{\epsilon_z}\right)^{4.5337} \quad (2)$$

N_r is the number of cumulative standard axles to produce rutting of 20 mm.

Design procedure

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:

1. Initial traffic in terms of CVPD
2. Traffic growth rate during the design life
3. Design life in number of years
4. Vehicle damage factor (VDF)
5. Distribution of commercial traffic over the carriage way.

1. **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.

2. 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.

3. 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.

4. 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.

5. 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.

Pavement thickness design charts

For the design of pavements to carry traffic in the range of 1 to 10 msa, use chart 1 and for traffic in the range 10 to 150 msa, use chart 2 of IRC:37 2001. The design curves relate pavement thickness to the cumulative number of standard axles to be carried over the design life for different sub-grade

CBR values ranging from 2 % to 10 %. The design charts will give the total thickness of the pavement for the above inputs. The total thickness consists of granular sub-base, granular base and bituminous surfacing. The individual layers are designed based on the the recommendations given below and the subsequent tables.

Pavement composition

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 msaan 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 o 5 msa and dense bituminous macadam (DBM) for traffic more than 5 msa.

Numerical example

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%.

Solution

Distribution factor = 0.75

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

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

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

Bituminous surfacing = 25 mm SDBC + 70 mm DBM

Road-base = 250 mm WBM

Sub-base = 315 mm granular material of CBR not less than 30 %

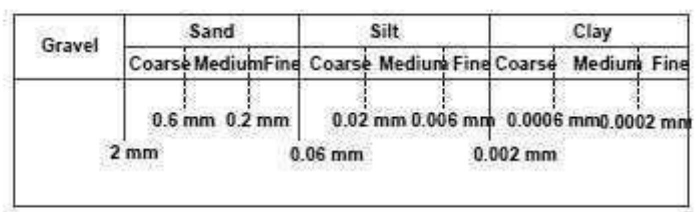
UNIT IV

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

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 ca n 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.

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:

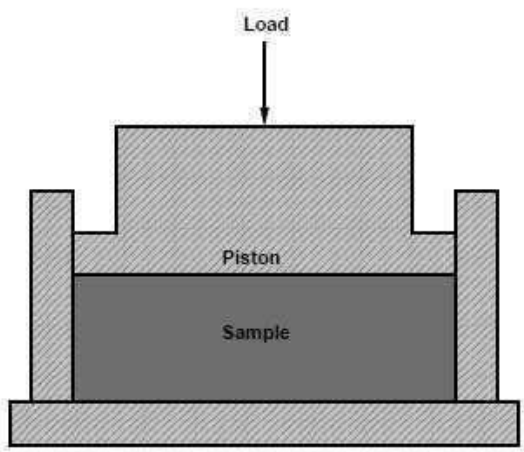
- **Shear tests**
- **Bearing tests**
- **Penetration tests**

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.

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 (W2) is expressed as percentage of the weight of the total sample (W1) which is the aggregate crushing value.

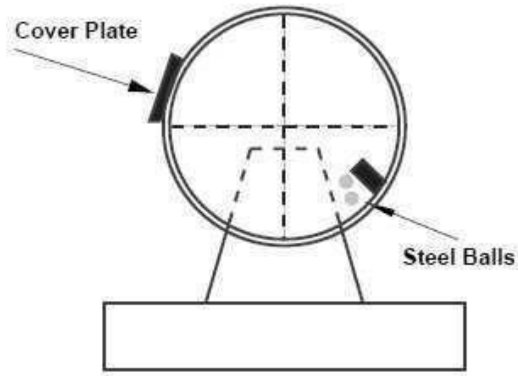
$$aggregate\ crushing\ value = \frac{w_1 \times 100}{w_2}$$

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

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.

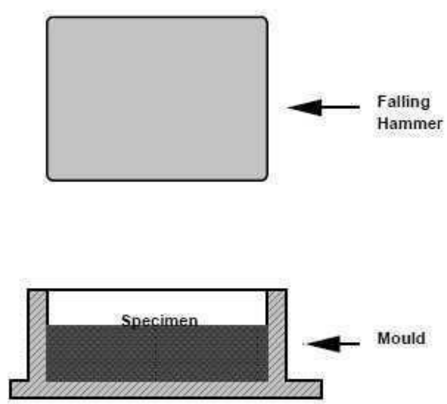


Los Angeles abrasion test setup

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.

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 (W2) to the total weight of the sample (W1)



Impact test setup

Aggregate impact value = ^{W1} 100 W2

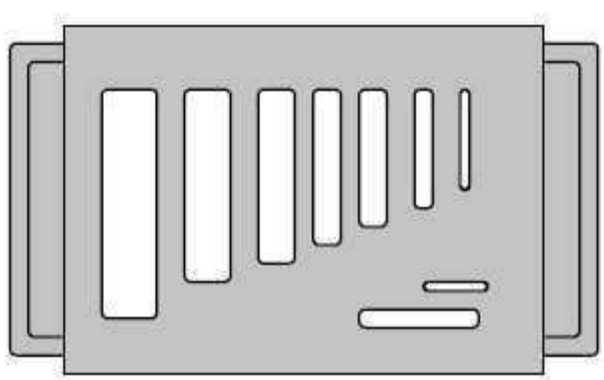
Aggregates to be used for wearing course, the impact value shouldn't exceed 30 percent. For bituminous macadam the maximum permissible value is 35 percent. For Water bound macadam base courses the maximum permissible value defined by IRC is 40 percent.

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 artain 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^{0}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.

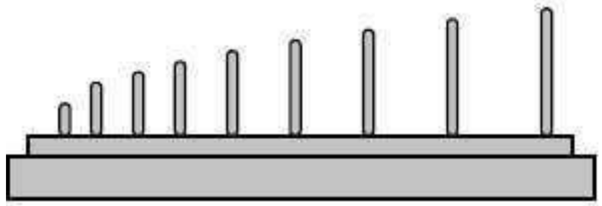
Shape tests

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.

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, Gapp , 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, MD is the dry mass of the aggregate, VN is the net volume of the aggregates excluding the volume of the absorbed matter, W is the density of water.

Bulk Specific Gravity: Gbulk , 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 aggregatesdry and in a saturated, surface dry condition, with all permeable voids filled with water. The difference of the above two is MW . MW 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.

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%.

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(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

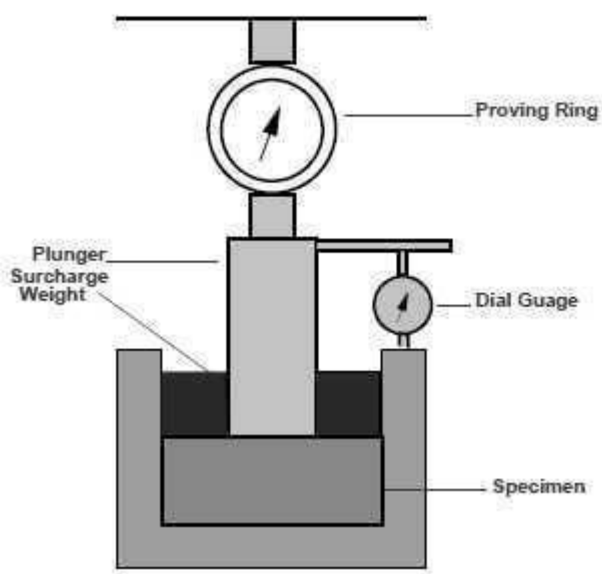
The laboratory CBR apparatus consists of a mould 150 mm diameter with a base plate and a collar, a loading frame and dial gauges for measuring the penetration values and the expansion on soaking. The specimen in the mould is soaked in water for four days and the swelling and water absorption values are 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.



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, flaky 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 bituminous materials, otherwise the bituminous coating on the aggregate will be stripped o in presence of water.

Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are sub-jested 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 tobe 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.

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 stabilized by suitable material. Normally cationic type emulsions are used in India. The bitumen content in the emulsion is around 60% and the remaining is water. When the emulsion is applied on the road it breaks down resulting in release of water and the mix starts to set. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC). Bitumen emulsions are ideal binders for hill road 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 stabilized surfaces and water bound macadam base courses. Bituminous primers are generally prepared on road sites by mixing penetration bitumen with petroleum distillate.

Modified Bitumen

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

Tests on bitumen

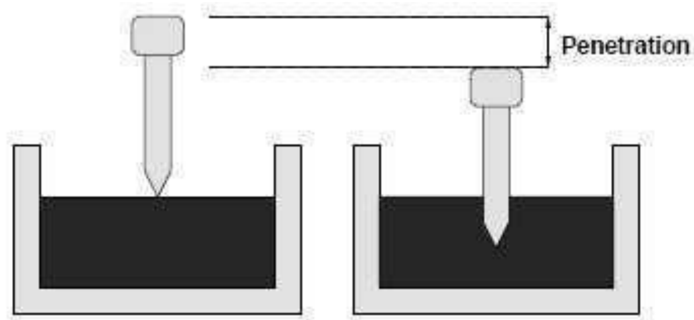
There are a number of tests to assess the properties of bituminous materials. The following tests are usually conducted to evaluate different properties of bituminous materials.

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

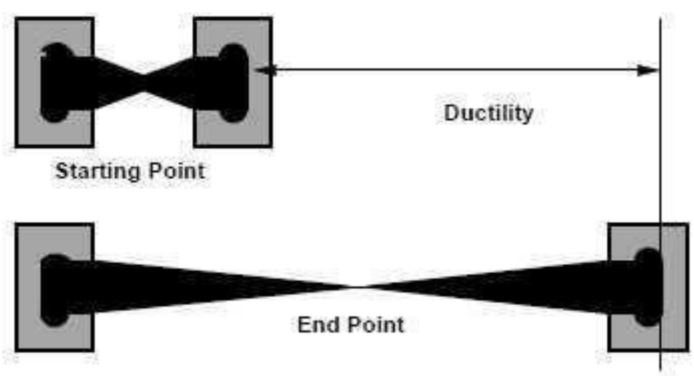
Penetration test

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

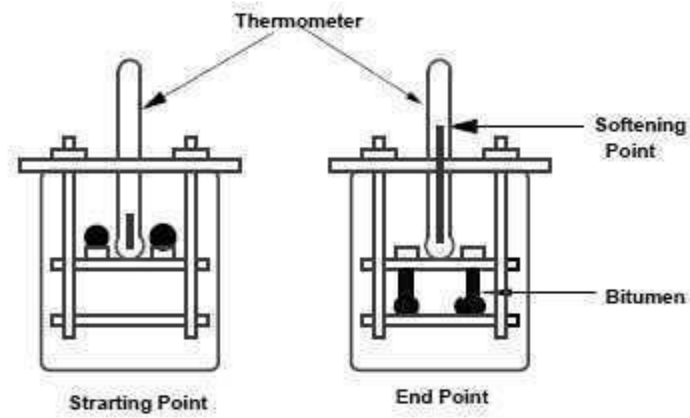


The Ductility test and softening point test



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.

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° 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 suitability and is preferred in hot climates.



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° 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.

Road Construction Machinery

Road construction equipments are found in a wide variety ranging from the very heavy ipment to portable and lighter equipment. These modern and high construction ipments make the construction job easier and quicker.

Also the work done my heavy machinery is of good quality, this is the reason that we d a wide variety of equipments at every construction site. The heavy machines make sible a lot of tasks to be completed safely and more reliably that cannot be carried out nually. However, the equipment always requires a person or two to perform its heavy ctions. The construction work carried out by the manifold heavy equipments can be ssified into three major categories which are as follows:

1. Earthwork Machinery
2. Road Works Machinery
3. Lifting Machinery

Earthwork Machinery:

This involves the engineering works where large quantities of materials such as soils or rocks are needed to be transferred from the origin to the site where the road is being constructed. The construction machines used to carry out the earthen works include excavators, loaders, dozers, graders and scrapers

Excavators:

As the name indicates excavators are used to dig the earth. They are quite commonly used in construction and are an essential part of the resources that are required for any building project.

Loaders:

They are also used for digging and are universally considered to perform faster than the excavators. Their main function is to move loose soil

Dozers:

The dozer machines are used to prepare the surface to be constructed by moving and changing the soil. A dozer is a useful machine which pushes and spreads the soil to create a flat and even surface.

Graders:

The function of a grader is quite similar to the dozer. It is used to smooth out the construction surface and level it. This equipment is particularly useful in road construction sites.

Scrapers:

Scraper is another type of construction equipment which is used to scrap a thin layer of soil and then carry it meters away as desired. They are commonly used in big project sites.

Road Work Machinery:

All the functions involved in the construction of roads fall under this category. Road construction is a common application of the construction equipments.

Milling Machine:

The milling machine in road works is used for repair works to remove a layer of unwanted material from roads so that a new layer can be created by disposing off the destroyed layer.

Paver:

A paver is an essential road construction machine used to lay out or spread asphalt or concrete layer on roadways.

Compactor:

Compactors are used for compacting the various layers of the roads after spreading them. As the name indicates compactors as a road construction machines are used to compress the materials in construction sites and roads. They compress and compact the soil for further construction purpose or compact the asphalt or concrete roads in a smooth layer enabling them to function properly.

Lifting Machinery:

These equipments are used to lift the heavy objects and materials on the construction sites. They occur in varying types depending on the requirement or height of lifting and the object to be lifted.

Tower Crane:

They are used to lift different building materials such as concrete, steel etc and they have the specific function of rising to a great height.

Tractor Crane:

They are also used for lifting and carrying heavy materials on the construction site and they can move about freely because of their compact structure.

Truck-Mounted Crane:

These cranes are most widely used because of the advantage that they can move easily on the roads. They are used for short duration projects.

IRC METHOD OF FLEXIBLE PAVEMENT MIX DESIGN

These guidelines will apply to design of flexible pavements for Expressway, National Highways, State Highways, Major District Roads, and other categories of roads. Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub-base courses conforming to IRC/MOST standards. These guidelines apply to new pavements.

Design criteria

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:

1. Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
2. Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
3. 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

Critical locations in pavement

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

Fatigue Criteria:

Bituminous surfacing 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

$$N_f = 2.21 \times 10^{-4} \times \left(\frac{1}{\epsilon_t}\right)^{3.89} \times \left(\frac{1}{E}\right)^{0.854} \quad (1)$$

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 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

$$N_r = 4.1656 \times 10^{-8} \times \left(\frac{1}{\epsilon_z}\right)^{4.5337} \quad (2)$$

N_r is the number of cumulative standard axles to produce rutting of 20 mm.

Design procedure

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:

1. Initial traffic in terms of CVPD
2. Traffic growth rate during the design life
3. Design life in number of years
4. Vehicle damage factor (VDF)
5. 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.

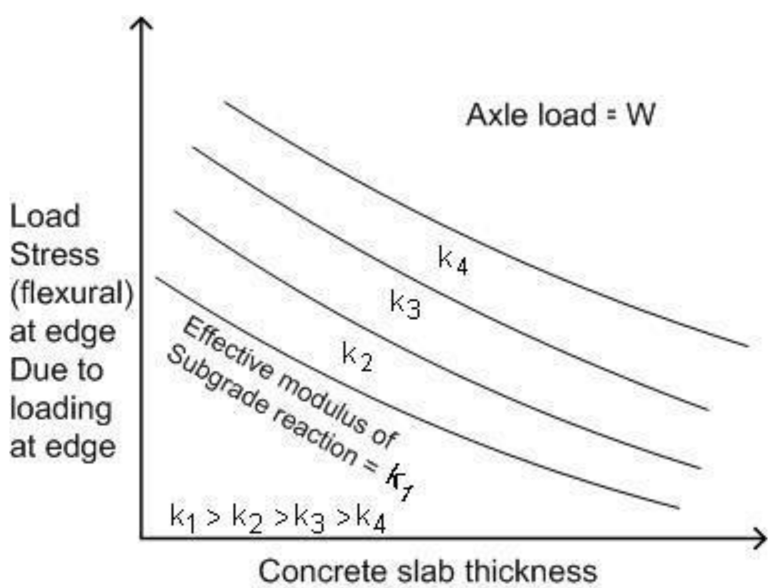
- **Single lane roads:** Traffic tends to be more channelized on single roads than two lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.
- **Two-lane single carriageway roads:** The design should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

Indian Roads Congress (IRC) method

The Indian Roads Congress (IRC) guidelines, IRC:58 (2002), has adopted the Westergaard's equation to estimate load stress and Brdabury's equation to estimate temperature stress. The load stress is highest at the corner of the slab, lesser in edge and least in the interior. The order of variation of temperature stress is just the reverse of this. As per IRC:58 (2002), it is recommended that the design needs to be done for edge stress condition and subsequently check needs to be performed for corner stress condition so as to finalize the design. The following are the steps followed as per IRC:58 (2002) guideline for the design of concrete pavement:

- The input parameters are obtained to formulate the design problem. The joint spacing and the slab dimensions are decided. If there is a bound sub-base layer over the subgrade, a suitable value of effective *k* is to be adopted.
- A trial thickness of the concrete slab is assumed.
- The edge stress is estimated for various axle loads from the given charts. Figure-20 schematically shows such a chart. The cumulative fatigue damage principle for fatigue is applied to check the adequacy of the slab thickness.
- The sum of edge stress due to load for the highest axle load group and the temperature stress should be less than the *MOR* of concrete, otherwise the design is revised. The adequacy of corner stress is checked with respect to *MOR* value and accordingly the design is finalized. Westergaard's corner stress formula is for estimation of corner stress due to load, and the corner stress due to temperature is assumed to be zero.



Estimation of layer thicknesses

- The thickness of the pavement is adjusted in such a way that the stress/ strain developed is less than the allowable values obtained from past performance information.
- The two major modes of structural failure of pavement are **fatigue and rutting.**

Fatigue: Traffic applies repetitive load to the pavement surface, and the cracks start from bottom the bound layer/ slab and propagate upwards. When the extent of surface cracks reaches a predefined level, the pavement is said to have failed due to flexural fatigue.

Functional design

The functional pavement design involves considerations of skid resistance, roughness, surface distresses, reflectivity of pavement surface etc. The functional pavement design considers mainly the surface features of a pavement.

Drainage design

A road needs to be designed in such a way that the rain/ snow precipitation is drained off the pavement and its surroundings. A suitable surface drainage system for the pavement is designed for this purpose. Some water, however, will percolate into the pavement fromits top surface and needs to be taken out of the pavement - this is done by providing an internal drainage system to the pavement. Water will also try to enter into the pavement from bottom due to capillary rise or due to rise in water table. A suitably designed sub-surface drainage system tries to avoid such a problem.

Pavement thickness design charts

For the design of pavements to carry traffic in the range of 1 to 10 msa, use chart 1 and for traffic in the range 10 to 150 msa, use chart 2 of IRC:37 2001. The design curves relate pavement thickness to the cumulative number of standard axles to be carried over the design life for different sub-grade CBR values ranging from 2 % to 10 %. The design charts will give the total thickness of the pavement for the above inputs. The total thickness consists of granular sub-base, granular base and bituminous surfacing. The individual layers are designed based on the the recommendations given below and the subsequent tables.

Pavement composition

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 . 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 o 5 msa and dense bituminous macadam (DBM) for traffic more than 5 msa.

Numerical example

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%.

Solution

Distribution factor = 0.75

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

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

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

Bituminous surfacing = 25 mm SDBC + 70 mm DBM

Road-base = 250 mm WBM

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

The horizontal tensile stress/ strain at the bottom of bound layer (bituminous surfacing, cemented base or concrete slab, as the case may be) is used as the governing parameter for fatigue failure.

- Conventionally, for design of concrete pavement stress is used as parameter, and for design of bituminous pavement strain is used as parameter.
- **Rutting:** Rutting is the accumulation of permanent deformation. This is the manifestation of gradual densification of pavement layers, and shear displacement of the subgrade.
- Vertical strains on the pavement layers, mainly the vertical strain on the subgrade is assumed to be governing factor for rutting failure.
- The rutting issue is not considered for concrete pavement design, because it does not have any permanent deformation.
- The fatigue/ rutting equations are developed from field or laboratory studies, where fatigue / rutting lives are obtained with respect to respective stress/ strain for fatigue/ rutting. For a given design life, thus, allowable fatigue and rutting stress/ strains can be estimated using the fatigue/ rutting equations.
- The various other types of pavement failures could be shrinkage, thermal fatigue, top down cracking (for bituminous pavement) etc.

Concrete pavement

- Concrete pavement is, in general, consists of three layers, subgrade, base layer and the concrete slab.
- Generally bound base layers are used for concrete pavement construction. As per Indian specification, some example of such base layers are Dry Lean Concrete (DLC), Roller Compacted Concrete (RCC) (IRC:15-2002)
- The concrete slab is generally of M40 to M50 grade of concrete as per Indian specifications, and is called as paving quality concrete (PQC) (IRC:15-2002).

Bituminous pavement

- The subgrade is a compacted soil layer.
- The base and sub-base course could be made up of bound or unbound granular layer. As per Indian specifications (MORT&H 2001), some examples of base or sub-base layers are: Granular sub-base (GSB), Water Bound Macadam (WBM), Wet Mix Macadam (WMM) etc.
- The binder course is made up bituminous material. As per Indian specifications (MORT&H 2001), some examples of binder course are: Bituminous Macadam (BM), Dense Bituminous Macadam (DBM) etc.
- The wearing course is the top bituminous layer which is comes in contact to the vehicle tyre. Wearing course provides impermeability to the pavement surface against water percolation (Chakroborty and Das 2003). The binder course and wearing course together are called bituminous surfacing.

UNIT V

EVALUATION AND MAINTENANCE OF PAVEMENTS

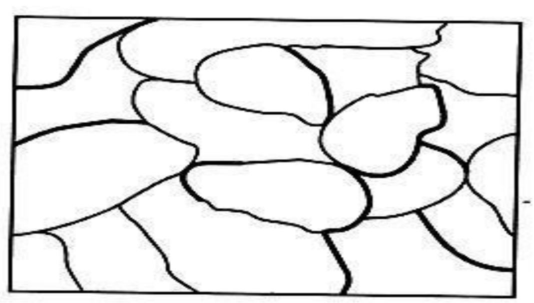
Pavement distress in flexible and rigid pavements – Pavement Management Systems Pavement evaluation, roughness, present serviceability index, skid resistance, structural evaluation, and evaluation by deflection measurements – Strengthening of pavements –Types of maintenance – Highway Project formulation.

Following are the some of the flexible pavement failures:

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

Alligator (map) cracking

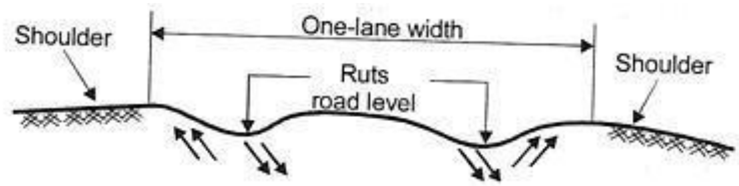
This is the most common type of failure and occurs due to relative movement of pavement layer materials. This may be caused by the repeated application of heavy wheel load resulting in fatigue failure or due to the moisture variations resulting in swelling and shrinkage of sub grade and other pavement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



Map cracking

Consolidation of pavement layers

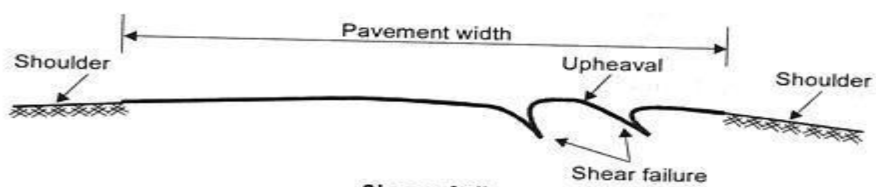
Formations of ruts are mainly attributed to the consolidation of one or more layers of pavement. The repeated application of loads along the same wheel path cause cumulative deformation resulting in consolidation deformation or longitudinal ruts. Shallow ruts on the surfacing course can also be due to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



Formation of ruts due to consolidation

Shear failure and cracking

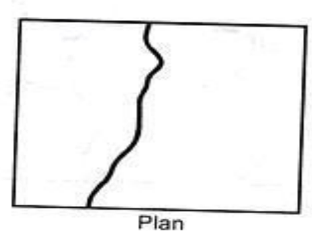
Shear failures are associated with the inherent weakness of pavement mixtures, the shearing resistance being low due to inadequate stability or excessively heavy loading. The shear failure causes upheaval of pavement materials by forming a fracture or cracking.



Shear failure cracking

Longitudinal cracking

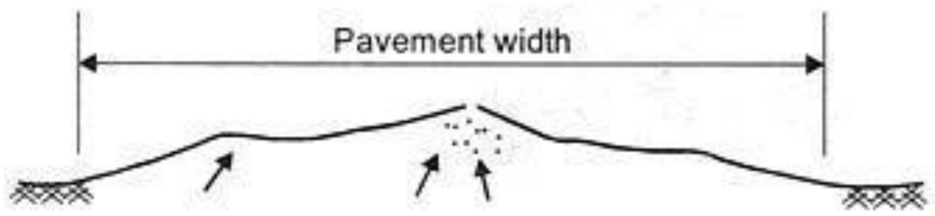
Due to frost action and differential volume changes in sub grade longitudinal cracking is caused in pavement traversing through the fall pavement thickness. Settlement of fill and sliding of side slopes also would cause this type of failure.



Longitudinal cracking due to differential volume change

Frost heaving

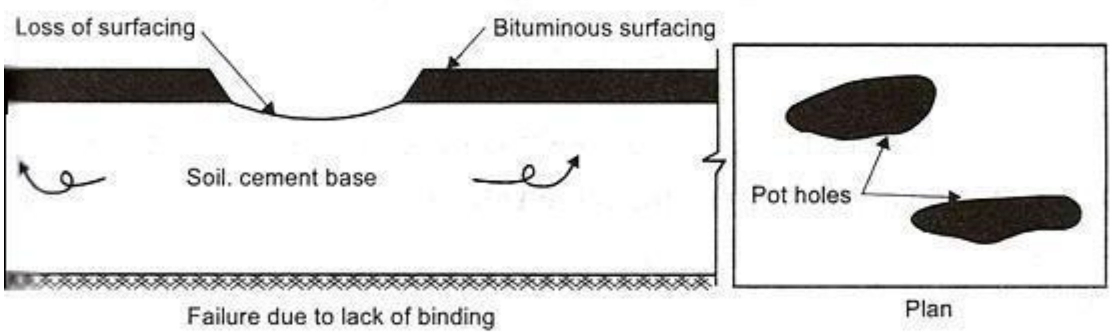
Frost heaving is often misunderstood for shear or other types of failure. In shear failure, the upheaval of portion of pavement is followed with a depression. In the case of frost heaving, there is mostly a localized heaving up pavement portion depending upon the ground water and climate conditions.



Failure due to frost heave

Lack of binding with lower layer

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

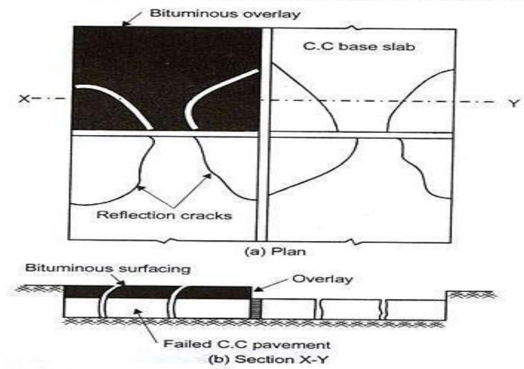


Failure due to lack of binding

Reflection cracking

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

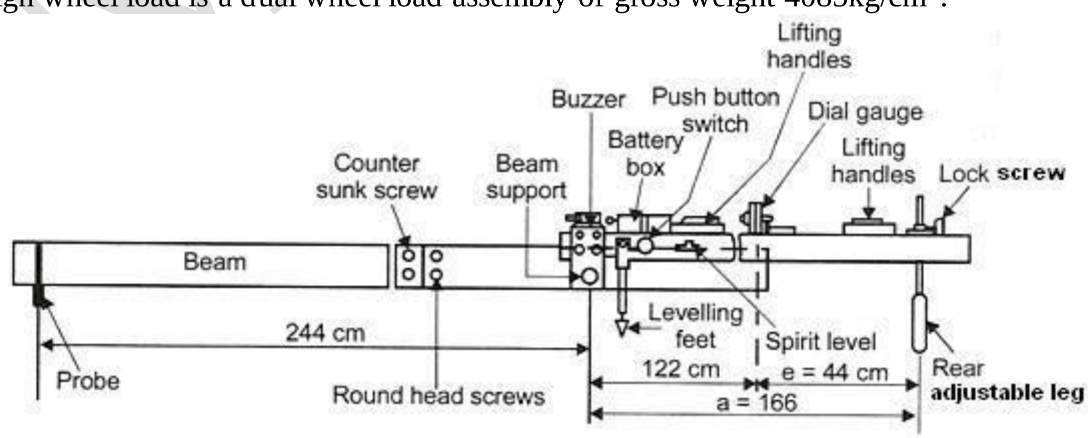
(a) and (b) show the pattern of reflection cracking.



Reflection cracking

Benkelman beam test

Benkelman beam is a device which can be conveniently used to measure the rebound deflection of a pavement due to a dual wheel load assembly or the design wheel load. The equipment consists of a slender beam of length 3.66m which is pivoted to a datum frame at a distance 2.44m from the probe end. The datum frame rests on a pair of front leveling leg with adjustable height. The probe end of the beam is inserted between the dual rear wheels of truck and rests on the pavement surface at the center of the loading area of the dual wheel load assembly. a dial gauge is fixed on the datum frame with its spindle in contact with the other end of the beam in such a way that the distance between the probe end and the fulcrum of the beam is twice the distance between the fulcrum and the dial gauge spindle. Thus the rebound deflection reading measured at the dial gauge is to be multiplied by two to get the actual movement of the probe end due to the rebound deflection of the pavement surface when the dial wheel load is moved forward. a loaded truck with rear axle load of 8170kg is used for the deflection study. The design wheel load is a dual wheel load assembly of gross weight 4085kg/cm^2.



Benkelman Beam

Procedure

The stretch of road length to be evaluated is first surveyed to assess the general condition of the pavement with respect to the ruts, cracks and undulations. Based on the above pavement condition survey, the pavement stretches are classified and grouped into different classes such as good, fair and poor for the purpose of Benkelman beam deflection studies. The loading points on the pavement for deflection measurements are located along the wheel paths, on a line 0.9 m from the pavement edge in the case of pavements of total width more than 3.5m, the distance from the edge is reduced to 0.6m on narrower pavements. The number of loading points in a stretch and the spacing between them for the deflection measurements are to be decided depending on the objective of the project and the precision desired. A minimum of 10 deflection observations may be taken on each of the selected stretch of pavement. The deflection observation points may also be staggered if necessary and taken along the wheel path on both the edges of the pavement.

After marking the deflection observation points, the study is carried out in the following steps:

a. The truck is driven slowly parallel to the edge and stopped such that the left side rear dual wheel is centrally placed over the first point for deflection measurement.
b. The probe end of the Benkelman beam is inserted between the gaps of the dual wheel and is placed exactly over the deflection observation point.
c. When the dial gauge reading is stationary or when the rate of change of pavement deflection is less than 0.025mm per minute, the initial dial gauge reading D_O is noted. Both the readings of the large and small needles of the dial gauge may be noted. The large needle may also be set to zero if necessary at this stage.
d. The truck is moved forward slowly through a distance of 2.7m from the point and stopped. The intermediate dial gauge reading D_i is noted. When the rate of recovery of the pavement is less than 0.025mm per minute.
e. The truck is then driven forward through a further distance of 9.0m and final dial gauge reading D_f is recovered as before.
f. The three deflection dial reading D_O, D_i and D_f from a set of readings at one deflection point under consideration. Similarly the truck is moved forward to the next deflection point, the probe of the Benkelman beam inserted and the procedure of noting the set of three deflection

observations is repeated. The deflection observations are continued at all the desired points.

g. The temperatures of the pavement surface are recorded at intervals of one hour during the study. The tyre pressure is checked and adjusted if necessary, at intervals of about three hours during the deflection study. The moisture content in the sub grade soil is also to be determined at suitable intervals.

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

i) If D_i- $D_f \leq 2.5$ divisions of the dial gauge or 0.025mm, D=2(D_O- D_f) divisions of 0.01mm units=0.02(D_O- D_f) mm.

ii) If D_i- $D_f \geq 2.5$ division, this indicates that correction is needed for the vertical movement of the front legs. Therefore,

$D=2(D_O- D_f)+2K(D_i- D_f)$ divisions.

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

$$k = \frac{3d\ 2e}{f}$$

Where

d=distance between the bearing of the beam and the rear adjusting leg. e=the distance between the dial gauge and rear adjusting leg f=distance between the front and rear legs.

The value of K of Benkelman beam generally available in India is found to be 2.91.therefore, the deflection value D in case (ii) with leg correction is given by:

$D=0.02(D_O- D_f) +0.0582(D_i- D_f)$ mm.

Procedure of overlap design by Benkelman beam method.

The overlay thickness required h_0 may be determined after deciding the allowable Deflection $D_a$in the pavement under the design load. According to equation, Ruiz 'overlay thickness h_0 in cm is given by:

$$h_o = \frac{R\log_{10}}{0.434}\frac{D_c}{Da}$$

Where

h_0=thickness of bituminous overlay in cm

R=deflection reduction factor depending on the overlay material (usual values for

Bituminous overlays range from 10 to 15, the average value that may be generally taken being 12)

D_a=allowable deflection which depends upon the pavement type and the desired design life, values ranging from 0.75 to 1.25mm are generally used in flexible pavements for overlay design.

The Indian road congress suggests the following formula for the design of overlay thickness equivalent to granular material of WBM layer. When superior materials are used in the overlay layer; the thickness value has to be suitably decreased taking equivalency factor of the material into consideration

$D_c=(D+\rho)$, after applying the corrections for pavement temperature and sub grade moisture.

D_a=1.00, 1.25 and 1.5mm, if the projected design traffic A is 1500 to 4500, 450 to 1500 and 150 to 450 respectively. Here

$A=\text{Design traffic}=P(1+r)^{(n+10)}$

When bituminous concrete or bituminous macadam with bituminous surface course is provided as the overlay, an equivalently factor o0f 2.0 is suggested by the IRC to decide the actual overlay thickness required. Thus the thickness of bituminous concrete overlay in mm will be $h_0/2$ when the value of h_0 is determined.

Resealing of cracks may be carried out in rigid pavements.

In cement concrete roads, the main defects are formation of cracks. Cracks are temperature cracks and structural cracks.

Temperature cracks initially form as fine cracks or hair cracks across the slab, in between a pair of transverse or longitudinal joints. These cracks divide the slab length into two or more parts due to temperature, shrinkage and warping stresses.

Structural cracks form near the edge or corner regions of the slab due to combined action of stress due to wheel load and warping stresses in the slab.

Shrinkage cracks form at the bottom portion of slab and propagate upwards. With the continued wheel load, temperature and moisture, the slab deteriorates further and the bottom portion goes on increasing. The situation becomes worst when water gets entry through the cracks into the sub grade.

Then the shrinkage cracks are cleaned by removing dirt, sand and other loose materials using sharp tool, stiff brush and a pressure brush. Kerosene oil is spread on the cleaned cracks so as to make proper bonding of the sealing material. Suitable grade bituminous sealing compound, heated to liquid consistency is filled. The sealer is placed 3mm above the level of the slab along the cracks. A layer of sand is then spread over the sealer so as to protect sealer temporarily.

Structural cracks have to be viewed seriously. Before attending to the repair, the causes for the cracks have to be analyzed first. The cracks may be due to some weak spot in the sub grade or due to localized settlement of embankment or underground drainage problem.

The maintenance work involves in attending to the basic cause of the failure of the pavement and then recasting the failed portion of the slab. For a general distress of pavement, immediate steps are to be taken to strengthening the pavement by providing a flexible or rigid overlay. Over a badly cracked and damaged slab it is not advisable to go in for an overlay instead the whole slab has to be replaced fully.

Methods for the structural evaluation of flexible and rigid pavements.

There are various approaches and methods of pavement evaluation. The various methods may be broadly classified into two groups:

Structural evaluation of pavement Evaluation of pavement surface condition

Structural evaluation of pavement

The structural evaluation of both flexible and rigid pavement may be carried out by plate bearing test. The structural capacity of the pavement may be assessed by the load carried at a specified deflection of the plate or by the amount of deflection at a specified load on the plate.

Field investigations and test carried out in various countries have shown that the performance of a flexible pavement is closely related to be elastic deflection under loads or its rebound deflection. Measurement of transient deflection of pavement under design wheel loads serves as an index of the pavement to carry traffic loads under the prevailing conditions. Assessment of flexible pavement overlay thickness requirements by Benkelman beam method. There are number of other non-destructive testing techniques for assessing the load carrying capacity of pavements.

Evaluation of pavement surface condition

The surface condition of flexible pavement may be evaluated by the unevenness, ruts, patches and caracks. The surface condition of rigid pavement may be assessed by the cracks developed and by faulty affecting the riding quality of the pavement.

The pavement unevenness may be using unevenness indicator, profilograph, profilometer or rough meter. Equipment capable of integrating the unevenness of pavement surface to a cumulative scale and that gives the unevenness index of the surface in cm/km length of the road may be called, bump integrator or unevenness integrator.

The pavement serviceability concept was introduced at the AASHO Road test for comparing relative performance of various test section during periods. The present serviceability of a pavement is related to a pre-determined scale by a panel of judges sensitive to the wishes of motor vehicle users by actually riding over the pavement. The present serviceability rating is the mean opinion of the members of the rating panel and this is corrected with the physical measurements such as longitudinal and transverse profile of the pavement, degree of cracking and patching etc… affecting pavement serviceable determining serviceability rating of pavements based on the physical measurements made on the pavement surface.

Maintenance of bituminous surface

Bituminous road generally need repair of only surface distress, viz., patches, pot holes, bleeding and resurfacing. Damaged or improper road surface forms patches which are repaired.
Using a cold premix the localized patches are made good.

Localized deep depressions are caused due to inadequate or defective binding material by removing aggregates during monsoons. Such depression causes pot holes. These pot holes are cut and made to rectangular shape and the affected material is removal till the sound materials are reached. These holes are cleaned well and some primer is applied. The material used to fill the holes is cutback or emulsion. The filled materials are well rammed to avoid any revelling.the finished level of patches is kept slightly above original level to allow for subsequent settlement if any to occur.

During original construction, if any excess bitumen materials are provided which bleed with time and the pavement becomes patchy and slippery. In such pavement surfaces corrugations or rutting shoving develop. In such places blotting materials, like aggregate chips of maximum size about 10mm or courses sand are spread. Then it is rolled to bind the new material with the old one. If necessary the surface is heated.

Sometimes the black top surface gets oxidized due to ageing. This development minute cracks on the pavement surface. On such surfaces a renewal coat or seal coat is applied. More than one layer of surface treatment may be needed on the surface is damaged seriously.

If the surface has totally worn out and poor riding surface is formed, then it may be more economical to provide an additional surface course on the existing surface.

Rutting

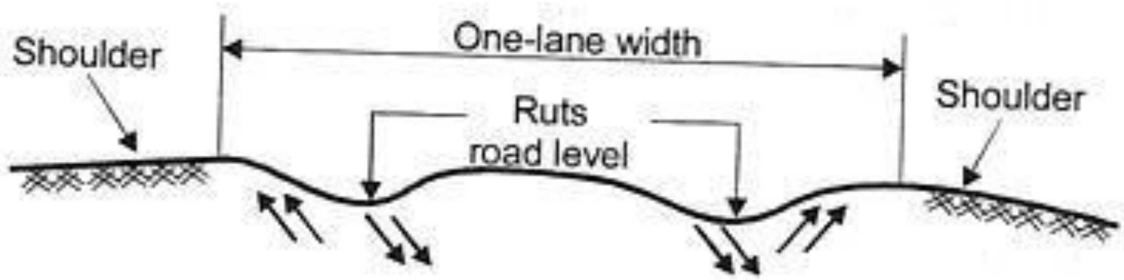
Repeated application of wheel loads on the same location of the road cause cumulative deformation called as consolidation deformation. Such consolidations of one or more layers of pavement leads to formation of ruts. Based on the width of the ruts it could be assessed whether the ruts are formed due to consolidation of sub grade or in subsequent layer.

Rutting is defined as the consolidation deformation is occurred in pavements the repair for the ruts is called rutting.

The main symptom is the surface of the pavement is look like a undulations in the top surface. The surface is uneven in various places like waves in the surface due to wheel load.

The treatment is over lay the existing surface by a new repair surface. The pavement surface is provided with addional load carrying capacity. The surface treatment is required for that type of failure.

Methods of strengthening damaged pavements.



Formation of ruts due to consolidation

Pavement:

The total thickness requirement is designed for the design traffic and the existing conditions of sub grade. Any one of the design methods is chosen for the design and appropriate strength test is carried out in the soil collected from the sub grade. The existing thickness of the pavement is found from test pits dug along the wheel path on the pavement. The overlay thickness required is given by the relation:

$$h_0 = h_d - h_c$$

Where,

h_0 =overlay thickness required, cm

h_d = total design thickness required, presently determined, cm h_c

= Total thickness of the existing pavement, cm

Rigid overlay over rigid pavement:

When a rigid or CC is constructed over and existing rigid or CC pavement. The interface between the old and new concrete cannot have perfect n\bond such that the two slabs could act as a monolithic one.

Two typical types of interface are possible;

i) Providing maximum possible interface bond by making the old surface rough

ii) Separating the two slabs at the interface by thin layer of bituminous material

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

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

Here,

h_0= rigid pavement thickness h_d

= design thickness

h_e = existing pavement thickness.

Flexible overlay over rigid pavement:

A flexible overlay when provided over a rigid pavement, the wheel load is distributed through larger area by the overlay, thus slightly reducing the wheel load stress in the old rigid pavement. For calculating the thickness of flexible overlay over rigid pavement the following relationship is employed:

$$h_f = 2.5\ (Fh_d - h_e)$$

Here,

h_f = flexible overlay thickness

h_e =existing rigid pavement thickness

h_d = design thickness of rigid pavement

F= factor which depends upon modulus of existing pavement.

Rigid overlay over flexible pavement:

The thickness of rigid overlay is calculated by using the design criteria for rigid pavement as laid down, the plate bearing test is conducted on the existing flexible pavement and K value is thus obtained. The design is made for this K value and the design wheel load.

Non-destructive testing methods of pavement deflection

The IDOT road rater

The road rater was the main testing device used in the program. The road rater is an electro hydraulic vibrator with the capability of generating harmonic loads of up to 8kips at driving frequencies between 6 and 60 Hz. When the vibrator is set over the testing point a static preload of 5kips is applied through the 12 inch diameter circular loading plate.

The desired peak to peak load is then generated at the preselected driving frequency, and peak to peak deflections are recorded with velocity transducers. The IDOT road rater has four deflection sensors located at the centre of the loading plate, and 1, 2, and 3 feet away from the centre. The following procedure for road rater deflection measurements were used in the program:

Road rater was operated at an 8kips peak to peak load and 15 Hz driving frequency. This type of testing was performed in the first 12 sections in table 1between four and six times during the program. The same 20points, 10 in each traffic lane, 10 feet, in a 100 feet stretch of pavement were tested on every occasion.

FST (frequency sweep test) selected stations were subjected to a frequency sweep test. The road rater peak to peak load was kept constant at 8 kips and driving frequency was varied in increments of 2 Hz from 6 to 30 Hz.

LFST (load frequency sweep test) the road rater was operated at peak to peak loads of 1, 2, 4, 6, and 8 kips, and the driving frequency was incremented at 2 Hz intervals from 6 to 30 Hz.

The falling weight deflectometer

The falling weight deflectometer is a deflection testing device operating on the impulse loading principle. A mass is dropped from a preselected height onto a footpath that is connected to a base plate by a set of springs. The base plate is placed in contact with the pavement surface over the testing point. By varying the drop height, the impulse load can be varied from 2 to 11 kips. The duration of the impulse loading is essentially constant ranging from 30 to 40 msec.

The falling weight deflectometer are measured with velocity transducers. One of these sensors is located at the center of the loading plate. Two additional sensors are movable and can be placed at any desired distance away from the center of the plate. During this testing program the falling weight deflectometer sensors were placed at 1, 2, and 3 feet away from the center of loading plate, the same spacing used for the road rater. Four to six load magnitudes between 2 to 11 kips were used.

Accelerometer measurements

An accelerometer was implanted in the surface of selected test road section to measure deflections under moving trucks, and under the falling weight deflectometer loading plate. The accelerometer was placed in a 2 inch diameter by 2 inch depth hole in the outer wheel path. The single wire coming off the accelerometer was buried in a slot to the direction of travel.

The following trucks were used in the testing

Truck	rear axle weight (lb)
Light	5100
Medium	9000
Heavy	18000

Maintenance of the pavements

Earth roads:

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

i) Formation of dust in dry weather.

ii) Formation of longitudinal ruts along wheel path or vehicles

iii) Formation of cross ruts along the surface after monsoons due to surface water.

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

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

Application of calcium chloride retains some water due to the hygroscopic nature of mix. Oiled earth roads are also common these days.

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

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

Maintenance of bituminous surfaces:

Mainly the maintenance works of bituminous surfacing consists of:

i) Patch repairs

ii) Surface treatments

iii)Resurfacing

Patch repairs:

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

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

Pot holes and repairs:

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

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

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

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

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

Surface treatment:

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

Resurfacing:

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

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

Maintenance of cement concrete roads:

Various types of cracking have been explained:

Treatment of cracks:

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

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

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

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

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

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

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

Maintenance of joints:

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

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

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

Various types of General failures in flexible pavement

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

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

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

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

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

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

Failures in flexible pavements:

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

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

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

Failures in sub grade:

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

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

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

i) Inadequate stability

ii) Excessive pavement thickness

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

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

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

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

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

Failures in sub base or base course:

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

i) Inadequate stability or strength

ii) Loss of binding action.

iii) Loss of base course materials

iv) Inadequate wearing course

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

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

Failures of wearing course:

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

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

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

General causes of pavement failures

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

a) Defects in the quality of materials used.

b) Defects in construction method and quality control during construction

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

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

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

f) Environmental factors including heavy rainfall, spil erosion, high water table, snow fall, frost action etc.

The various items of highway maintenance works may be broadly classified under three heads:

Routine maintenance:

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

Periodic maintenance:

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

Special repair:

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

Maintenance management system

The type and extent of maintenance requirement for a road depend on the serviceability standard laid down, the maintenance needs funds available and the priorities for the maintenance operarions.As several interlinked factors are involved in the maintenance works of road net work consisting of different categories of road, a system approach is appropriate for the road maintenance management. The various factors to be included in the maintenance management system are:

1. Minimum acceptable serviceability standards for the maintenance of different categories of roads.
2. Field surveys for the evaluation of maintenance requirements.
3. Various factors influencing the maintenance needs such as sub grade soil, drainage, climate, traffic, environmental conditions.
4. Estimation of rate of deterioration of the pavement under the prevailing set of conditions. Type and extent of maintenance requirements and various possible alternatives and their economic evaluation.
5. Availability of funds.
6. Maintenance cost, availability of materials, man power and equipment.