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**SCHOOL OF BUILDING AND ENVIRONMENT**

**DEPARTMENT OF CIVIL ENGINEERING**

**HIGHWAY ENGINEERING**

# UNIT – I – HIGHWAY DEVELOPMENT, PLANNING AND ALIGNMENT
# SCIA1304

**Introduction to Transportation systems - Highway development in India - Classification of Roads - Planning of roads – Significance of Highway planning - Highway alignment - factors influencing highway alignment - Planning or Engineering surveys for alignment: objectives, conventional and modern methods – Sustainability and its importance in Highway engineering.**

## INTRODUCTION

## TRANSPORTATION SYSTEMS

Transportation system means the state transportation infrastructure and related systems, including highways and toll roads open to the public and associated rights-of-way, bridges, vehicles, equipment, park and ride lots, transit stations, transportation management systems, intelligent vehicle highway systems, and other ground transportation systems. Transportation systems are a fundamental part of logistics and planning whenever vehicles are used to move people or items from one location to another. They allow people to get to work on time using the local bus or train service, and they allow airlines to tell their customers when they can expect an airplane to arrive at its destination. Definition of a transportation system or mode is a system for moving persons or goods consisting of three components: (a) The vehicle (equipment) is what moves objects or traffic (people, goods). The vehicle consists of a container and some type of motive power, either onboard or elsewhere

What was the first mode of transport?
Transport on land. The first form of transport on land was, of course, WALKING! Then, thousands of years ago, people started to use donkeys and horses to travel and to transport things on land. Around 3,500 BC, the wheel was invented

What are different types of transportation systems?
The different modes of transport are air, water, and land transport, which includes Rails or railways, road and off-road transport. Other modes also exist, including pipelines, cable transport, and space transport.

What is importance of transportation?

Transport is important because it enables communication, trade and other forms of exchange between people, that in turn establishes civilizations. Transport plays an important part in economic growth and globalization, but most types cause air pollution and use large amounts of land.

What are the uses of transport?
Modes of transport include air, land (rail and road), water, cable, pipeline and space. The field can be divided into infrastructure, vehicles and operations. Transport enables trade between people, which is essential for the development of civilizations

What are the principles of transportation?
There are two fundamental principles guiding transportation management and operations. They are economy of scale and economy of distance. It refers to the characteristic that transportation cost per unit of weight decreases when the size of the shipment increases

Transportation Systems Management is a set of techniques used to increase the capacity of transportation infrastructure without increasing its physical size. TSM techniques may include changes to traffic signals, such as coordinating them or introducing ramp metering, or minor changes to road geometry, such as straightening corners or lengthening merge lanes. These low-cost interventions can be very effective in reducing congestion under some circumstances. Due to the low cost of transportation systems management, it is often included as a reference option in cost-benefit analyses and environmental impact statements for new roadways or mass transit links, such as bus ways, metros, and light rail lines. It is typically considered in conjunction with the default "no-build" option.

An intelligent transportation system (ITS) is an advanced application which aims to provide innovative services relating to different modes of transport and traffic management and enable users to be better informed and make safer, more coordinated, and 'smarter' use of transport networks. Some of these technologies include calling for emergency services when an accident occurs, using cameras to enforce traffic laws or signs that mark speed limit changes depending on conditions. Although ITS may refer to all modes of transport, the directive of the European Union 2010/40/EU, made on July 7, 2010, defined

ITS as systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport. ITS may improve the efficiency of transport in a number of situations, i.e. road transport, traffic management, mobility.

## HIGHWAY DEVELOPMENT IN INDIA

India has embarked on a rapid pace of road development since after late 1990s by giving a high priority to highway development. The back ground to this is the economic liberalization that was kick-started in 1992. The National Highway Development Programme (NHDP) was the first major programme launched in 1997 to develop a large highway network across the country. The Public Private Partnerships (PPP) was adopted as a means of road and highway development in India starting from 2001, given the larger challenges and the need for leveraging private investments into the sector. Pursuant to it, a large number of contracts were awarded under Build, Operate and Transfer (BOT) variants of PPP and other PPP models.

India had a network of roads in the ancient times.

The road development in India can be discussed by taking different phases of the history at one time.

**Ancient Times**:

The excavation of the Mohn-Jodaro and Harappa civilization shows the traces of the roads in the ancient Indian times, in a period f 35th to 25th B.C.

Aryan Period and Road Construction**:**

There are various scriptures available, which script about the road development in India in the Aryan period. "Arthashastra" written by Kautilya (Chanakya), the prime minister of the Chandra Gupta Mourya, discusses the rules laid down for the depth of the road construction for different purposes in the 4th century. There were punishments for obstruction of roads.

Emperor **Ashoka** has improved the quality of the roads in India for the travelers, in his ruling period i.e. **5$^{th}$** century A.D.

**Mughal period and Road construction**:

The Mughal and Pathans improved the quality of the roads in India. Sher Shah Suri is still remembered for the construction of the Grand Trunk Road(GT Road) from Bangladesh-India to Kabul in Afghanistan.

19$^{th}$ Century and Road Construction in India:

After the fall of the Mughal Empire in India in 19th century the Britishers participated in the road construction for the military and administrative purposes. The work was carried out by the British Military Engineers. **Railway was introduced** later but the existing roads were metalled and bridges were provided. Dalhousie in the mid of 19$^{th}$ century introduced the Public works department (PWD), which still runs the various public works in India. Later after the introduction of the railways in India the attention was shifted to the railways construction and only the feeder roads and railways got the prime importance afterwards.

Jayakar committee:
The committee was formed by the both chambers of the Indian Legislature in the year 1927 to examine the roads in the India and ways of their development. The number of vehicles on the Indian roads increased after the first world war, so it was felt necessary to develop a good network of the roads in India.

**Indian Road development committee** was formed in the year 1927, with M.R.Jayakar as its chairman. The committee submitted its report in the year 1928, and made some important recommendations:

The road development in India should be considered a national interest, because it is out of control of the local bodies

- An extra tax should be put on the petrol consumers to develop a road development fund, called the Central Road Fund.

- Road development to be under union control
- A semi-official body should be formed to pool technical ideas, knowledge from the various parts of the country and to act as an advisory body on various aspects of roads. (IRC constituted)
- A research organisation should be organised to carry out the research and development work. (CRRI constituted)

As a result of these recommendations a Central Road Fund (CRF) was formed by the year 1929, a semi-official body called Indian Roads Congress was formed in 1934 and the Central Roads Research Institute was started in 1950.

- **Central Road Fund (1929):**

Central Road Fund was formed in the year 1929, extra money 2.64 paisa per liter of the petrol, was charged from all the petrol buyer in the country. This fund was kept separate for the use in the road development in India.

About 20% of the fund was kept to be used for the expenses of the administrative meetings and the research work of the highways of the national importance in the country. The rest of the 80% of the funds were distributed among the provinces at that time, according to their road users, for the development of the roads by the state governments.

- **Indian Roads Congress (1934**):

A semi-government organisation named, Indian Roads Congress was formed in the year December 1934, and was registered in the year 1937 under the registration act. Function of the IRC was to act as a forum for the regular pooling of the technical knowledge and know how, from the various parts of the country. IRC performed the various planning, and also it has become the most important agency to provide the standards and the specifications for the road construction in the country.

- **Motor vehicle act (1939):**

The increased numbers of vehicle on the Indian roads demanded for the rules and regulations. The motor vehicle act was passed in 1939, which laid down the rules for the road users and also for the identity of the vehicles. It is still running in the country in almost same way as it was at that time.

- **Central Road Research Institute(1951):**

A series of laboratories, known as the Central Science and Industrial Research Centre situated at Delhi, contains the research centre for the research work of the road construction in India, it is known as the Central Road Research Institute. The main function of the CRRI is to do the research work for the road construction and to provide the consultation services for the state government also. They designed Bump indicator

- **First 20-years road plan (Nagpur Road Plan-1943 to 1963):**

The first 20 years road network plan was prepared in the meeting of the Chief Engineers from the various parts of the country at the Nagpur, in 1943, which is also known as the Nagpur road plan. It was the first ever major planning which contributed a lot for the development of the roads in the country. It classified the Indian roads according to their location and purpose, and also it laid down a target for a density of road network of 16 km per 100 sq. Km in the country at the end of the 20 years road network in the year 1963.

After the starting of the 5 years plans in the year 1951, the first two 5 years plans also contributed to the target set by the first 20 years plan of the Nagpur so the density of 16 km per 100 sq. Km was achieved in the year 1961, 2 years earlier to the target year.

A typical hill road (Ghaghas to Shimla- Himachal Pradesh) - in 2013

- **Second 20-years road plan (Mumbai Road Plan- 1961 to 1981):**

As the earlier target was achieved before the planned year, so a need to set a new target arises and another 20 years road plan was laid down at the meeting of the various authorities from different states at Bombay. The road density target was doubled this time.

- **Third 20-years road plan (Lucknow road congress 1984)**

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

- This was the third 20 year road plan (1981-2001). It is also called *Lucknow road plan*.

- It aimed at constructing a road length of 12 lakh kilometres by the year 1981 resulting in a road density of 82kms/100 sq.km

- The plan has set the target length of NH to be completed by the end of seventh, eighth and ninth five year plan periods.

- It aims at improving the transportation facilities in villages, towns etc. such that no part of country is farther than 50 km from NH.

Vision 2010 focus on 20km of road/day. More than 1.6L tonne bitumen per year produced from 12 refineries and more than 4L cr spend on road. but not withstand after one rain.

**CLASSIFICATION OF ROADS IN INDIA:**

As per the Nagpur Plan, the roads are classified as

- National highways
- State highways
- District highways

- major district roads
- minor district roads
- village roads

**NECESSARY OF CLASSIFYING ROADS**:- To plan a road network for efficient and safe traffic operation , and for knowing the clear information of a particular root in a country, the classification of roads is necessary.

- NATIONAL HIGHWAYS:- These are the important roads of the country. They connect state capitals, ports and foreign highways. They also include roads of military importance. They are financed by the central government.
- STATE HIGHWAYS:- these are the important roads of a state. They connect important cities and district head quarters in the state , national highways & state highways of neighbouring states. They are financed by state government roads and buildings department of the state government constructs & maintain these roads.
- DISTRICT ROADS:- these are the roads within a district . they are financed by zillaparishads with the help of grants given by state government.
- THE MAJOR DISTRICT ROADS:- They are roads connecting district head
- quarters, taluk head quarters and other important town in the district production and market centers with each other and with state & national highways & railways.
- OTHER DISTRICT ROADS :- They are district roads of less importance
- VILLAGE ROADS: - they connect villages with each other and to the nearest district road. They are financed by panchayats with the help of zilla parishads and state government

What are the 4 major types of roads?

The following photos and information illustrate the 4 major road function classifications:

- Interstates,
- Other Arterials,

- Collectors, and
- Local roads.

The amount of mobility and land access offered by these road types differs greatly.

**Road classification in India**

In some ways it can be said that structured road networks have existed in India for almost 5,000 years. The Mohenjo-Daro urban settlement in the Indus valley (estimated population about 35,000) had a rectangular road grid and a system of major and lesser roads.

More recently the Nagpur Plan of 1943 proposed four classes of roads (link) :

- National highways which would pass through states, and places having national importance for strategic, administrative and other purposes.
- State highways which would be the other main roads of a state.
- District roads which would take traffic from the main roads to the interior of the district. According to the importance, some are considered as major district roads and the remaining as other district roads.
- Village roads which would link the villages to the road system.
- In 1990 and 1991 the Indian Roads Congress (IRC) (link) published two documents which described urban and rural road hierarchy (refs. 93 and 293). The IRC documents relate road class and terrain to design speed, recommended roadway and carriageway widths

**TABLE 1 INDIAN ROAD CLASSIFICATION BASED ON INDIA ROADS CONGRESS**

| Non Urban roads | Urban roads | Rural roads |
|---|---|---|
| Expressway | Arterial | Other District Roads |
| National Highways | Sub-Arterial | Village Roads |
| State Highways | Collector Street | |
| Major District Roads | Local Street | |

The website of the national highways authority of India (NHAI) (link) gives the classes as

- Expressways
- National highways
- State highways
- Major district roads
- Rural and other roads

**Other road classes**

Some of India's roads can be classed as International Highways, as they are for example part of the developing Asian Highway Network and of the planned Trilateral Highway which will link India with Myanmar and Thailand. Another road class might be "border roads", which are roads that serve the border areas of India and which are the resonsibility of the Border Roads Organisation. Concerning rural road classes, in 2007 the government of India started the PMGSY scheme, a programme to provide all-weather road access to presently un-connected rural habitations. The scheme considers the minor rural roads as a core network which consists of through routes and link routes. According to the PMGSY programme guidelines (ref. 282) the programme defines a core network as "that minimal network of roads (routes) that is essential to provide basic access to essential social and economic services to all eligible unconnected habitations in the selected areas through at least a single all-weather road connectivity". The document appears to define basic access (connectivity?) as (a place) being within 500m of a connected habitation or of an all-weather road. The document also refers to "main rural links", which suggests there may also be a road class for "minor rural links". Opinion Perhaps it is time for India to review its road classification, allowing for additional detail at urban and rural levels.

**PLANNING OF ROADS**

**Introduction to Highway Planning**:

Planning is a prerequisite for any engineering activity or project; this is particularly true for the development of a highway network or system in a country.

The **objectives of highway planning** are:

- Planning a highway network for safe, efficient and fast movement of people and goods.
- Keeping the overall cost of construction and maintenance of the roads in the network to a minimum.
- Planning for future development and anticipated traffic needs for a specific design period.
- Phasing road development programmes from considerations of utility and importance as also of financial resources.
- Evolving a financing system compatible with the cost and benefits.

To fulfil these objectives, the following principles have to be borne in mind:

- The proposed road links should be a part of the planned road network for the state/nation.
- The importance of the road shall be based on the traffic demand, and hence its type should fall under the standard classification.
- The maintenance needs of the roads should receive prompt attention by setting aside funds for this purpose.
- Statutory provisions for traffic regulation should be in place.

**Classification of Roads:**

The classification of roads depends on the criterion considered.

They may be **all-weather roads** if they can be used during all seasons of a year; **fair-weather roads**, if traffic is interrupted during monsoon at course ways where water overflows for a few hours. Based on the type of carriage-way or the road pavement, it may be a paved road with at least a water-bound macadam layer; or it may be an unpaved road. **Earth roads and gravel roads** fall in this category. Superior paved roads have bituminous surface or concrete surface for the carriage-way. A bituminous road is also known as a **black-top road**. Traffic volume, load transported per day, and the location and function are important criteria for classification of roads. These criteria have been taken into account in the classification recommended by the Nagpur Plan—NH, SH, MDR, ODR and VR, as also in the one modified by the Lucknow Plan—with categories of Primary, Secondary and Tertiary roads.

Urban roads are classified based on their function and location:

- Expressways— for movement of heavy volume of traffic.
- Arterial streets—for connecting the central area to expressways.
- Sub-arterial streets—similar to arterial roads but with less spacing.
- Collector streets—for collection and distribution of traffic through local streets in residential areas.
- Local streets—to access private property like residences, shops and industries. Traffic originates here or ends here.

In this context, certain definitions are relevant:

- Road – A convenient way over which vehicles may lawfully pass for going from one place to another.
- Service road – Used for servicing and as a means of access to adjacent property; constructed parallel to the main road adjacent to roadside buildings.
- Street – A road within a town or a residential locality with buildings on one or both sides.
- Country road – Road connecting one place to another on the country-side.
- Urban road – A road within a town or a city.
- Bypass road – A road constructed skirting a village or a small town, taking off through a highway and joining it after bypassing the inhabited area; this helps through traffic to move fast without having to enter the village or town.
- Highway – Any public road or a street may be called a highway.
- Arterial road – Road passing within a city and linking the state or national highway, with limited access.
- Freeway – An arterial highway with controlled access crossing other roads at different levels.
- Boulevard – Very wide road with avenue on its either side; generally used for ceremonial processions or considered as prestigious roads in a city.

**Urban Road Patterns:**

Although road patterns in a country are historically inherited, later additions can be planned bearing in mind the requirements of the day. Road patterns are of great use in urban highway planning. The choice of a road pattern depends upon the extent of land use or the distribution of residential, industrial and business areas in a city, the nature of the terrain, and the planner's preferences.

**The patterns in use in urban areas are**:

- **Grid Iron Pattern**:

This is also known as rectangular or block pattern and is perhaps the simplest (Fig. 1.5). The Romans preferred it, as have the Americans who adopted it in many of their cities. This is easy to set out in straight lines and rectangular co-ordinates, and is suitable for flat terrain.

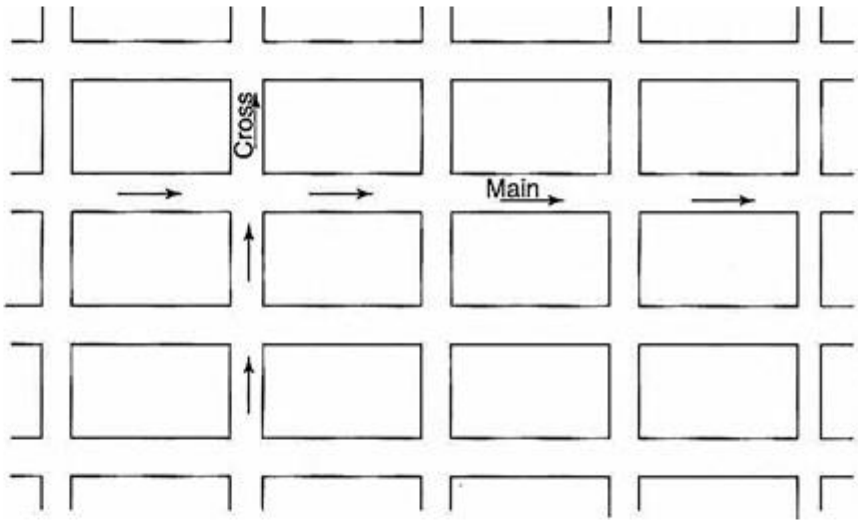


**FIG.1 GRIT IRON PATTERN**

The disadvantages of this pattern are monotonously long streets and the inconvenience in traffic operation. There are also certain advantages such as bypassing any road with traffic congestion and the convenience of imposing one-way traffic, if necessary, making alternate streets with one- way traffic in opposite directions. Chandigarh city is an excellent example of this pattern. Recently developed localities in most major cities such as Bangalore City have been built on this pattern.

- **Radial Pattern**:

In this pattern, roads emanate from a central focal area, which may be a business centre or an important public building. In order to ease the congestion in the focal area, ring roads are provided; there can be several such roads—inner, intermediate and outer—depending on the requirements of the traffic. The shape of a ring road may be round, square, or elongated. Based on this, the pattern may be star and grid, or star and circular. The star and grid pattern, or the radial and block pattern has been the basis of the Nagpur Road Plan, and it has been adopted in a number of Indian cities.

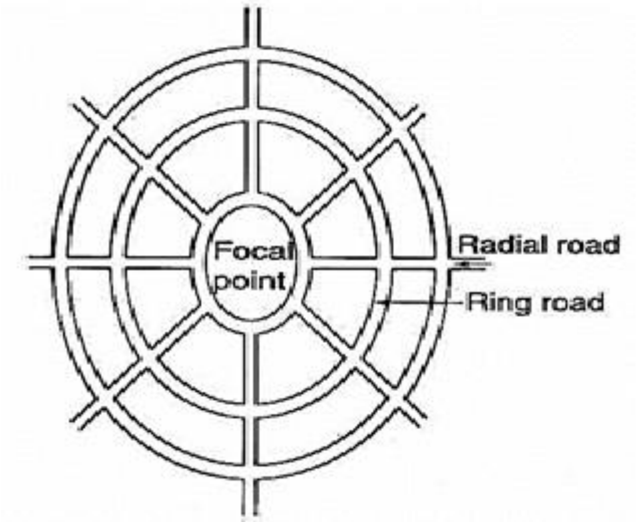


**FIG.2 STAR AND GRID PATTERN**

The star and circular pattern, also known as the radial and circular pattern, has been adopted in certain cases, although in a limited way. A classic example is the Connaught Place area of New Delhi.

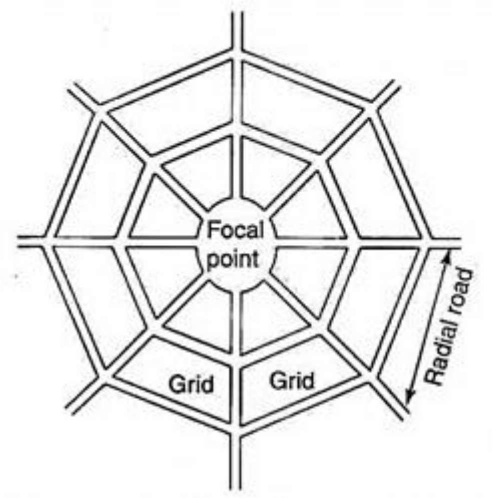


**FIG.3 STAR AND CIRCULAR PATTERN**

- **Hexagonal Pattern**:

The basic figure of the road network in this case is a hexagon; each hexagon has at least one side common with an adjacent pattern, as shown in Fig. 4.

**FIG. 4 HEXAGONAL ROAD PATTERN**

The hexagonal pattern can be modified by dividing the hexagon into six triangle units by link roads; this facilitates travel from one place to any other place in the area in the minimum possible time, compared to any other pattern. This, in fact, is known as a 'minimum travel pattern' and was used in certain cities to great advantage.

**Highway Planning Studies:**

Highway planning involves the assessment of the length of road required for a given area, which may be a city, district, state or a country; further, it includes the preparation of a master plan for the area taking into consideration future needs, and phasing the programme in annual or five-year plans, based on the priorities and utility.

For assessing the required road length for the area, field studies are to be carried out to collect the necessary data.

These are:

- **Economic Studies**:

Details of the existing facilities, their utility, distribution of the existing population in the area, population growth trends, existing products in the agricultural and industrial sectors, future trends of development in these sectors, existing communication and education facilities, and the per capita income are to be collected.

- **Road Use Studies**:

Details of the existing road facilities, traffic volume in vehicles per day, traffic flow patterns, classes of traffic such as passenger cars, busses and trucks, loads carried, average speeds, anticipated future trends of traffic growth, and other traffic-related studies are to be conducted.

- **Engineering Studies:**

These include study of the topography, soil, road life and special problems, if any, relating to construction, drainage and maintenance.

- **Financial Studies**:

Various financial aspects such as the sources of funding, estimated revenue from taxes on vehicles, toll tax, and indirect benefits of raising the living standards of the people due to the proposed road network are considered.

A systematic study of all these data will help the planner in the preparation of a Master Plan to serve the needs of the area for a specified design period of say, 20 to 25 years. These studies also help in fixing priorities of various routes or sectors based on their utility per unit length. Based on the priorities and the maximum utility per unit length, the entire development plan for the design period will be phased in 5-year intervals, depending upon the availability of financial resources. This is known as phasing of the Master Plan for road development.

For calculating the optimum road length a system called saturation system or maximum utility system is used. This system is based on the principle of qualifying the utility of a proposed road network based on the villages and towns of different populations it serves, as also the weight of agricultural or industrial products it carries.

For example, consider the ‘utility units’ attached to villages with certain population ranges as given below:

**TABLE 1 UTILITY UNIT WITH POPULATION**

| Population | Utility Unit |
|---|---|
| Lesser than 500 | 0.10 |
| 501 - 1000 | 0.25 |
| 1001 - 2000 | 0.50 |
| 2001 – 5000 | 1.00 |
| 5001 – 10000 | 1.50 |
| More than 10000 | 2.50 |

The total utility units for all the villages served by a proposed road may be called, based on this. Similarly, the utility unit for 1000 tonnes of agricultural products may be taken as 1.00, and that for 100 tonnes of industrial product as 10.00. If the break-up is not known, a suitable average value may be taken as the utility unit for the entire productivity. The total utility units may be got by summing up the values from both these criteria and divided by the length of the roads, to obtain the total utility per unit length. Thus, the value for different options under investigation may be compared and the best option with the highest total utility units chosen. This option is supposed to be utilised to the maximum extent by traffic in all stretches of the road, reaching saturation.

This system has been used extensively in the U.S.A. The disadvantage of this system is the element of arbitrariness of the utility coefficients assigned to the various factors; but with sound judgment and professional skill and experience, balanced weightage may be arrived at for choosing the best option.

## HIGHWAY ALIGNMENT:

The laying out of the **centre line of a proposed highway on the ground** is called its ‘alignment’. A new road should be aligned carefully since any change in alignment may not be possible or may be expensive at a later stage, owing to increased land acquisition costs and roadside structures constructed after the road has taken shape.

Requirements of an Ideal Alignment:

- **Directness**: straight

The aligned route between end points should be as direct as possible and result in the minimum possible length under the circumstances.

- Ease of Construction, Maintenance and Operation: **easy access**

The alignment should be such that it is easy to construct, maintain and operate the highway. The curves and gradients should be easy.

- **Safety**:

Safety for the road-users should be the primary consideration; the stability of natural slopes and man-made slopes for embankments and cuttings should be ensured to prevent possible accidents.

- **Economy**:

The overall cost of construction and maintenance of the road, as also the operation cost of the vehicles should be as low as possible.

- **Special Considerations**:

Depending upon the purpose of the highway and the characteristics of the terrain, special considerations may be needed as in the case of hill roads.

**Horizontal Alignment**:

This is the alignment of the roadway in the horizontal plane; although it is ideal to have a straight route between end points, it is practically impossible owing to several constraints. A change in direction necessitates the use of horizontal curves for smooth flow of traffic.

**Vertical Alignment**:

Although it is ideal to have a roadway at the same elevation throughout, this is almost impractical and gradients or slopes along the length become mandatory. A change in gradient calls for curves in the vertical plane; vertical curves should be designed and constructed for smooth flow of traffic based on several criteria. The alignment may be smoothened as shown in Fig. 5

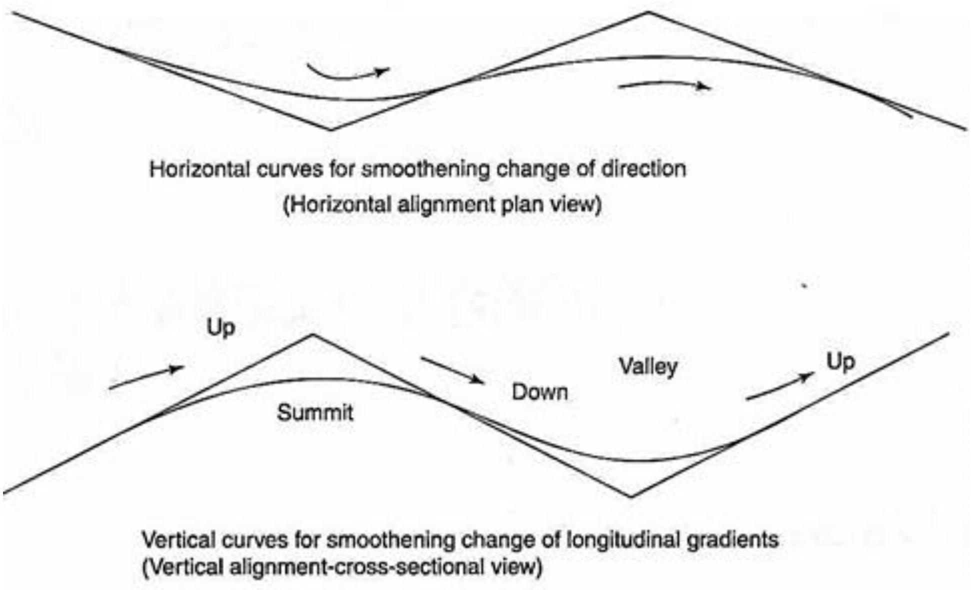


**FIG. 5 SMOOTHERNING OF ALIGNMENT**

**Factors Controlling Alignment**:

The selection of alignment of a proposed new highway route will be based on a careful consideration of the following factors:

- **Obligatory Points**:

These are the points through which the alignment has to necessarily pass for maximum utilisation of the road (Figure 2.2). While aligning a new highway route between two end points, it would be necessary to make it pass through places of importance. This may be based on the population that can be served, or places of business or industrial importance.

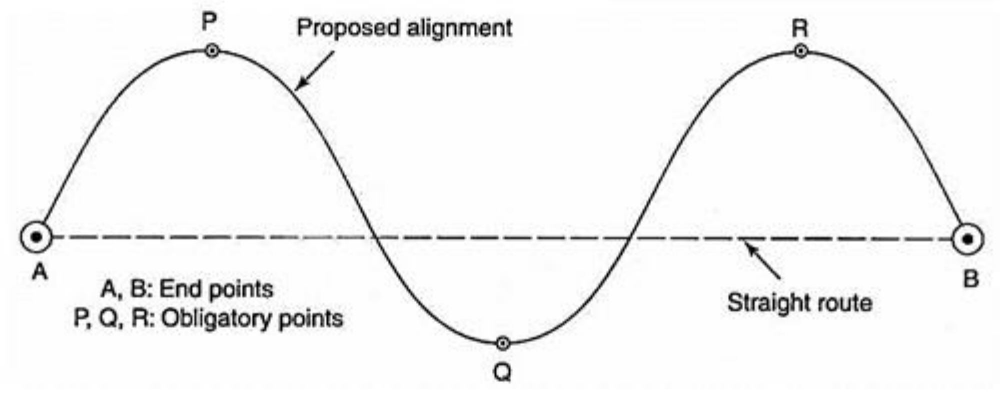


**FIG.6 ALIGNMENT TO CONNECT OBLIGATORY POINTS**

- **Topographical Features**:

Topographical features like a lake or a hillock may require the alignment to be taken around them. In the case of a big hill the option of constructing a tunnel through it for maintaining a straight alignment can be considered. The relative costs of these options have to be studied to finalise the alignment. Figure 7 shows a change in alignment around an obstruction caused by a lake and a hillock.

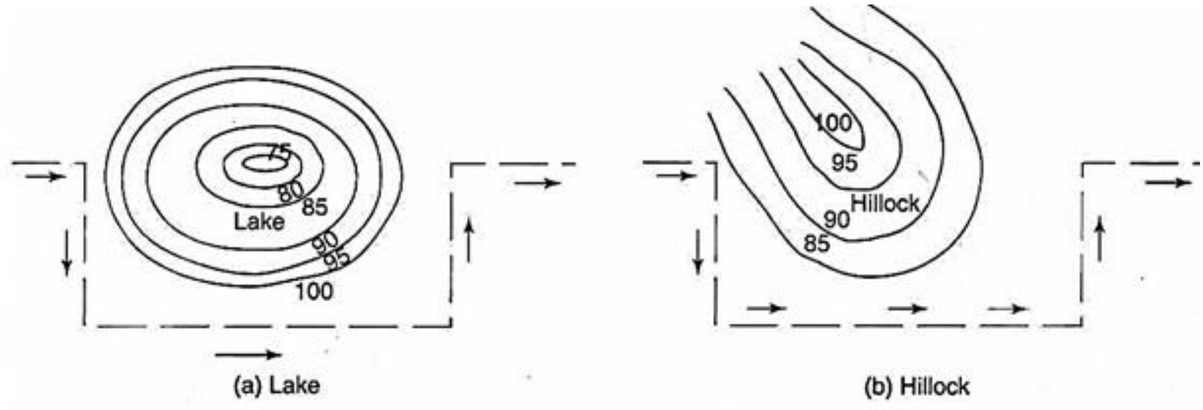


**FIG.7 ALIGNMENT NEAR TOPOGRAPHICAL FEATURES**

- **Geometric Design Aspects**:

Factors such as radius of curve, longitudinal gradients, sight distances, road intersections, design speed, lateral friction, and super-elevation govern the alignment to a considerable degree; radii of horizontal curves and longitudinal gradients should facilitate easy manoeuvring of vehicles.

- **Cross-Drainage Needs**:

The alignment should be such that bridges are located at right angles to the direction of flow of the stream or river Fig. 8.

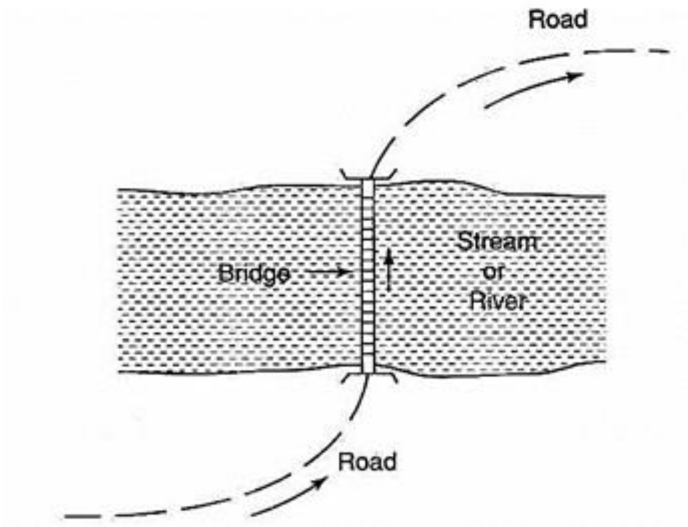


**FIG.8 ROAD ALIGNMENT ACROSS THE RIVER**

- **Deviations Dictated by Circumstances**:

Although a straight horizontal road is the best option, it is highly monotonous for a driver; so, to divert attention on a straight road and break the monotony, a slight bend or curve may be created at least once in a kilometre or two to make the driver alert. Obstructions such as places of worship (such as established temples and churches), monuments of historical interest, public buildings such as hospitals and educational institutions and utility services like water supply and sewerage lines and overhead transmission lines may necessarily have to be bypassed. This may dictate deviation in the alignment of the roadway, leaving sufficient margin for these hindrances. Sometimes, the alignment may have to be changed to bypass expensive private property or agricultural or industrial area.

- **Proximity to Materials and Labour**:

Proximity to the sources of materials for road-making and the availability of cheap labour may be a criterion for fixing the alignment.

- **Economic Considerations**:

Before an alignment is chosen, two or three alternative routes may have to be investigated and their overall cost – initial outlay and maintenance cost over a design period – compared. The route with the best economy is then selected.

- **Political Considerations**:

Sometimes, political considerations may dictate the choice of alignment, setting aside even economic considerations. Of course, the other important criteria have to be necessarily borne in mind.

**Highway Project Preparation**:

A highway project may be an entirely new route or it may involve re-alignment and re-design of an existing road such as for upgrading its geometric design standards.

The work of a new highway project involves:

- Selection of the alignment.
- Geometric design.
- Testing and selection of the materials for the subgrade and the pavement.
- Pavement construction including surfacing.
- Rolling and compaction and curing, if necessary.
- Quality control during construction.
- Performance of review and appraisal under traffic.

**Realignment of an Existing Road**:

An existing road may have to be realigned under a variety of circumstances:

- Redesign and improvement of geometric design aspects owing to increased traffic needs.
- Raising the level of a road subjected to flooding.
- Reconstruction of weak culverts and bridges to take care of increased traffic needs.
- Construction of over-bridges and under-bridges at road intersections and level crossing.
- Construction of a bypass near a busy town.

**Project Report**:

Any project should be submitted to the competent authority along with a report.

The report should contain the following:

- Name of the project

- Authority for execution
- Necessity
- Summary of alignment details
- Summary of geometric design aspects
- Traffic details including anticipated future needs for a chosen design period
- Details of important drainage and cross-drainage works
- Specifications for the materials
- Details of quantities required
- Rate analysis
- Detailed and abstract estimated
- Total cost and duration of the project
- Material sourcing, labour and equipment
- Construction scheduling (using project analysis tools such as CPM and PERT)
- Temporary facilities like diversion roads, work-sheds, water supply and power
- Signals and traffic signs
- Lighting
- Roadside arboriculture
-

**Engineering Surveys**:

Highway alignment and location are facilitated by a systematic step-by-step procedure of conducting 'engineering surveys'.

These surveys include:

- Study of Topographic Maps
- Reconnaissance Survey
- Preliminary Survey
- Location Survey
- Soil Survey
- Construction Survey.

- **Study of Topographic Maps**:

Topographic maps are available from the Survey of India; these are contour maps with 15 to 30 m contour intervals and show important topographic features like rivers, valleys, ridges, and hills. By a careful study of these maps, it is possible to align highways bearing in mind the obligatory points. Depending upon the elevations of the terminal points, and considering the ruling gradients and other factors, two or three alternative routes may be chosen.

- **Reconnaissance Survey**:

The objective of reconnaissance survey is to physically examine the possible alignments observed during the study of topographical maps. This is generally carried out using simple surveying instruments such as prismatic compass, Abney level, hand level or tangent clinometers. Details of certain features not available from the map study are collected during the reconnaissance survey.

Some of the details that may be gathered are:

- Approximate gradients, radii of horizontal curves necessary.
- Obstructions such as permanent structures not shown in the maps.
- Ponds, lakes, valleys, bridges, hillocks, and similar topographical features with relevant details.
- Information relating to cross-drainage structures such as culverts, causeways and bridges required along each of the possible routes.
- Geological features and information on soil types along the route.
- Stability of slopes in the case of hilly terrain.
- Sources of construction materials – borrow areas for earth materials and quarries for stones and broken stone.
- Climatic factors, hydrological information, water-table levels, water sources and maximum flood levels in the case of streams and rivers.
- Availability of labour, power and water supply along the route.

- **Preliminary Survey**:

The objectives of a preliminary survey are:

- To compare the proposed routes chosen during reconnaissance for a good alignment.
- To carry out accurate field work for detailed surveys on the chosen alternative routes
- To estimate the quantities of the earth work and other materials to facilitate the preparation of detailed and abstract estimates of the project cost.

- To choose the best alignment from all angles.

- **Detailed Survey**:

The various kinds of detailed survey carried out are:

**Traverse Survey**:

Open traverse are run with the help of a theodolite and tapes, the lengths of each of the lines and the deflection angles wherever a change in direction is required are measured accurately.

**Levelling**:

Longitudinal section along the proposed route and cross-sections at intervals of 30 m to 100 m along the route are to be taken, depending upon the nature of terrain – plain or rolling.

Contouring is also done in the vicinity of the route by using either tachometry or precise levelling. Bench-marks are connected to GTS bench-marks.

**Additional Details**:

Drainage, cross-drainage works, hydrological data, soil data and details of existing features like buildings, lakes, rivers, power lines and geological landmarks are collected more accurately than during reconnaissance. Instruments used for the conventional method of surveying include the theodolite, chain, tapes, levelling instrument, prismatic compass, plane table and clinometers. Where the area is large, modern methods involving the use of aerial photogrammetry, remote sensing and photointerpretation techniques, geographic positioning system (GPS), geographic information system (GIS), and total stations may be gainfully employed for modelling and precise determination of the topographic features.

**Environmental Impact:**

With a view to assess the effects of highway projects on the environment and the surrounding areas, environmental impact assessment (EIA) has been made mandatory by the government. Environmental impact analysis deals with positive and negative effects of the project and presents cost-effective preventive measures against any possible damage due to soil erosion, submergence due to floods, loss of vegetation, forest cover and wild life ecological balance.

Economic justification needs economic analysis including cost-benefit studies with reference to IRC specification-IRC: SP: 30. Based on these studies, the final location of the selected route is made on paper, before being translated on to the ground in the next stage of location survey.

- **Location Survey**:

This involves the location of the final alignment on the ground and includes pegging the centre-line; establishing bench marks, and determining levels at the pegged stations and at critical points of change in slope.

**Pegging the Centre-Line**:

The centre-line of the final route is marked by establishing pegs on the ground. All angles are accurately measured using a transit theodolite. The recommended spacing of the pegs depends on the nature of the terrain. It is 50 m for plain terrain and 20 m for hilly terrain. The pegs should be fixed in relation to at least three reference marks, so that they may be re-established in case they are disturbed.

**Cross-Sections:**

Cross-sections are taken at 50-100 m intervals on plain terrain, 50 m intervals on rolling terrain and 20 m intervals on hilly terrain.

**Precise Levelling**:

Precise levelling has to be performed and suitable benchmarks, temporary and permanent, have to be established.

The following dates are obtained for the implementation of the project:

- Right of way available along the route.
- Land acquisition costs.
- Date required for geometric design aspects.
- Data for pavement design.
- Cost calculation.
- Construction materials, equipment, and labour.

- **Soil Survey**:

The nature and extent of the soils available in and around the chosen route have to be ascertained. The purpose of soil survey is to identify and classify soil for use in the design and construction of the road.
Information is gathered on the presence of unstable strata or marshy areas, subsoil water level, and demarcation of possible borrow areas along the road in accordance with IRC recommendations.

- **Construction Survey**:

This consists of removing all under-growths such as shrubbery, thickets, tree stumps and rubbish along the route, setting out the centre-line and the right of way by affixing pegs at appropriate intervals, cutting a narrow V- shaped cut called 'Lockspit' in between the pegs along the route and making the necessary preparations for implementation of the project.
The final centre-line and profile can be selected using the Digital Terrain Model (DTM).

- **Engineering Drawings and Implementation of a Highway Project**:

Details of engineering drawings necessary for the implementation of a highway project are set out by IRC in its specification IS: SP: 19-2001.
The salient features of these drawings are given below:

- **Locality Map**:

The location of the area, its existing roads and the alignment of the proposed road along with the important places it would connect are shown in the locality map. The recommended scale for this map is 1:25000.
Site or Index Map:
This shows the general topography of the area. The scale recommended for the map is 1:50000.

- **Land Acquisition Plans and Schedules**:

All relevant information relating to the details such as buildings, adjacent properties, agricultural and other land-use details with the probable land acquisitions costs and schedules are put forth in the land acquisition plans. The scale of these plans can vary from 1:2000 to 1:8000.

- **Plan and Longitudinal Section**:

This should consist of 1 km length of alignment for a single sheet with all relevant details. The recommended scales are 1:2500 (horizontal scale) and 1:250 (vertical scale) for plain and rolling terrain.

- **Cross Sections**:

Cross sections should be given at 50 m intervals indicating cuts and fills, for estimation of earthwork. The recommended scale is 1:00.

- **Cross-Drainage Structures**:

These provide standard designs of causeways, culverts, small bridges and major bridges that are to be included along the proposed route. The recommended scale is 1:50.

- **Road Intersections**:

These are details of intersections of the proposed road with the existing roads and road signs. The recommended scale is 1:500. Drawings of Roadside Amenities, Retaining Structures and Sign Boards: Relevant information regarding roadside amenities and retaining structures should be shown at appropriate places along the proposed route. A suitable scale should be chosen to show the required details clearly.

The following IRC Codes may be referred to for further information on these surveys:

- IRC: SP: 19-2001 for NH, SH and MDR
- IRC: SP: 20-2001 for ODR and RR
- IRC: SP: 13 for minor bridges (span < 6 m)
- IRC: SP: 54 for bridges

## CONVENTIONAL AND MODERN METHODS OF ALIGNMENT

Compared to the traditional method of highway alignment, the modern method of highway alignment by using remote sensing and GIS techniques , reduce time, low man power, less cost and economic

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## Design of railway alignment: conventional and modern method

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## SUSTAINABILITY IN HIGHWAY ENGINEERIG

Thus, "**sustainable**" in the context of pavements refers to system characteristics that encompasses a pavement's ability to: achieve the **engineering** goals for which it was constructed, preserve and (ideally) restore surrounding ecosystems, use financial, human, and environmental resources economically

*F. Kehagia, Int. J. Sus. Dev. Plann. Vol. 4, No. 1 (2009) 61–69*

## THE IMPLEMENTATION OF SUSTAINABILITY IN HIGHWAY PROJECTS

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ABSTRACT
Today, the implementation of the notion of sustainability in highway construction is an imperative need since economic and social development simultaneously with the environmental protection is worldwide accepted. Well-planned highway projects add to the quality of life. The main question is how to provide innovative and high serviceability roads all by preserving the environment. In this paper, the practical and conceptual aspects of sustainable highway are presented. Additionally, it is pointed out how traditional highway construction process can be improved by incorporating the basic guidelines of sustainable development.
*Keywords: construction, design, environment, highway, sustainable development.*

## IMPORTANCE OF HIGHWAY ENGINEERING

## POLICY STATEMENT 418 - THE ROLE OF THE CIVIL ENGINEER IN SUSTAINABLE DEVELOPMENT POLICY

The American Society of Civil Engineers (ASCE) defines sustainability as a set of economic, environmental and social conditions (aka "The Triple Bottom Line") in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality or the availability of economic, environmental and social resources. Sustainable development is the application of these resources to enhance the safety, welfare, and quality of life for all of society.

Civil engineers shall be committed to the following ASCE Principles of Sustainable Development:

- Principle 1- Do the Right Project. A proposed project's economic, environmental and social effects on each of the communities served and affected must be assessed and understood by all stakeholders before there is a decision to proceed with a project. Consider non-structural as well as structural (built) solutions to the needs being addressed; and

- Principle 2 - Do the Project Right. The civil engineer shall actively engage stakeholders and secure public understanding and acceptance of a projects economic, environmental and social costs and benefits. To move toward conditions of sustainability, engineers must design and deliver projects that address sustainability holistically (from concept to demolition or reuse) rather than adding a variety of "green" features onto a conventional project.

ASCE supports the following steps to achieve a sustainable project:

- Perform Life Cycle Assessment from Planning to Reuse. Project participants should use rigorous life cycle methodologies that quantify the economic, environmental and social effects of the project;

- Use Resources Wisely. Minimize Use of Non Renewable Resources. Sustainable development shall include progressive reductions in resource use for a given level of service and resiliency. The feasibility of restoration, or return of depleted resources, shall be evaluated by the civil engineer;

- Plan for Resiliency. Sustainability requires planning for the impact natural and man-made disasters and changing conditions can have on economic, environmental, and social resources; and

- Validate Application of Principles. Civil engineers must guide project development and validate the application of these principles by using metrics and rating tools such as the EnvisionTM Rating System for sustainable infrastructure.

**ISSUE**

ASCE recognizes the leadership role of engineers in sustainable development, and their responsibility to provide effective and innovative solutions in addressing the challenges of sustainability. The ASCE Code of Ethics states that "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties." ASCE works on a global scale to promote public recognition and understanding of the needs and opportunities for sustainable development and contribute to health communities. Environmental, economic, social and technological development must be seen as interdependent and complementary concepts, where economic competitiveness and ecological sustainability are complementary aspects of the common goal of improving the quality of life.

**RATIONALE**

Civil engineers have a leading role in planning, designing, building, and ensuring a sustainable future by providing the bridge between science and society. In this role, engineers must actively promote and participate in multidisciplinary teams with other professionals, such as ecologists, economists, and sociologists, and work with the communities served and affected to effectively address the issues and challenges of sustainable development.

What is importance of highway?

The highways enabled the fast and safe delivery of food. Having food allowed the population of our urban areas to grow. What do we call our system of roads andhighways?

What is the scope of highway engineering?

In nutshell,it may be said that the highway engineering deals with various phase like development,planning,alignment,highway geometric design and location, highwaytraffic operation and its control,materials,pavement design,construction and maintenance,economic considerations,finance and administration

## SUSTAINABILITY IN HIGHWAY ENGINEERING

Sustainability and Its Importance In Pavement Engineering

### Background

An ever-growing number of agencies, companies, organizations, institutes, and governing bodies are embracing principles of sustainability in managing their activities and conducting business. This approach focuses on the overarching goal of emphasizing key environmental, social, and economic factors in the decision-making process. In many ways, sustainability considerations are not new, since they were often considered indirectly or informally in the past, but recent years have seen increased efforts to quantify their effects and to incorporate them in a more systematic and organized fashion.

There are many reasons for this emphasis on applying sustainability, among which are a growing recognition of how human activity affects the environment (e.g., climate change, ecosystem changes, non-renewable resource depletion) and a better appreciation for considering key societal factors (e.g., land use, access, aesthetics) and economic considerations (net benefits, life-cycle costs) in decision making. Thus, a focus on sustainability reflects a commitment to address the entirety of impacts associated with human existence, not only in monetary terms but also in terms of environmental and social impacts. For example, greenhouse gas (GHG) emissions, a commonly used surrogate for assessing environmental sustainability, are known to trap heat in the atmosphere and contribute to climate change. The burning of fossil fuels (in manufacturing, electricity production, and transportation) is the largest contributor of GHG emissions, the most prevalent of which is carbon dioxide (CO2). According to the Environmental Protection Administration (EPA 2013), and using 2011 data as the basis, the transportation industry (including cars, trucks, aircraft, rail, ships, and pipelines) accounts for over 27 percent of all human-caused GHG emissions in the U.S. (see figure 1); this is second only to the amount of GHG emissions attributed to the electric power industry. In addition, the construction of transportation facilities also contributes to GHG emissions, which are represented as part of the industry section. As a result, any significant reductions in GHG emissions made in the transportation sector will have an effect on the total amount of GHG emissions in the U.S.

## What is Sustainability?

Most definitions of sustainability begin with that issued by the World Commission on Environment and Development (WCED), often referred to as the Brundtland Commission Report (WCED 1987):

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

This definition is focused on the concept of "needs" and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. In a shorter version of this, sustainability is often described as being made up of the three components of environmental, social, and economic needs, collectively referred to as the "triple-bottom line."

For many years, the economic component has been the dominant decision factor, but more recent years have seen the growing emergence of both the environmental and social components (even though there are some current limitations associated with their measurement and assessment). A focus on sustainability can then be interpreted in such a way that all triple-bottom line components are considered important, but the relative importance of these factors (and how each are considered) are case sensitive, very much driven by the goals, demands, characteristics, and constraints of a given project. Thus, "sustainable" in the context of pavements refers to system characteristics that encompass a pavement's ability to:

- Achieve the engineering goals for which it was constructed,
- Preserve and (ideally) restore surrounding ecosystems,
- Use financial, human, and environmental resources economically, and
- Meet basic human needs such as health, safety, equity, employment, comfort, and happiness.

A "sustainable pavement" is, at present, an aspiration goal. That is, it is unlikely any pavement system based on current knowledge and technology could satisfy all or even most of the characteristics in the previous sustainability definition. However, continual improvement with an emphasis on each of these characteristics leads to more sustainable pavements, and, ultimately, to pavements that actually meet the rather demanding standards of sustainability. Progress towards sustainability may at first mean reducing bad outcomes (e.g., less pollution, reduced extraction of non-renewable resources, less waste). Further progress would transition to achieving a pavement system that is essentially a neutral player in the larger and surrounding systems (i.e., it does no harm). Importantly, however, progress should continue so that the pavements could ultimately produce positive outcomes (e.g., pavements that produce more energy than they consume, construction that restores more land than it uses). Current efforts at reducing the impact or amount of bad outcomes and improving efficiency should be viewed as good transitional strategies on the long path towards the ultimate goal of producing only positive outcomes. This interpretation of sustainability is substantially different, and ultimately more positive, than one limited to reducing negative outcomes.

Improving sustainability can be achieved through the adoption of "sustainable best practices"; these are practices that work to either (1) go above and beyond required regulatory minimums or standard practice, or (2) show innovation in meeting these minimums and standards. Because a pavement must exist and function within larger systems, practices that support sustainability must contribute to more sustainable systems and thus depend on context. As a result, a full accounting of surrounding systems and a pavement's influence on them is necessary in order to define the most appropriate sustainability practices associated with a particular pavement system.

**Importance of Sustainability in Pavement Engineering**

The nation's roadway system is one part of a transportation network that provides mobility and access to a range of users. The roadway network is not only important to the nation's overall economic vitality by providing for the movement of freight and commodities, but it also provides societal benefits as well (e.g., access to schools, services, and work; leisure travel; and general mobility). Pavements are an integral part of this roadway network. Pavements provide a smooth and durable all-weather traveling surface that benefits a range of vehicles (cars, trucks, buses, bicycles) and users (commuters, commercial motor carriers, delivery and service providers, local users, leisure travelers). Given their key role and widespread use, there is a unique opportunity to improve the sustainability of pavement structures with the potential to deliver tremendous environmental, social, and economic benefits. With regard to those components, listed below are just a few examples of how pavements can impact sustainability:

- Environmental component: energy consumption; GHG emissions; noise; air quality; storm water treatment.
- Social component: safety (fatalities, injuries, property damage); smoothness; vehicle operating costs; GHG emissions; access, mobility; aesthetics.
- Economic: construction, maintenance, and rehabilitation costs; vehicle operating costs; crash costs.

Moreover, the current timing is such that transportation agencies and the general public alike are demanding increased consideration of sustainability principles and practices. This evolution in the role that transportation plays in society is well summarized as follows (AASHTO 2009):

Transportation's mission is no longer about just moving people and goods. It's much broader. Transportation fundamentally allows us to achieve economic, social, and environmental sustainability. Transportation supports and enhances our quality of life. As state transportation professionals, we need to model the way toward achieving a sustainable future...Sustainable transportation requires innovative approaches and partnerships like never before.

Transportation and highway agencies are already making advancements to improve and enhance overall sustainability. Recent years have seen significant strides being made to better align current practices and technologies with more long-term sustainable strategies. In fact, the pavement engineering community has adopted a number of technologies as a way of improving sustainability, such as the increased use of recycled materials in pavement structures, the incorporation of modified binders to increase pavement performance, and the development of rating systems to measure sustainability. At the same time, there is considerable research being conducted on energy use, GHG emissions, and other impacts associated with pavement materials and construction activities to support the development of life-cycle assessment tools.

Nevertheless, there are no universal characteristics or design features that describe a sustainable pavement. Although a general sustainability framework for pavement can be defined, it is context sensitive in that each situation is unique, with specific needs depending on the location, climate, available materials, facility type, required level of service, and so on, as well as on the overall goals of the organization. Furthermore, it is important to recognize that, in some cases, it may even be counterproductive to try to introduce certain features that are thought to be sustainable without a complete assessment; for example, trucking in recycled materials from a great distance when an acceptable local aggregate is readily available could actually have negative environmental consequences

**Pedestrians and cyclists, to ensure mobility**.

Adding to Chennai's traffic woes is its management. Little has been done on the part of officials to manage traffic bottlenecks. Devasahayam says traffic policing should be professional and competent to deal with the peak hour rush. The urban planning expert also observes that the city's poor integrated transport system is another factor leading to an increase in vehicular traffic. He says, "Despite Chennai having a four-direction train system, there is no connectivity either with the sub-urban train, the MRTS or the metro." He also hits out at successive state governments for not implementing the Second Master Plan 2026, despite the issue of integrated transport being highlighted.

"What Chennai needs is soft solutions, not hard solutions," opines Devasahayam, who argues that the city does not need the metro or more flyovers. He concludes that more infrastructure is not always the solution but utilising what's already there is key for putting an end to Chennai's nightmarish traffic.

Chennai: 1985 and Today

Chennai, the birthplace of the Indian railway system, was also home to the nation's first electric trams, in 1895. Unfortunately, politicians chose to end the service in the early 1950s, with the idea of building "modern" roads and bridges for cars. By 1985, Chennai, then known as Madras, had seen its car and motorcycle populations accelerate to more than

200,000. It would rise to 600,000 by 1992, 3.6 million in 2012, and is nearly six million today. Combined with an emphasis on building roads and elevated highways, the city quickly began to see air quality worsen, and travel times grow, as the city lacks sufficient public transport options.

## CHENNAI BEFORE

The capital of the state of Tamil Nadu, Chennai is a city of ten million, located on the Bay of Bengal in South India. Chennai is a tech hub, and home to Tamil Cinema Studios, as well much of India's automotive industry. Chennai is also a city at the forefront of climate change, with increased floods that cost lives and city damage. Fortunately, Chennai is beginning to move in the right direction, with an emphasis on improved transport management, and a budget commitment to redesign streets to prioritize cycling and walking.

In 2015, Chennai began a redesign of kilometers of pedestrian paths and today has completed 100 kilometers, and began Car free Sundays. In the same year, Chennai opened a metro line, which now has grown to a daily ridership around 120,000. In 2019, Chennai opened a pedestrian plaza on a busy shopping street and has launched a bike share system with facilities close to other transit stations. These actions are important steps in creating a safer, more welcoming pedestrian and cycling environment, but are still not enough to transform the city away from cars. The vast majority of Chennaties travel by walking, two wheeled vehicles, or buses. The question is if Chennai can continue to create space on its streets for these users, rather than creating more and more space for cars.

## CHENNAI TODAY


**FIG.8 PEDESTRIAN VOLUME IN CHENNAI**

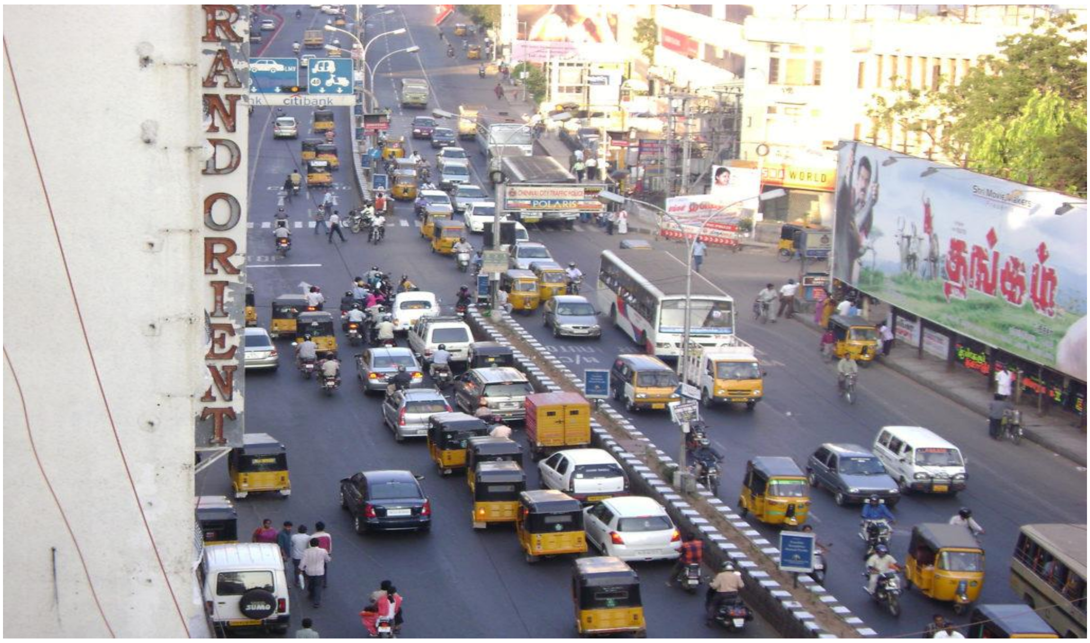



**FIG.9 FLOW VOLUME IN CHENNAI**

## Chennai in Numbers

To measure and study cities' growth objectively, metrics were employed looking at population, density, transit. Kilometers of rapid transit is defined as rapid transit that meets the definition of BRT basics in the BRT Standard, in Chennai kilometers of rapid transit grew from 54.1 in 1985 to 101.8 in 2018. While the kilometers doubled, so too did the population and built up area, meaning that service remained relatively the same. To study how a population is served by rapid transit, the Rapid Transit to Resident Ratio (RTR)compares the population with the length of rapid transit lines – this number shows how well a population is served by rapid transit. Unfortunately for Chennai residents, RTR has remained relatively unchanged in the past 35 years

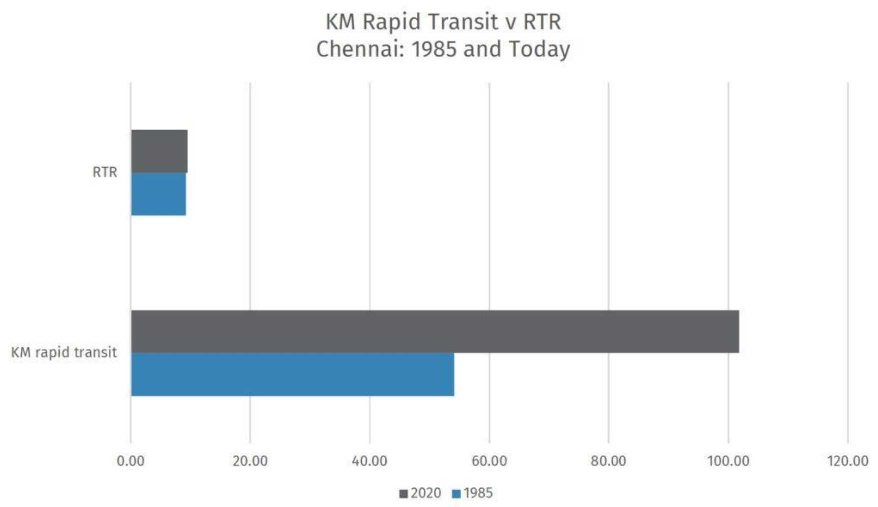



**FIG.10 GROWTH OF VOLUME IN CHENNAI**

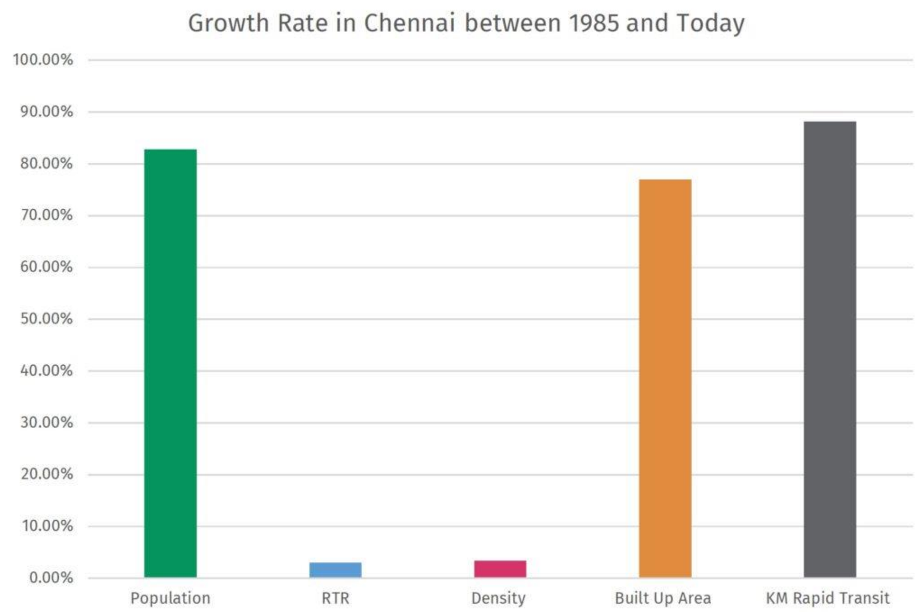



**FIG.11 GROWTH RATE OF VOLUME IN CHENNAI**

**THE SLOWEST ROADS IN URBAN AREAS OF INDIA**

Among the country's six metros, Kolkata and Mumbai have the slowest arterial roads, while Hyderabad and Chennai have the fastest ones

**New Delhi:** An unintended consequence of economic growth in cities is traffic congestion. Everyday, millions of vehicles across Indian cities are stuck in gridlock, but some cities seem to be more affected than others.

A Mint analysis of about 300 arterial roads across the country's six largest metropolitan regions (New Delhi, Mumbai, Kolkata, Chennai, Hyderabad and Bengaluru) shows that on an average, the slowest arterial roads are in Kolkata and Mumbai, while Hyderabad and Chennai have roads with the highest average speeds.

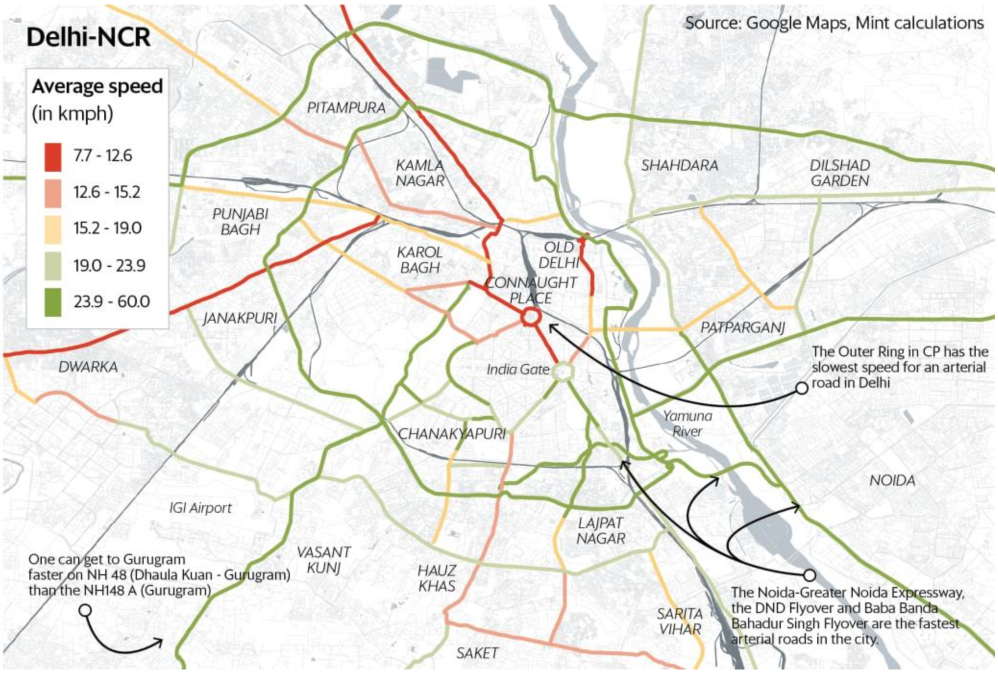



**FIG.12 ROAD NETWORK IN DELHI**

A 10km commute in Hyderabad takes 26 minutes on average. In Chennai and Delhi, it takes 29 minutes while the same distance takes 34 minutes in Bengaluru, 37 in Mumbai and 39 minutes in Kolkata. The average 10km urban commute takes 24 minutes, according to a World Bank study that calculated commute times across 154 Indian cities. In Singapore and London, the 10km commute takes an average of 21 minutes, show official documents.

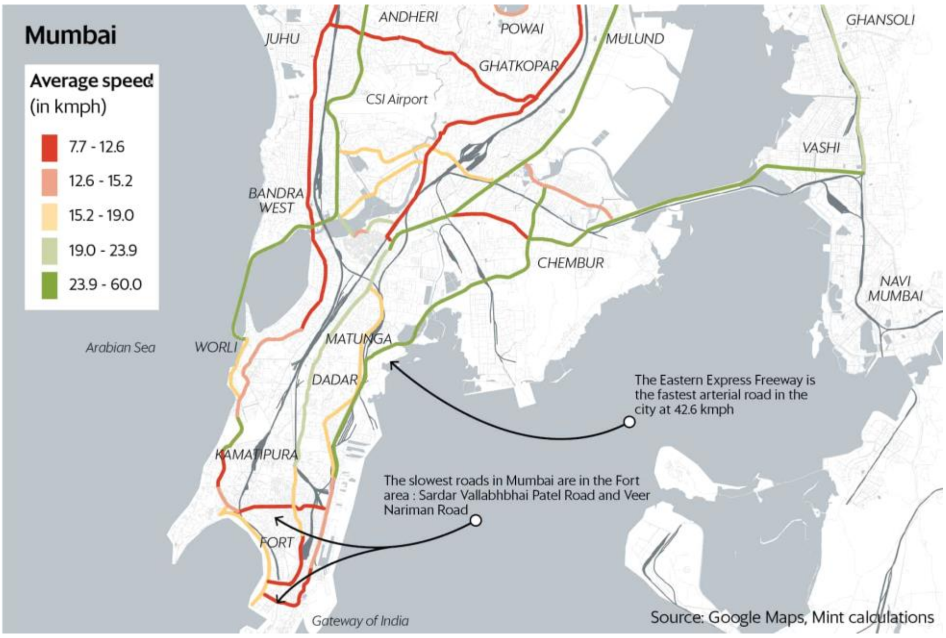



**FIG.13 ROAD NETWORK IN MUMBAI**

In India, official data on traffic and road speeds is often unavailable, and outdated when it is available. For this analysis, we identified arterial roads by referring to the Comprehensive Mobility Plan reports for these cities prepared by the respective municipal corporations and state governments. Using Google Maps data, we collected data on how long it would take to traverse these roads from end to end at hourly intervals from 4 August to 11 August this year. This weekly period represents a typical non-rainy week, and the average speeds in this week matched the “typical speed" ranges provided by Google Maps.

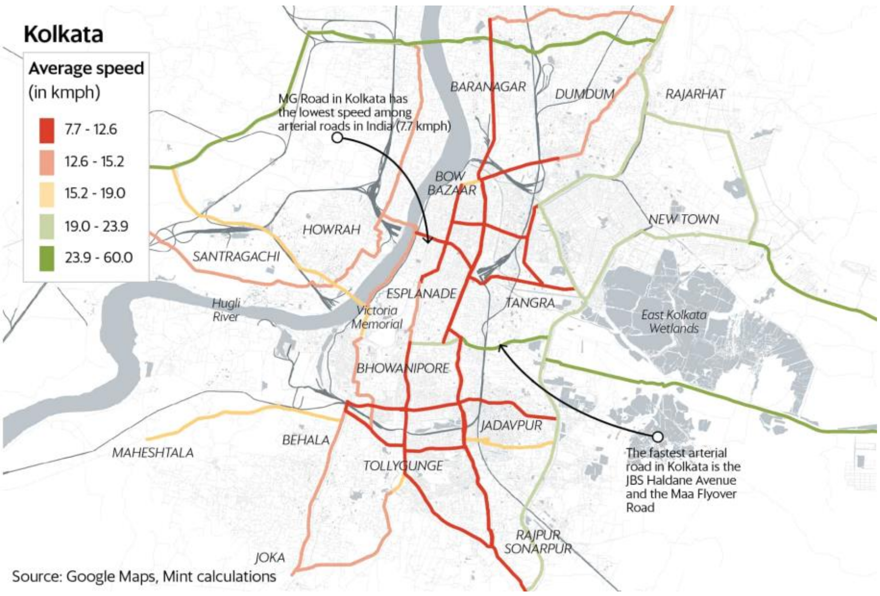


**FIG.11 ROAD NETWORK IN KOLKATTA**

The analysis suggests that morning commutes (8am -11am) are slightly faster than evening commutes (5pm-8pm). A 10km commute would take six minutes longer in the evenings on average, across all these cities.

Mahatma Gandhi Road in Kolkata (7.7km per hour) has the dubious distinction of being the slowest road considered in this analysis, followed by Sardar Vallabhbhai Patel Road in Mumbai (8.1 kmph) and the Kanakapura Road stretch from JP Nagar to Outer Ring Road (8.4 kmph) in Bengaluru.


**FIG.12 ROAD NETWORK IN CHENNAI**

Kolkata has 11 of the slowest 20 roads across these cities, followed by six in Mumbai and three in Bengaluru.

Most of these roads are in the colonial-era neighbourhoods of these cities and are constrained by the fact that widening them is expensive. In Mumbai, the geography of the city itself is a constraint. A city with a narrow strip of densely populated land jutting out into the sea makes it more difficult to ease traffic pains.

The fastest arterial metro road in India is the Outer Ring Road in Hyderabad, where the average speed is 60 kmph. The much-maligned Noida-Greater Noida Expressway is a distant second at 52.7 kmph, followed by the Chennai Outer Ring Road at 48.5 kmph.

Eight out of the top 10 fastest arterial roads are access controlled (toll roads), which helps limit congestion and improve speeds. While this seems to work, it is not a sustainable solution. Expressways—even access controlled—can eventually fill up, as the demand for private vehicles rise when more and wider roads are built, suggests urban transportation research.

The most effective way to improve road speeds and reduce congestion is congestion pricing on key roads during rush hours, suggests research. Another solution is to build segregated bus lanes and encourage people to shift to public transportation modes. These solutions are yet to find support in India.

**Advantages and Limitations of Forecasting**

We know that planning is an important process in the management of any enterprise. It is the cornerstone of effective management. Forecasting is actually an integral part of the planning process. They both go hand in hand. Let us learn the meaning and advantages and limitations of forecasting

**What is Forecasting?**

Forecasting is essentially a process of analyzing the past and present business movements and trends to obtain some idea or clues regarding future trends and business movements. Forecasting is looking into the future so that we can accordingly plan for it.

However, forecasting is not a haywire process. It is a systematic approach with well thought-out, scientific methods and procedures. It involves a thorough and proper analysis of data and facts with the help of both quantitative and qualitative techniques

**Advantages of Forecasting**

- Assists in Planning

One of the biggest advantages of forecasting is that it enables the manager to plan for the future of the organization. Planning and forecasting actually go hand in hand. Without an idea of what the future hols for the company, we cannot plan for it. Thus, forecasting plays a very important role in planning.

- Environmental Changes

When done correctly, forecasts should be able to point out the upcoming changes in the environment. This means that it can allow the company to benefit from such environmental changes. When the changes are favorable to the company it can expand and grow its business. And in conditions that are adverse, it can plan and prepare to protect itself.

- Identifying Weak Spots

Another advantage of forecasting is that it will help the manager identify any weak spots, or ignored areas that the organization may have. Once attention has been drawn to these areas, the manager can put into effect effective controls and planning techniques to rectify them.

- Improves Co-ordination and Control

Forecasting requires information and data from a lot of external and internal sources. This information is collected by the various managers and staff from various internal sources. So almost all units and verticals of the organization are involved in the process of forecasting. This allows for better communication and coordination amongst them.

**Limitations of Forecasting**

Along with the benefits, there are also some limitations of forecasting. Let us take a look at a few of them,

- Just Estimates

The future will always be uncertain. Even if use the best of forecasting techniques and account for every aspect imaginable, a forecast is still just an estimate. One can never predict future events with 100% success. So even the best-laid plans may amount to nothing. This will always remain one of the biggest limitations of forecasting.

- Based on Assumptions

The basis of any forecasting method is assumptions, approximations, normal conditions, etc. This makes these forecasts unreliable. So one must always keep in mind the inherent limitations of forecasting and be cautious in being over-reliant on them.

- Time and Cost Factors

The data and information required to make formal forecasts are generally a lot. And the collection and tabulation of such data involve a lot of time and money. The conversion of qualitative data into quantitative data is also another factor. One must be careful that the time, money and effort spent forecasting must not outweigh the actual benefits from such forecasts.

**Question on Limitations of Forecasting**

Q: A forecast involves no guesswork at all. True or False?

Ans: The statement is False. While a forecast is done with meticulous scientific process and application of methods, it does involve some guesswork on the part of the manager

**URBANTRAFFIC PROBLEMS IN INDIA**

Cities are locations having a high level of accumulation and concentration of economic activities and are complex spatial structures that are supported by transport systems. The larger the city, the greater its complexity and the potential for disruptions, particularly when this complexity is not effectively managed.

Among the most notable urban transport problems are:

- Congestion and parking
- Longer commute
- Inadequate public modes
- Difficult in non motorized vehicles
- Minimum public space
- High maintenance cost

Among the most notable urban transport problems are:

- Environmental impact and energy consumption
- Accident and safety
- Land consumption fright distribution
- Dependent on automobile

- On par with congestion people are spending an increasing amount of time commuting between their residence and workplace
- Public Transport Inadequacy
- During peak hours, crowdedness creates discomfort for users as the system copes with a temporary surge in demand.
- Difficulties for non-motorized transport

These difficulties are either the outcome of intense traffic, where the mobility of pedestrians, bicycles and vehicles is impaired

Environmental impacts and energy consumption

- Pollution, including noise, impediment to the quality of life and the health of urban populations.
- Energy consumption by urban transportation has increased and so the dependency on petroleum.
- public transit will bring down this issue.

Accidents and safety

- Growing traffic in urban areas is linked with a growing number of accidents and fatalities, in developing countries.
- Accidents account for a significant share of recurring delays.
- As traffic increases, people feel less safe to use the streets.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

# UNIT – II – GEOMETRIC DESIGN ELEMENTS - SCIA1304

## INTRODUCTION

# GEOMETRIC DESIGN OF ROAD

Geometric design for transportation facilities includes the design of geometric cross sections, horizontal alignment, vertical alignment, intersections, and various design details. The **geometric design of roads** is the branch of highway engineering concerned with the positioning of the physical elements of the roadway according to standards and constraints.

The **basic objectives** in geometric design are to optimize efficiency and safety while minimizing cost and environmental damage.

***Definition of Geometric Design*** - Geometric design of highways deals with the dimensions and layout of visible features of the highway. It fulfills the requirements of the driver and the vehicle, such as comfort, efficiency and safety. The proper geometric design will help in the reduction of accidents and their severity

***Goals of Geometric design***

- Minimize the environmental impacts.
- Provide maximum safety at reasonable cost.
- Provide efficiency in traffic operation.
- Maximize the comfort, safety and economy of facilities.
- Goals of geometric design

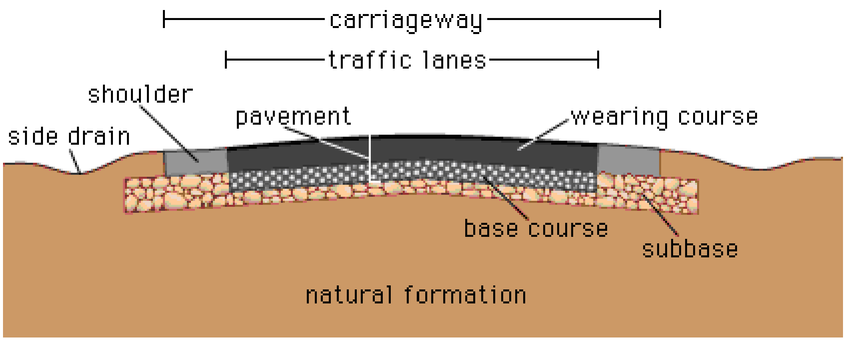



**FIG.1 CROSS SECTION OF A ROAD (a)**

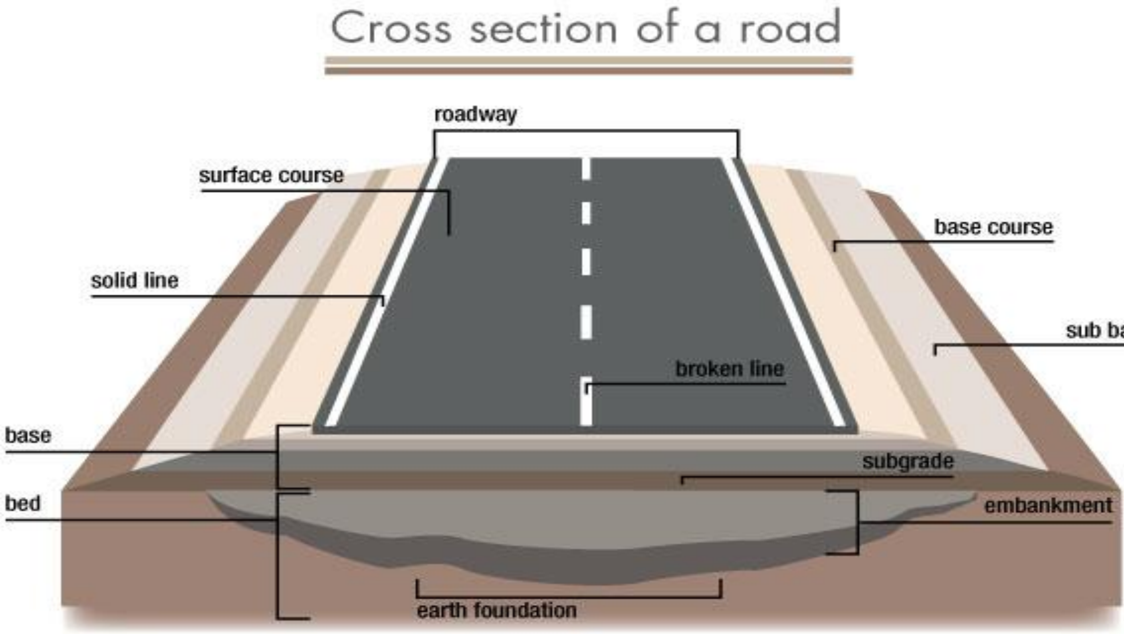



**FIG.2 CROSS SECTION OF A ROAD (b)**

# FACTORS INFLUENCING GEOMETRIC DESIGN

- **Design speed -** Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.
- **Topography -** It is easier to construct roads with required standards for a plain terrain. However, for a given design speed, the construction cost increases multi form with the gradient and the terrain.
- **Traffic factors -** It is of crucial importance in highway design, is the traffic data both current and future estimates. Traffic volume indicates the level of services (LOS) for which the highway is being planned and directly affects the geometric features such as width, alignment, grades etc., without traffic data it is very difficult to design any highway
- **Design Hourly Volume and Capacity -** The general unit for measuring traffic on highway is the Annual Average Daily Traffic volume, abbreviated as AADT. The traffic flow (or) volume keeps fluctuating with time, from a low value during off peak hours to the highest value during the peak hour. It will be uneconomical to design the roadway facilities for the peak traffic flow.

- **Environmental and other factors -** The environmental factors like air pollution, noise pollution, landscaping, aesthetics and other global conditions should be given due considerations in the geometric design of roads.

## CROSS SECTIONAL ELEMENTS OF URBAN AND RURAL ROADS

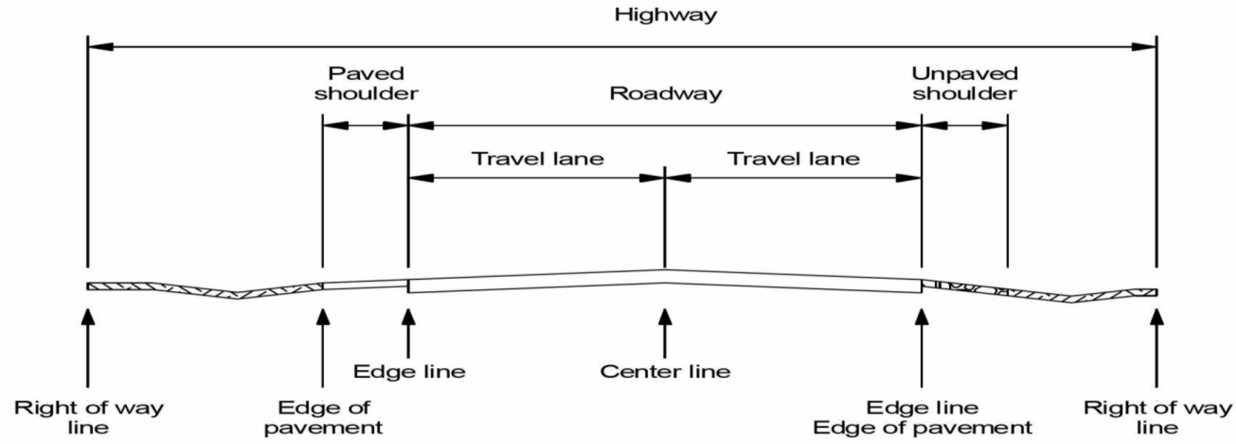



**FIG.3 CROSS SECTION ELEMENTS OF A ROAD**

### 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.

**TABLE 1 ROAD GEOMENTRY**

| **Road classification** | **Roadway width (m)** | |
|---|---|---|
| | **Plain and Rolling Terrain** | **Hilly Terrain** |
| **Rural Area** | | |
| NH/SH | 45 | 24 |
| MDR | 25 | 18 |
| ODR | 15 | 15 |
| VR | 12 | 9 |

| Urban Area | | |
|---|---|---|
| NH/SH | 30 | 20 |
| MDR | 20 | 15 |
| ODR | 15 | 12 |
| VR | 10 | 9 |

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.

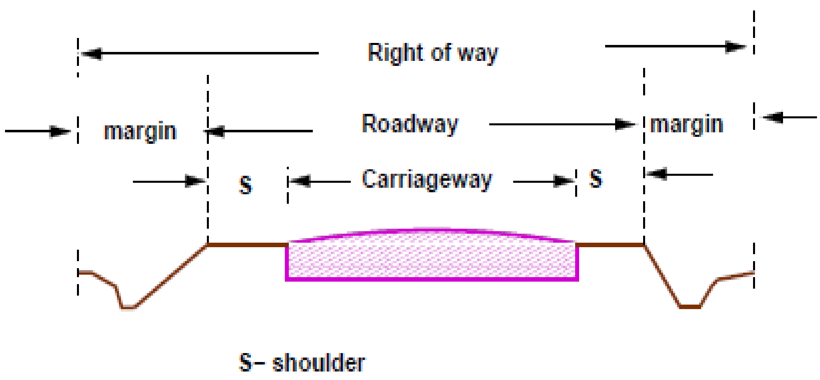



**FIG.4 CROSS SECTION ELEMENTS OF A ROAD**

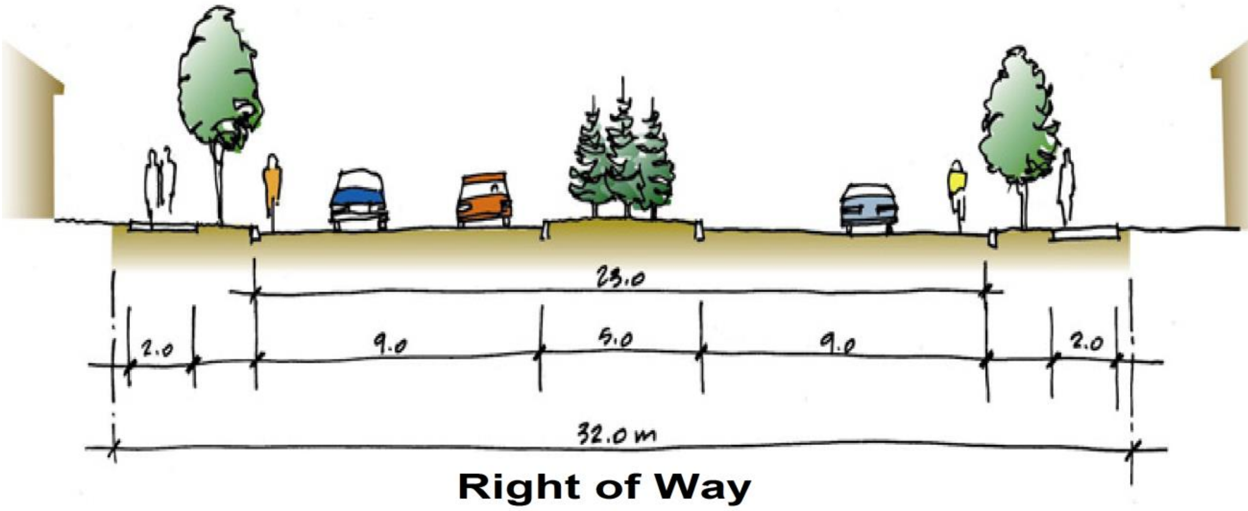



**FIG.5 CROSS SECTION ELEMENTS OF URBAN ROAD**

**Carriage Way –**

It is a portion of road which is paved to carry traffic flows. The width of the traffic lane governs the safety and convenience of traffic and has profound influence on the capacity of the road.

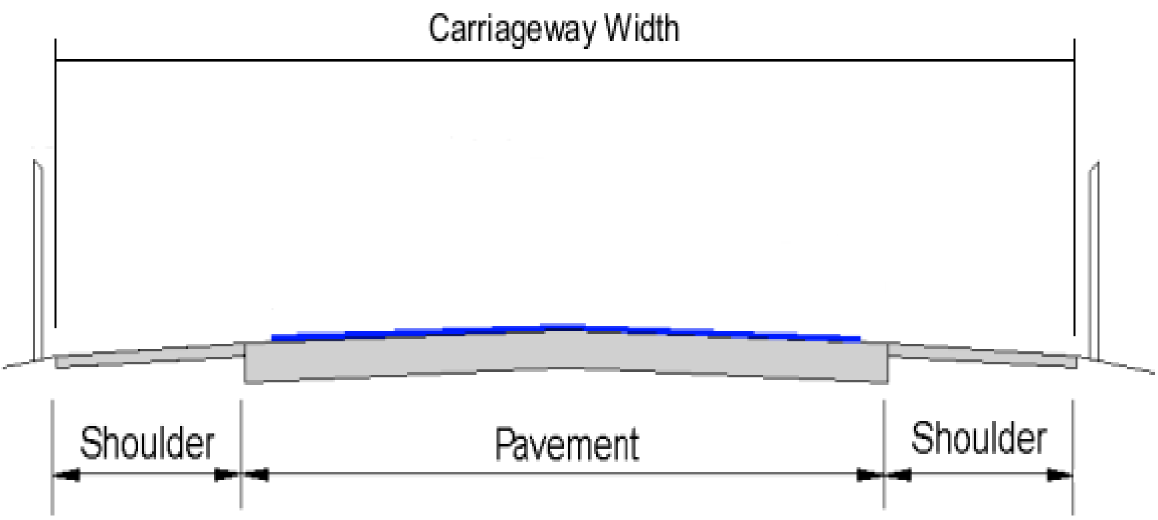



**FIG.6 ELEMENTS OF CARRIAGEWAY**

As per IRC standards the carriage way width are in to various category based on lane

**TABLE 2 WIDTH OF CARRIAGEWAY**

| Sl. No. | Class of Road | Width of Carriage way |
|---|---|---|
| 1 | Single Lane | 3.75 m |
| 2 | Two lanes, Without Raised Kerbs | 7.0 m |
| 3 | Two lanes, With Raised Kerbs | 7.5 m |
| 4 | Intermediate carriageway | 5.5 m |
| 5 | Multi lane pavements | 3.5 m Per Lane |

**Formation Width** –

The total width of embankment in filling is called formation, it includes carriage & shoulder. Formation or road width is the top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

**TABLE 3 WIDTH OF FORMATION OF VARIOUS ROADS**

| **Road classification** | **Roadway width (m)** | |
|---|---|---|
| | **Plain and Rolling Terrain** | **Hilly Terrain** |
| NH/SH | 12 | 6.50-8.80 |
| MDR | 9.0 | 4.80 |
| ODR | 7.50-9.00 | 4.80 |
| VR | 7.50 | 4.00 |

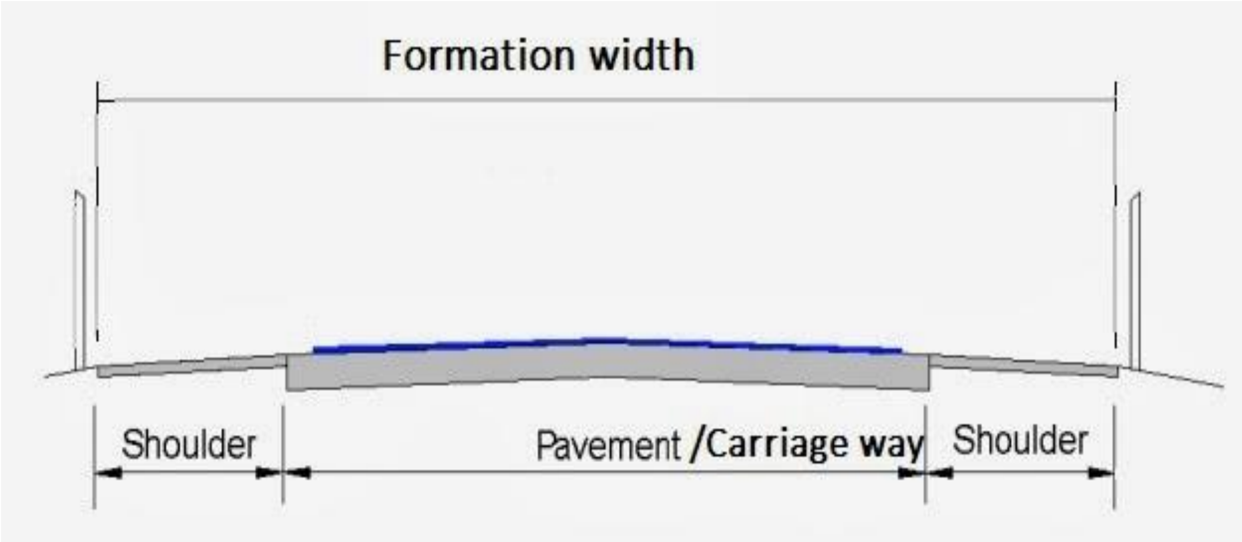



**FIG.7 FORMATION COMPONENTS**


**FIG. 8 FORMATION WIDTH**

**Median** –

A central reservation or a median is the longitudinal space separating dual carriageways. The main function of medians is

- To separate the opposing streams of traffic
- To minimize head light glare
- To include space for safe operation of crossing and turning the roads at intersection.


**FIG. 9 MEDIAN ON ROAD**

**Camber** –

***Camber is*** also known as cross slope, facilitates drainage of the pavement laterally, the pavement can have a crown or a high point in the middle width slopes downwards towards both edges. Camber is depends on, width of road, Amount of rainfall and type of pavement.

There are three types of Camber

- Curved camber
- Straight camber
- Combined camber

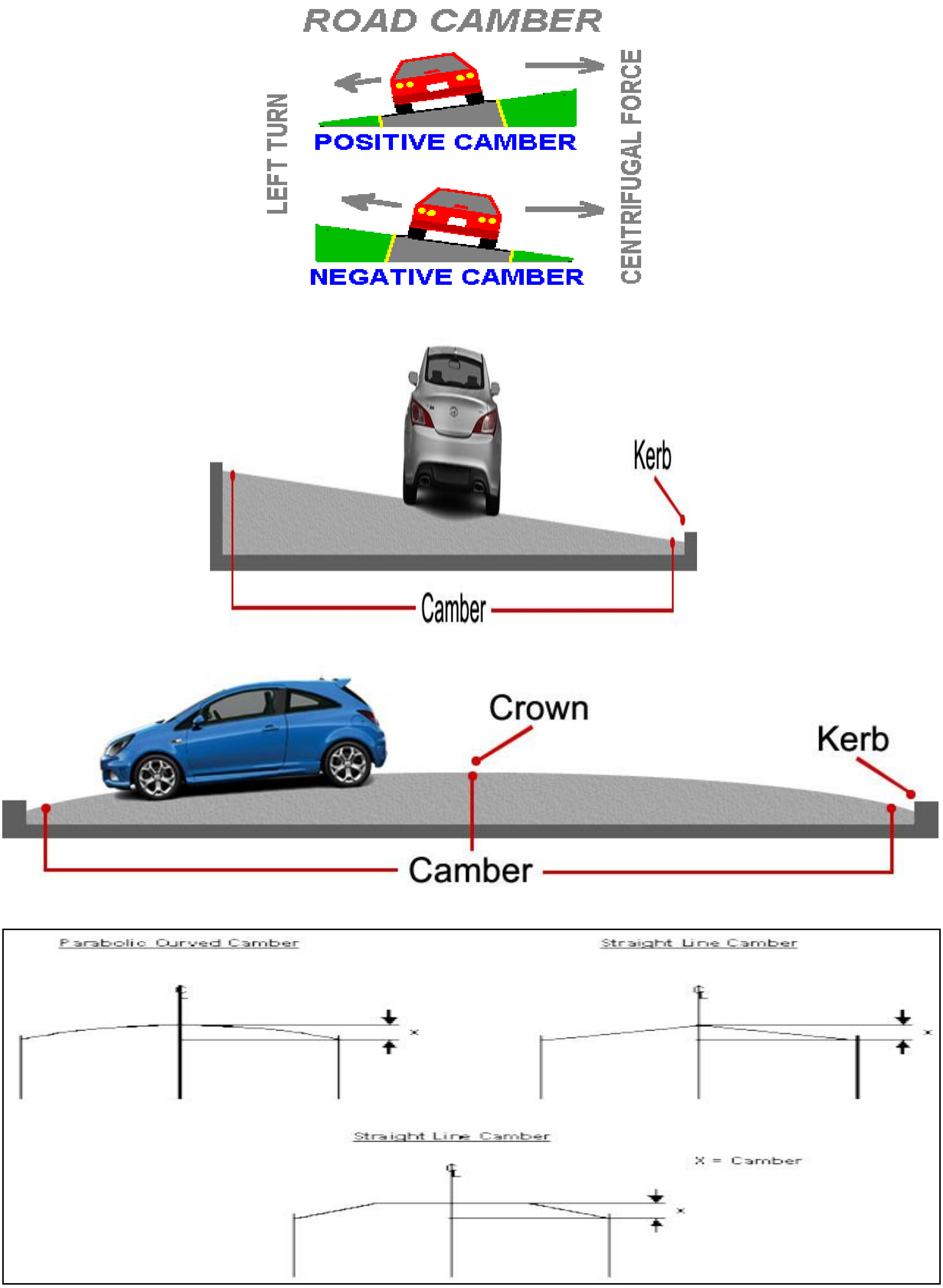



**FIG. 10 CAMBER AND ITS TYPES**

***Curbs/Kerbs*** - A curb is a vertical or slopping portion member along the edge of a pavement or shoulder forming part of a gutter, strengthening or protecting the edge and clearly defining the edge to vehicle operators. The types of Kerbs are given below:

- ***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.

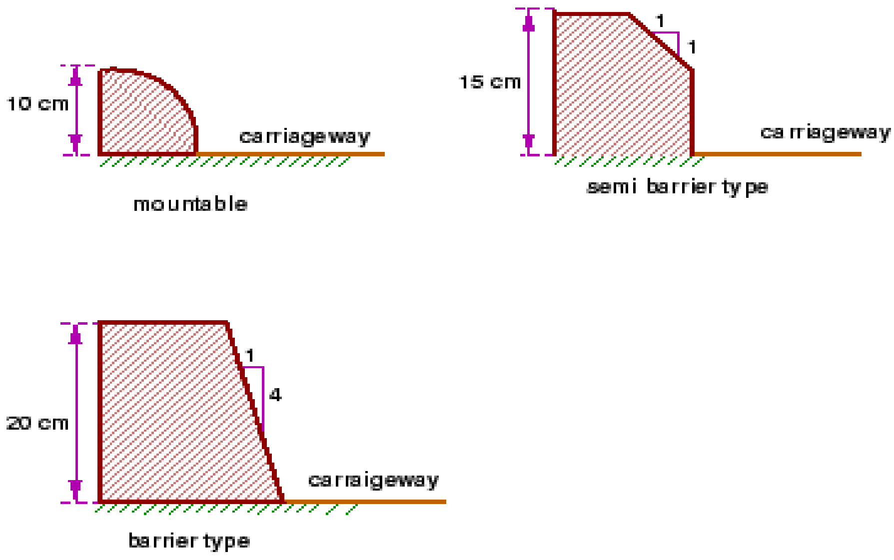



**FIG. 11 TYPES OF KERBS**


**FIG. 12 KERBS WITH AND WITHOUT DRAIN**

**Road Margins** –

The portion of the road beyond the carriageway and on the roadway can be generally called road margin. Various elements that form the road margins are given below.

**Shoulders** –

Shoulders are provided along the road edge and is 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.


**FIG. 12 SHOULDERS ON ROAD**

*Parking lanes* –

Parking lanes are provided in urban lanes for side parking. Parallel parking is preferred because it is safe for the vehicles moving in the road. The parking lane should have a minimum of 3.0 m width in the case of parallel parking. If the right of way is wide, next to the carriageway, parking lanes are provided. Parking lanes are provided based on the types of roads.

There are 3 types of parking

- Angular Parking - 60°, 45° and 30°
- Perpendicular Parking - 5.5 m x 2.5 m
- Parallel Parking - 3m wide

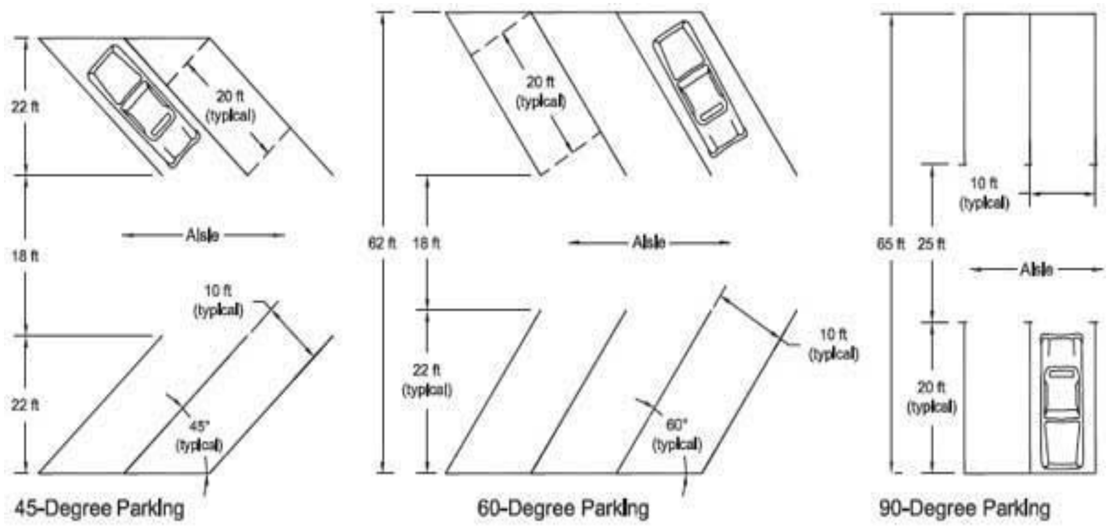



**FIG. 13 TYPES OF PARKING OF VEHICLES**

**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.


**FIG. 14 BUS BAY ON ROAD**

**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.

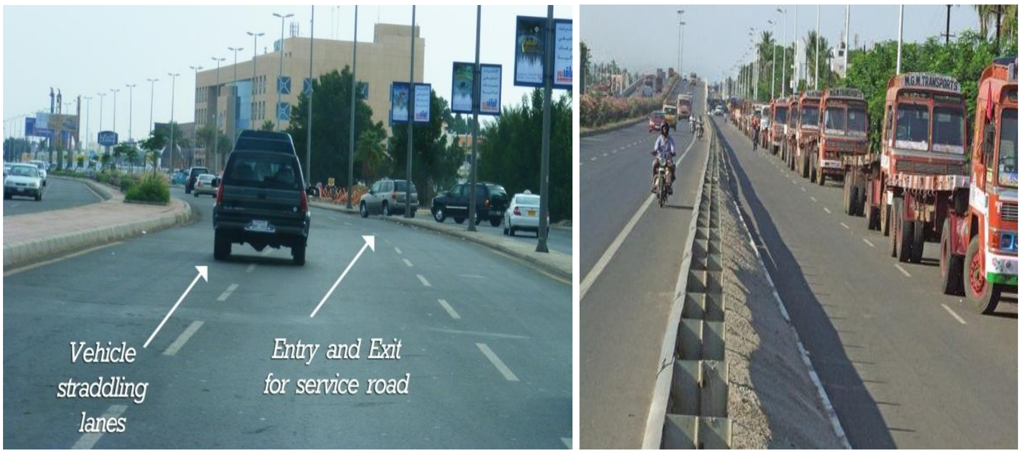



**FIG. 15 SERVICE ROAD**

**Cycle track** –

Cycle tracks are provided in urban areas when the volume of cycle traffic is high Minimum width of 2 meter is required, which may be increased by 1 meter for every additional track.


**FIG. 16 CYCLE TRACK ON ROAD**

**Foot path** –

It is the area provided for walking. In urban areas if pedestrian's traffic crosses over 400 persons per hour, footpath is recommended. They are exclusive right of way to pedestrians. 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, generally width of the footpath is considered as 2 m. The footpath should be either as smooth as the pavement or smoother than that to induce the pedestrian to use the footpath.


**FIG. 17 FOOT PATH ON ROAD**

**Guard Rail** –

If the embankment is more than 3m, guardrail should be provided on edges of the carriageway. Normally guided rails will be in steel, but in some cases it will be provide in cement concrete. They are provided at the edge of the shoulder usually when the road is on an embankment. They serve to prevent the vehicles from running off the embankment, especially when the height of the fill exceeds 3 m. Guard stones painted in alternate black and white are usually used. They also give better visibility of curves at night under headlights of vehicles.


**FIG. 18 GUARD RAILS ON EDGE OF ROAD**

## SIGHT DISTANCE

The safe and efficient operation of vehicles on the road depends very much on the visibility of the road ahead of the driver. Thus the geometric design of the road should be done such that any obstruction on the road length could be visible to the driver from some distance ahead. This distance is said to be the sight distance.

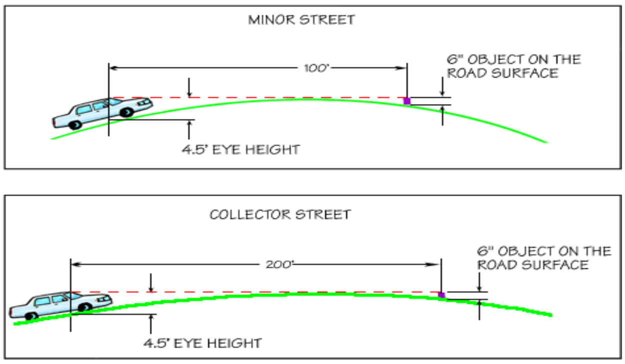



**FIG. 19 SIGHT DISTANCE AT ROAD**

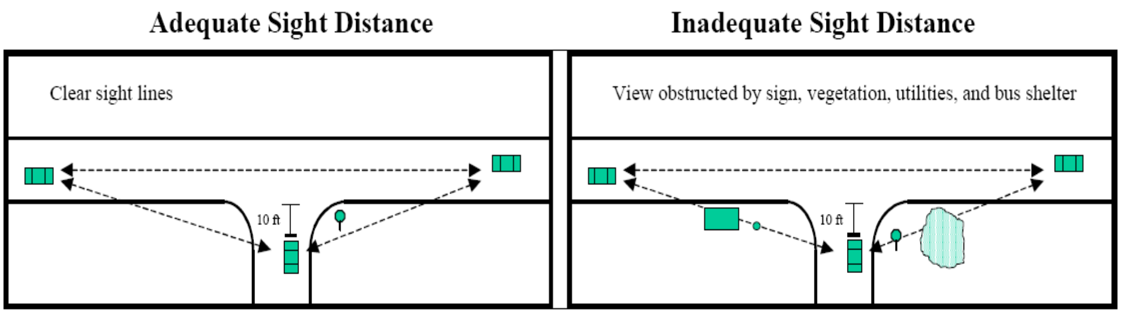



**FIG. 20 SIGHT DISTANCE AT INTERSECTION**

### Types of sight distance

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

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

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

***Stopping sight distance (SSD) or the absolute minimum 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.

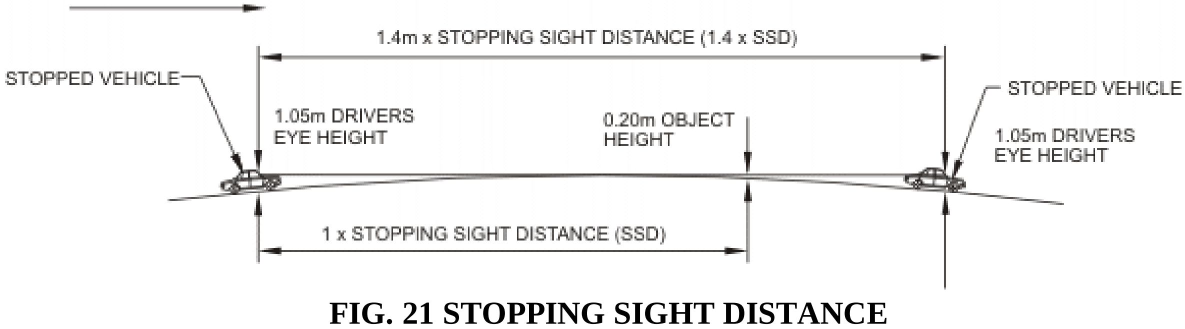



**FIG. 21 STOPPING SIGHT DISTANCE**

SSD = lag distance + braking distance

**Intermediate sight distance (ISD) is defined as twice SSD**

At intersections where two or more roads meet, visibility should be provided for the drivers approaching the intersection from either side. They should be able to perceive a hazard and stop the vehicle if required. Stopping sight distance for each road can be computed from the design speed. The sight distance should be provided such that the drivers on either side should be able to see each other.

This is illustrated in the figure

- Design of sight distance at intersections may be used on three possible conditions:
- Enabling approaching vehicle to change the speed
- Enabling approaching vehicle to stop

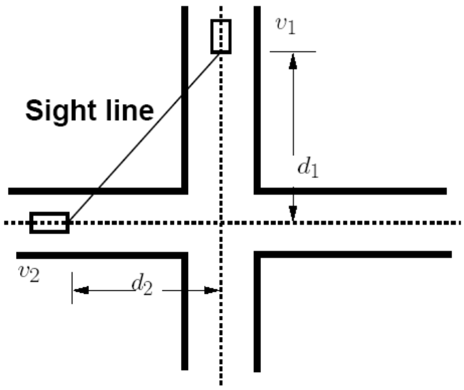



**FIG. 22 INTERMEDIATE SIGHT DISTANCE**

**Overtaking sight distance (OSD) for safe overtaking operation**

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 1.2m above the road surface can see the top of an object 1.2 m above the road surface.

The factors that affect the OSD are:

- Velocities of the overtaking vehicle, overtaken vehicle and of the vehicle coming in the opposite direction.
- Spacing between vehicles, which in-turn depends on the speed

- Skill and reaction time of the driver
- Rate of acceleration of overtaking vehicle
- radiant of the road

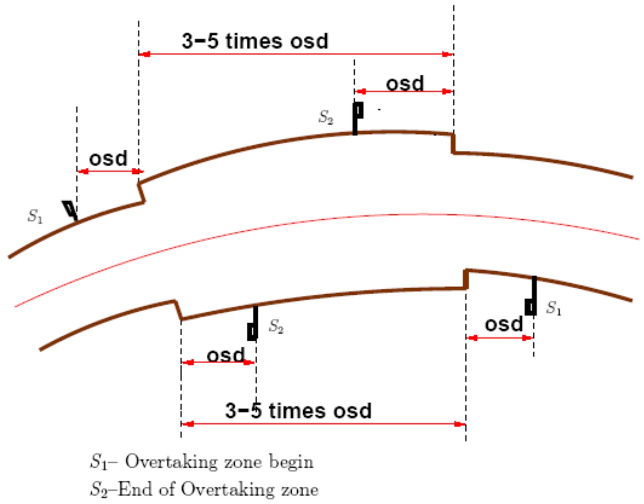



**FIG. 23 OVER TAKING SIGHT DISTANCE**

**PIEV Theory**

**Perception-intellection-Emotion-Volition**

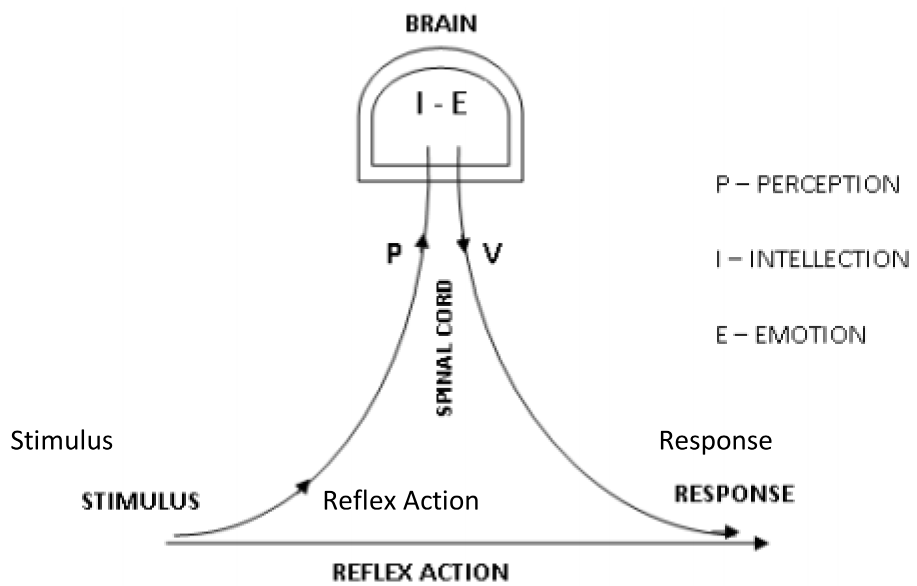



**FIG. 24 DRIVER REACTION TIME**

**Perception time –**

Perception time is the time required for the sensations received by the eyes or ears to be transmitted to the brain through the nervous system and spinal cord.

**Intellection time –**

Intellection time is the time required for understanding the situation. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

**Emotion time –**

Emotion time is the time elapsed during emotional sensations and disturbance such as fear, anger or any other emotional feelings such as superstition etc. with reference to the situation. Therefore the emotion time of driver is likely to vary considerably depending upon the problem involved.

**Volition –**

Volition time is the time taken for the final actions.

***Analysis of stopping distance***

The stopping distance of a vehicle is the sum of,

**Sight distance = Lag Distance + Brake Distance**

**Lag distance**

The distances travelled by the vehicle during the total reaction time know as **lag distance.**

$$\textbf{Lag distance} = \mathbf{t} = 0.278\ V.\ t \text{ meters}$$

**Braking distance**

The distance travelled by the vehicle after the application of the brakes, to a dead stop position which is known as the **braking distance**

$$\textbf{Braking distance} = \mathbf{l} = \frac{v^2}{2gf}$$

If speed is V kmph, stooping distance

$$\textbf{SD, m} = \left(0.278\ V_t + \frac{V^2}{254f}\right)$$

**Where,**

l = braking distance

v = speed of vehicles, m/sec.

f = design coefficient of friction

= 0.4 to 0.35 depending on speed, from 30 to 80 kmph

g = acceleration due to gravity = 9.8 m/sec$^2$

**The general equation for stopping sight distance with respect to gradient**

$$\textbf{SD, m} = \left[ 0.278V.t + \frac{v^2}{254\,(f \pm 0.01\,n)} \right]$$

**Problem in Sight distance**

- Calculate the safe stopping distance for the design speed of 70 kmph for
  a. two way traffic on a two lane road
  b. two way traffic on a single plane road

Assume the reaction time of the driver as 2.7 seconds and coefficient of friction as 0.4

**Solution**

Sight distance = Lag Distance + Brake Distance

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

$$V = 70 \text{ Kmph} \quad \text{or} \quad v = \frac{70}{3.6} = 19.44 \text{ m/sec}$$

t = 2.7 sec

g = 9.8 m/sec$^2$

f = 0.4

$$\textbf{Stopping Distance} = \mathbf{19.44 \times 2.7 + \frac{(19.44)^2}{2 \times 9.8 \times 0.4} = 100.7\ m}$$

$$\textbf{Stopping Distance} = \mathbf{0.278 \times 70 \times 2.7 + \frac{70^2}{254 \times 0.4} = 100.7\ m}$$

Stopping g Sight distance when there are two lanes = SD = 100.7 m

Stopping g Sight distance for two-way traffic with single lane = 2 x (SD) = 201.4 m

- Calculate the minimum sight distance required to avoid a head on collision of two cars approaching from the opposite directions at 100 and 75 kmph. Assume any other data. Brake efficiency of 45 %, in either case.(f = 0.65), (t = 2.6)

**Solution**

Sight distance = Lag Distance + Brake Distance

$$SD., m = v.t + \frac{v^2}{2gf}$$

$$V_1 = 100 \text{ Kmph} \quad \text{or} \quad v = \frac{100}{3.6} = 27.77 \text{ m/sec}$$

$$V_2 = 75 \text{ Kmph} \quad \text{or} \quad v = \frac{75}{3.6} = 19.44 \text{ m/sec}$$

As the brake efficiency is 50 %. The values of co-efficient of frictions developed f may be taken as (f = 0.65 x 0.5) = 0.325

$$\text{Stopping Distance 1} = 27.77 \times 2.6 + \frac{(27.77)^2}{2 \times 9.8 \times 0.325} = 193.26 \text{ m}$$

$$\text{Stopping Distance 2} = 19.44 \times 2.6 + \frac{(19.44)^2}{2 \times 9.8 \times 0.4} = 56.63 \text{ m}$$

Stopping Sight distance when there are two lanes = SD = 193.26+56.23 = 249.49 m

- Calculating the stopping sight distance on a highway at a descending gradient of 3% for a design speed of 100 kmph. Assume any other data.

**Solution**

Sight distance = Lag Distance + Brake Distance

Assume the data, (f = 0.5), (t = 2.5)

$$\textbf{SD, m} = \left[ 27.77 \text{x } 2.5 + \frac{27.77^2}{2 \text{ x } 9.81\ (0.5\text{-}.0.03)} \right]$$

$$\textbf{SD., m} = \textbf{153.05 m}$$

- Calculate the safe stopping sight distance for design speed of 60kmph for a two way traffic on a two lane road and two way traffic on a single plane road, Assume that coefficient of friction as 0.35 and reaction time of the driver as 2 seconds.

**Solution**

If speed is V kmph, stooping distance

The stopping sight distance $\textbf{SD., m} = \left(0.278\, V_t + \frac{V^2}{254f}\right)$

$$= (0.278 \text{ x } 60 \text{ x } 2) + \left(\frac{60^2}{(254 \text{ x } 0.35)}\right)$$

$$= \textbf{73.85 m}$$

1. The Stopping Sight distance when two lanes = 73.85 m
2. The Stopping Sight distance for two way traffic with single lane = ***2 x SD***

   **= 2 x 73.85**

   **= 147.70 m**

- Calculate the stopping sight distance on a highway at a descending gradient of 2.1% for a design speed of 85kmph. Assume other data as per IRC Recommendation.

**Solution**

Assuming reaction time of the driver as 2.5 seconds and design coefficient as f = 0.37.

**The general equation for stopping sight distance with respect to gradient**

$$SD, m = \left[ 0.278V.t + \frac{v^2}{254\,(f \pm 0.01\ n)} \right]$$

$$SD, m = \left[ 0.278 \times 85 \times 2.5 + \frac{85^2}{254\,(0.37 - 0.01 \times 2.1)} \right]$$

$$= 140.58 \text{ m say } 141 \text{ m}$$

**OVERTAKING SIGHT DISTANCE (OSD) FOR SAFE OVERTAKING OPERATION**

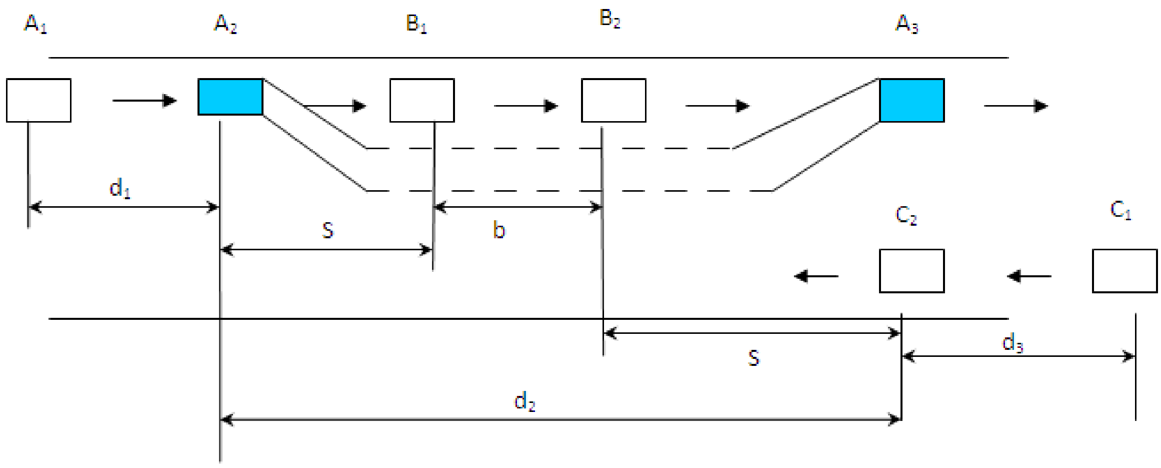



**FIG. 25 OVER TAKING OF SMV BY FMV**

A is travelling at design speed, and another slow vehicle B on a two-way traffic. Third vehicle C comes from the opposite direction. The overtaking man oeuvre may be split up to into three operations, thus dividing the overtaking sight distance into three parts $d_1$, $d_2$ and $d_3$.

Where,

$d_1$ = the distance traveled by overtaking vehicle **'A'** during the reaction time t sec of the driver from position **$A_1$ to $A_1$**

$d_2$ = the distance traveled by the vehicle **A from $A_2$ to $A_3$** during the actual overtaking operation, in time **t sec**

$d_3$ = the distance traveled by oncoming vehicle **C from $C_1$ to $C_2$** during the overtaking operation A, in time **t sec**

In KMPH units, equations

OSD = $0.28V_{b.}t + 0.28\ V_{b.}T + 2\ s + 0.28\ V.T$

**Where,**

$V_{b.}t$ = speed of overtaking vehicle, kmph

t = reaction time of driver = 2 secs

V = speed of overtaking vehicle or design speed, kmph

T = $\sqrt{\dfrac{14.4 \times S}{A}}$

S = Spacing of vehicles = $(0.2\ V_b + 6)$

A = Acceleration,, kmph/sec

In case the speed of overtaken vehicle $V_b$ is not given, the same may be assumed as (V - 16) Kmph where V is the design speed in kmph or (V – 4.5) m/sec and v is in m/sec.

- For One way traffic OSD = $(d_1 + d_2)$
- For Two way traffic OSD = $(d_1 + d_2 + d_3)$
- Over taking zone(one way) = $3\ (d_1 + d_2)$ Minimum length
- Over taking zone(two way) = $3\ (d_1 + d_2 + d_3)$ Minimum length
- Over taking zone(one way) = $5\ (d_1 + d_2)$ Desirable length
- Over taking zone(two way) = $5\ (d_1 + d_2 + d_3)$ Desirable length

**Problem**

- The speed of overtaking and over taken vehicles is 90 and 60 kmph, respectively on two way traffic. If the acceleration of overtaking vehicle is 2.98kmph/sec. take t as 2.5 sec.

a. Calculate safe overtaking sight distance

b. Mention the minimum length of overtaking zone and

c. Draw a neat sketch of the overtaking zone and show the position of the sign posts.

**Solution,**

a) overtaking sight distance for the two way traffic = $(d_1 + d_2 + d_3)$

The design speed of the overtaking vehicle V = 90 kmph

The design speed of the overtaken vehicle $V_b$ = 60 Kmph

OSD = $0.28V_{b.}t + 0.28\ V_{b.}T + 2\ s + 0.28\ V.T$

$d_1$ = $0.28V_{b.}t$

$d_2$ = $0.28\ V_{b.}T + 2\ s$

$d_3 = 0.28\ V.T$

$d_1 = 0.28 \times 60 \times 2.5 = \mathbf{42m}$

$S = (0.2\ V_b \times t) = (0.2 \times 60 \times 2.5) = \mathbf{30}$

$$T = \sqrt{\frac{14.4 \times S}{A}} = \sqrt{\frac{14.4 \times 30}{2.98}} = \mathbf{12.04}$$

$d_2 = 0.28 \times 60 \times 12.04 + (2 \times 30) = \mathbf{262.272\ m}$

$d_3 = 0.28 \times 90 \times 12.04 = \mathbf{303.408}$

a) Overtaking sight distance for the two way traffic $= (d_1 + d_2) =$ **304.272**

b) Overtaking sight distance for the two way traffic $= (d_1 + d_2 + d_3)$

**= (42 + 262.272 + 303.408)**

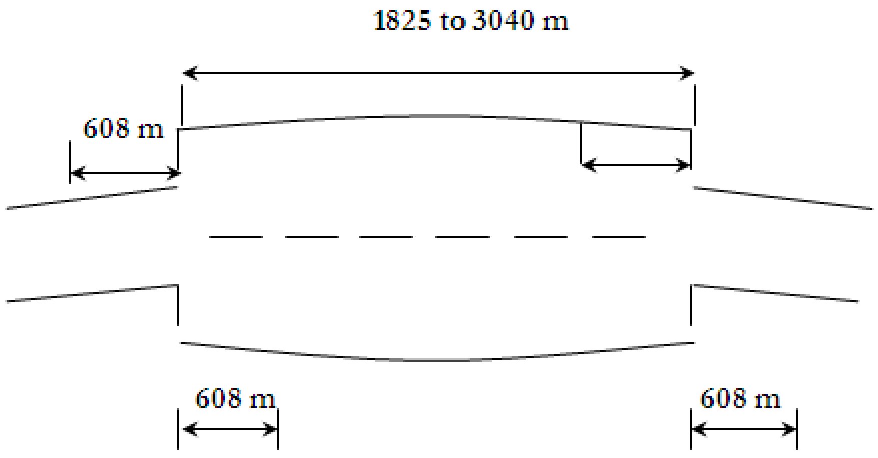
**= 607.68m**

- Over taking zone(two way) = $3\ (d_1 + d_2 + d_3)$ Minimum length
- Over taking zone(two way) = $5\ (d_1 + d_2 + d_3)$ Desirable length

**= 3 (607.68) = 1823.04 m**

**= 5 (607.68) = 3038.40 m**

Details of the Overtaking Zone




## HORIZONTAL CURVES

As a highway changes horizontal direction, turning to change the vehicle direction at the point of intersection between the two straight lines is not feasible.

The change indirection would be too abrupt and too risky for the safety of modern, high-speed vehicles, the driver and its passengers. It is therefore necessary to interpose a curve between the straight lines.

Horizontal curves occur at locations where two roadways intersect, providing a gradual transition between the two. The straight lines of a road are called tangents because the lines are tangent to the curves used to change direction.


**FIG. 26 HORIZONTAL CURVE**

**Factors depends on horizontal curve**

- The vehicle negotiating horizontal line will be affected by centrifugal force. this force is depends upon the radius of curve and velocity of the vehicles.
- This centrifugal force will be counteracted by friction between tyre and the surface.
  - Spiral curve
  - Lemniscates
  - Cubic Parabola

**Setback Distance** –

Setback distance m or the clearance distance is the distance required from the centerline of a horizontal curve to an obstruction on the inner side of the curve to provide adequate sight distance at a horizontal curve. The setback distance depends on:

- Sight distance (OSD, ISD and OSD),
- Radius of the curve, and
- Length of the curve.

**Types of Horizontal Curves**

There are four types of horizontal curves. They are described as follows

- Simple Curve - The simple curve is an arc of a circle. The radius of the circle determines the sharpness or flatness of the curve as given in A

**FIG. 27 SIMPLE CURVE ON ROAD**

- Compound Curve - Frequently, the terrain will require the use of the compound curve. This curve normally consists of two simple curves joined together and curving in the same direction as given in B.

**FIG. 28 COMPOUND CURVES ON ROAD**

- Reverse Curve - A reverse curve consists of two simple curves joined together, but curving in opposite direction as given in C. For safety reasons, the use of this curve should be avoided when possible.

**FIG. 29 REVERSE CURVE ON ROAD**

- Spiral Curve - The spiral is a curve that has a varying radius. It is used on railroads and most modem highways. Its purpose is to provide a transition from the tangent to a simple curve or between simple curves in a compound curve as given in D.

**FIG. 30 HAIR-PIN BEND CURVE ON ROAD**

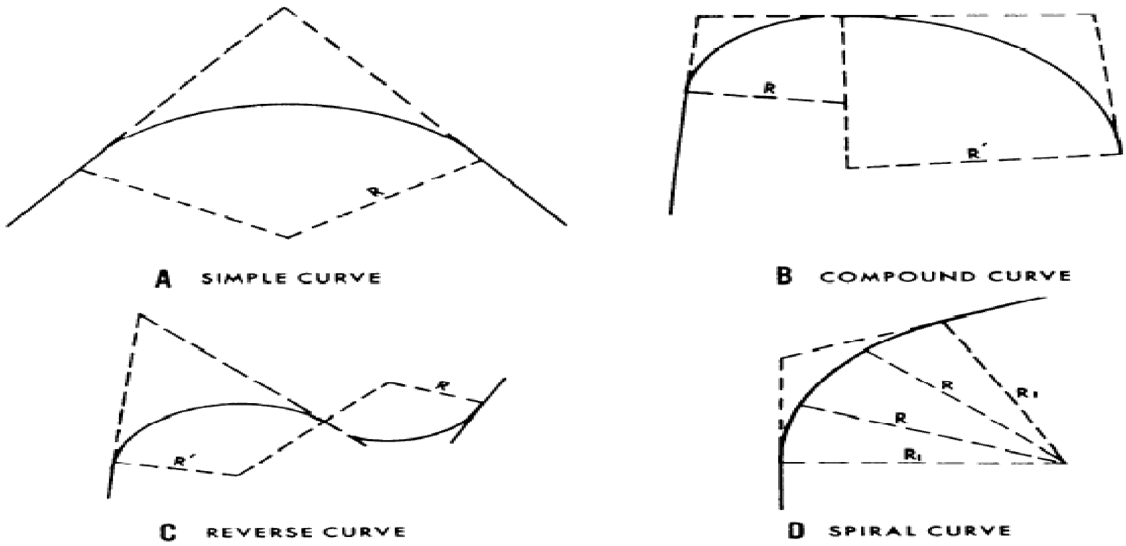



**FIG. 31 VARIOUS TYPES OF CURVES ON ROAD**

### Super elevation

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavements is raised with respect to the inner edge, thus providing a traverse slope throughout length of the horizontal curve.

When a vehicle is moving on a curved path, it is subjected to an outward force, commonly known as the centrifugal force. In order to resist this force, it is the usual practice to super elevate the roadway cross section.

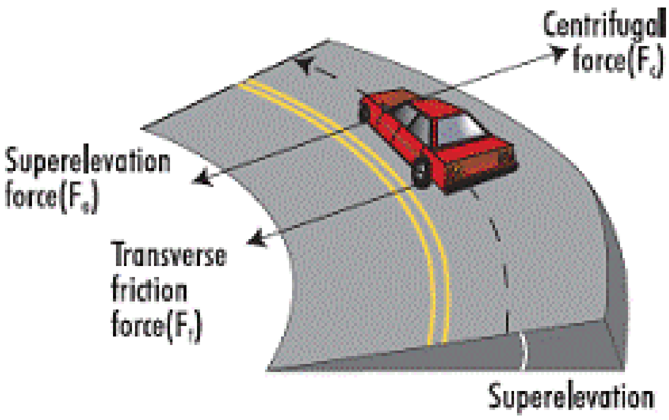
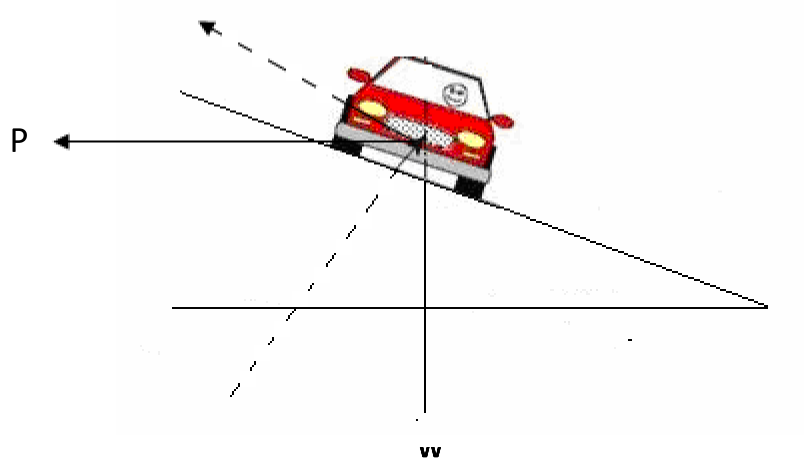



**FIG. 32 SUPER ELEVATION ON ROAD (a)**

FIG. 32 SUPER ELEVATION ON ROAD (b)




Let,

| | | |
|---|---|---|
| m | = | mass of vehicle |
| v | = | speed of the vehicle m/sec |
| R | = | Radius of the curve |
| P | = | side force resisting the centrifugal force |
| N | = | normal force |
| M | = | coefficient of lateral friction |
| g | = | Acceleration due o gravity (9.81 m/sec$^2$) |
| α | = | angle of super elevation |

e = Super elevation

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

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

$P(\cos\theta - f \sin\theta) = W \sin\theta + f W \cos\theta$ ------------- (1)

Dividing by W Cos θ in equation (1)

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

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

The value of the coefficient of lateral friction 'f' is taken as 0.15 for design parameters. The value of tan θ or transverse slope due to super elevation seldom exceeds 0.07 or about 1/15. Hence the value of tan θ is about 0.01.thus the value of (1- f tan θ) in the above equation is equal to 0.99 and may be equal to 1.0

Therefore,

$$\frac{P}{W} = \tan\theta + f = e + f$$

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

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

If the speed of the vehicle is represented as V kmph, the equation is written as

$$E + f = \frac{0.278V^2}{9.8\,R} = \frac{V^2}{127\,R}$$

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

Where,

V = Speed, KMPH

R = radius of curve (m)

**Problem**

- The radius of a horizontal circular curve is 100 m. the design is 5o kmph and design coefficient of lateral friction is 0.15

a) Calculate the super elevation required is full lateral friction is assumed to develop

b) Calculate the coefficient of friction needed if no super elevation is provided.

c) Calculate the equilibrium super elevation, if the pressure on inner and outer wheels should be equal.

**Calculation**

**Case – I -** The super elevation required is full lateral friction is assumed to develop

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

$$e + 0.15 = \frac{50^2}{127 \times 100}$$

$$e = 0.047$$

**Case – II - No** super elevation is provided.

$$f = \frac{50^2}{127 \times 100} =- 0.197$$

**Case – III -** The pressure on inner and outer wheels should be equal.(f=0)

$$e = \frac{50^2}{127 \times 100} =- 0.197$$

**VERTICAL CURVES**

In addition to horizontal curves that go to the right or left, roads also have vertical curves that go up or down. Vertical curves at a crest or the top of a hill are called summit curves, or over verticals. Vertical curves at the bottom of a hill or dip are called sag curves, or under verticals.

**FIG. 32 VERTICAL CURVE ON ROAD**

The meeting points of two differential gradients are known as vertical curve.

The vertical curves used in highway may be classified into two categories

- **Summit curves or crest curves with convexity upwards**
- **Valley or sag curves with concavity upwards**

**Summit curves or crests curves with convexity upwards**

The deviation angle between the two interacting gradient is equal to the algebraic difference between them.

There are four cases arrived in summit curves

- When a positive gradient meets another positive gradient [a].
- When positive gradient meets a at gradient [b].
- When an ascending gradient meets a descending gradient [c].
- When a descending gradient meets another descending gradient [d]

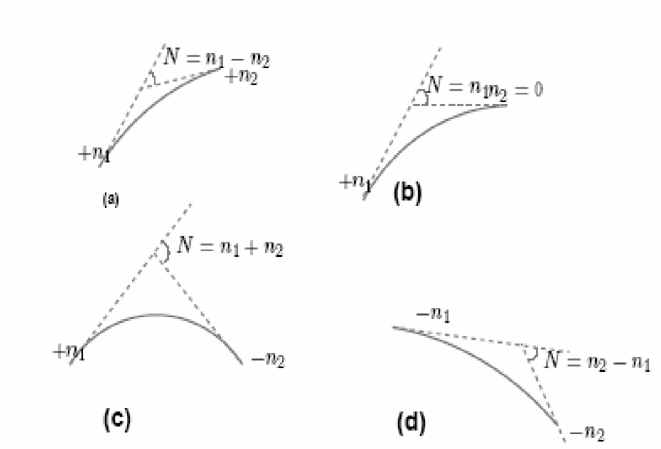


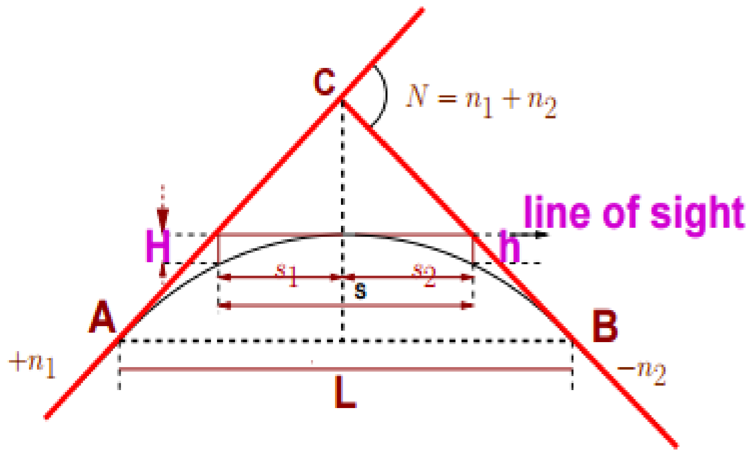

**FIG. 33 VARIOUS TYPES OF VERTICAL CURVES ON ROAD**

**Length of 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 a = N 2L , where N is the deviation angle and L is the length of the In deriving the length of the curve, two situations can arise depending on the uphill and downhill gradients when the length of the curve is greater than the sight distance and the length of the curve is greater than the sight distance. Let L is the length of the summit curve, S is the SSD/ISD/OSD, N is the deviation angle, h1 driver's eye height (1.2 m), and h2 the height of the obstruction, then the length of the summit curve can be derived for the following two cases.

***Case I - Length of summit curve greater than sight distance (L > S)***

The situation when the sight distance is less than the length of the curve as shown in figure.

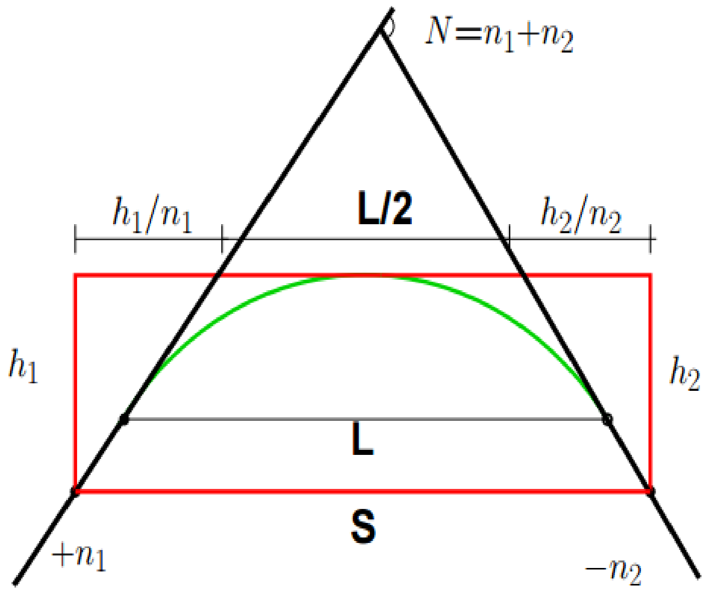



Length of summit curve $(L > S)$

$$
\begin{aligned}
y &= ax^2 \\
a &= \frac{N}{2L} \\
h_1 &= aS_1^2 \\
h_2 &= aS_2^2 \\
S_1 &= \sqrt{\frac{h_1}{a}} \\
S_2 &= \sqrt{\frac{h_2}{a}} \\
S_1 + S_2 &= \sqrt{\frac{h_1}{a}} + \sqrt{\frac{h_2}{a}} \\
S^2 &= \left(\frac{1}{\sqrt{a}}\right)^2 \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
S^2 &= \frac{2L}{N} \left(\sqrt{h_1} + \sqrt{h_2}\right)^2 \\
L &= \frac{NS^2}{2\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}
\end{aligned}
$$

***Case II - Length of summit curve less than sight distance (L<S)***

The situation when the sight distance is greater than the length of the curve as shown in figure




Length of summit curve $(L < S)$

From the basic geometry, one can write

$$S = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{n_2} = \frac{L}{2} + \frac{h_1}{n_1} + \frac{h_2}{N - n_2}$$

Therefore for a given L, h1 and h2 to get minimum S, differentiate the above equation with respect to h1 and equate it to zero. Therefore

$$\frac{dS}{dh_1} = \frac{-h_1}{n_1^2} + \frac{h_2}{N - {n_1}^2} = 0 h_1 (N - n_1)^2 = \quad h_2 n_1^2$$

$$\begin{aligned} h_1\left(N^2+n_1^2-2Nn_1\right) &= h_2 n_1^2 \\ h_1N^2+h_1n_1^2-2Nn_1h_1 &= h_2n_1^2 \\ \left(h_2-h_1\right)n_1^2+2Nh_1n_1-h_1N^2 &= 0 \end{aligned}$$

Solving the quadratic equation for $n_1$,

$$\begin{aligned} n_1 &= \frac{-2Nh_1 \pm \sqrt{\left(2Nh_1\right)^2-4\left(h_2-h_1\right)\left(-h_1N^2\right)}}{2\left(h_2-h_1\right)} \\ &= \frac{-2Nh_1+\sqrt{4N^2h_1^2+4h_1N^2h_2-4h_1^2N^2}}{2\left(h_2-h_1\right)} \\ &= \frac{-2Nh_1+2N\sqrt{h_1h_2}}{2\left(h_2-h_1\right)} \\ n_1 &= \frac{N\sqrt{h_1h_2}-h_1N}{h_2-h_1} \end{aligned}$$

Now we can substitute $n$ back to get the value of minimum value of $L$ for a given $n_1$, $n_2$, $h_1$ and $h_2$. Therefore,

$$S=\frac{L}{2}+\frac{h_1}{\frac{N\sqrt{h_1h_2}-Nh_1}{h_2-h_1}}+\frac{h_2}{N-\frac{N\sqrt{h_1h_2}-Nh_1}{h_2-h_1}}$$

Solving for $L$,

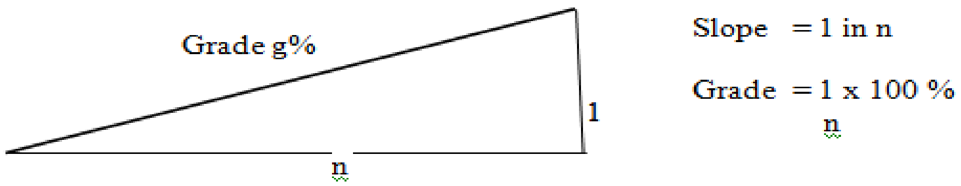
$$\begin{aligned} &= \frac{L}{2}+\frac{h_1\left(h_2-h_1\right)}{N\left(\sqrt{h_1h_2}-h_1\right)}+\frac{h_2\left(h_2-h_1\right)}{Nh_2-Nh_1-N\sqrt{h_1h_2}+Nh_1} \\ &= \frac{L}{2}+\frac{h_1\left(h_2-h_1\right)}{N\left(\sqrt{h_1h_2}-h_1\right)}+\frac{h_2\left(h_2-h_1\right)}{N\left(h_2-\sqrt{h_1h_2}\right)} \\ &= \frac{L}{2}+\frac{h_1\left(h_2-h_1\right)\left(h_2-\sqrt{h_1h_2}\right)+\left(h_2-h_1\right)h_2\left(\sqrt{h_1h_2}-h_1\right)}{N\left(\sqrt{h_1h_2}-h_1\right)\left(h_2-\sqrt{h_1h_2}\right)} \\ &= \frac{L}{2}+\frac{\left(h_2-h_1\right)\left(h_1h_2-h_1\sqrt{h_1h_2}+h_2\sqrt{h_1h_2}-h_1h_2\right)}{N\left(\sqrt{h_1h_2}-h_1\right)\left(h_2-\sqrt{h_1h_2}\right)} \\ &= \frac{L}{2}+\frac{\left(h_2-h_1\right)\left(\sqrt{h_1h_2}\left(h_2-h_1\right)\right)}{N\left(h_2\sqrt{h_1h_2}-h_1h_2+h_1\sqrt{h_1h_2}-h_1h_2\right)} \\ &= \frac{L}{2}+\frac{\left(h_2-h_1\right)\sqrt{h_1h_2}\left(\sqrt{h_2}+\sqrt{h_1}\right)\left(\sqrt{h_2}-\sqrt{h_1}\right)}{N\sqrt{h_1h_2}\left(h_2-2\sqrt{h_1h_2}+h_2\right)} \\ &= \frac{L}{2}+\frac{\left(h_2-h_1\right)\left(\sqrt{h_2}+\sqrt{h_1}\right)\left(\sqrt{h_2}-\sqrt{h_1}\right)}{N\left(\sqrt{h_2}-\sqrt{h_1}\right)^2} \\ &= \frac{L}{2}+\frac{\left(h_2-h_1\right)\left(\sqrt{h_2}+\sqrt{h_1}\right)}{N\left(\sqrt{h_2}-\sqrt{h_1}\right)} \\ &= \frac{L}{2}+\frac{\left(\sqrt{h_2}+\sqrt{h_1}\right)\left(\sqrt{h_2}-\sqrt{h_1}\right)\left(\sqrt{h_2}+\sqrt{h_1}\right)}{N\left(\sqrt{h_2}-\sqrt{h_1}\right)} \\ &= \frac{L}{2}+\frac{\left(\sqrt{h_2}+\sqrt{h_1}\right)^2}{N} \\ L &= 2S-\frac{2\left(\sqrt{h_2}+\sqrt{h_1}\right)^2}{N} \end{aligned}$$

$$L=2S-\frac{\left(\sqrt{2h_1}+\sqrt{2h_2}\right)^2}{N}$$

When stopping sight distance is considered the height of driver’s eye above the road surface (h1) is taken as 1.2 meters, and height of object above the pavement surface (h2) is taken as 0.15 meters. If overtaking sight distance is considered, then the value of driver’s eye height (h1) and the height of the obstruction (h2) are taken equal as 1.2 metres.

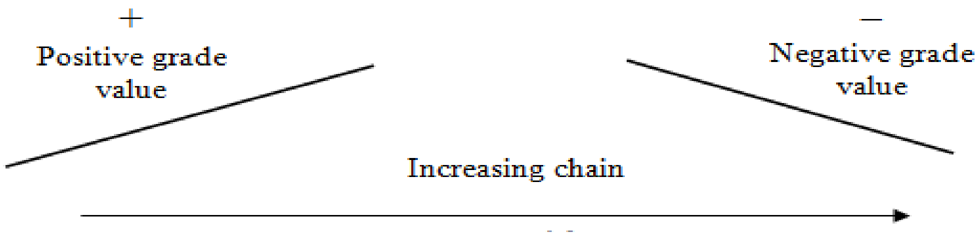
Different types of gradients and IRC recommendations for their maximum and minimum limit were discussed. At points of combination of horizontal curve and gradient, grade compensation has to be provided. Due to changes in grade in the vertical alignment of the highway, vertical curves become essential. Summit curve, which is a type of vertical curve was discussed in detail in the chapter. One of the applications of summit curves that can be seen usually in the urban areas is where fly-overs come

Vertical curves are drawn on a **long section** which is a vertical section through a road taken along its centerline. Conventionally, long sections are drawn with chain age increasing from left to right. The gradient is expressed in terms of the **grade value** as a percentage:




**Grade value.**

The following sign convention is used:




**Valley or sag curves with concavity upwards**

Valley curve or sag curves are vertical curves with convexity downwards. They are formed when two gradients meet in four ways as given below:

- When a descending gradient meets another descending gradient
- When a descending gradient meets a flat gradient
- When a descending gradient meets an ascending gradient

- When an ascending gradient meets another ascending gradient

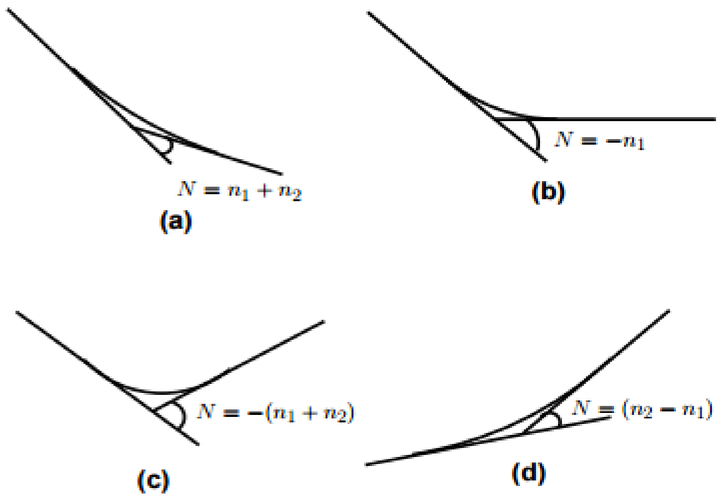



**FIG. 33 VARIOUS TYPES OF VERTICAL CURVES ON ROAD**

Similarly, a convention is used to differentiate between curves which are convex on the upper (i.e. road) surface and those which are concave.

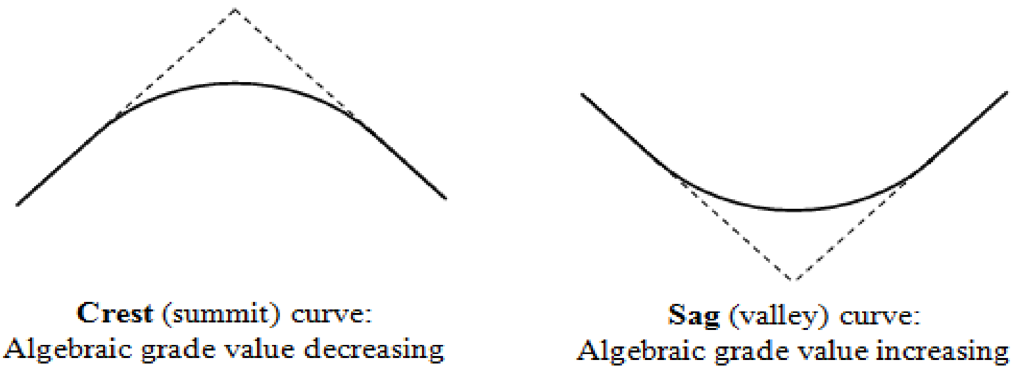



**FIG. 33 TYPES OF VERTICAL CURVES ON ROAD**

**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 $y = bx^3$ where $b = 2N/3L^2$ 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 the time, then c is given as:

$$\begin{aligned} c &= \frac{\frac{v^2}{R} - 0}{t} \\ &= \frac{\frac{v^2}{R} - 0}{\frac{L}{v}} \\ &= \frac{v^3}{LR} \\ L &= \frac{v^3}{cR} \end{aligned}$$

For a cubic parabola, the value of $R$ for length $L_s$ is given by:

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

Therefore,

$$\begin{aligned} L_s &= \frac{v^3}{\frac{cL_s}{N}} \\ L_s &= \sqrt[2]{\frac{Nv^3}{c}} \\ L &= 2\sqrt[2]{\frac{Nv^3}{c}} \end{aligned}$$

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

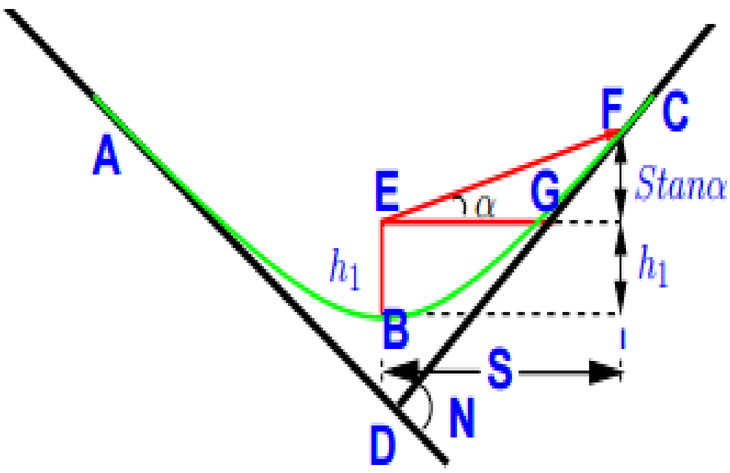
(2) Length of the valley curve less than the stopping sight distance.

***Case 1 Length of valley curve greater than stopping sight distance (L > S)***

The total length of valley curve L is greater than the stopping sight distance SSD. The sight distance available will be minimum when the vehicle is in the lowest point in the valley. This is because the beginning of the curve will have infinite radius and the bottom of the curve will have minimum radius which is a property of the transition curve.

$$\begin{aligned} h_1 + S\tan\alpha &= aS^2 \\ &= \frac{NS^2}{2L} \\ L &= \frac{NS^2}{2h_1 + 2S\tan\alpha} \end{aligned}$$

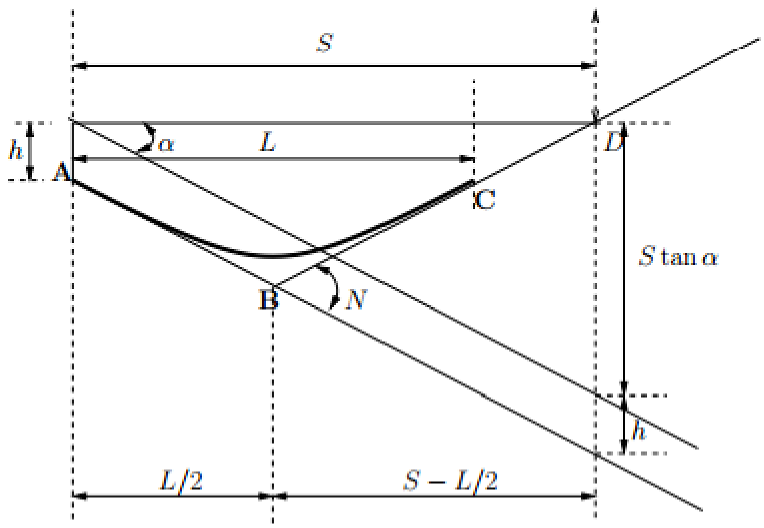
Where, N is the deviation angle in radians, h1 is the height of headlight beam, α is the head beam inclination in degrees and S is the sight distance. The inclination α is ≈ 1 degree.




Valley curve, case 1, $L > S$

**Case 2 Length of valley curve less than stopping sight distance (L < S)**

The length of the curve L is less than SSD. In this case the minimum sight distance is from the beginning of the curve. The important points are the beginning of the curve and the bottom most part of the curve. If the vehicle is at the bottom of the curve, then its headlight beam will reach far beyond the endpoint of the curve whereas, if the vehicle is at the beginning of the curve, then the headlight beam will hit just outside the curve. Therefore, the length of the curve is derived by assuming the vehicle at the beginning of the curve. The case is shown in figure above.




Valley curve, case 2, $S > L$

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

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

Note that the above expression is approximate and is satisfactory because in practice, the gradients are very small and is acceptable for all practical purposes. We will not be able to know prior to which case to be adopted. Therefore both has to be calculated and the one which satisfies the condition is adopted.

The valley curve should be designed such that there is enough headlight sight distance. Improperly designed valley curves results in extreme riding discomfort as well as accident risks especially at nights. The lengths of valley curve for various cases were also explained in the section. The concept of valley curve is used in underpasses.

***Gradient***

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. While aligning a highway, the gradient is decided for designing the vertical curve. Before finalizing the gradients, the construction cost, vehicular operation cost and the practical problems in the site also has to be considered. The rate of rise or fall along the road with respect to horizontal plane is called gradient. Generally a road follows the natural topography of earth surface. Gradient is expressed in 1 in x. super elevation is in transverse direction and gradient is in longitudinal direction.

***Effect of gradient***

The effect of long steep gradient on the vehicular speed is considerable. This is particularly important in roads where the proportion of heavy vehicles is significant. Due to restrictive sight distance at uphill gradients the speed of traffic is often controlled by these heavy vehicles. As a result, not only the operating costs of the vehicles are increased, but also capacity of the roads will have to be reduced. Further, due to high differential speed between heavy and light vehicles, and between uphill and downhill gradients, accidents abound in gradients.

**TABLE 4 GRADIENTS OF DIFFERENT TERRAIN**

| Terrain | Ruling | Limiting | Exceptional |
|---|---|---|---|
| Plain/Rolling | 3.3 | 5.0 | 6.7 |
| Hilly | 5.0 | 6.0 | 7.0 |
| Steep | 6.0 | 7.0 | 8.0 |

**Types of gradient**

- Minimum Gradient
- Ruling Gradient
- Limiting Gradient
- Exceptional Gradient

**Minimum Gradient**

The minimum gradient would depend on rain fall runoff, type of soil, topography and other site conditions. A minimum gradient of about 1 in 500 may be sufficient to drain rain water in concrete drains

**Ruling Gradient**

Ruling Gradient is the maximum gradient within which the designer attempts to design the vertical profile of a road. Gradient up to the ruling gradient are adopted as a normal course in design of vertical alignment and accordingly the quantities of cut or fill are balanced. Hence ruling gradient is also known as design gradient. For designed gradient 1 in 20 for hilly terrain and 1 in 30 for plain terrain.

**Limiting Gradient**

Where topography of a place compels adopting steeper gradient than ruling gradient, limiting gradient are used in view of enormous increase in cost in constructing roads with gentler gradient.

**Exceptional Gradient**

In some extra ordinary situation it may be unavoidable to provide still steeper gradients at least for stretches and in such cases the steeper up to exceptional gradients may be provided. The exceptional gradient should be strictly limited only for short stretches not exceeding about 100 m at stretch.

**Critical length of the grade**

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

## WIDENING OF PAVEMENT ON CURVES

Widening refers to the additional width of carriageway that is required on a curved section of a road over and above that required on a straight alignment. This widening is done due to two reasons: the first and most important is the additional width required for a vehicle taking a horizontal curve and the second is due to the tendency of the drivers to ply away from the edge of the carriageway as they drive on a curve. The first is referred as the ***mechanical widening*** and the second is called the ***psychological widening.***

## MECHANICAL WIDENING

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 ***off-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 travelling 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 is using the road. Trailer 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.

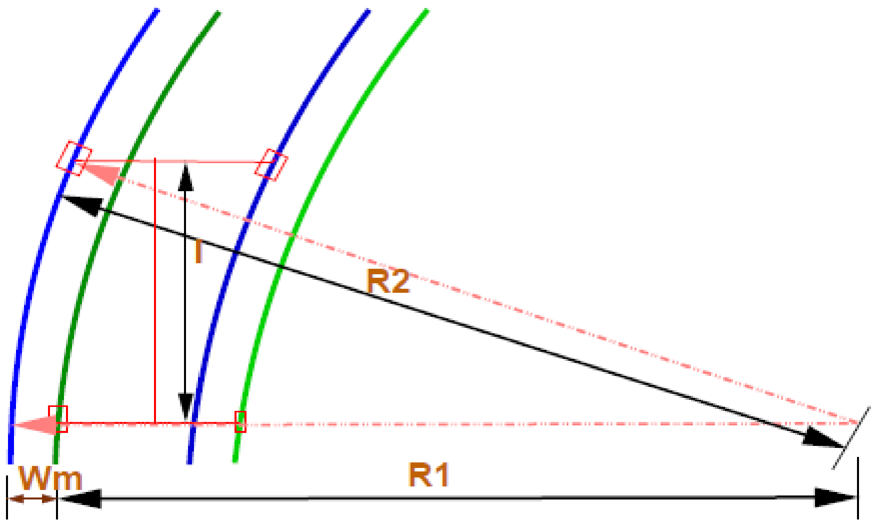



**FIG.34 WIDENING OF PAVEMENT ON CURVES**

Let $R_1$ is the radius of the outer track line of the rear wheel, $R_2$ is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, and then the mechanical widening $\mathbf{W_m}$ is derived below:

$$\begin{aligned} R_2^2 &= R_1^2 + l^2 \\ &= (R_2 - W_m)^2 + l^2 \\ &= R_2^2 - 2R_2W_m + W_m^2 + l^2 \\ 2R_2W_m - W_m^2 &= l^2 \end{aligned}$$

Therefore the widening needed for a single lane road is:

$$W_m = \frac{l^2}{2R_2 - W_m}$$

If the road has n lanes, the extra widening should be provided on each lane. Therefore, the extra widening of a road with n lanes is given by,

$$W_m = \frac{nl^2}{2R_2 - W_m}$$

Please note that for large radius, $R_2 \approx R$, which is the mean radius of the curve, then $\mathbf{W_m}$ is given by:

$$W_m = \frac{nl^2}{2R}$$

**PSYCHOLOGICAL WIDENING**

Widening of pavements has to be done for some psychological reasons also. There is a tendency for the drivers to drive close to the edges of the pavement on curves. Some extra space is to be provided for more clearance for the crossing and overtaking operations on curves. IRC proposed an empirical relation for the psychological widening at horizontal curves $\mathbf{W_{ps}}$

$$W_{ps} = \frac{v}{2.64\sqrt{R}}$$

Therefore, the total widening needed at a horizontal curve $\mathbf{W_e}$ is:

$$\begin{aligned} W_e &= W_m + W_{ps} \\ &= \frac{nl^2}{2R} + \frac{v}{2.64\sqrt{R}} \end{aligned}$$

**Problems**

- A national highway passing through a rolling terrain has two horizontal curves of radius 450 m and 150m. Design the required super elevation for the curves as per IRC guidelines.

*Solution*

Assumptions - The ruling design speed for NH passing through a rolling terrain is 80 kmph. The

Coefficient of lateral friction f=0.15. The maximum permissible super elevation e=0.07.

***Case1: Radius = 450m***

Step 1: Find e for 75 percent of design speed, neglecting f, i.e., $e_1 = \mathbf{(0.75v)^2/gR}$

**v = V/3.6** = 80/3.6 = 22.22m/sec

$e_1 = (0.75*22.22)^2/9.81*450 = 0.0629$

Step 2: $e_1 \leq 0.07$. Hence the design is sufficient.

*Answer* - Design superelevation: 0.06.

***Case2: Radius = 150m***

Step 1: Find $e$ for 75 percent of design speed, neglecting f, i.e., $\mathbf{e_1 = (0.75v)^2/gR}$

**v = V/3.6** = 80/3.6 = 22.22m/sec

$e_1 = (0.75*22.22)^2/9.81*150 = 0.188$. But $e$ to be provided is 0.07

Step 2: Find $f_1$ for the design speed and max $e$, i.e., $f_1 = (v^2/gR) - e = (22.22^2/9.81*150) - 0.07$

$= 0.265$

Step 3: Find the allowable speed $v_a$ for the maximum $e = 0.07$ and $f = 0.15$,

$$v_a = \sqrt{0.22gR}$$
$$= \sqrt{0.22*9.81*150}$$
$$= 17.99 \text{ m/sec}$$
$$= 17.99*3.6$$
$$= 64 \text{ kmph}$$

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**DEPARTMENT OF CIVIL ENGINEERING**

# UNIT – III – HIGHWAY MATERIALS AND CONSTRUCTION PRACTICE
# SCIA1304

## INTRODUCTION

Pavements are assembly of materials. This chapter deals with the selection and use of naturally occurring materials for pavement construction. These materials, their associated properties, and their interactions determine the properties of the resultant pavement. Thus, a good understanding of these materials, how they are characterized, and how they perform is fundamental to understanding pavement.

## DESIRABLE PROPERTIES OF MATERIALS

### TABLE 1 PROPERTY OF MATERIALS

| Soil | Aggregates | Bitumen | Cement |
|---|---|---|---|
| Short and long term stability of the subgrade and slope of embankment | Sufficient Strength and resistance to crushing | Easy to get mixed | Provides strength to masonry |
| Compressibility within the permissible limits | Hard enough to resist wear | Attainment to desired stability | Stiffens or hardens early |
| Adequate permeability | Toughness | Maintain stability for all weather conditions | Possesses good plasticity |
| Compaction should be ease and economical | Durability | Sufficient flexibility to avoid cracking | An excellent building material |
| Minimum volume change at all weather conditions | Shape | Sufficient adhesion | Easily workable and Good moisture-resistant |

**Soil** **Aggregate** **Bitumen** **Cement**

**FIG.1 MATERIALS USED IN ROAD**

**Various Tests to be conducted on road materials**

**TABLE 2 TESTS ON ROAD MATERIALS**

| **Tests on Soil** | **Tests on Aggregates** | **Tests on Bitumen** |
|---|---|---|
| Shear Test | Crushing test | Penetration test |
| Direct Shear Test | Abrasion test | Ductility test |
| Triaxial Compression test | Impact test | Softening point test |
| Unconfined Compression test | Soundness test | Flash and fire point test |
| Bearing Test | Water absorption test | Specific gravity test |
| Plate Bearing Test | Shape test | viscosity test |
| Penetration Test | Abrasion test | |
| California Bearing Ratio Test | | |

**SOIL**

Soil is an accumulation or deposit of earth material, derived naturally from the disintegration of rocks or decay of vegetation that can be excavated readily with power equipment in the field or disintegrated by gentle mechanical means in the laboratory. The supporting soil beneath pavement and its special under courses is called sub grade. Undisturbed soil beneath the pavement is called natural sub grade. Compacted sub grade is the soil compacted by controlled movement of heavy compactors.

**FIG.2 COMPACTION OF SOIL**

The desirable properties of sub grade soil as a highway material are

- Stability
- Incompressibility
- Permanency of strength
- Minimum changes in volume and stability under adverse conditions of weather and ground water
- Good drainage, and
- Ease of compaction

The wide range of soil types available as highway construction materials have made it obligatory on the part of the highway engineer to identify and classify different soils. A survey of locally available materials and soil types conducted in India revealed wide variety of soil types, gravel, moorum and naturally occurring soft aggregates, which can be used in road construction. Broadly, the soil types can be categorized as Laterite soil, Moorum / red soil, Desert sands, Alluvial soil, Clay including Black cotton soil.

The following tests are used to evaluate the strength properties of soil.

**TABLE 3 TESTS ON SOIL**

| **Shear Test** | **Bearing Test** | **Penetration test** |
|---|---|---|
| These are usually carried out on relatively small soil samples in the laboratory | These are loading tests carried out on subgrade soil in situ with a load bearing area | These may be considered as small scale bearing tests in which the size of the loading area is relatively much smaller and ratio of the penetration to size of loaded area is much greater than the ratios in bearing tests. |
| Direct Shear Test (Lab)<br>Triaxial Compression Test (Lab)<br>Unconfined Compression Test (Lab)<br>(3) Vane shear test (field) | Plate Bearing Test | California Bearing Ratio Test |

**DIRECT SHEAR TEST**

This test is used to determine the shear parameters (cohesion and angle of internal friction) of a soil sample and to determine the stress-strain characteristics. Shear strength of the soil means the maximum resistance offered by the soil against shearing forces. Failure occurs by slip for cases where the shearing force exceeds this particular value.

By Coulomb's law, S = C+□ tan □

Where S-Shear resistance or shear strength of soil, □-the normal stress applied, C-cohesion of the soil and □-Angle of internal friction of the soil

A direct shear test is one in which failure of a soil specimen in shear is caused along a pre-determined plane. The shear force and the normal load are applied directly to the specimen.

**Apparatus**

- Shear box. container for shear box, grid plates, porous stones, base plate, loading pad
- Loading frame for applying shear force at a constant rate of shearing displacement (with different speeds)
- Loading yoke for applying normal loads
- Weights.
- Proving ring- to measure shear load
- Dial gauges- 2 nos with least count of 0.01 mm
- Balance, spatula, straight edge etc.

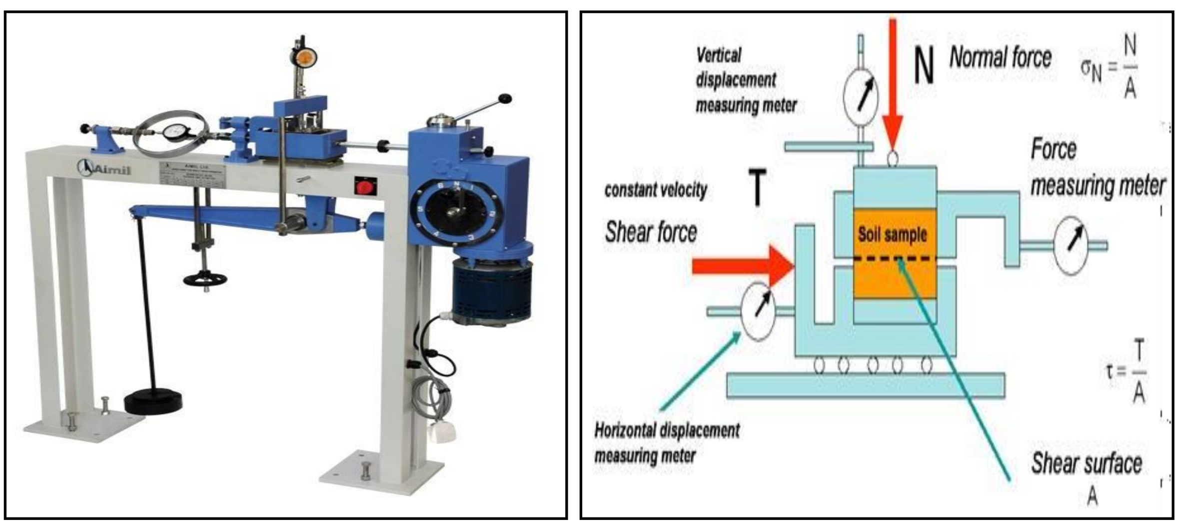



**FIG.3 DIRECT SHEAR TEST APPARATUS**

**Test Procedure**

- The required quantity of sand is weighed to make the volume of the test specimen in shear box as per the density specified.
- The two halves of the shear box are held together by locking pins, the bottom plate is inserted and on the top of this, the plane grid is placed with segregations at right angles to the direction of shear.
- The sample is prepared over the arrangement.
- The plane grid is inserted on the top of the specimen and insert the top loading plate
- The shear box is kept in the container for shear and set up the loading frame.
- The loading arm of the shear box is kept in contact with the proving ring. The normal load is applied on the soil sample.
- The locking pins are removed
- The sample is sheared at a constant rate of deformation ( 1.25mm/rnin)
- The maximum reading of the proving ring is noted which gives the shear load
- The test is repeated on fresh samples of sand with different normal loads and the shear load at failure is noted in each case.
- For the last normal load, dial gauges are attached so that the normal and shear displacements are measured until the soil fails.

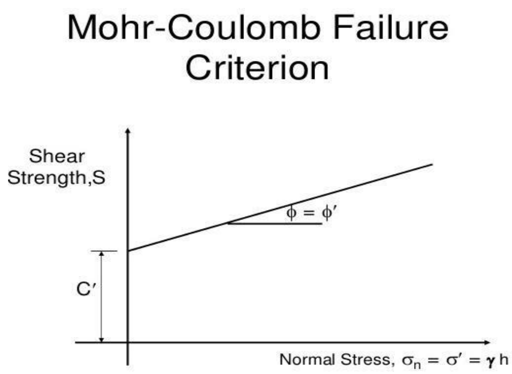



**FIG.4 SHEAR FAILURE PROFILE**

The graph is plotted for normal stress vs peak values of shear stress.

For the last normal load the following graphs are also drawn.

- Shear stress by normal stress Vs shear displacement
- Shear displacement Vs normal displacement.

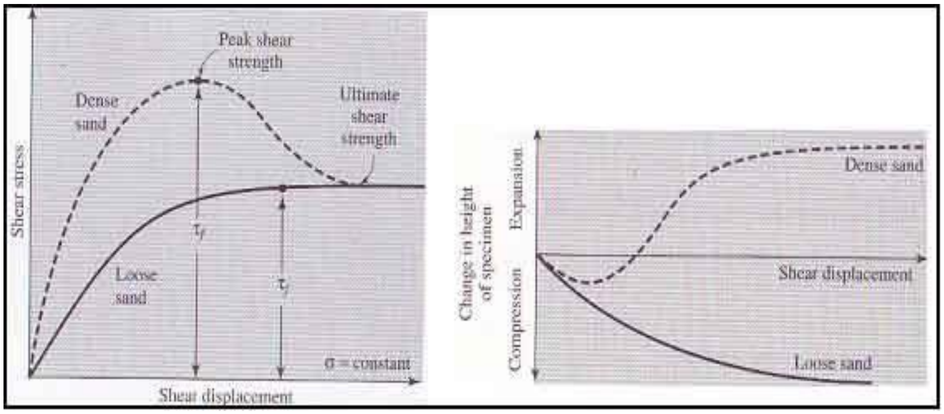



**FIG.5 SHEAR DISPLACEMENT PROFILE**

The Mohrs circle is drawn and the principal stresses at failure for a particular normal stress is determined.

Observation

Constant-of proving ring 1 div = 0.455kg

Wt. of loading hanger = 5.25 kg

Size of shear box =

Rate of strain =

L.C. of horizontal displacement dial =

L.C. of vertical displacement dial =

**TABLE 4 SHEAR TEST DATA**

| Trial No. | Normal Load, kg | Normal Stress, kg/cm$^2$ | Proving Ring reading (N) | Shear load N x 0.455 | Shear stress, kg/cm$^2$ |
|---|---|---|---|---|---|
| | | | | | |

**TABLE 5 SHEAR DISPLACEMENT DATA**

| Shear Displacement | | Normal Displacement | | Shear Load | | Shear Stress | Normal Stress |
|---|---|---|---|---|---|---|---|
| Dial Reading | Displacement (mm) | Dial Reading | Displacement (mm) | Proving Ring | Load (kg) | | |
| | | | | | | | |

Cohesion (C), Angle of internal friction, Normal stress, Minor principal stress, Major Principal Stress and Direction of plane of rupture with the major principal plane are noted.

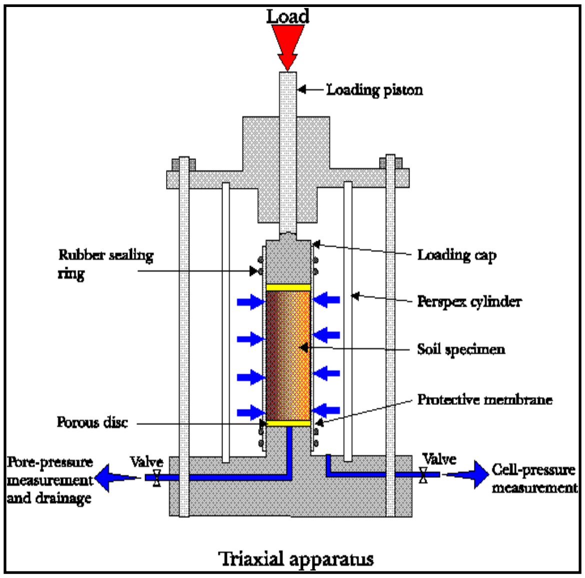
## TRIAXIAL COMPRESSION TEST

(Ref: IS 2720 (Part 11) – 1993

The test is to determine shear parameters of undisturbed soil specimen in the triaxial compression apparatus by unconsolidated un-drained test without the measurement of pore pressure.

**Theory:**

The Triaxial compression test is used for the determination of shear characteristics of all types of soils under different drainage conditions. In this test, a cylindrical specimen is stressed under conditions of axial symmetry as shown in fig.



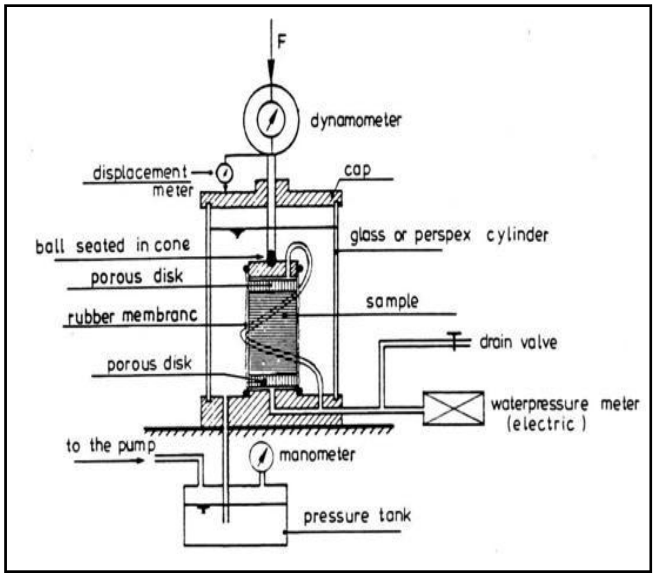




**FIG.6 TRIAXIAL COMPRESSION TEST APPARATUS**

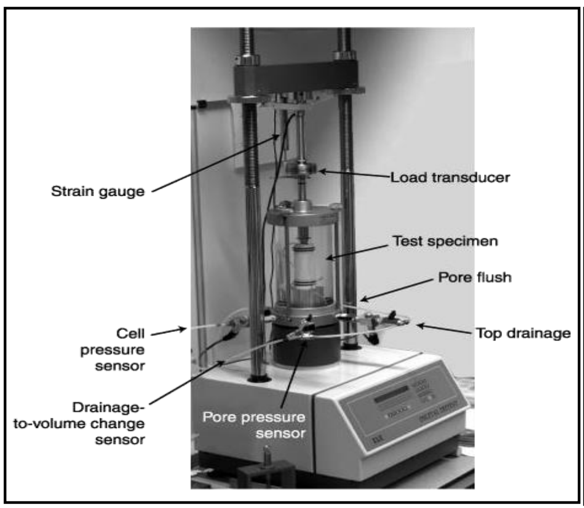



**FIG.6 TRIAXIAL COMPRESSION TEST APPARATUS**

In this test, the applications of the all-round pressure and of the deviator stress form two separate stages of the test. The first stage is known as the consolidation stage and the specimen is subjected to an all round confining pressure (□c). In the second stage of the test, called the shearing stage, an additional axial stress, known as the deviator stress (□d) is applied on the top of the specimen through a ram. Thus the total stress in the axial direction at the time of shearing is equal is (□c + □d).

Apparatus

- Triaxial cell, with all accessories.
- Apparatus for applying and maintaining the desired fluid pressure in the cell
- Compression machine, capable of applying axial compression to the specimen, at convenient speeds
- Dial gauge to measure axial compression
- Seamless rubber membranes
- Membrane stretcher
- Rubber rings
- Split mould, trimming knife, sample extruder, thin walled rubes
- Water content determination containers
- Balance
- Stop watch

**Test Procedure**

- An air dried soil is taken. The required amount of water is mixed up to give a required density for a given volume. The soil is compacted in constant volume. The hollow cylindrical cutters are pressed into the compacted soil and the requisite size specimen is obtained.
- The pedestal in the triaxial cell is covered with a solid end cap or the drainage valve is kept closed. The specimen assembly is placed centrally on the pedestal. The cell is assembled with the loading ram initially the top of the specimen is cleared and placed it in the loading machine
- The operating fluid is admitted in the cell, and its pressure is raised to the desired value. The loading machine is adjusted to bring the loading ram a short distance away from the seat on the top cap of the specimen. The initial reading of the load measuring gauge is noted. The loading machine is adjusted so that the loading ram comes just in contact with the seat of the top of the

specimen. The initial reading of the dial measuring axial compression is noted.

- The compressive force at constant rate of axial compression is applied. The simultaneous readings of load and deformation dials are taken, and the stress strain curve is defined. The test until failure or 20% axial strain is continued.
- Upon completion of the test, the loading is shut off. The specimen is unloaded and cell fluid is drained off. The cell is dismantled and the specimen is taken out. The samples for water content determination are kept.
- The test is repeated on three or more identical specimens under different cell pressures

**Observation**

Height of specimen 'I' - Area '$A_0$' Diameter - Volume-

Initial weight: Initial water content

Final weight: Final water content Cell pressure (□$_3$)

Load gauge constant

**TABLE 6 TRIAXIAL COMPRESSION TEST DATA**

| Compression dial reading | Load gauge reading | Compression of sample | Strain 'e' | Corrected area | Load | Vertical Stress | Deviator Stress |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**TABLE 6 TRIAXIAL COMPRESSION TEST OUTPUT**

| Test No | Cell pressure | Deviator stress at failure | at failure |
|---|---|---|---|
| | | | |

**Graphs**

- A graph with deviator stress on the Y axis and % strain on the X'-axis is plotted to obtain deviator stress at failure. The deviator stress at failure (□ -□3) is known as the compressive strength of the soil.
- Mohr's circles are plotted with minor principal stress (□3) is equal to the cell pressure (□c). The major principal stress (□1) is equal to the sum of the cell pressure and the deviator stress. For different cell pressures, Mohr circles are drawn and thus obtaining the failure envelopes.

**UN CONFINED COMPRESSION TEST**

**(**Reference: IS: 2720 Part (10)-1991)

This test is used to determine the unconfined compression of clayey soils using controlled strain.

**Definition and Theory**

Unconfined compressive strength is the maximum compressive stress which a cylindrical soil sample is able to carry when its sides ere net confined The U.C.C. test is sometimes referred to as un-drained test, because the condition □ =0 is same as that developed in unconsolidated un-drained test of saturated soils. In a plot of normal stress Vs shear stress all the Mohr circles will pass through the origin. Mohr-envelop are horizontal. Shear strength due to cohesion is given by half the compressive strength. Because of the lack of Lateral support, the compressive strength is given by UCC test is lower than those given by other tests.

Some amount of confining effect is provided by the surface tension due to moisture in the soil and will be more if the soil is saturated. But in this test the internal soil condition like pore water pressure and degree of saturation can't be controlled. The friction at the ends of the test specimen provides a lateral restraint which alters the internal stress and this friction can be minimised by using special conical, lubricated end plates. In this test more uniform stresses and strains are developed and failure surface will tend to form in the weakest portion and not along a predetermined surface.

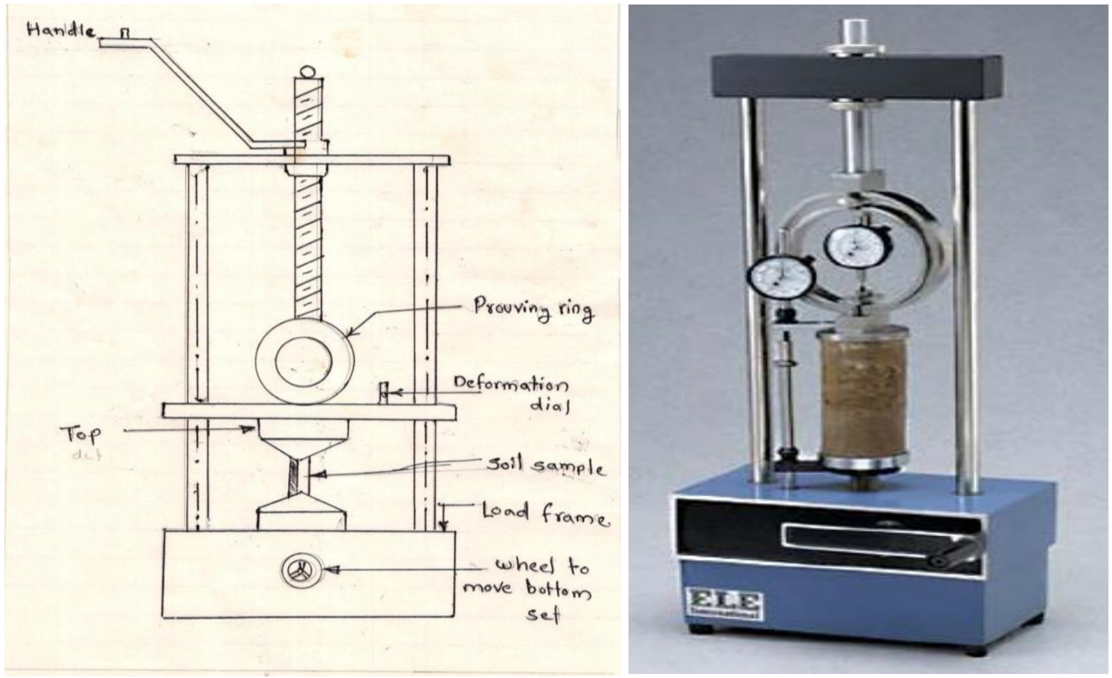



**FIG.7 UN CONFINED COMPRESSION TEST**

## Apparatus

- Load frame to apply compressive load at constant rate of strain
- Proving ring
- Dial gauge
- Vernier calipers
- Split moulds and compaction device for making remolded specimens

## Test Procedure

- The cylindrical soil sample at the required density and water content is prepared 1 : 2 ratio dia to height.
- The length and cross-sectional area (A) 01 the sample is measured.
- The cylindrical soil sample in the machine is placed.

- The dial gauge and the proving ring are set up to measure deflection and axial load
- A strain -rate of 0.5 to 1.0 percent per minute is used.
- The proving ring reading corresponding to specific deformation dial readings is recorded.
- The sample is compressed until failure planes have definitely developed or the stress strain cure is well past its peak or until an axial strain of 20 percent is reached
- The failure pattern is sketched.
- Moisture content of the specimen is found
- The graph is plotted for stress Vs % strain graph with stress in $kg/cm^2$ along Y axis and % of strain along X-axis

**Observation**

Sample diameter

Cross-sectional area of the sample (A) =

Height of the sample =

Strain rate =

Proving ring constant =

Least count of deformation dial gauge =

**TABLE.7 UN CONFINED COMPRESSION TEST**

| Sl. No | Proving ring reading | Load kg | Deformation Dial gauge reading | Compression □1 | Strain □1 / l = e | Increased c/s area of sample $A_1 \square \frac{A}{1 \square e}$ | Actual stress load A1 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

**Graph**

- The unconfined compressive strength (qu) is determined from the graph
- The Mohr's circle is drawn for the soil sample.

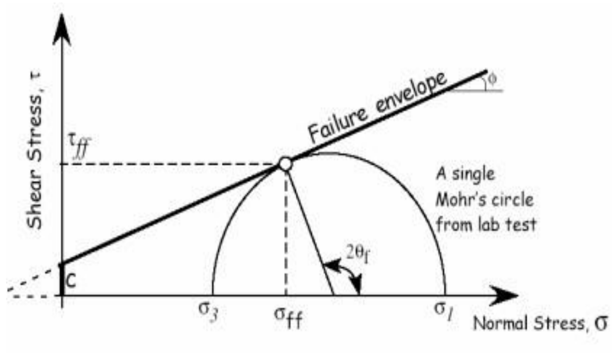



**FIG.7 MOHRS CIRCLE**

Unconfined compressive strength of the soil (qu), The angle of internal friction of soil ( ),

The shear strength of soil at failure, The normal stress at failure and Cohesion of soil (c) are listed.

**PLATE BEARING TEST**

This test is used to evaluate the supporting power of subgrade.

**Apparatus**

- Set of plates of diameters 75, 60, 45 and 30 cm
- A loading device consisting of jack and a proving ring arrangement
- A reaction frame against which the jack can give a thrust to the plate
- A datum frame with a dial gauge fitted to measure the settlement and resting far from the loaded area

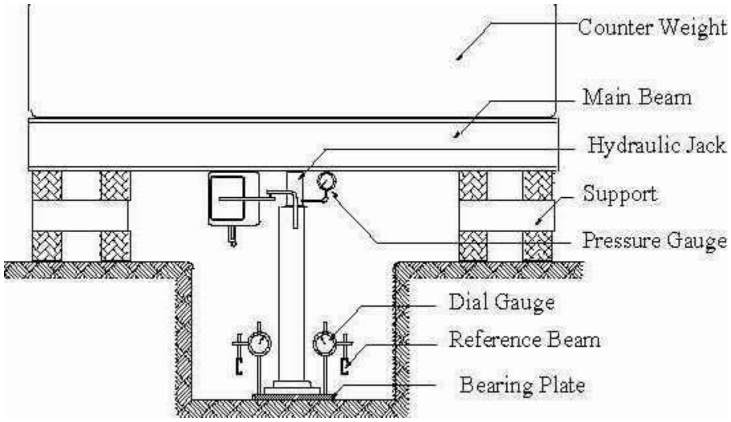



**FIG.8 PLATE BEARING TEST**


**FIG.8 PLATE BEARING TEST ARRANGMENT**


**FIG.8 PLATE BEARING FIELD TEST**

**Procedure**

- The test site is levelled and the test plate is properly seated on the prepared surface.
- The stiffening plates of decreasing diameters are placed centrally on the test plate
- Jack and the proving ring assembly are fitted to provide reaction against the frame
- Three or four dial gauges are fitted to the independent datum frames and positioned on the periphery of the test plate
- A seating load of 0.07 kg/cm$^2$ is applied and released after a few seconds
- A load sufficient to cause a settlement of 0.25 mm is applied
- If there is no appreciable increase in settlement or when the rate of settlement is less than 0.025 mm per minute, the readings of the settlement gauges are taken
- Average settlement is found and at the same time the proving ring dial reading is noted to calculate the load
- The load is then increased till the settlement increases to a further amount of about 0.25 mm and the average settlement and the load from proving ring reading are found
- The procedure is repeated till the settlement reaches a value of 0.175 cm.
- The load calculated from proving ring readings are divided by the area of the plate and the

pressure corresponding to 0.25 mm, 0.50 mm, etc up to 0.175 cm are calculated and the graph is plotted as bearing pressure Vs Mean settlement.

The pressure p corresponding to deflection 0.125 cm is read. Then the modulus of subgrade reaction K is calculated by the relation

$$K = \frac{p}{0.125}$$

kg / cm$^2$ / cm

**CALIFORNIA BEARING RATIO TEST**

To determine the California Bearing Ratio value of the given soil specimen.

Apparatus

- CBR Test apparatus
- Rammer

**Machine Description**

The laboratory CBR apparatus consists of a mould 150 mm diameter with a base plate and a collar, a loading frame with the cylindrical plunger of 50 mm diameter and dial gauges for measuring the expansion on soaking and the penetration values.

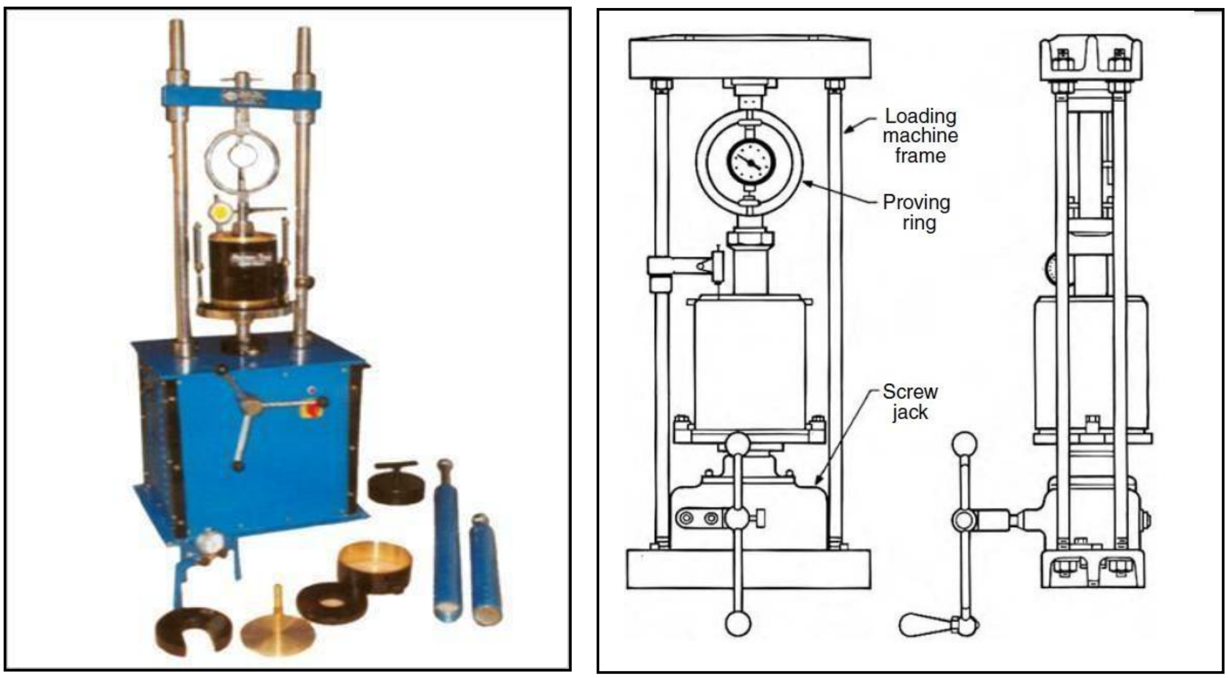



**FIG.8 CALIFORNIA BEARING RATIO TEST APPARATUS**

**Procedure**

- The specimen is filled in the mould in 3 layers and compacted by a rammer.
- The specimen in the mould is subjected to 4 soaking 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.
- The load values are noted corresponding to penetration values of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.
- The load-penetration graph is plotted.
- From the graph, loads corresponding to 2.5 and 5.0 mm penetration values are noted.
- The CBR value is calculated using the formula given below for 2.5mm and 5.0 mm penetration values.
- Normally the CBR value at 2.5 mm penetration which is higher than at 5.0 mm is reported as CBR value of the material.
- If the CBR value obtained from the test at 5.0 mm penetration is higher than at 2.5 mm, the test is to be repeated for checking.

**Formula**

$$\text{CBR (\%)} = \frac{\text{Load sustained by the specimen at 2.5 or 5.0 mm penetration}}{\text{Load sustained by the standard aggregates at the corresponding penetration level}} \times 100$$

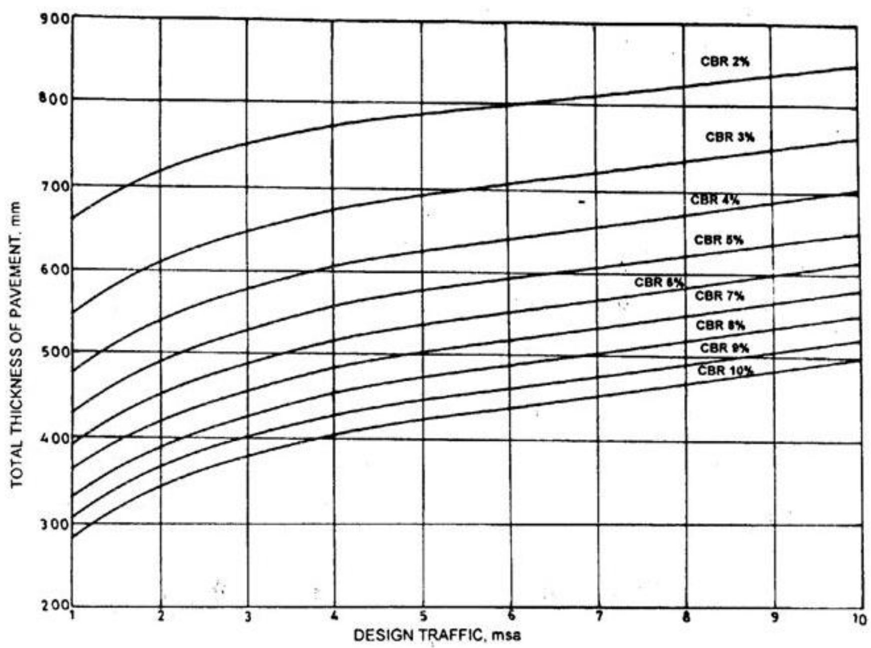
The standard load values obtained from the average of a large number of tests on aggregates are:

At 2.5 mm, Std. Load value = 1370 kg At 5.0 mm, Std. Load value = 2055 kg Tabulation

### TABLE.8 CALIFORNIA BEARING RATIO TEST APPARATUS

| S.No. | Penetration (mm) | Load (kg) |
|---|---|---|
| | | |

**Graph**




Pavement Thickness Design Chart for Traffic 1-10 msa

**FIG.9 CALIFORNIA BEARING RATIO VALUE WITH PAVEMENT THICKNESS**

## VANE SHEAR TEST

**FIG. VANE SHEAR APPARATUS**

**FIG. VANE SHEAR NEEDLE**

**FIG. VANE SHEAR MOULD**

- Clean the vane shear apparatus and apply grease to the lead screw for better movement of handles.
- Take the soil specimen in container which is generally 75 mm in height and 37.5 mm in diameter.
- Level the soil surface on the top and mount the container on the base of vane shear test apparatus using screws provided.
- Lower the vane gradually into the soil specimen until the top of vane is at a depth of 10 to 20 mm below the top of soil specimen.
- Note down the reading of pointer on circular graduated scale which is initial reading.
- Rotate the vane inside the soil specimen using torque applying handle at a rate of $0.1^{o}$ per second.
- When the specimen fails, the strain indicator pointer will move backwards on the circular graduated scale and at this point stop the test and note down the final reading of pointer.
- The difference between Initial and final readings is nothing but the angle of torque.

  - Repeat the procedure on two more soil specimens and calculate the average shear strength value.
  - Measure the diameter and height of vane using Vernier callipers.

- Sensitivity of given soil sample is determined by repeating the above test procedure on remoulded soil which is nothing but soil obtained after rapid stirring of vane in the above test.
- Sensitivity of soil = undisturbed shear strength/ remoulded shear strength.

## AGGREGATES

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete). By volume, aggregate generally accounts for 92 to 96 percent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a bye product of other manufacturing industries.

**The desirable properties of aggregates** are:

**Strength** –

The aggregates used in top layers are subjected to

- Stress action due to traffic wheel load,
- Wear and tear,
- 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 cause 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 material otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

**Durability** –

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

**Freedom from deleterious particles** –

Specifications for aggregates used in bituminous mixes usually require the aggregates to be clean, tough and durable in nature and free from excess amount of flat 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, silt and other organic impurities.

## TEST FOR ROAD AGGREGATES

## CRUSHING VALUE TEST

These measures the resistance the test sample offers to crush under a gradually applied crushing load

**Apparatus required**

The apparatus for the standard aggregate crushing test as per IS 2386 – 1963 (part IV) consists of the following.

- The test mould of 15.2 cm diameter open ended steel cylinder with square base plate plunger having a piston of diameter 15 cm, with a hole provided across the stem of the plunger so that a rod could be inserted for lifting or placing the plunger in the cylinder.
- A straight metal tamping rod of circular cross section 16 cm in diameter and 45 to 60 cm long, rounded at one end.
- A balance of capacity 5kg readable and accurate up to 1 gm.
- IS sieves of sizes 12.5mm, 10mm and 2.36 mm
- A compression testing machine capable of applying load up to 40 tons at a uniform rate of 4 tons per minute.
- A cylindrical measure having internal diameter of 11.5 cm and height 18 cm.

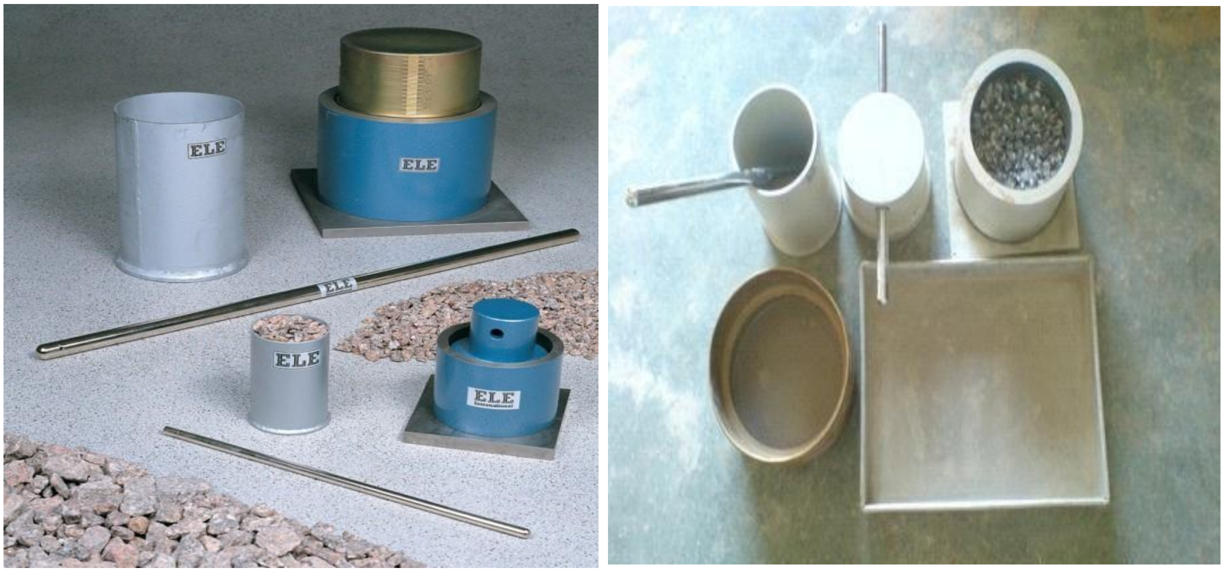



**FIG. 10 AGGREGATE CRUSHING VALUE TEST APPARATUS**


**FIG. 10 AGGREGATE CRUSHING VALUE TEST APPARATUS JAR**

**Procedure**

- The material for the standard test consists of aggregates sized 10 mm to 12.5 mm. The aggregates should be in surface dry conditions before testing. The aggregates may be dried by heating at 100 – 110 c for not more than 4 hours and cooled to room temperature before testing, if necessary.

- The material is sieved through 12.5mm and 10mm IS sieves. The aggregates passing through 12.5mm sieves and retained on 10mm sieve comprises the test material.
- About 3.25kg of this material is taken.
- The aggregates are poured to fill about just one third depth of measuring cylinder.
- The material is compacted by giving 25 gentle blows with the rounded end of the taming rod.
- Two more layers are added in similar manner, so that cylinder is full.
- The excess material is removed with a straight edge. The quantity contained in the measuring cylinder is that amount of aggregates with will be used to prepare the test specimen.
- The weight of the aggregates is taken after emptying the cylinder to an accuracy of 1gm.
- The whole of this weighed quantity is transferred to the test mould by filling in the three layers in the same manner as for cylindrical measure. The total depth of the sample is then about 10 cms and the surface a little below the top of mould.
- The surface is leveled and the plunger is placed over it so that it rests horizontally on the surface of the aggregates.
- This assembly is placed on the pedestal of compression testing machine and apply load up to 40 tones.
- The load is applied at a uniform rate of 4 tons per minute until the total applied load is 40 tones.
- The load is released.
- The aggregate are taken out of cylinder and sieve them through 2.36mm IS sieve. This fraction passing through is weighed it to an accuracy of 0.1 gm. This fraction is a measure of loss of material due to crushing.
- The observations are noted down and the aggregates crushing value is computed. The mean of two observations, rounded to nearest whole number is reported as the Aggregate

crushing Value.

**TABLE 9 AGGREGATE CRUSHING VALUE TEST**

| **Observations** | **Sample I** | **Sample II** |
|---|---|---|
| Total weight of dry sample taken ( $W_1$ gm ) | | |
| Weight of portion passing 2.36mm Sieve ( $W_2$ gm ) | | |
| Aggregate Crushing Value ( % ) =( $W_2/W_1$ )X 100 | | |

## AGGREGATE IMPACT TEST

It is the relative measure of resistance of aggregates to sudden shock of impact.

### Apparatus required

The apparatus for the standard aggregate impact test as per IS 2386 – 1963 (part IV) consists of the following.

- A testing machine weighing 45 to 60 kg and having a metal base with a plane lower surface of not less than 30 cm in diameter. It is supported on level and plane concrete floor of minimum 45 cm thickness. The machine should also have provisions for fixing its base.
- A cylindrical steel cup of internal diameter 102mm, depth 50mm and minimum thickness 6.3mm.
- A metal hammer or tube weighing 13.5 to 14kg with lower end in cylindrical shape is 50mm long, 100mm diameter with a 2mm chamfer at the lower edge and case hardened. The hammer should slide freely between vertical guides and be concentric with the cup.
- A cylindrical metal measure having internal diameter of 75mm and depth 50mm for measuring aggregates.
- A balance of capacity not less than 500gm, readable and accurate up to 0.1g

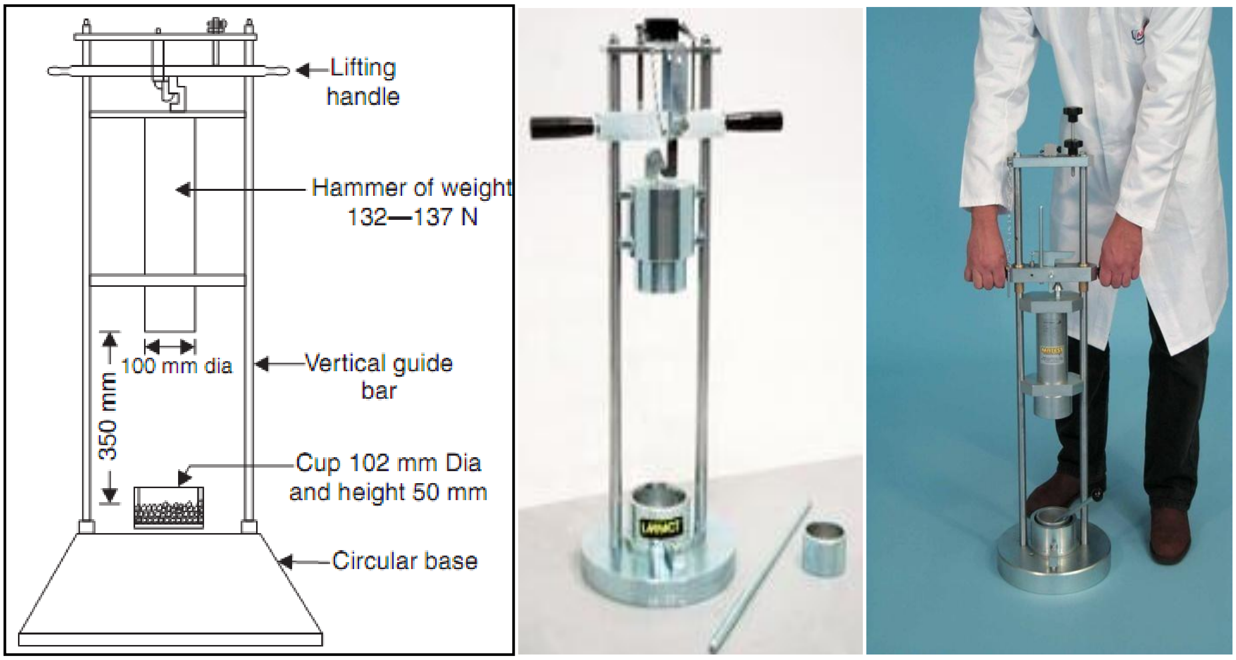



**FIG. 11 AGGREGATE IMPACT TEST APPARATUS**

**Procedure**

- The test sample: It consists of aggregates sized 10mm to 12.5mm. The aggregates should be dried by heating at 100 – 110˚c periods of 4 hours and cooled.
- The material is sieved through 12.5mm and 10mm IS sieves. The aggregates passing through 12.5mm sieve and retained on 10mm sieve comprises the test material.
- The aggregate is poured to fill about just one – third depth of measuring cylinder.
- The material is compacted by giving 25 gentle blows with the rounded end of the tamping rod.
- Two more layers are added in similar manned, so that cylinder is full.
- The surplus aggregates are strike off.
- The net weight of the aggregates is determined to the nearest gram ($w_1$ )
- The impact machine is brought to rest without wedging or packing upon the level plate, block or floor so that it is rigid and the hammed guide columns are vertical.

- The cup is fixed firmly in position on the base of the machine and plate whole of the test sample in it and compact by giving 25 gentle strokes with taming rod.
- The hammer is raised until its lower face is 380mm above surface of the aggregate sample in the cup and allows it to fall freely on the aggregate sample. Give 15 such blows at an interval of not less than one second between successive falls.
- The crushed aggregates is removed from the cup and sieve it through 2.36mm IS sieves until no further significant amount passes in one minute. The fraction passing the sieve is weighed to an accuracy of 1gm ($w_2$). Also the fraction retained in the sieve is weighed.
- The observations are noted down and the aggregate impact value is computed. The mean of two observations, rounded to nearest whole number is reported as the 'Aggregate Impact Value.

**TABLE 10 AGGREGATE IMPACT TEST**

| **Observations** | **Sample I** | **Sample II** |
|---|---|---|
| Total weight of dry sample taken ( $W_1$ gm ) | | |
| Weight of portion passing 2.36mm Sieve ( $W_2$ gm ) | | |
| Aggregate Impact Value ( % ) =( $W_2/W_1$ )X 100 | | |

Aggregate impact value is used to classify the stones in respect of their toughness property as indicated below.

**TABLE 11 AGGREGATE IMPACT VALUES**

| **Aggregate Impact Value** | **Classification** |
|---|---|
| 10 % | Exceptionally strong |
| 10 – 20 % | Strong |
| 20 – 30 % | Satisfactory for road surfacing |
| 35 % | Weak for road surfacing |

## SPECIFIC GRAVITY, DENSITY AND WATER ABSORPTION TEST

### SPECIFIC GRAVITY

It is the ratio of the weight of a given volume of aggregate, including the permeable and impermeable voids in the particles, to the weight of an equal volume of water. Bulk specific gravity of aggregate is important information for designing HMA because it is used to calculate VMA and VFA. Since different procedures are used to determine the Gsb of coarse and fine aggregate, this section is divided into two parts, one for coarse aggregate and one for fine aggregate.

### Significance of the Test

Specific gravity of aggregates is made use of in design calculations of concrete mixes. By knowing the specific gravity of each constituent, the theoretical yield of concrete per unit volume can be calculated. Specific gravity of aggregate is also required in calculating the compaction factor in connection with the workability measurements. Bulk density or unit weight of an aggregate gives valuable information regarding the shape and grading of the aggregate. It is used in proportioning of concrete mix. The sample which gives the maximum bulk density is taken as the right sample of aggregate for making economical mix. The absorption of aggregate will affect the water/ cement ratio and hence the workability of concrete. It will also affect of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

### Apparatus required

- Wire basket
- Cylinder of standard size
- Tamping rod 16mm diameter and 60 cm long
- Balance
- Scale
- Dry cloth

**Procedure**

- Sample of aggregate not less than 2 kg is taken and thoroughly wash it to remove the finer particles and dust adhering to the aggregates.
- It is placed in wire basket and kept immersed in distilled water at a temperature between $22^{o}$ C and $32^{o}$ C.
- The entrapped air is removed from the sample by lifting the basket 25mm above the tank and allowing it to drop 25 times at the rate of about one drop per second. During the operation care is taken that the basket and aggregate remain completely immersed in water.
- The basket is shacked and aggregate are weighed it in water at a temperature $22^{o}$ C and $32^{o}$

  C. Let it be $W_1$ gm.
- The basket and aggregate are removed from water and allowed it to drain for few minutes. The aggregates are taken from the basket and placed in on dry cloth and the surface is gently dried with cloth. The aggregates are transferred to the second dry cloth and dry further.
- The empty basket is immersed again in water and shaked 25 times and weighed it in water. Let it be $W_2$ gm.
- The aggregate is dried in atmosphere away from direct sunlight for 10 minutes.
- The aggregate is weighed in air. Let it be $W_3$ gm.
- The aggregate is kept in oven at a temperature of $100^{o}$ C to $110^{o}$ C.
- The aggregates are cooled and weighed it. Let it be $W_4$ gm.

- The specific gravity and water absorption are calculated using the formulae.


**FIG. 11 AGGREGATE SPECIFIC GRAVITY TEST APPARATUS**

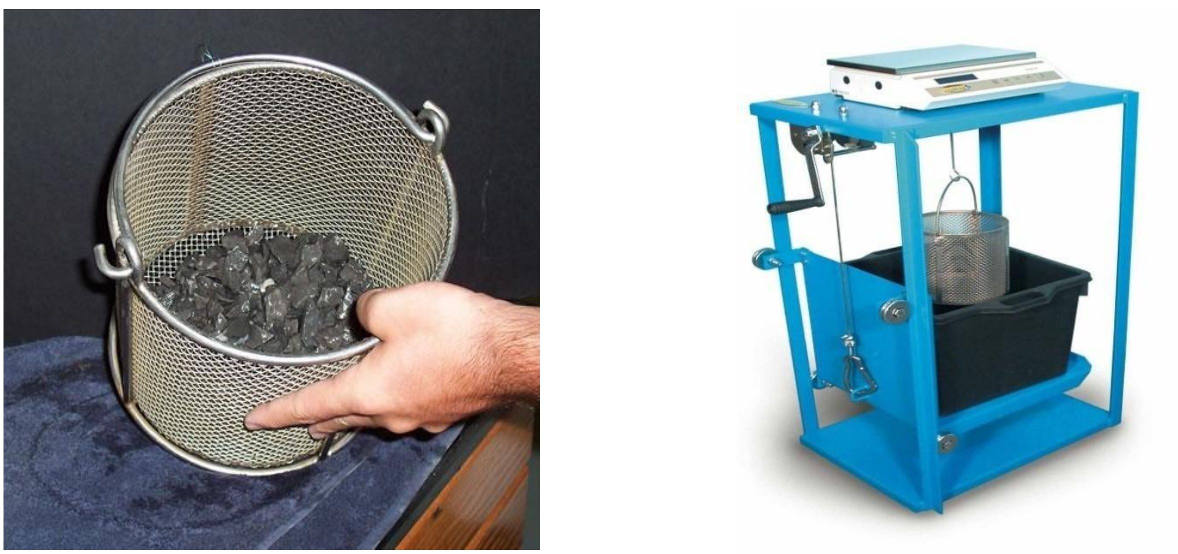


**FIG. 12 AGGREGATE WATER ABSORPTION TEST APPARATUS**

**Specific gravity and water absorption observation**

Weight of basket + aggregate in water $W_1$ = gm

Weight of basket in water $W_2$ = gm

Weight of saturated surface dry aggregate in air $W_3$ = gm

Weight of oven dried aggregate in air $W_4$ = gm

**Calculation**

Weight of saturated aggregate in water W = $(W_1 – W_2)$ gm Specific gravity = $W_4$ / $(W_3$ – W) gm

Water absorption, % = $((W_3 - W_4) / W_4)$ X 100

**BULK DENSITY**

- The internal diameter (d) and height (h) of the cylinder are measured and weight of the cylinder is taken. Let it be $W_1$ gm.
- The cylinder is filled with about one – third each time with thoroughly mixed aggregate and tamped it with 25 strokes by a tamping rod.
- Carefully struck off level using tamping rod as straight edge. Determine and weigh the cylinder with aggregate. Let it be $W_2$. Gm.
- The Bulk density of the aggregate is calculated.

Bulk density observation

Internal diameter of cylinder (d) = cm

Height of cylinder (h) = cm

Weight of empty cylinder $(W_1)$ = gm

Weight of cylinder + aggregate $(W_2)$ = gm

Calculation

Volume of cylinder (V) = $m^3$

| | | |
|---|---|---|
| Weight of aggregate (w) | = | gm |
| Bulk Density of aggregate | = | kg/m$^3$ |

## SHAPE TEST FOR AGGREGATES

### Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than 0.6 times of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm.

### Elongation Index

The elongation index of aggregate is the percentage by weight of particles in it whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

### Angularity Number

The shape of aggregate can be expressed by a parameter called Angularity Index which depends on Angularity number. If the void is 33% the angularity of such aggregate is considered zero. If the void is 44% the angularity number of such aggregate is considered as 11. Angularity number zero represents the most practicable rounded aggregates and the angularity number 11 indicates the most angular aggregates that could be tolerated for making concrete.

### Apparatus Required

- Balance to weigh coarse aggregate with cylinder
- Cylinder of 3 liters Capacity
- Thickness gauge
- Length gauge
- I.S. sieve - 63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm and 6.3 mm.

### Significance of the Test

In reinforced concrete construction, the size of aggregates affects the thickness of section, spacing of reinforcement and clear cover. The cement content and water requirements depend on the size of aggregates. It also affects the mixing, handling and placing of

concrete. Hence the flakiness index and Elongation index of aggregates are determined which are measures of size of aggregates.

The shape of aggregates is an important characteristic since it affects the workability of concrete and hence the water/cement ratio. Water/cement ratio affects the strength of concrete. The shape of aggregate also influences the interlocking effect and hence a knowledge about shape of aggregate expressed as angularity number is necessary.

### Procedure

Flakiness Index

- First the weight of each fraction of aggregate passing and retained on the specified set of sieves is noted.
- 200 pieces of the aggregate passing 63mm sieve and retained on 50mm sieve be =w1 g.
- Each of the particles from this fraction of aggregate is tried to be passing through the slot of the specified thickness of the thickness gauge.
- The weight of the flaky material passing this gauge is w1 g.
- Similarly the weights of the fractions passing and retained the specified sieves, W1, W2, W3 etc. are weighed and the total weight W1 + W2 + W3 +… = W g is found.
- Also the weights of material passing each of the specified thickness gauges are found = w1, w2, w3… and the total weight of material passing the different thickness gauges = w1 + w2 + w3 + …= w g. is found.
- Then the flakiness index is the total weight of the flaky material passing the various thickness gauges expressed as a percentage of the total weight of the sample gauged.

**Flakiness Index** = (w1 + w2 + w3 + …)/ (W1 + W2 + W3 +…) x 100 percent.

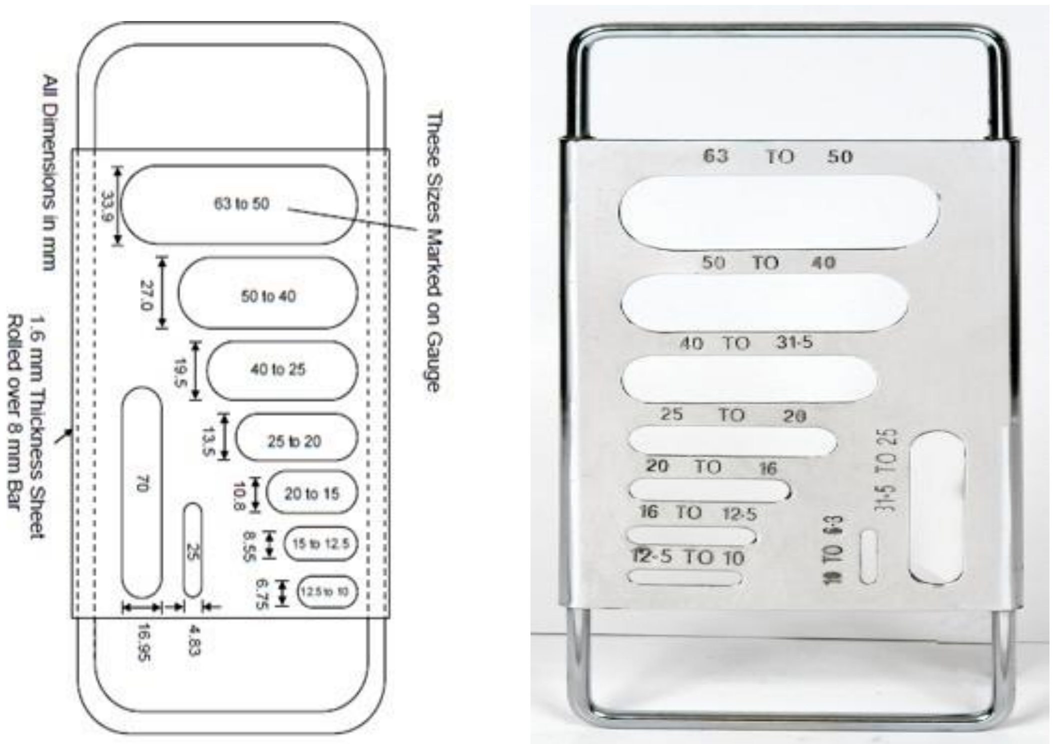



**FIG. 13 AGGREGATE FLAKINESS TEST GAUGE**

Tabulation for flakiness Index

According to IS: 2386 (Part I) - 1963.

**TABLE 12 AGGREGATE FLAKINESS TEST VALUES**

| S. No. | Size of aggregates, mm | | Thickness gauge (mm) | Wt. of aggregates taken, gm (W) | Wt. of aggregates passing on Thickness gauge, gm (w) |
|---|---|---|---|---|---|
| | Passing | Retained | | | |
| 1 | 63 | 50 | 33.90 | | |
| 2 | 50 | 40 | 27.00 | | |
| 3 | 40 | 31.5 | 19.50 | | |
| 4 | 31.5 | 25 | 16.95 | | |
| 5 | 25 | 20 | 13.50 | | |

| | | | | | |
|---|---|---|---|---|---|
| 6 | 20 | 16 | 10.80 | | |
| 7 | 16 | 12.5 | 08.55 | | |
| 8 | 12.5 | 10 | 06.75 | | |
| 9 | 10 | 6.3 | 04.89 | | |

**Elongation Index**

- The weight of the aggregates which is retained on the specified gauge length from each fraction is noted.
- 200 pieces of the aggregate passing 50mm sieve and retained 40mm sieve weight W1 g.
- Each piece of these are tried to be passed through the specified gauge length with its longest side and those elongated pieces which do not pass the gauge are separated and the total weight determined = w1 g. Similarly the weight of each fraction of aggregate passing and the retained on specified sieves sizes are found, W1, W2, W3 …. And the total weight of the sample determined = W1 + W2 + W3 + … = W g.
- Also the weight of material from the each fraction retained on the specified gauge length is found = x1, x2, x3…. and the total weight of the retained determined = x1 + x2 + x3 + …and the total weight retained determined = x1 + x2 + x3 + …=X g.
- The elongation index is the total weight of the material retained on the various length gauges, expressed as a percentage of the total weight of the sample gauged.

**Elongation Index** = (x1 + x2 + x3 + …)/(W1 + W2 + W3 + …) x 100 percent

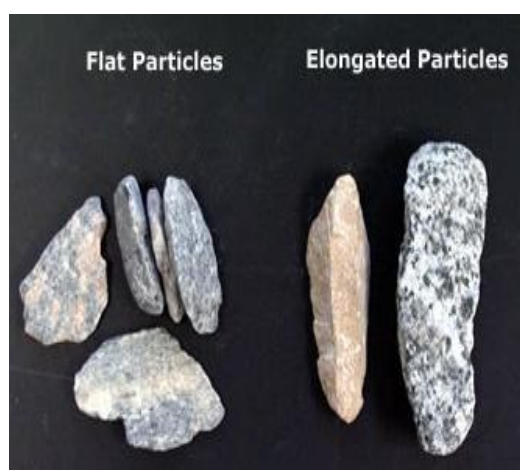



**FIG. 14 ELONGATION LENGTH GAUGE**

**TABLE 13 ELONGATION INDEX VALUE**

| S. No. | Size of aggregates, mm | | ngth gauge, mm | Wt. of aggregates taken, gm (W) | Wt. of aggregates retained on Thickness gauge, gm (w) |
|---|---|---|---|---|---|
| | Passing | Retained | | | |
| 1 | 50 | 40 | 81.0 | | |
| 2 | 40 | 25 | 58.5 | | |
| 3 | 25 | 20 | 40.5 | | |
| 4 | 20 | 16 | 32.4 | | |
| 5 | 16 | 12.5 | 25.9 | | |
| 6 | 12.5 | 10 | 20.2 | | |
| 7 | 10 | 6.3 | 14.7 | | |

Ref According to IS: 2386 (part I) – 1963

**Angularity Number**

- The sample of single sized aggregate retained between the specified pair of sieves is dried in an oven at a temperature $100^o$ C to $110^o$ C for 24 hours
- The aggregate are filled in the cylinder.

- The aggregate in the cylinder are subjected to 100 blows of the tamping rod at a rate of about 2 blows per second.
- The 100 blows must be distributed evenly over the surface to the aggregates
- The aggregate with cylinder is then weighed to the nearest 5 g. The separate determinations are made and the mean weight of the aggregate in the cylinder is calculated.

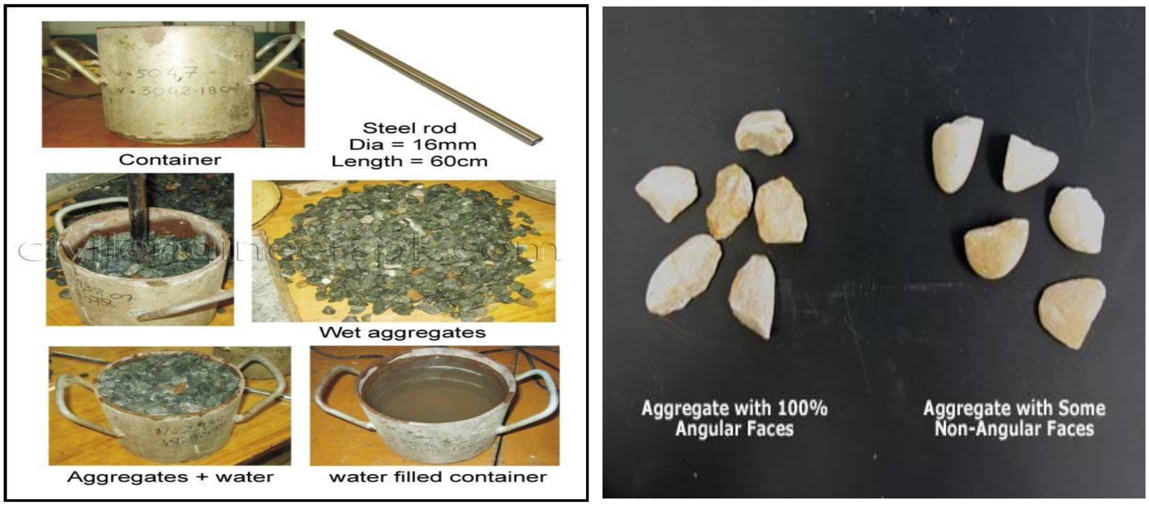



**FIG. 15 ANGULARITY NUMBER OF AGGREGATES**

**TABLE 14 ANGULARITY VALUE OF AGGREGATES**

| **Particulars** | **Trial Number** | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| Weight of aggregate filling the cylinder to the nearest five grams, g (W) | | | | |
| Weight of water filling the cylinder, g (C) | | | | |

Ref According to IS: 2386 (part I) – 1963

Angularity Number = 67 – 100W/CG

Flakiness index of aggregate to be used in road construction should not exceed 25 %. It is preferred if it is kept below 15 %. Value of elongation index should also not exceed 15 % for a good aggregate and normally must not exceed 25 %. Angularity number of a good aggregate should lie between 0 and 10.

**LOS ANGELES ABRASION TEST**

The principle of the Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregate and the steel balls used as abrasive charge. Pounding action of these balls also exist during the test and the resistance to wear and impact is evaluated.

Apparatus Required Los Angeles machine Abrasive charge Machine Description

- The Los Angeles machine consists of a hollow cylinder closed at both ends, having inside diameter 70 cm and length 50 cm and mounted so as to rotate about its horizontal axis.
- The abrasive charge consists of cast iron spheres of approximate diameter 4.8 cm and each of weight 390 to 445 g. The number of spheres to be used as abrasive charge and their total weight have been specified based on grading of the aggregate sample.

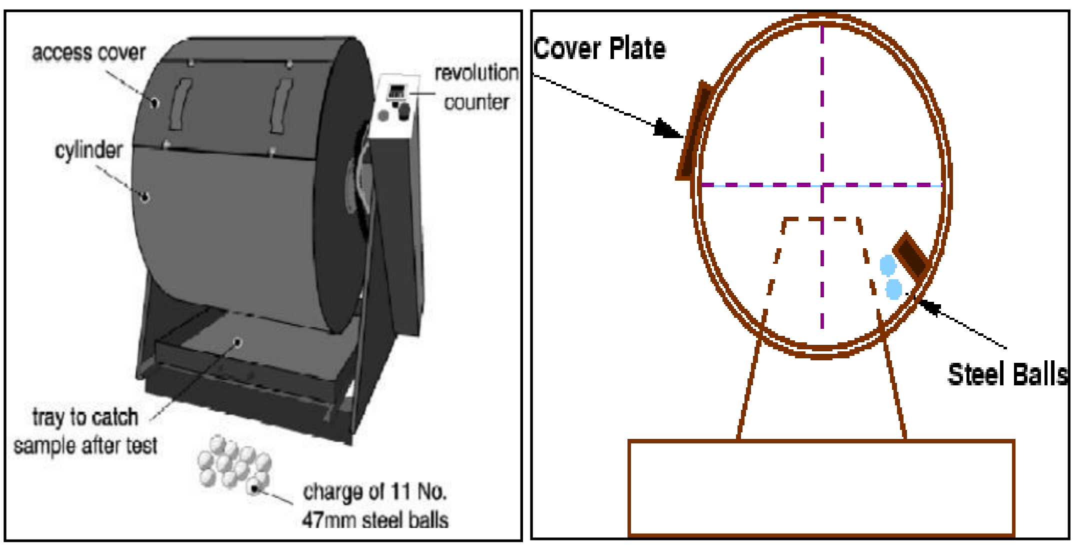



**FIG.16 LOS ANGELES ABRASION TEST APPARATUS**


**FIG.17 LOS ANGELES ABRASION TEST APPARATUS**

**Procedure**

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

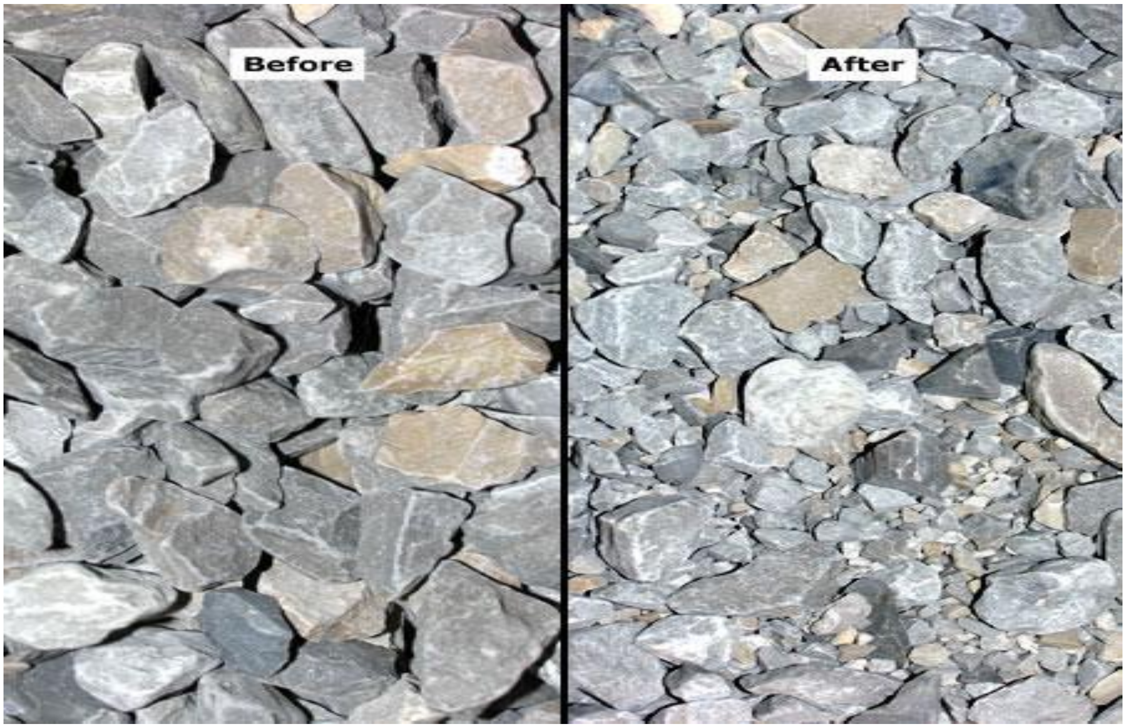



**FIG.18 ABRASION OF AGGREGATES BEFORE AND AFTER ABRATION TEST**

**Observation**

Initial weight of aggregate sample, $W_1$ gm = Weight of the aggregate passing thro' 1.7mm IS sieve, $W_2$ gm =Formula Used

% Percentage wear or abrasive value = $\frac{W2}{W1}$ X 100

According to ISI, acceptable aggregate for cement concrete should have abrasive value of 16 %. For aggregate to be used in bituminous mixes, this value may be allowed up to 30% for quality surface courses and 50% for base courses of bitumen bound macadam.

## BITUMINOUS MATERIALS

Bituminous materials or asphalts are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost.

**Production of Bitumen -** Bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties.

### Vacuum steam distillation of petroleum oils

In the vacuum-steam distillation process the crude oil is heated and is introduced into a large cylindrical still. Steam is introduced into the still to aid in the vaporization of the more volatile constituents of the petroleum and to minimize decomposition of the distillates and residues. The volatile constituents are collected, condensed, and the various fractions stored for further refining, if needed. The residues from this distillation are then fed into a vacuum distillation unit, where residue pressure and steam will further separate out heavier gas oils. The bottom fraction from this unit is the vacuum-steam-refined asphalt cement.

### 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. There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC).

### 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. 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.

**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.

**Requirements of Bitumen**

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should posses following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

**TABLE 15 COMPARISON BETWEEN BITUMEN AND TAR**

| Sl.No. | Bitumen | Tar |
|---|---|---|
| 1 | Hydrocarbon material found in gaseous, liquid, semi-solid or solid form obtained during the distillation of petroleum | Viscous liquid produced when natural organic materials such as coal, petroleum, wood, etc are carbonized. |
| 2 | Blackish Brown colour | Blackish Brown colour |
| 3 | Faster Stripping action | Slower Stripping action |
| 4 | Less Temperature Susceptibility | More Temperature Susceptibility |
| 5 | More durability | Less durability |
| 6 | Good Water Resistance | Poor Water Resistance |
| 7 | Soluble in carbon-di-sulphide | Soluble in Toulene |

**TABLE 16 COMPARISONS BETWEEN DIFFERENT TYPES OF BITUMEN**

| Straight Run Bitumen | Cutback bitumen | Bitumen Emulsion |
|---|---|---|
| It is the one distilled to a definite viscosity or penetration without further treatment | Bitumen mixed with a volatile solvent. | It is the liquid product formed by mixing together molten bitumen with hot water in the presence of an emulsifying agent |
| | Types:<br>Rapid curing (RC) Cutback bitumen<br>Medium curing (MC) Cutback bitumen<br>Slow curing (SC) Cutback bitumen | Types:<br>Rapid Setting (RS)<br>Medium Setting (MS)<br>Slow Setting (SS) |

## TESTS ON BITUMEN

## PENETRATION TEST ON BITUMEN

The penetration test is carried out to find the softness of bitumen by penetration test.

Apparatus

- Container, Needle
- Water Bath
- Penetrometer
- Stop Watch

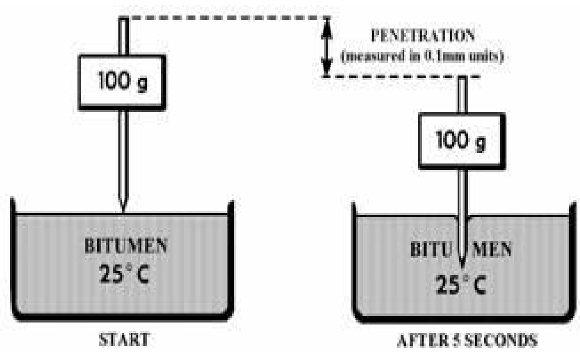



**FIG.19 PENETROMETER APPARATUS**

**Procedure**

- The Bitumen is softened to a pouring consistency between 75° and 100° C above the approximate temperature at which bitumen softens.
- The sample material is then poured into a container to a depth at least 15mm more than the expected penetration.

- The sample containers are cooled in atmosphere of temperature not lower than 13 $^{o}$C for one hour.
- Then they are placed in temperature controlled water bath at a temperature of 25$^{o}$C for a time of one hour.
- The needle is cleaned with benzene, dried and loaded with the weight.
- The total moving load required is 100 + 0.25 gms, including the weight of the needle, carried and super-imposed weights.
- Using the adjusting screw, the needle assembly is lowered and adjusted in such a way that the tip of the needle is in contact with the surface of the sample.
- The pointer of the dial is made to read zero or the initial dial reading is noted.
- The needle is released for exactly five seconds. Final readings are taken on the dial gauge.
- Three penetration tests are made at least on the sample by testing at distances of 10mm apart.
- After each trial, the needle is disengaged and wiped with benzene and dried.
- Mean of three trials is reported as penetration value.

**TABLE 17 PENETROMETER READING ON BITUMEN**

| **Penetrometer dial reading** | **Test 1** | **Test 2** | **Test 3** |
|---|---|---|---|
| Initial | | | |
| Final | | | |
| Penetration value | | | |
| Mean Penetration Value | | | |

Penetration test is a commonly adopted test on bitumen to grade the material in terms of its hardness. A 80/100 grade represents the penetration value ranges between 80 and 100 at standard test conditions. The grading of bitumen helps to assess its suitability for use in different climatic conditions and types of construction. The Penetration values of various types of bitumen used in

pavement construction in this country range between 20 and 225 for bituminous macadam and penetration macadam, IRC suggests bitumen grades 30/40, 60/70 and 80/100. In warmer regions lower penetration grades are preferred to avoid softening whereas higher penetration grades like 180/200 are used in colder regions so that excessive brittleness does not occur. Highest penetration grade is used in spray application works. This test is used for bitumen only and cannot be used for tar as they are very soft materials.

**DUCTILITY TEST ON BITUMEN**

Ductility is the distance in centimeters that a standard briquette of itumen will stretch before breaking.

Apparatus

- Briquette mould
- Ductility machine
- Water bath
- Knife

**Procedure**

- The bitumen sample is melted to a temperature of 75 to 100$^{o}$C above the approximate softening point until it is fluid.
- It is strained thro' IS sieve 30, poured in the mould assembly and placed on brass plate, after a solution of glycerin and dextrin is applied at all surfaces of the mould exposed to bitumen.
- 30 to 40 minutes after the sample is poured into the moulds, the plate assembly is placed in water bath at 27$^{o}$C for 30 minutes.
- The sample and the mould assembly is removed from water bath and excess bitumen material is cut off by leveling the surface using hot knife.
- After trimming the specimen, the mould assembly containing the sample is replaced in water bath maintained at 27$^{o}$C for 85 to 95 minutes.
- The sides of the mould are removed and the clips are carefully hooked on the machine without

any initial strain. The pointer is set to read zero.

- Two or more specimens are prepared in the moulds and clipped to the machine so as to conduct these tests are in operation, it is checked whether the sample is immersed in water at depth of atleast 10 mm.
- The distance at which the bitumen thread of each specimen breaks is recorded (in cm) to report as ductility value.

**FIG. 20 DUCTILITY APPARATUS ON BITUMEN**

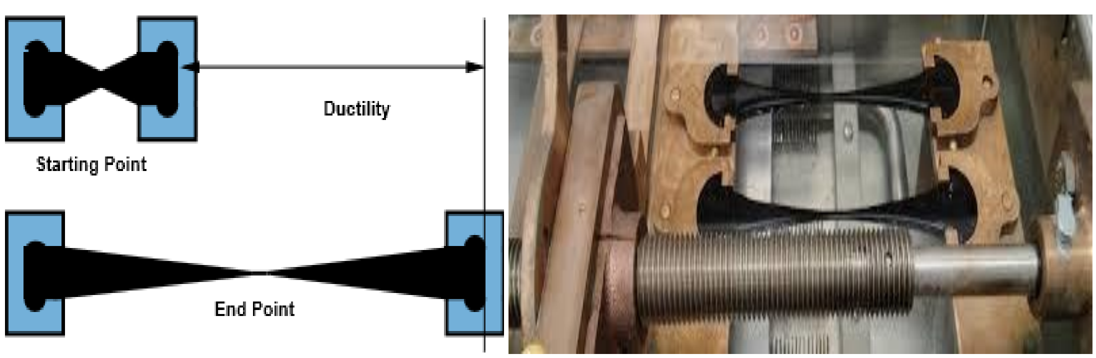



**FIG. 21 DUCTILITY SPECIMEN OF BITUMEN**

**TABLE 18 DUCTILITY VALUE OF BITUMEN**

| Test property | Sample | | Mean value (cm) |
|---|---|---|---|
| | 1 | 2 | |
| Ductility value (cm) | | | |

Ductility for various grades of bitumen varies from 5 to 100. For satisfactory use in road pavement, ductility value should not be less than 50 cm. Ductility value is affected by factors like pouring temperature, briquette dimensions, presence of air voids in briquette, rate of pull and test temperature.

## SOFTENING POINT TEST ON BITUMEN

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. Generally higher softening indicates lower susceptibility and is preferred in warm climates.

**Apparatus**

- The ring and ball apparatus (Steel balls, Brass rings, Ball guides, Support)
- Thermometer
- Bath
- Electric Heater

**Procedure**

- In the ring and ball apparatus, a brass ring containing test sample is suspended in a liquid like water or glycerin at a given temperature.
- A steel ball is placed upon the bitumen sample and liquid medium is then heated at the rate of five degree centigrade per minute.

- The temperature at which the softened bitumen touches the metal placed at a specified distance below the ring is recorded as the softening point of bitumen.
- Preparation of test sample: Heat the material to a temperature between 75–100 $^{o}$C above its softening point; stir until, it is completely fluid and free from air bubbles and water. If necessary filter it through IS sieve 30. Place the rings, previously heated to a temperature approximately to that of the molten material, on metal plate which has been coated, with a mixture of equal parts of glycerin and dextrin. After cooling for 30 minutes in air, level the material in the ring by removing the excess with a warmed, sharp knife.
- Assemble the apparatus with the rings, thermometer and ball guides in position.
- Fill the bath with distilled water to a height of 50 mm above the upper surface of the rings. The starting temperature should be 5 $^{o}$C.
- Apply heat to the bath and stir the liquid so that the temperature rises at a uniform rate of 5 + 0.5$^{o}$C per minute.
- As the temperature increases the bituminous material softens and the ball sinks through the ring, carrying a portion of the material with it.
- Note down the temperature when any of the steel ball with bituminous coating touches the bottom plate.
- Record the temperature when the second ball also touches the bottom plate. The average of the two readings to the nearest 0.5 $^{o}$C is reported as the softening point.

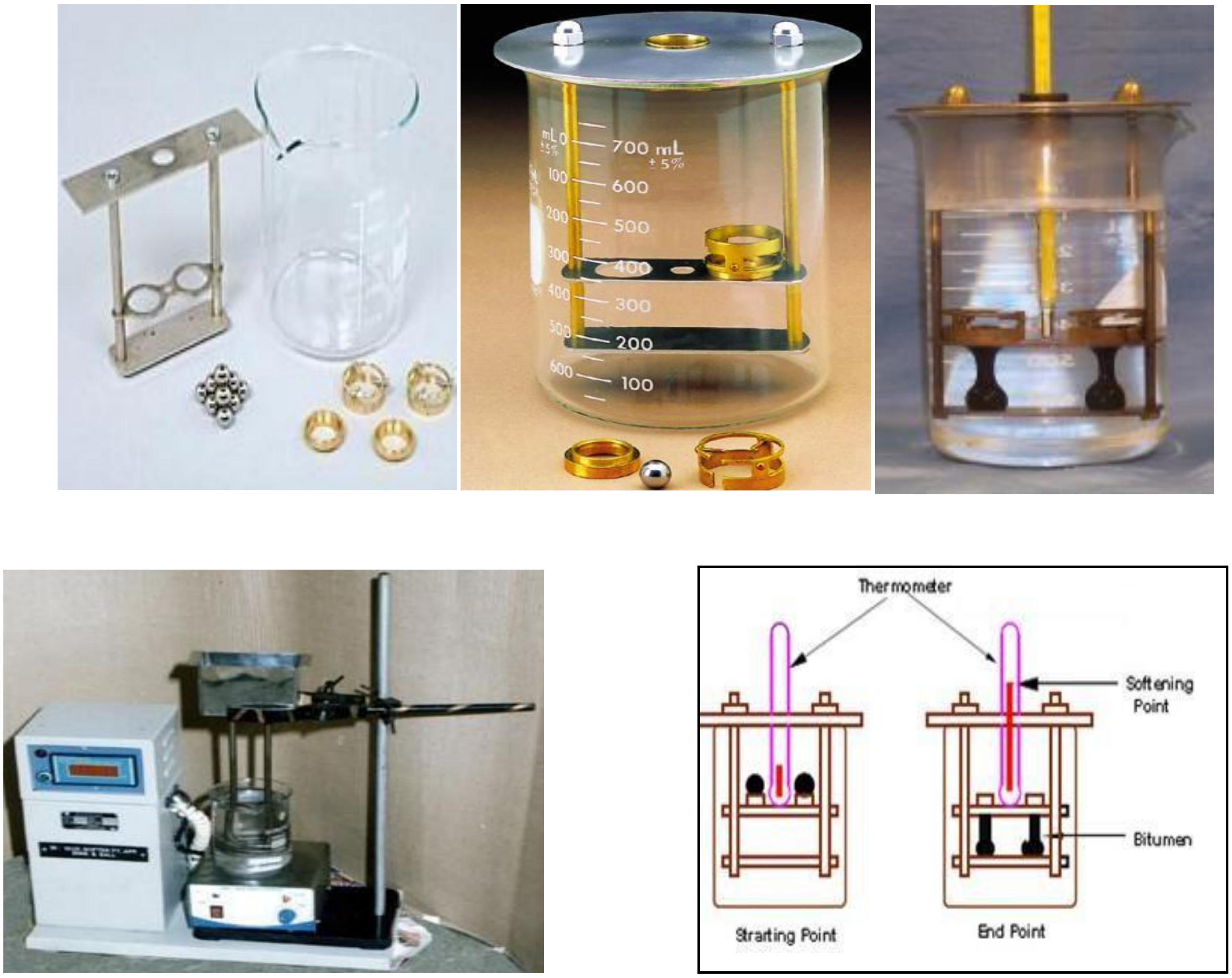



**FIG. 22 SOFTENING POINT TEST APPARATUS ON BITUMEN**

**TABLE 19 SOFTENING POINT VALUE ON BITUMEN**

| **Description** | **Sample** | | **Mean value** |
|---|---|---|---|
| | **Ball 1** | **Ball 2** | |
| Initial Temperature $^{o}$ C | | | |
| Final Temperature $^{o}$ C | | | |
| **Mean Softening point** | | | |

Softening point indicates the temperature at which binders possess the same viscosity. Bituminous materials do not have a definite melting point. Rather the change of state from solid to liquid is gradual and over a wide range of temperature. Softening point has particular significance for materials that are to be used as joint and crack fillers. Higher so softening point ensures that they will not flow during service. In general the higher the softening point the lesser the temperature susceptibility. Bitumen with higher softening point may be preferred in warmer places. Softening point of the bitumen to be used as paving bitumen should lie between 35 $^{o}$ C to 70 $^{o}$ C.

**FLASH AND FIRE POINT TEST**

Flash Point - The flash point of a material is the lowest temperature at which the vapour of a substance momentarily takes in the form of a flash under specified condition of test.

Fire Point - The fire point is the lowest temperature at which the material gets ignited and burns under specified condition of test.

Apparatus

- Cleveland open cup test apparatus with cup
- Flame exposure device
- Thermometer



**FIG. 23 FLASH AND FIRE POINT TEST APPARATUS ON BITUMEN**

**Procedure**

- All parts of the cup are cleaned and dried thoroughly before the test is started.
- The material is filled in the cup upto filling mark.
- All accessories including thermometer of the specified range are suitably fixed.
- The bitumen sample is then heated. The test flame is lit and adjusted in such a way that the size of the bed is of 4 mm diameter. The heating is done at the rate of 5°C to 6°C per minute.
- The stirring is done at rate of approximately 60 rpm.
- The test flame is applied at intervals depending upon the expected flash and fire points. First application is made atleast 17°C below the actual flash point and then at every 1°C to 3°C. The stirring is discontinued during the application of the test flame.

Observation and Tabulation

**TABLE 20 FLASH AND FIRE POINT ON BITUMEN**

| Test property | Sample |
|---|---|
| Flash Point | |
| Fire Point | |

The flash point is taken as temperature read on the thermometer at the time of flame application that causes a bright flash in the interior of the cup in closed system. For open cup it is the instance when flash appears first at any point on the surface of the material. The heating is continued until the volatiles ignite and are material continues to burn for 5 seconds. The temperature of the sample material when this occurs is recorded as the fire point.

**SPECIFIC GRAVITY TEST FOR BITUMEN**

Specific Gravity of the material is the ratio of volume of bitumen to the equal volume of water.

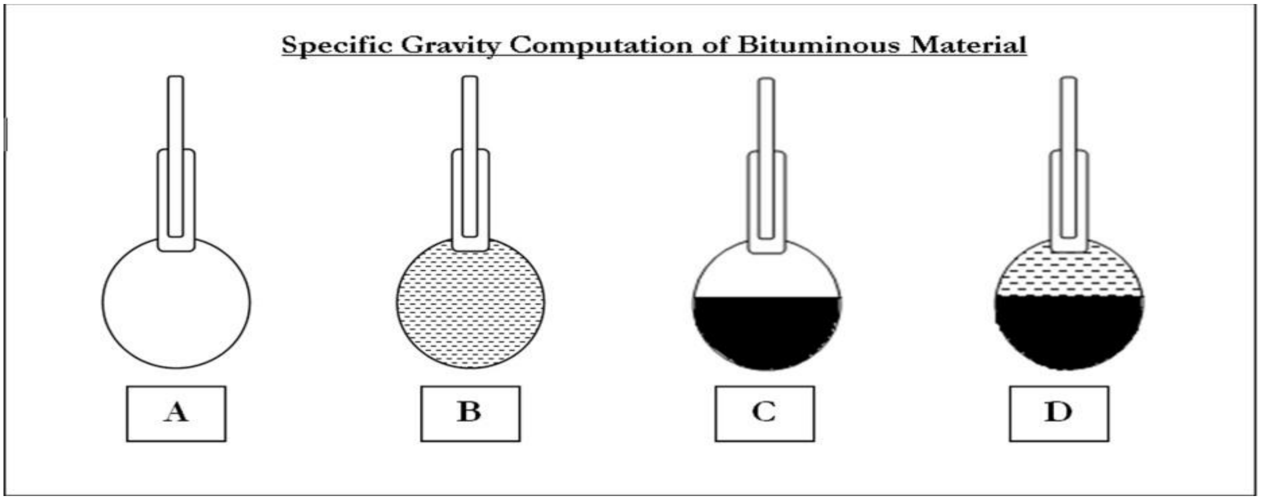
Apparatus

- Pycnometer of 1000 cc capacity
- Weighing balance

**Procedure**

- The pycnometer bottle is cleaned, dried and weighed along with stopper (a).
- It is then filled with fresh distilled water and weighed (b).
- The distilled water is then removed and cleared from pycnometer bottle.
- The bitumen is heated to a pouring temperature and is poured in the above empty bottle taking all the precautions so that it occupies about the three fourth of the volume of the pycnometer and obtained the weight of the pycnometer with the sample (c) .
- Next fill the pycnometer containing the sample with distilled water upto the brim taking care that no air bubbles are entrapped. Weigh the pycnometer with the sample and water filled (d).
- Calculate the specific gravity of the sample using the formula given below.

$(c - a)$




$$\mathit{Specific\ Gravity} = b - a \;-\; (d - c)$$

**FIG. 24 SPECIFIC GRAVITY TEST APPARATUS FOR BITUMEN**

**TABLE. 21 SPECIFIC GRAVITY TEST ON BITUMEN**

| Sample No. | Weight of bottle gm (a) | Wt. of bottle + Distilled water, gm(b) | Wt. of bottle + half filled material, gm(c) | Wt. of bottle +half filled material + distilled water gm (d) | Specific Gravity |
|---|---|---|---|---|---|
| | | | | | |

Knowledge of the correct specific gravity of bituminous materials has mainly two applications. First, to convert the specified bitumen content be weight to volume basis when the binder is measured by volume Here it is necessary to know the coefficient of expansion or the specific gravity values at different temperatures, Second the specific gravity is useful to identify the source of a bitumen binder, pure bitumen has a specific gravity in the range 0.97 to 1.02: The specific gravity of tars depends on the type of carbonization process used for their production. Vertical retort have a specific gravity range 1.10 to 1.15

## VISCOSITY TEST ON BITUMEN

It is the time taken in seconds to collect 50 ml of tar sample to flow through the orifice is noted.

Apparatus

- Ten millimetre orifice viscometer with cup
- Valve
- Sleeves
- Stirrer
- Receiver
- Thermometer

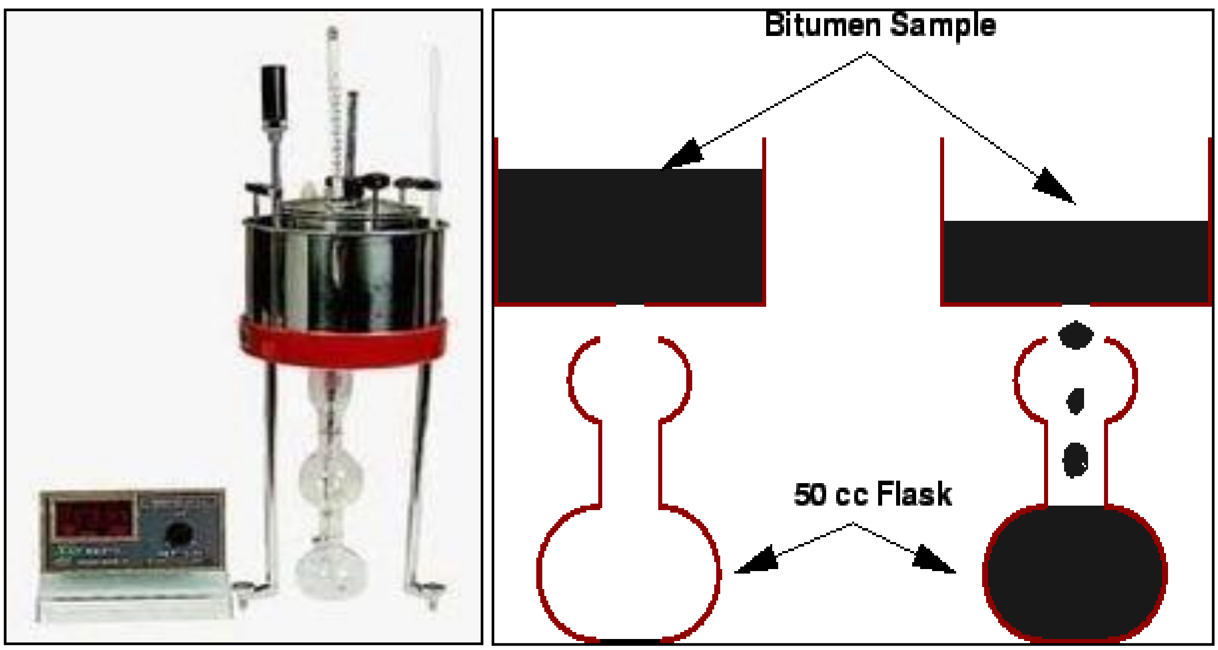



**FIG. 25 VISCOSITY TEST ON BITUMEN**

**Procedure**

- The tar cup in the viscometer is cleaned and properly leveled and the water in the bath is heated to the temperature of 35°C and is maintained through the test.
- The tar sample is heated to a temperature 20°C above the test temperature that is 55°C and the material is allowed to cool and it is continuously stirred.
- When the tar sample reaches slightly above the test temperature, it is poured in the tar cup, until the leveling peg on the valve rod is just immersed.
- In a graduated receiver, 20 ml of mineral oil is poured and the receiver is placed under the orifice.
- When the sample reaches the specified testing temperature that is 35°C, the valve is opened.
- The stopwatch is started, when the receiver records 25 ml and the time recorded for flow upto a mark of 75 ml.
- The time in seconds thus obtained for 50 ml of tar sample to flow through the orifice is noted as the viscosity of the sample.

Observations and Tabulation

**TABLE. 22 VISCOSITY VALUE ON BITUMEN**

| **Description** | **Test 1** | **Test 2** |
|---|---|---|
| Test Temperature | | |
| Time taken to flow 50 cc of the binder | | |
| Viscosity | | |

The determination of time of flow of binder through the orifice gives an indirect measure of viscosity of tars and cut backs. Higher the duration of flow, greater is the viscosity. Viscosity of binder is one of the criteria for their classification. Binders having very low viscosity can be advantageously used in exceptionally cold weather conditions. High viscosity binder have to be heated before their application.

**BITUMINOUS MIX DESIGN**

**MARSHALL STABILITY TEST –** This test is to determine the optimum bitumen content of the given mix.

Apparatus

- Mould Assembly
- Sample Extractor
- Compaction pedestal and Hammer
- Breaking head
- Loading machine
- Flow meter

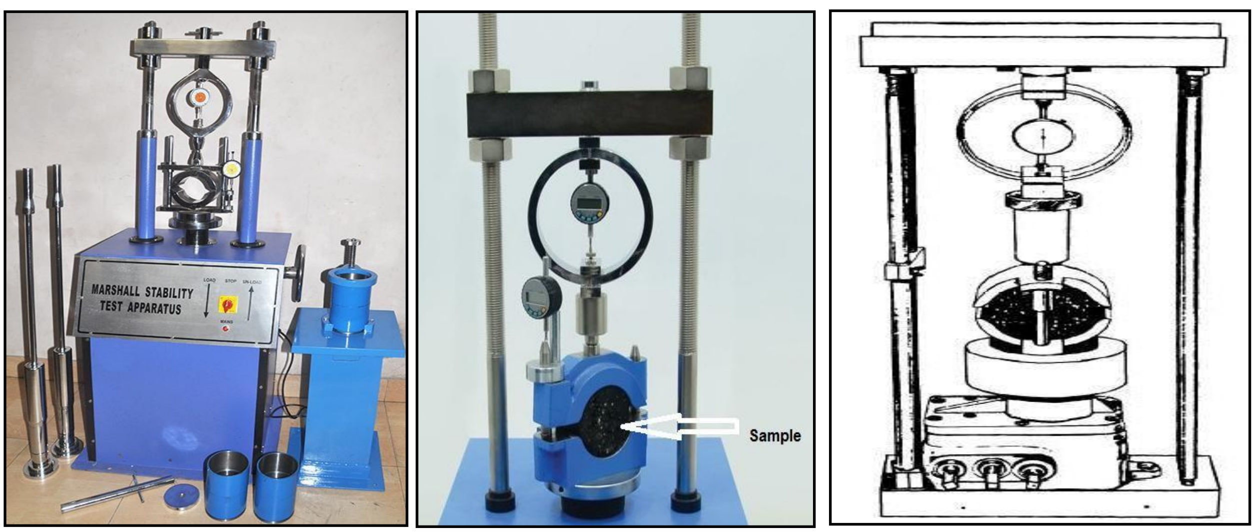



**FIG. 25 MARSHALL STABILITY TEST APPARATUS**

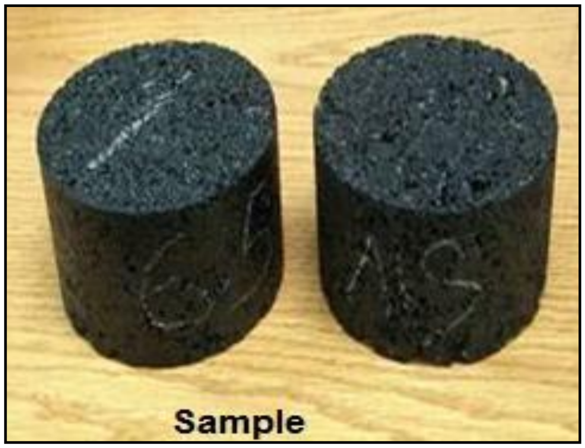



**FIG. 26 MARSHALL STABILITY TEST SAMPLE**

**Procedure**

- Sieve analysis for the given aggregates sample is done to obtain the design grading to be employed in the mix.
- The proportion of each aggregate required is determined to produce the design grading.
- The specific gravity of aggregates, filler material and bitumen to be used in the mix are determined.
- Preparation of test specimen

Approximately 1200 g of aggregates and filler material are taken and heated to a temperature of 175 to 190ºC. The required quantity of bitumen for the first trial, say 4% by weight of the mineral aggregates and heated to a temperature of 121 to 138ºC.

Then the heated bitumen is mixed with the heated aggregates and thoroughly mixed by hand mixing with trowel. The mixing temperature is kept around 154ºC. The mix is placed in a mould and compacted with mechanical rammer with 75 blows on either side. Similarly specimen for each trial is prepared by increasing the bitumen such as 4.5%, 5%, etc. The specimen is allowed to cool, by immersing it in a water for about 4 hours.

- The specimen is taken out of water and it is extracted from the mould with the help of sample extractor. The diameter, height, weight and combined specific gravity of each specimen is determined.
- The specimen is placed in the Marshall test head and the Marshall stability value and flow value are noted.
- To determine the optimum bitumen content, five graphs are plotted with the values of bitumen content against the values of
    - Density
    - Marshall Stability
    - Voids in total mix
    - Flow value
    - Voids filled with bitumen

- The optimum bitumen content is the average of the bitumen content corresponding to maximum density, maximum stability and specified voids in the mix. For this, optimum bitumen content, flow value and voids filled with bitumen are found out from the corresponding graphs with the specific requirements of the mix.

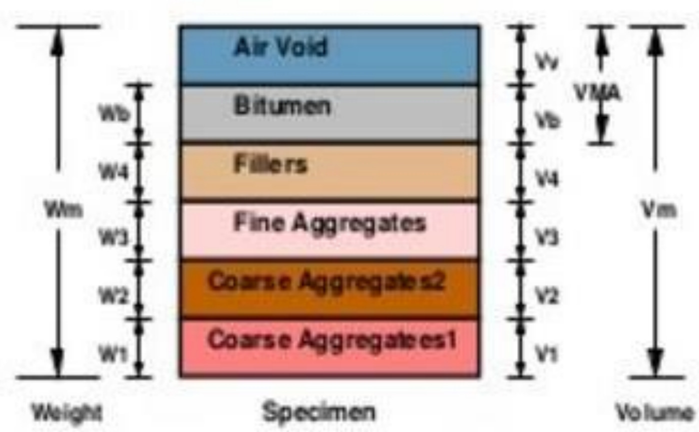



**FIG. 27 BITUMINUS MIX PROPORTION**

(W1/G1) + (W2/G2) + (W3/G3) + (W4/G4)

Where $W_1$ - Percentage weight of coarse aggregates $W_2$ - Percentage weight of fine aggregates $W_3$ - Percentage weight of filler material

$W_4$ - Percentage weight of bitumen in total mixes $G_1$ - Apparent specific gravity of coarse aggregate $G_2$ - Apparent specific gravity of fine aggregate $G_3$ - Apparent specific gravity of filler material

$G_4$ - Apparent specific gravity of bitumen in total mixes

**Percent voids in mineral aggregate (VMA)**

$VMA = V_v + V_b$

where $V_v$ = Volume of air voids, %

$V_b$ = Volume of biutmen, % = $G_b$ x ($W_4$/ $G_4$)

**Percent voids in filled with bitumen or Tar (VFB)**

**TABLE 23 MARSHALL STABILITY TEST VALUES**

| Description | Specimen 1 | Specimen 2 | Specimen 3 |
|---|---|---|---|
| Bitumen Content | | | |
| Unit Weight, gm/cm$^3$ | | | |
| Combined Specific Gravity, Gt | | | |
| % Air Voids, $V_a$ | | | |
| % Volume of bitumen, $V_b$ | | | |
| % Voids in mineral aggregate, VMA | | | |
| % Voids filled by bitumen, VFB | | | |
| Stability Value, kg | | | |
| Flow value in 0.25 mm units | | | |

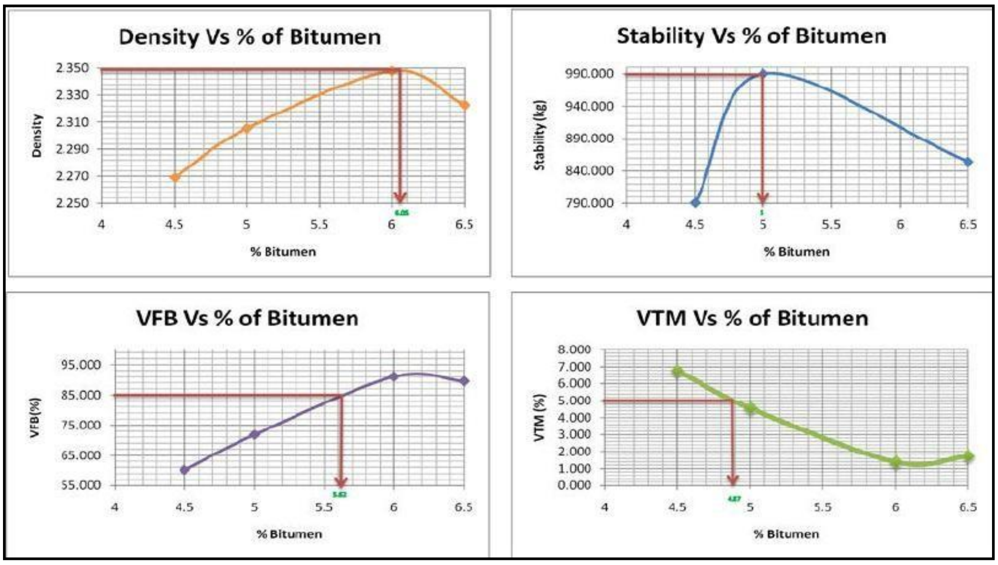



**FIG. 27 BITUMINUS MIX DESIGN GRAPHS**

**From the graph**

- The bitumen content corresponding to maximum stability value is determined
- The bitumen content corresponding to maximum density is determined

- Percent air voids between 3 & 5 (usually 4%)

The optimum bitumen content of the mix is the numerical average of the three values for the bitumen contents determined as mentioned above.

Interpretation of Results

**TABLE 24 MARSHALL STABILITY TEST RESULTS**

| Sl.No | Test property | Traffic Intensity | | |
|---|---|---|---|---|
| | | **Heavy** | **Medium** | **Light** |
| 1. | Stability kg (min) | 340 | 227 | 227 |
| 2. | Flow value 0.25 mm units | 8 - 16 | 8 - 18 | 8 - 20 |
| 3. | Maximum air voids in total mix % | | | |
| | a) for 5 m facing | 3 - 5 | 3 - 5 | 3 - 5 |
| | b) for base course | 3 - 8 | 3 - 8 | 3 - 8 |

Assume the following specific gravity values for the class work. $G_1 = 2.690$ $G_2 = 2.630$ $G_3 = 2.400$ $G_4 = 1.017$

## HIGHWAY CONSTRUCTION

**Highway Construction Project** consists of 2 phases:

- Earthwork and Preparation of Subgrade
- Construction of Pavement Structure

### Earthwork

Excavation and Embankment

**FIG. 28 EARTH MOVING EQUIPMENTS**

**Earthwork excavation**


**FIG. 29 EARTH EMBANKMENT**

**Embankment preparation on earth**

**Preparation of Sub grade**

Site clearance, grading and compaction


**FIG. 30 SUBGRADE PREPARATION**

**Factors influencing the selection of pavement types**

- Type and intensity of traffic
- Funds available
- Subgrade soil and drainage conditions
- Availability of construction materials
- Climatic condition
- Plants and equipments available
- Time available for completing
- Altitude at which construction has to be done

**Types of Highway construction based on location and function**

- Earth road
- Gravel road
- Soil stabilized road
- Water Bound Macadam Road
- Bituminous road
- Cement Concrete Road

**CONSTRUCTION OF EARTH ROAD**

Earth road is a type of road whose whole pavement section is constructed with the locally available earth material preferably. Borrow pits are located at the nearby sites preferably outside the land width where, the required earth is available.

Sub-grade and the surface of the earth roads are given larger camber of 1in 33 to 1 in 20 because they need faster drainage to be safe from the moisture. A maximum value of camber of 1 in 20 is the limit because higher camber will result in the formation of cross ruts and corrosion of pavement soils.

Material specifications

**TABLE 25 EARTHERN ROAD COMPOSITIONS**

| **Description** | **Base Course** | **Wearing Course** |
|---|---|---|
| Clay | < 5 % | 10 – 18 % |
| Silt | 9 – 32 % | 5 – 15 % |
| Sand | 60 – 80 % | 65 – 80 % |
| Liquid Limit | < 35 % | < 35 % |
| Plasticity Index | < 6 % | 4 – 10 % |

**Construction procedure**

- Material - Suitable borrow pits are located by doing the survey of the adjacent land which are easy to reach and at economical haulage distance. The various organic materials like trees, shrubs and grass roots are removed before the excavation of the earth.
- Location of the center line - The center line and the road boundaries are marked on the ground by driving the wooden pegs. To follow the desired vertical profile of the road, reference pegs are also driven at a certain spacing which depends upon the estimated length of the road construction per day.
- Preparation of the sub-grade - Following steps are necessary for the preparation of the

sub- grade:

- Clearing site
- Excavation and construction of fills
- Shaping of sub-grade

The site clearance may be done manually using appliances like spade, pick and hand shovel or using the mechanical equipment like Bulldozer and scraper etc.

- Excavation and construction of fills may also be done manually or using the excavation, hauling and compaction equipment.
- Dozers are considered very useful for haulage of short distances.
- If the compaction is done manually it will not be sufficient and proper, it should be left to get consolidated under atmospheric conditions.
- The various equipments used by labor are shovel, spade, pick-axe, baskets, rammers and hand rollers.
- The sub-grade should be compacted to the desired grade, camber and longitudinal profile.
- Pavement construction - The soil is dumped on the prepared sub-grade and pulverized. The soil may be a mixture of more than one soil to get the desired properties. The moisture content is checked and if extra moisture is needed, is added to bring it to OMC.
- The soil is mixed, spread and rolled in layers such that the compaction thickness of each layer does not exceed 10 cm. The type of roller for compaction is decided based on soil type, desired amount of compaction and availability of equipment. Atleast 95% of dry density of I.S. light compaction is considered desirable. The camber of the finished surface is checked and corrected when necessary.
- Opening to traffic: The compacted earth surface is allowed to dry out for few days and then is opened to traffic.

**FIG.31 EARTHERN ROAD OR UNPAVED ROAD**

## CONSTRUCTION OF GRAVEL ROAD

A **gravel road** is a type of unpaved **road** surfaced with **gravel** that has been brought to the site from a quarry or stream bed. They are common in less-developed nations, and also in the rural areas of developed nations.

### Materials

The gravel used consists of varying amount of crushed stone, sand, and fines. Fines are silt or clay particles smaller than .075 mm, which can act as a binder. Crushed stone is used because gravel with fractured faces will stay in place better than rounded river pebbles. A good gravel for a gravel road will have a higher percentage of fines than gravel used as a sub-base for a paved road. This often causes problems if a gravel road is paved without adding sand and gravel sized stone to dilute the percentage of fines.

### Construction procedure

- Soil survey and cleaning of top soil
- Marking the centre line and edges of the road on the ground
- Preparation of subgrade
- Pavement construction

- Spreading of Crushed gravel aggregates
- Rolling
- Spraying of water and rolling
- Verification of camber
- After final rolling, allowed for drying

**FIG.32GRAVEL ROAD**

**CONSTRUCTION OF WATER BOUND MACADAM ROAD**

Macadam - Pavement base course made of crushed or broken aggregate mechanically interlocked by rolling and the voids filled with screening and binding material with the assistance of water.

**WBM (Water Bound macadam) roads construction**

The water bound macadam road construction technique was given by the John Macadam.

This technique in present day is used as given below. For WBM construction we use three materials:

- Aggregates
- Screeners
- Binders.

## Aggregates

Use of aggregates of different grades. IRC (Indian Roads Congress) has classified the coarse aggregates into 9 grades, according to their size. For the construction of the WBM roads aggregates are used in the sub-base, base and surface course and so the aggregates are divided into 3 grades according to their size.

Grade 1 - particles of size 90 mm to 40 mm Grade 2 - particles of size 63 to 40 mm Grade 3 - particles of size 50 to 20 mm. The grade 1 aggregates having size of 90 mm to 40 mm are preferred for the sub-base material and grade 2 for the base and grade 1 for the surface course. However, if we only use the WBM as the surface course, it gets deteriorated fast due to abrasion with the traffic so, bituminous surfacing over the WBM is general practice.

**Screeners** are the aggregates of the smaller sizes, generally 12.5 mm or 10 mm, for grade A and grade B. They are of the same chemical composition as of the coarse aggregates. For economic considerations IRC has suggested non plastic materials such as, crushed over burnt bricks, moorum, gravels, etc. provided the liquid limit of the material is less than 20%, plasticity index is less than 6.0% and the portion of fines passing 0.075 mm sieve is less than 10%. However if crush-able type of aggregates are used, use of the screeners may be disposed off.

## Binders

Binders are the layers of materials which are laid after the compaction of the aggregates and the screening materials one after another. Kankar dust or lime stone dust may be utilized if locally available. The binding material with plasticity index value of 4% to 9% is used in surface course construction; the plasticity index of binding course material should be less than 6% in the case of the WBM layers used as base course or sub-base course, with bituminous surfacing. However if the screening used are of crushable material like moorum or soft gravel, there is no need to apply binding material, unless the plasticity index value is low.

Materials

**TABLE 26 WBM ROAD COMPOSITIONS**

| Description | Base Course | Wearing Course |
|---|---|---|
| Coarse Aggregates | < 5 % | 10 – 18 % |
| Silt | 9 – 32 % | 5 – 15 % |
| Sand | 60 – 80 % | 65 – 80 % |
| Liquid Limit | < 35 % | < 35 % |
| Plasticity Index | < 6 % | 4 – 10 % |

**TABLE 27 WBM ROAD MATERIALS SPECIFICATION**

| Materials used | Description | |
|---|---|---|
| Coarse aggregates | Hard aggregates – crushed aggregates / broken stones | |
| | Soft aggregates – over burnt bricks / kankar / literate | |
| Screenings | aggregates of smaller size of same material as coarse aggregates | |
| Binding material | fine grained material | |
| **Sub-base course** | Size of coarse aggregates | Thickness of layer |
| | 40 – 90 mm | 100 mm |
| | 40 – 63 mm & 20 – 50 mm | 75 mm |

**Construction procedure**

- Soil survey and cleaning of top soil
- Marking the centre line and edges of the road on the ground
- Preparation of subgrade
- Pavement construction
    - Spreading of Crushed gravel aggregates
    - Rolling
    - Spraying of water and rolling
    - Verification of camber
    - After final rolling, allowed for drying
- Preparation of foundation for receiving the wbm course
- Provision of lateral confinement

- Spreading of coarse aggregates uniformly to even thickness
- Compaction using rollers
- Application of dry screening
- Sprinkling with water and rolling
- Grouting with wet screenings
- Application of binding material
- Setting and drying
- Checking the surface evenness and rectification of surface defects


**FIG.33 WBM ROAD CONSTRUCTION**

**WMM (Wet mix macadam) road construction**

Aggregates used are of the smaller sizes, varies between the 4.75 mm to 20 mm sizes and the binders(stone dust or quarry dust having PI(Plasticity Index) not less than 6%) are premixed in a batching plant or in a mixing machine. Then they are brought to the site for overlaying and compaction.

The PI (Plasticity Index) of the binding material is kept low because it should be a sound and non plastic material. If the plasticity index is more then there are the chances of the swelling and more water retention properties. So this value should be kept in mind.

**FIG.34 WMM ROAD CONSTRUCTION**

**Comparison of the WBM and WMM road construction**

The cost of construction of the WMM is said to be more than that of the WBM sub-base and bases but the advantages given below will compensate it. Here are the points of difference:

- The WMM roads are said to be more durable.
- The WMM roads gets dry sooner and can be opened for traffic within less time as compare to the WBM roads which take about one month for getting dry.
- WMM roads are soon ready to be black topped with the bituminous layers.
- WMM roads are constructed at the faster rate.
- The consumption of the water is less in case of the WMM roads.
- Stone aggregates used in WBM is larger in size which varies from 90 mm to 20 mm depending upon the grade but in case of the WMM size varies from 4.75 mm to 20 mm.
- In case of WBM, stone aggregates, screenings and binders are laid one after another in layers while in WMM, aggregates and binders are pre-mixed in the batching plants and then brought to the site for overlaying and compacting.
- Materials used in the WBM are the stone aggregates, screenings and binder material(Stone dust with water) while in WMM material used are only stone aggregates and binders.
- Quantity of the WBM is generally measured in cubic meters while that of the WMM in square meters.

## CONSTRUCTION PROCEDURE OF BITUMINOUS PAVEMENT

Bituminous pavements support loads through bearing rather than flexural action. They comprise several layers of carefully selected materials designed to gradually distribute loads from the pavement surface to the layers underneath. The various layers composing a flexible pavement and the functions they perform are described below:

### Bituminous Surface (Wearing Course)

The bituminous surface, or wearing course, is made up of a mixture of various selected aggregates bound together with asphalt cement or other bituminous binders. This surface prevents the penetration of surface water to the base course; provides a smooth, well-bonded surface free from loose particles, which might endanger aircraft or people; resists the stresses caused by aircraft loads; and supplies a skid-resistant surface without causing undue wear on tires.

### Base Course

The base course serves as the principal structural component of the flexible pavement. It distributes the imposed wheel load to the pavement foundation, the subbase, and/or the subgrade. The base course must have sufficient quality and thickness to prevent failure in the subgrade and/or subbase, withstand the stresses produced in the base itself, resist vertical pressures that tend to produce consolidation and result in distortion of the surface course, and resist volume changes caused by fluctuations in its moisture content. The materials composing the base course are select hard and durable aggregates, which generally fall into two main classes: stabilized and granular. The stabilized bases normally consist of crushed or uncrushed aggregate bound with a stabilizer, such as Portland cement or bitumen. The quality of the base course is a function of its composition, physical properties, and compaction of the material.

### Subbase

This layer is used in areas where frost action is severe or the subgrade soil is extremely weak. The subbase course functions like the base course. The material requirements for the subbase are not as strict as those for the base course since the subbase is subjected to lower load stresses. The subbase consists of stabilized or properly compacted granular material.

**Frost Protection Layer**

Some flexible pavements require a frost protection layer. This layer functions the same way in either a flexible or a rigid pavement.

**Subgrade**

The subgrade is the compacted soil layer that forms the foundation of the pavement system. Subgrade soils are subjected to lower stresses than the surface, base, and subbase courses. Since load stresses decrease with depth, the controlling subgrade stress usually lies at the top of the subgrade. The combined thickness of subbase, base, and wearing surface must be great enough to reduce the stresses occurring in the subgrade to values that will not cause excessive distortion or displacement of the subgrade soil layer.

**Different methods of construction**

**Interface treatments**

Thin layer of bituminous binder are sprayed over the surface to provide bond between old and new layers

**Prime coat:** first application of low viscosity liquid bituminous material over the existing surface.

**Tack coat:** application of high viscosity bitumen over an existing impervious surface.

**Bituminous surface dressing -** Thin wearing coat over the existing surface in one or two layers.

**Seal coat -** Very thin surface treatment of bitumen is usually applied over the worned out existing pavement.

- **Penetration macadam -** Coarse aggregates are spread and compacted well. Hot bitumen of high viscosity is sprayed and thus penetrates into the voids from the surface of aggregates.
- **Full grout -** bitumen is penetrated to the full depth of compacted aggregates.
- **Semi grout -** bitumen is penetrated to the half depth of compacted aggregates.
- **Built-up grout -** Two layers of composite construction of compacted crushed aggregate with bitumen.
- **Pre-mix method -** Aggregates and bitumen are mixed thoroughly before spreading and compacting

- Bituminous macadam: one or more course of compacted crushed aggregates premixed with bitumen, laid immediately after mixing.
- Bituminous premixed carpet: coarse aggregates of 12.5 mm and 10 mm sizes are premixed with bitumen and compacted to a thickness of 20 mm.
- Asphalt concrete: dense graded premixed bituminous mix ( coarse aggregates, fine aggregates, mineral filler and bitumen) are well compacted.
- Sheet asphalt: dense sand bitumen premix of thickness of 25 mm over cement concrete pavement.
- Mastic asphalt: bitumen, fine aggregates and filler material for surfacing the bridge deck slabs.

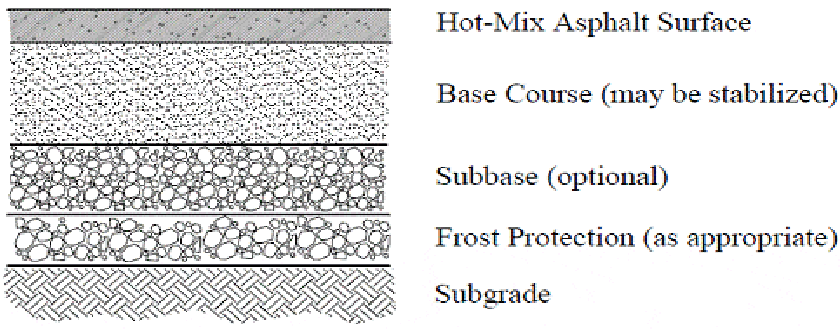



**FIG.35 LAYERS OF WMM ROAD**

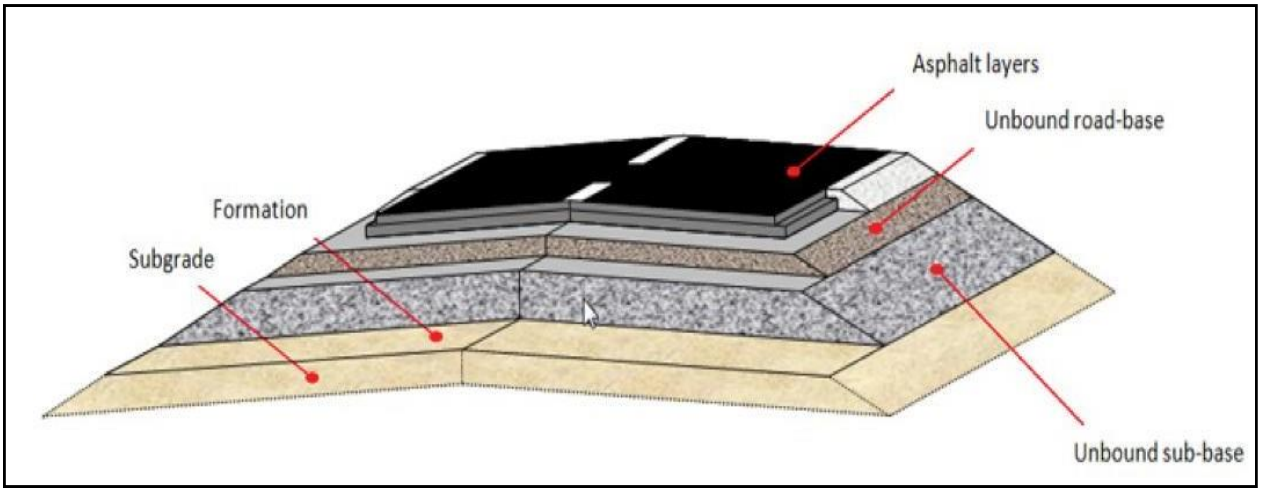



**FIG.36 LAYERS OF FLEXIBLE ROAD**

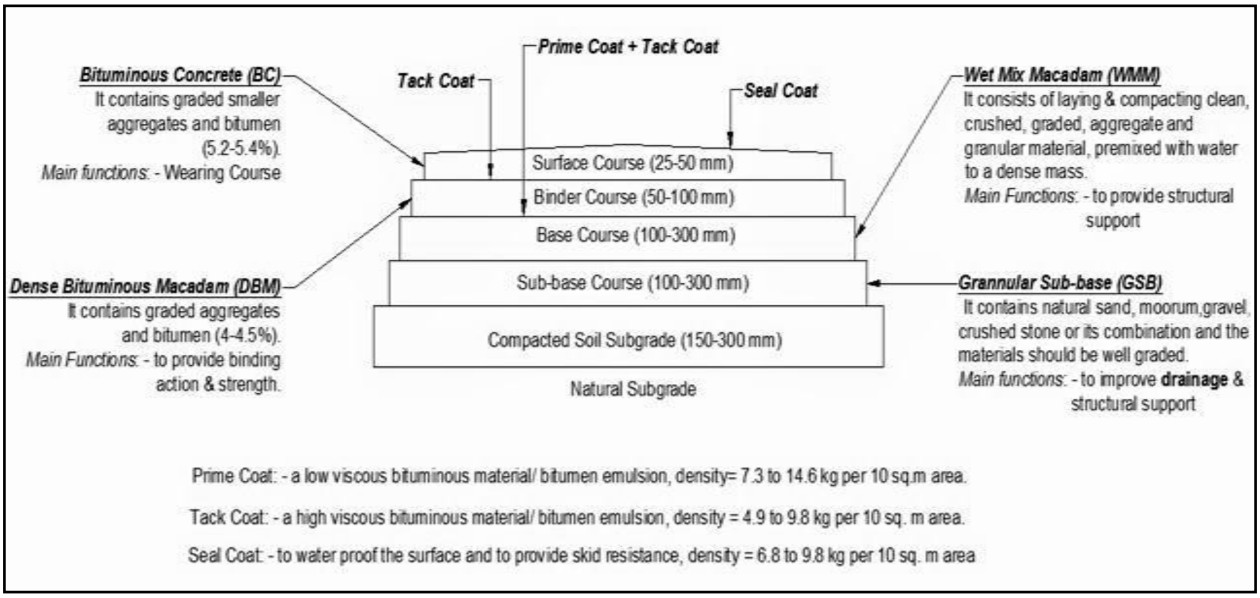



**FIG.37 LAYERS OF WMM ROAD CONSTRUCTION**

**Procedure of bituminous construction**

- Preparation of existing surface
- Application of binder
- Application of stone chipping
- Rolling of 1st cost
- Application of binder and stone chipping for 2nd coat

- Rolling of 2nd cost
- Finishing and opening to traffic

**Procedure of Penetration Macadam**

- Preparation of existing surface
- Spreading the coarse aggregates
- Rolling using 10 tons roller
- Application of bitumen
- Spreading of key aggregates
- Application of seal coat
- Finishing and opening to traffic

**Procedure of Built-up spray grout**

- Preparation of existing surface
- Application of tack coat
- Spreading of 1st coat and Rolling
- Application of binder
- Spreading of coarse aggregates and Rolling
- Second application of binder
- Application of key aggregates
- Finishing and opening to traffic

**Procedure of Bituminous Macadam**

- Preparation of existing surface
- Application of tack coat or prime coat application
- Premix preparation – heating and mixing
- Placement
- Rolling and finishing

**Procedure of pre-mixed bituminous carpet**

- Preparation of existing surface
- Application of tack coat

- Preparation and placing of premix
- Rolling and finishing
- Application of seal coat
- Surface finish and open to traffic

**Procedure of bituminous concrete**

- Preparation of existing surface
- Application of tack coat
- Preparation and placing of premix
- Rolling
- Quality control
- Finishing

**FIG.38 BITUMINUS ROAD CONSTRUCTION PROCESS**

## CONSTRUCTION OF CEMENT CONCRETE PAVEMENTS

Cement concrete roads, though costly in initial investment, are cheap in long run because of low maintenance costs; the cost of construction of single lane rigid pavement varies from 35 to 50 lakhs per km in plain area

Cement concrete roads have:

- Life span is more as compare to bituminous (Low Maintenance Cost)
- Have low repairing cost but completion cost is high
- No such phenomenon of grain to grain load transfer exists
- Have high flexural strength
- Design is based on flexural strength or slab action
- Deformation in the subgrade is not transferred to subsequent layers

**Materials used**

The materials for the cement concrete road construction may be divided into two parts. These are mentioned as follows:-

- Selection of basic component materials
- Mix design and production of pavement quality concrete(PQC) mix required to construct the cement concrete road pavement

The Selection of Component of Materials

The basic component materials for the cement concrete road construction are consists of Portland cement, coarse aggregate, water, admixture and also steel is used at the joints, in the form of dowel bars and tie bars.

Portland cement - The type of cement that may be used for the preparation of PQC and construction of cement concrete road construction pavement are:-

- Ordinary Portland cement of 43 Grade
- Ordinary Portland 53 Grade
- Portland Pozzolana cement with fly ash content up to 20% by weight
- Portland slag cement

However most commonly used cement for the cement concrete road construction is ordinary Portland cement of 43 Grade.

Coarse Aggregate Values of Cement Concrete Road

The coarse aggregate that is used for PQC of cement concrete road construction should fulfill the following requirements apart from this the maximum size being limited to 31.5 mm.

**TABLE 28 REQUIRED QUALITIES OF AGGREGATE**

| | |
|---|---|
| Los angles abrasion value | Lesser than 35% |
| Combined flakiness and elongation index | Lesser than 35% |
| Water absorption | Lesser than 3.0% |
| Soundness test after five cycles: loss with sodium sulphate | Lesser than 12% |
| Loss of magnesium sulphate | Lesser than 18% |

Fine Aggregates Used in Road Construction - Fine aggregate consists of clean natural sand or crushed stone sand or a combination of both; the fine aggregate shall be from clay, coal and lignite. The fine aggregate shall be well graded, with 100 percent passing 10 mm sieve. The IRC has suggested four gradations of fine aggregate for the preparation of the PQC mix.

Water used for mixing of the cement concrete, and also that used for curing of the cement concrete road construction shall be clean and portable. The water should be free from salt, acid, oil and other organic matter.

Admixture in Cement Concrete Road Construction - Commonly used chemical admixture in the cement concrete road construction are:

- To improve the workability of the concrete; a suitable air entraining agent may be used.

- To provide an adequate extension of setting time of the concrete mix without adversely affecting the other desirable properties of the concrete; super-plasticizers which retard the setting time may be used. The total quality of chemical admixture used is limited to a maximum of 2.0 %by weight of the cement or used.

**Steel**

Steel dowel bars with yield strength 2400 kg/sq. cm or 240 Mpa is used for the load transfer across in the expansion joints and construction joints of cement concrete roads. Plan or twisted steel bars are used as tie bars at longitudinal joints. All steel rods shall be coated with epoxy paint for protection against corrosion.

Concrete pavements are rigid pavements having very high flexure strength as compared to flexible pavements. Concrete pavements can be constructed using two different methods:

- Alternate Bay method
- Continuous bay method

In alternate bay method, concrete pavement slab are laid on whole width of pavement in alternate bays.

In continuous bay method, concrete pavement slabs are laid continuously only on one bay and another bay is open for the traffic.

Generally the second method of continuous bay, is preferred over alternate bay method because, traffic movement is allowed while it is restricted in the first. Also, the alternate empty spaces invite the rainwater collection and create in-convenience to the construction work.

**Various steps for the construction of concrete pavements**

- Preparation of Sub-grade and Sub-base
- Placing of forms
- Batching of material and Mixing
- Transporting and Placing of Concrete
- Compaction and Finishing
- Floating and Straight Edging
- Belting, Brooming and Edging
- Curing of Cement concrete

The concrete pavements are constructed in two ways such as

- Construction of pavement slabs
- Construction of joints

**Construction of pavement slabs**

- Preparation of subgrade and sub-base
- Placing of forms
- Batching of materials - fine aggregates and coarse aggregates are proportioned by weight in

  a weight batching plant and placed in a hopper with the required quantity of cement
- mixing
- Transporting and placing of concrete
- Compaction and finishing
- Floating and straight edging
- Belting –surface is belted with a 2 – ply canvas belt
- Brooming - finishing is given using fiber broom brush transversely from edge to edge
- Edging – edges of the slab are carefully finished with an edging tool
- Curing of cement concrete
- Initial curing –using water saturated cotton / jute mats
- Final curing – curing with wet soil and impervious membrane method

**FIG.39 LAYING OF CEMENT CONCRETE ROAD**

**Construction of Joints**

Joints are the discontinuities in the concrete pavement slab, and help to release stresses due to temperature variation, subgrade moisture variation, shrinkage of concrete etc. There are various types of joints in concrete pavement, e.g. contraction joint, construction joint, expansion joint and warping joint.

The functions of these joints are as follows:

**Contraction joint**

Contraction joints are provided **along the transverse direction** to take care of the contraction of concrete slab due to its natural shrinkage.

**Construction joint**

Construction joints are provided whenever the construction work stops temporarily. The joint direction could be **either along the transverse or longitudinal direction.**

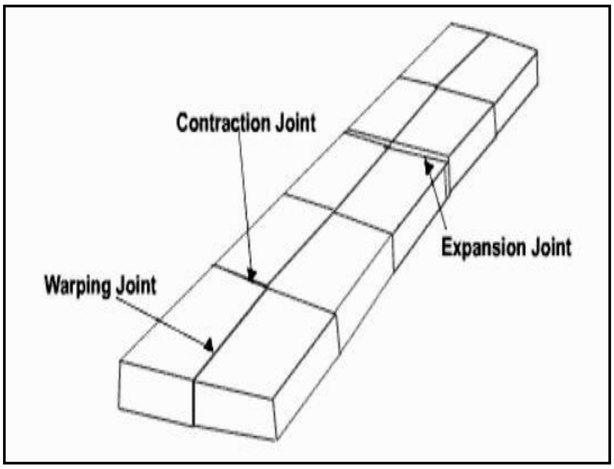
**Expansion joint**

Expansion joints are provided **along the transverse direction** to allow movement (expansion/ contraction) of the concrete slab due to temperature and subgrade moisture variation.

**Warping joint**

Warping joints are provided **along the longitudinal direction** to prevent warping of the concrete slab due to temperature and subgrade moisture variation.

These discontinuities (joints) could be extended to the full or partial depth of the slab. Sometimes iron bars are provided across the joints; the iron bars along the longitudinal joints are called **tie bars** and along the transverse joints are called **dowel bars**.



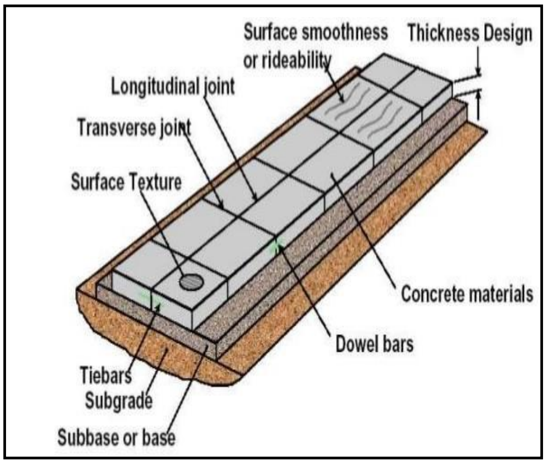




**FIG.40 JOINTS IN CEMENT CONCRETE ROAD**

**FIG.40 BARS IN CEMENT CONCRETE ROAD JOINTS**

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

# UNIT – IV – PAVEMENT DESIGN SCIA1304

## INTRODUCTION

Pavement is a structure comprises of superimposed stratum of coursed materials above the existing soil sub-grade, whose prime function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of adequate riding quality, satisfactory skid resistance, constructive light reflecting characteristics, and less noise pollution. The vital aim is to make sure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade.

### *Requirements of a pavement*

An ideal pavement should meet the following requirements:

- Sufficient thickness to distribute the wheel load stresses to a safe value on the sub-grade soil,
- Structurally strong to withstand all types of stresses imposed upon it,
- Adequate coefficient of friction to prevent skidding of vehicles,
- Smooth surface to provide comfort to road users even at high speed,
- Produce least noise from moving vehicles,
- Dust proof surface so that traffic safety is not impaired by reducing visibility,
- Impervious surface, so that sub-grade soil is well protected, and
- Long design life with low maintenance cost.

### Factors affecting pavement design

There are many factors that affect pavement design which can be classified into four categories as

- Traffic and loading,
- Structural models,
- Material characterization and
- Environment.

**Traffic and loading** - Traffic is the most important factor in the pavement design. The key factors include

- Contact Pressure - The tyre pressure is an important factor, as it determines 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 sub-grade soil is not failed. Wheel configuration affects the stress distribution and deflection within a pavement.
- 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.
- Load Repetitions - 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.

**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.

**Material characterization**

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 sub- grade 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

**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
- Precipitation

**TYPES OF PAVEMENTS**

The pavements can be classified based on the structural performance into two, Flexible pavements (Bituminous Pavement) and Rigid pavements (Cement Concrete Pavement)

**TABLE 1 COMPARING FLEXIBLE WITH RIGID PAVEMENT**

| Flexible Pavements | Rigid Pavements |
|---|---|
| Deformation in the sub-grade is transferred to the upper layers | Deformation in the sub-grade is not transferred to subsequent layers |
| Design is based on load distributing characteristics of the component layers | Design is based on flexural strength or slab action |
| Have low flexural strength | Have high flexural strength |
| Load is transferred by grain to grain contact | No such phenomenon of grain to grain load transfer exists |
| Have low completion cost but repairing cost is high | Have low repairing cost but completion cost is high |
| Have low life span (High Maintenance Cost) | Life span is more as compare to flexible (Low Maintenance Cost) |
| Surfacing cannot be laid directly on the sub grade but a sub base is needed | Surfacing can be directly laid on the sub grade |

| | |
|---|---|
| No thermal stresses are induced as the pavement have the ability to contract and expand freely | Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete |
| Expansion joints are not needed | Expansion joints are needed |
| Strength of the road is highly dependent on the strength of the sub grade | Strength of the road is less dependent on the strength of the sub grade |
| Rolling of the surfacing is needed | Rolling of the surfacing in not needed |
| Road can be used for traffic within 24 hours | Road cannot be used until 14 days of curing |
| Force of friction is less Deformation in the sub grade is not transferred to the upper layers. | Force of friction is high |
| Damaged by Oils and Certain Chemicals | No Damage by Oils and Greases |

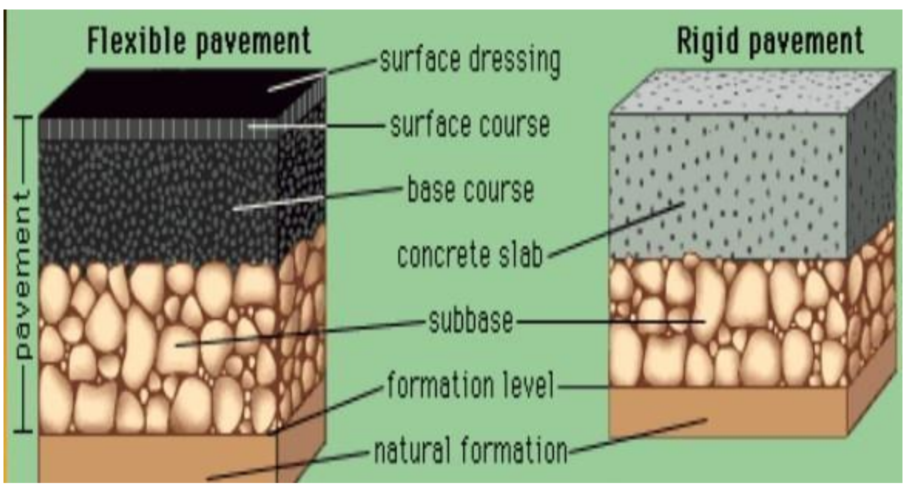



**FIG. 1 LAYERS OF PAVEMENT**

## FLEXIBLE PAVEMENTS /BITUMINOUS PAVEMENT

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. The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these 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 less quality material can be used.


**FIG.2 LAYERS OF FEXIBLE PAVEMENT**

**Flexible Pavement Components and their role**

**Seal Coat**

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

**Tack Coat**

**I**t 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**

It 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**

It 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.
- 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. Its 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**

It 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**

It 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.

**Flexible pavement design procedure (IRC Method – IRC: 37 2001)**

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 sub-grade 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 (N) ; and
- CBR value of sub-grade (in %)

**Design traffic in terms of cumulative number of standard axles (N)**

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 traffic (A)**

It 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 tones 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 (r)**

It can be estimated (a) by studying the past trends of traffic growth, and (b) 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 (n)**

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 (F)**

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.

**Distribution factor of vehicles (D)**

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.

It is considered in terms of the cumulative number of standard axles in the lane carrying maximum traffic during the design life of the road. This can be computed using the following

$$N = \frac{365 \times [(1+r)^n - 1]}{r} \times A \times D \times F$$

equation:

Where,

$N$ is the cumulative number of standard axles to be catered for the design in terms of million standards axle (msa)

$A$ is the initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day

$D$ is the lane istribution factors is the vehicle

$F$ damage factor is the design life in years

$F$ is the annual growth rate of commercial vehicles $r$ ( =-0.075 if growth rate is 7.5 percent per annum) The traffic in the year of completion is estimated using the following formula:

$$A = P(1 + r)^x$$

Where,

P is the number of commercial vehicles as per last count, and x is the number of ears between the last count and the year of completion between the last count and the year of completion of the project.

**Pavement thickness design CBR charts**

For the design of pavements to carry traffic in the range of 1 to 10 msa, use Figure1 and for traffic in the range 10 to 150 msa, use Figure 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 recommendations given below and the subsequent tables.

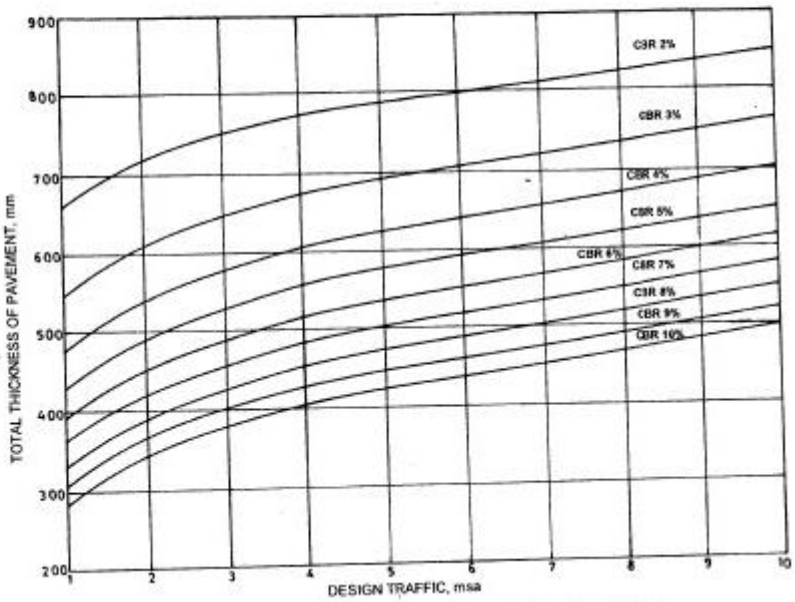



**FIG.3 PAVEMENT THICKNESS DESIGNCHART 1-10 msa**

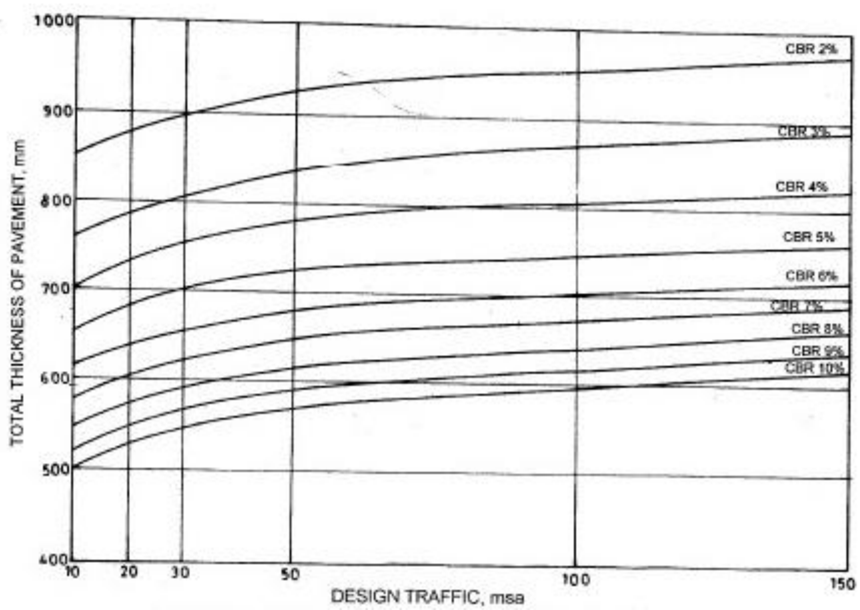



**FIG.4 PAVEMENT THICKNESS DESIGN CHART 10-150 msa**

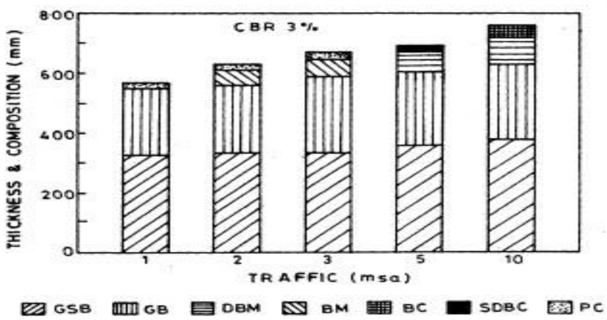
IRC:37-2001

PAVEMENT DESIGN CATALOGUE

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 3%

| Cumulative Traffic (msa) | Total Pavement Thickness (mm) | PAVEMENT COMPOSITION | | | |
|---|---|---|---|---|---|
| | | Bituminous Surfacing | | Granular Base (mm) | Granular Sub-base (mm) |
| | | Wearing Course (mm) | Binder Course (mm) | | |
| 1 | 550 | 20 PC | | 225 | 435 |
| 2 | 610 | 20 PC | 50 BM | 225 | 335 |
| 3 | 645 | 20 PC | 60 BM | 250 | 335 |
| 5 | 690 | 25 SDBC | 60 DBM | 250 | 335 |
| 10 | 760 | 40 BC | 90 DBM | 250 | 380 |




PAVEMENT DESIGN CATALOGUE

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 4%

| Cumulative Traffic (msa) | Total Pavement Thickness (mm) | PAVEMENT COMPOSITION | | | |
|---|---|---|---|---|---|
| | | Bituminous Surfacing | | Granular Base (mm) | Granular Sub-base (mm) |
| | | Wearing Course (mm) | Binder Course (mm) | | |
| 1 | 480 | 20 PC | | 225 | 255 |
| 2 | 540 | 20 PC | 50 BM | 225 | 265 |
| 3 | 580 | 20 PC | 50 BM | 250 | 280 |
| 5 | 620 | 25 SDBC | 60 DBM | 250 | 285 |
| 10 | 700 | 40 BC | 80 DBM | 250 | 330 |

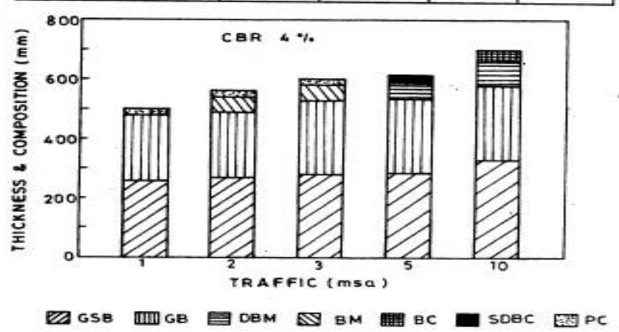



**FIG.5 PAVEMENT DESIGN CHART OF 1-10 msa WITH CBR VALUE 3% - 4%**

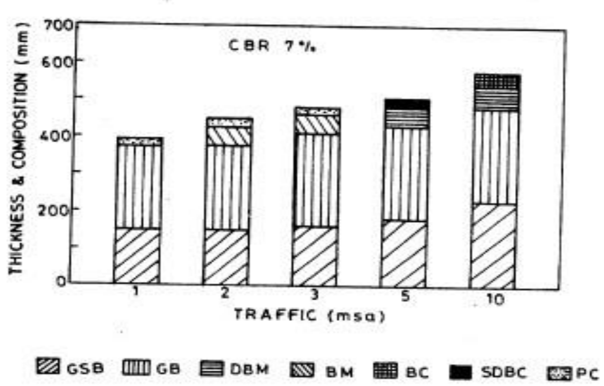
IRC:37-2001

PAVEMENT DESIGN CATALOGUE

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 7%

| Cumulative Traffic (msa) | Total Pavement Thickness (mm) | PAVEMENT COMPOSITION | | | |
|---|---|---|---|---|---|
| | | Bituminous Surfacing | | Granular Base (mm) | Granular Sub-base (mm) |
| | | Wearing Course (mm) | Binder Course (mm) | | |
| 1 | 375 | 20 PC | | 225 | 150 |
| 2 | 425 | 20 PC | 50 BM | 225 | 150 |
| 3 | 460 | 20 PC | 50 BM | 250 | 160 |
| 5 | 505 | 25 SDBC | 50 DBM | 250 | 180 |
| 10 | 580 | 40 BC | 60 DBM | 250 | 230 |




IRC:37-2001

PAVEMENT DESIGN CATALOGUE

PLATE 1 – RECOMMENDED DESIGNS FOR TRAFFIC RANGE 1-10 msa

CBR 8%

| Cumulative Traffic (msa) | Total Pavement Thickness (mm) | PAVEMENT COMPOSITION | | | |
|---|---|---|---|---|---|
| | | Bituminous Surfacing | | Granular Base (mm) | Granular Sub-base (mm) |
| | | Wearing Course (mm) | Binder Course (mm) | | |
| 1 | 375 | 20 PC | | 225 | 150 |
| 2 | 425 | 20 PC | 50 BM | 225 | 150 |
| 3 | 450 | 20 PC | 50 BM | 250 | 150 |
| 5 | 475 | 25 SDBC | 50 DBM | 250 | 150 |
| 10 | 550 | 40 BC | 60 DBM | 250 | 200 |

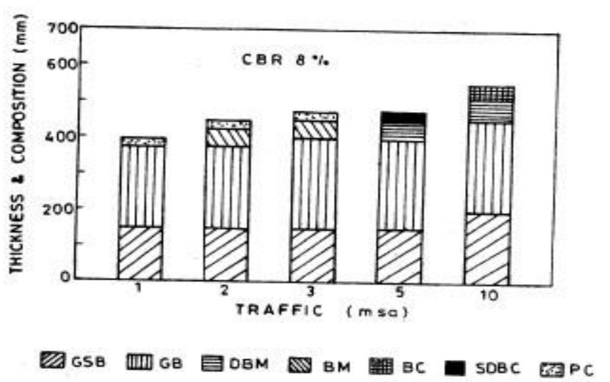



**FIG.6 PAVEMENT DESIGN CHART OF 1-10 msa WITH CBR VALUE 7% - 8%**

**Problem no.1**

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

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

**Solution**

1. Distribution factor = 0.75

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

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

**Summary**

The design procedure given by IRC makes use of the CBR value, million standard axle concept, and vehicle damage factor. Traffic distribution along the lanes is taken into account. The design is meant for design traffic which is arrived at using a growth rate.

**Problem No.2**

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 sub-grade soil=4%.

**Solutions**

1. Distribution factor = 0.75

$$\begin{aligned} N &= \frac{365 \times [(1+0.05)^{15}-1)]}{0.05} \times 300 \times 0.75 \times 2.5 \\ &= 4430348.837 \\ &= 4.4\ msa \end{aligned}$$

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

**RIGID PAVEMENT/CEMENT CONCRETE PAVEMENT**

The rigid characteristic of the pavement are associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of sub-grade soil. Rigid pavement is laid in slabs with steel reinforcement.

- The rigid pavements are made of cement concrete either plan, reinforced or pre-stressed concrete.
- Critical condition of stress in the rigid pavement is the maximum flexural stress occurring in the slab due to wheel load and the temperature changes.
- Rigid pavement is designed and analyzed by using the elastic theory.

Rigid pavements are rigid in nature which means they do not flex much under loading like flexible pavements. They are constructed using cement concrete. In this case, the load carrying capacity is mainly due to the rigidity ad high modulus of elasticity of the slab (slab action). H.M.Westergaard is who initiated in providing the rational treatment of the rigid pavement analysis.

**Modulus of sub-grade reaction (K)**

It considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection. Base on this assumption, Westergaard defined a modulus of sub-grade reaction K in kg/cm$^3$ given by

$$\mathbf{K = p/\Delta}$$

Where, **Δ** is the displacement level taken as 0.125 cm

**p** is the pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm.

**Relative stiffness of slab to sub-grade**

A certain degree of resistance to slab deflection is offered by the sub-grade. The sub-grade deformation is same as the slab deflection. Hence the slab deflection is direct measurement of the magnitude of the sub-grade pressure. This pressure deformation characteristics of rigid pavement lead Westergaard to the define the term **radius of relative stiffness** $l$ in cm is given by the equation,

$$\boxed{l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}}}$$

Where **E** is the modulus of elasticity of cement concrete in kg/cm$^2$ (3.0*10$^5$), **μ** is the Poisson's ratio of concrete (0.15), **h** is the slab thickness in cm and **K** is the modulus of sub-grade reaction.

**Critical load positions**

Since the pavement slab has finite length and width, either the character or the intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface. There are three typical locations namely the **interior, edge** and **corner**, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

**Equivalent radius of resisting section**

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard gives a relation for equivalent radius of the resisting section in cm in the equation

$$b = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675\ h & \text{if a} < 1.724\text{ h} \\ a & \text{otherwise} \end{cases}$$

Where, **a** is the radius of the wheel load distribution in cm and **h** is the slab thickness in cm.

**Wheel load stresses**

**Westergaard's stress equation**

The cement concrete slab is assumed to be homogeneous and to have uniform elastic properties with vertical sub-grade reaction being proportional to the deflection. Westergaard developed relationships for the stress at interior, edge and corner regions, denoted $\boldsymbol{\sigma_i}$ **,** $\boldsymbol{\sigma_e}$ and $\boldsymbol{\sigma_c}$ as in kg/cm$^2$ respectively and given by equation:

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

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

$$\sigma_c = \frac{3\ P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

Where, **h** is the slab thickness in cm, **P** is the wheel load in kg, **a** is the radius of the wheel load distribution in cm, **l** the radius of the relative stiffness in cm and **b** is the radius of the resisting section in cm.

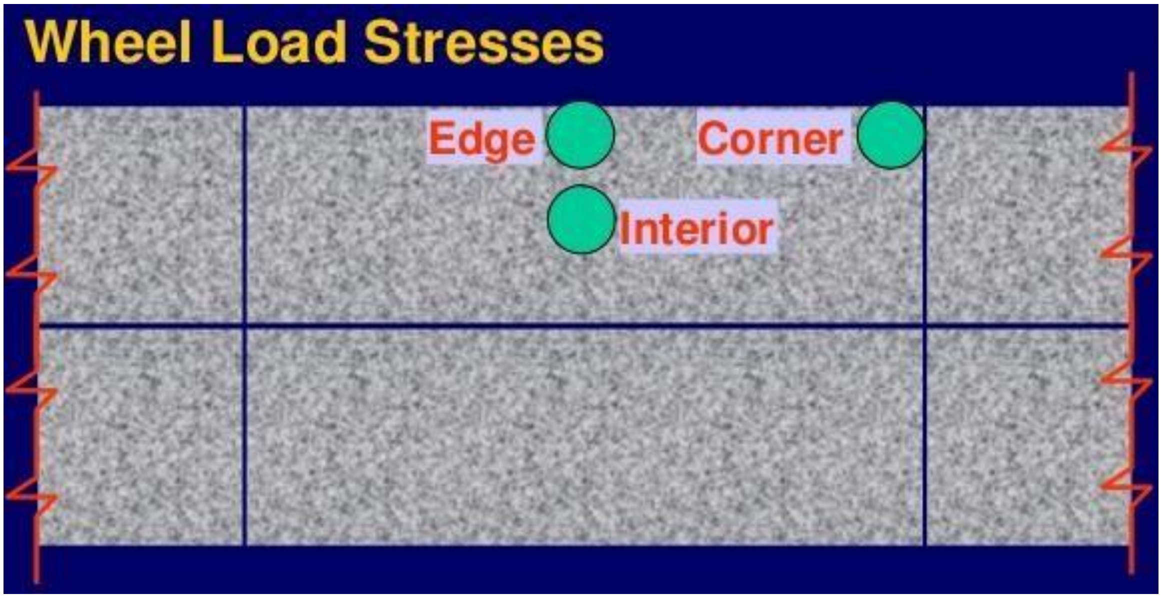



**FIG.7 PAVEMENT WHEEL LOAD STRESS AT VARIOUS POSITION**

**Temperature stresses**

They are developed in cement concrete pavement due to variation in slab temperature. This is caused by (i) **daily variation** resulting in a temperature gradient across the thickness of the slab and (ii) **seasonal variation** resulting in overall change in the slab temperature. The former result is **warping** stresses and the later is **frictional** stresses.

**Warping stress**

The warping stress at the interior, edge and corner regions, denoted $\sigma_{ti}$ ,$\sigma_{te}$ and $\sigma_{tc}$ as in kg/cm$^2$ respectively and given by the equation

$$\sigma_{t_i} = \frac{E\epsilon t}{2}\left(\frac{C_x + \mu C_y}{1-\mu^2}\right)$$

$$\sigma_{t_e} = \text{Max}\left(\frac{C_x E\epsilon t}{2}, \frac{C_y E\epsilon t}{2}\right)$$

$$\sigma_{t_c} = \frac{E\epsilon t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Where **E** is the modulus of elasticity of concrete in kg/cm$^2$ (3 X $10^5$), **ε** is the thermal coefficient of concrete per $^{o}$C (1 X $10^{-7}$) t is the temperature difference between the top and bottom of the slab, $\mathbf{C_x}$ and $\mathbf{C_y}$ are the coefficient based on $\mathbf{L_x}$ **/l** in the desired direction and $\mathbf{L_y}$**/l** right angle to the desired direction, **μ** is the Poisson's ration (0.15), **a** is the radius of the contact area and l is the radius of the relative stiffness.

**Frictional stresses**

The frictional stress $\boldsymbol{\sigma_f}$ in kg/cm$^2$ is given by the equation

$$\sigma_f = \frac{WLf}{2 \times 10^4}$$

Where **W** is the unit weight of concrete in kg/cm$^2$ (2400), **f** is the coefficient of sub grade friction (1.5) and **L** is the length of the slab in meters.

Combination of stresses - The cumulative effect of the different stress give rise to the following thee critical cases:

- **Summer, mid-day**: The critical stress is for edge region given by

$$\sigma_{critical} = \sigma_e + \sigma_{t_e} - \sigma_f$$

$$\sigma_{critical} = \sigma_e + \sigma_{t_e} + \sigma_f$$

- **Winter, mid-day**: The critical combination of stress is for the edge region given by

- **Mid-nights**: The critical combination of stress is for the corner region given by

$$\sigma_{critical} = \sigma_c + \sigma_{t_c}$$

## DESIGN OF JOINTS

**Expansion joints**

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature. The design consideration is:

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

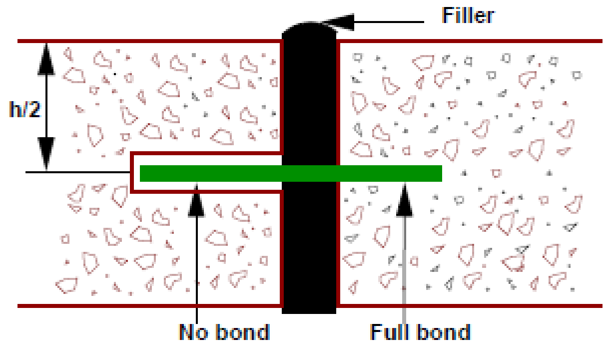



**FIG.8 EXPANSION JOINT IN RIGID PAVEMENT**

**Contraction joints**

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

- The movement is restricted by the sub-grade friction

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

- Design involves the length of the slab given by:

Where, $\mathbf{S_c}$ is the allowable stress in tension in cement concrete and is taken as 0.8 kg/cm$^2$, **W** is the unit weight of the concrete which can be taken as 2400 kg/cm$^3$ and **f** is the coefficient of sub-grade friction which can be taken as 1.5.

- Steel reinforcements can be use, however with a maximum spacing of 4.5 m as per IRC.

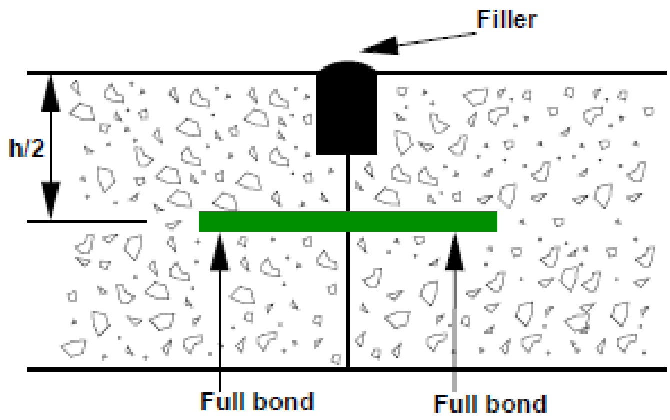



**FIG.9 CONTRACTION JOINT IN RIGID PAVEMENT**

**Dowel bars**

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

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

**Bradbury's analysis**

Bradbury's analysis gives load transfer capacity of single dowel bar in shear, bending and bearing as follows:

$$P_s = 0.785\ d^2\ F_s$$

$$P_f = \frac{2\ d^3\ F_f}{L_d + 8.8\delta}$$

$$P_b = \frac{F_b\ L_d^2\ d}{12.5\ (L_d + 1.5\delta)}$$

Where, **P** is the load transfer capacity of a single dowel bar in shear **s**, bending **f** and bearing **b**, **d** is the diameter of the bar in cm, $\mathbf{L_d}$ is the length of the embedment of dowel bar in cm, $\boldsymbol{\delta}$ is the joint width in cm, $\mathbf{F_s}$, $\mathbf{F_f}$ and $\mathbf{F_b}$ are the permissible stress in shear, bending and bearing for the dowel bar in kg/cm$^2$.

**Design procedure**

**Step: 1** Find the length of the dowel bar embedded in slab $L_d$ by equating $P_f$ and $P_b$ i.e.

$$L_d = 5d\sqrt{\frac{F_f}{F_b}\frac{(L_d+1.5\delta)}{(L_d+8.8\delta)}}$$

**Step: 2** Find the load transfer capacities $P_s$, $P_f$ and $P_b$ of single dowel bar with the $L_d$

**Step: 3** Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as

$$\max\left\{\frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b}\right\}$$

**Step: 4** Spacing of the dowel bars.

- Effective distance up to which effective load transfer takes place is given by **1.8 l**, where **l** is the radius of relative stiffness.
- Assume a linear variation of capacity factor of 1.0 under load to 0 at **1.8 l**.
- Assume dowel spacing and find the capacity factor of the above spacing.
- Actual capacity factor should be greater than the required capacity factor.
- If not, then do iteration again with new spacing.

**Example Problem 1**

Design size and spacing of dowel bars at an expansion joint of concrete pavement of thickness 25 cm. Given are the radius of relative stiffness of 80 cm and design wheel load 5000 kg. Load capacity of the dowel system is 40 percent of design wheel load. Joint width is 2.0 cm and the permissible stress in shear, bending and bearing stress in dowel bars are 1000, 1400 and 100 kg/cm$^2$ respectively.

Solution

Given, $P = 5000\ kg$, $l = 80\ cm$, $h = 25\ cm$, $\delta = 2\ cm$, $F_s = 1000\ kg/cm^2$, $F_f = 1400\ kg/cm^2$ and $F_b = 100\ kg/cm^2$; and assume $d = 2.5\ cm$ diameter.

Step: 1 Length of the dowel bar $\mathbf{L_d}$

Solve for $L_d$ by trial and error:
put $L_d = 45.00 \Rightarrow L_d = 40.95$
put $L_d = 45.95 \Rightarrow L_d = 40.50$
put $L_d = 45.50 \Rightarrow L_d = 40.50$
Minimum length of the dowel bar is $L_d + \delta = 40.5 + 2.0 = 42.5\ cm$, So, provide 45 $cm$ long and 2.5 $cm$ $\phi$.
Therefore $L_d = 45 - 2 = 43\ cm$.
Step 2: Find the load transfer capacity of single dowel bar

$$\begin{aligned} P_s &= 0.785 \times 2.5^2 \times 1000 &= 4906\ kg \\ P_f &= \frac{2 \times 2.5^3 \times 1400}{43.0 + 8.8 \times 2} &= 722\ kg \\ P_b &= \frac{100 \times 2.5 \times 43.0^2}{12.5\ (43.0 + 1.5 \times 2)} &= 804\ kg \end{aligned}$$

Therefore, the required load transfer capacity

$$\max\left\{\frac{0.4 \times 5000}{4906}, \frac{0.4 \times 5000}{722}, \frac{0.4 \times 5000}{804}\right\}$$
$$\max\{0.41, 2.77, 2.487\} = 2.77$$
$$\begin{aligned} L_d &= 5 \times 2.5 \sqrt{\frac{1400}{100} \frac{(L_d + 1.5 \times 2)}{(L_d + 8.8 \times 2)}} \\ &= 12.5 \times \sqrt{14 \frac{(L_d + 3)}{(L_d + 17.6)}} \end{aligned}$$

Step: 3 Find the required spacing: Effective distance of load transfer = 1:8 l = 1:8 X 80 = 144 cm. Assuming 35 cm spacing,

$$1 + \frac{144 - 35}{144} + \frac{144 - 70}{144} + \frac{144 - 105}{144} + \frac{144 - 140}{144}$$
$$= 2.57 < 2.77 \quad \text{(the required capacity)}$$

Actual capacity is

Therefore assume 30 cm spacing and now the actual capacity is

$$1 + \frac{144 - 30}{144} + \frac{144 - 60}{144} + \frac{144 - 90}{144} + \frac{144 - 120}{144}$$
$$= 2.92 > 2.77 \quad \text{(the required capacity)}$$

Therefore provide 2.5 cm φ mild steel dowel bars of length 45 cm @ 30 cm center to center.

**Step 1** Diameter and spacing: The diameter and the spacing is first found out by equating the total sub-grade friction tot he total tensile stress for a unit length (one meter). Hence the area of steel per one meter in $cm^2$ is given by:

$$A_s \times S_s = b \times h \times W \times f$$
$$A_s = \frac{bhWf}{100S_s}$$

where, $b$ is the width of the pavement panel in $m$, $h$ is the depth of the pavement in $cm$, $W$ is the unit weight of the concrete (assume 2400 $kg/cm^2$), $f$ is the coefficient of friction (assume 1.5), and $S_s$ is the allowable working tensile stress in steel (assume 1750 $kg/cm^2$). Assume 0.8 to 1.5 $cm$ $\phi$ bars for the design.

**Step 2** Length of the tie bar: Length of the tie bar is twice the length needed to develop bond stress equal to the working tensile stress and is given by:

$$L_t = \frac{d\ S_s}{2\ S_b}$$

where, $d$ is the diameter of the bar, $S_s$ is the allowable tensile stress in $kg/cm^2$, and $S_b$ is the allowable bond stress and can be assumed for plain and deformed bars respectively as 17.5 and 24.6 $kg/cm^2$.

**Tie bars** In contrast to dowel bars, tie bars are not load transfer devices, but serve as a means to tie two slabs. Hence tie bars must be deformed or hooked and must be firmly anchored into the concrete to function properly. They are smaller than dowel bars and placed at large intervals. They are provided across longitudinal joints.

**Example**

A cement concrete pavement of thickness 18 cm, has two lanes of 7.2 m with a joint. Design the tie bars.

(Solution:)
Given h=18 cm, b=7.2/2=3.6m, $S_s = 1700\ kg/cm^2$ $W = 2400\ kg/cm^2$ $f = 1.5$ $S_b = 24.6\ kg/cm^2$.

Step 1: diameter and spacing: Get $A_s$ from

$$A_s = \frac{3.6 \times 18 \times 2400 \times 1.5}{100 \times 1750} = 1.33\ cm^2/m$$

Assume $\phi = 1\ cm$, $\Rightarrow$ $A = 0.785\ cm^2$. Therefore spacing is $\frac{100 \times 0.785}{1.33} = 59\ cm$, say $55\ cm$

Step 2: Length of the bar: Get $L_t$ from

$$L_t = \frac{1 \times 1750}{2\ 246} = 36.0\ cm$$

[Ans] Use 1 $cm$ $\phi$ tie bars of length of 36 $cmi$ @ 55 $cm$ $c/c$

## INTRODUCTION TO PAVEMENT DESIGN SOFTWARE

Given are the few list of software used for the design of pavement.

- CIRCLY 6.0
- MnPAVE Flexible
- AASHTOWare
- PaveXpress
- FAARFIELD
- PCASE
- HIPAVE
- EverStressFE

### CIRCLY 6.0 design software

It is a powerful, user-friendly, Windows-based package for mechanistic pavement design and analysis.

**Defining Inputs**- Pavement and loading databases save re-keying information. You can define your own material properties and loadings.

**Viewing the Results**- CIRCLY 6.0 generate graphs that show the damage factor across the pavement. CIRCLY 6.0can also generate graphs of any component of displacement, strain or stress in two- dimensional or three-dimensional form.

### MnPAVE design software

MnPAVE Flexible is a computer program that combines known empirical relationships with a representation of the physics and mechanics behind flexible pavement behavior. The mechanistic portions of the program rely on finding the tensile strain at the bottom of the asphalt layer, the compressive strain at the top of the subgrade, and the maximum principal stress in the middle of the aggregate base layer.

MnPAVE Flexible consists of three input modules: Climate, Structure, and Traffic; and three design levels: Basic, Intermediate, and Advanced. The level is selected based on the amount and quality of information known about the material properties and traffic data. In the basic mode, only a general knowledge of the materials and traffic data are required. The intermediate level corresponds to the amount of data currently required for Mn/DOT projects. The advanced level requires the determination of modulus values for all materials over the expected operating range of moisture and temperature

MnPAVE Flexible output includes the expected life of the pavement, the damage factor based on Miner's Hypothesis. Reliability has been incorporated into the latest version. There is also a batch section for testing a range of layer thicknesses. In Research Mode (accessible from the "View" menu in the main MnPAVE window), output includes various pavement responses for each season.

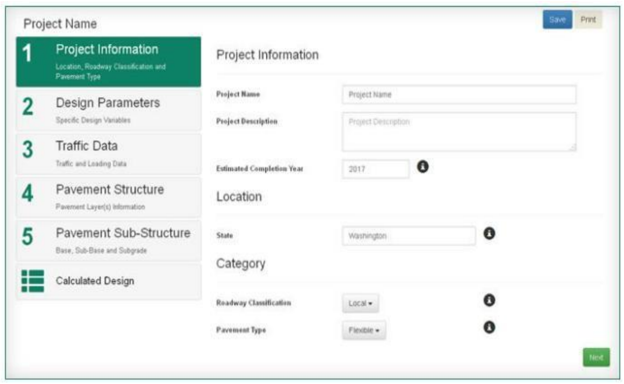
### AASHTOWare design software

AASHTOWare pavement ME Design is the next generation of pavement design software, which builds upon the National Cooperative Highway Research Program mechanistic-empirical pavement design guide. State-of-the-art procedures incorporated in the software reflect eight years of research and development involving both AASHTO members and the National Cooperative Highway Research Program (NCHRP). The research and development process and resulting software beautifully illustrate the power and effectiveness of the cooperative development practice behind all AASHTOWare products. Continuous improvement of pavement process continues under NCHRP, the Federal Highway Administration and state agencies. Pavement ME Design represents a quantum leap forward from previous processes. Engineers can now precisely predict pavement performance because the software incorporates material mechanics, climate data, axle-load spectra and other advances.

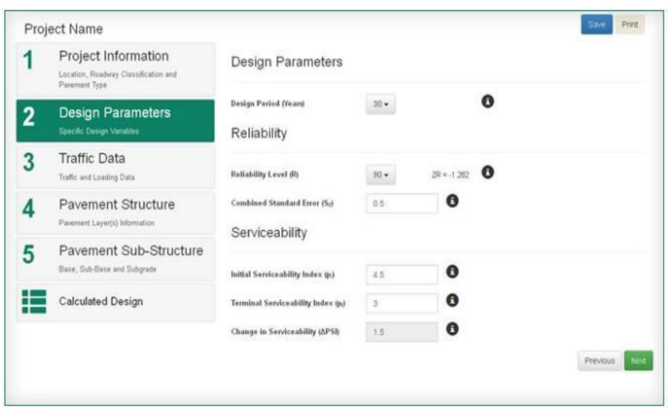
**PaveXpress Software -** PaveXpress is a scoping tool to help you create simplified pavement designs while taking into account key engineering inputs. It includes access to resources such as design guides from state DOTs and industry associations so you can build formal designs from its simple recommendations.

Link to tutorial for this software - http://www.pavexpressdesign.com/#gettingStarted

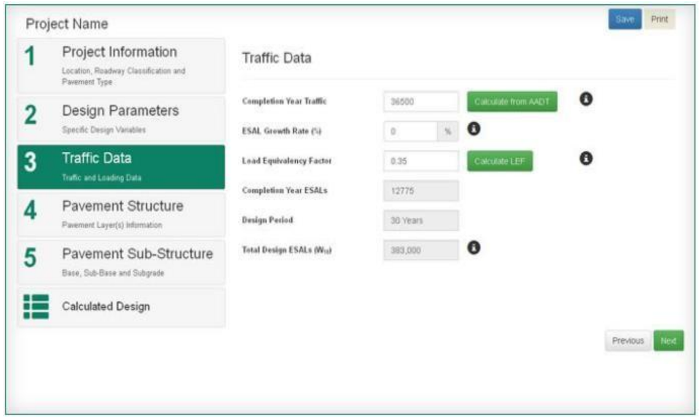
**Step 1 -** To identify your project, provide a basic description and information about the location and type of pavement.



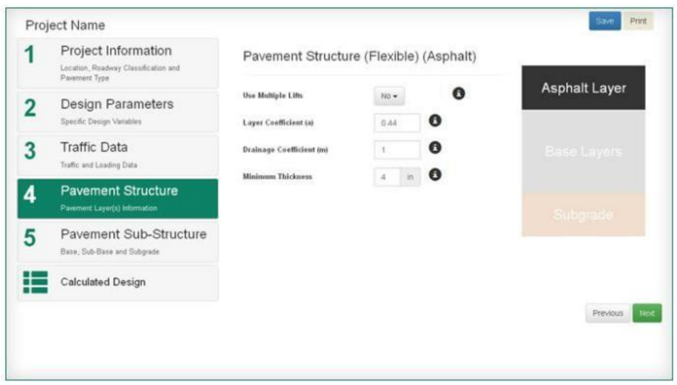

**Step 2** - Set the design period and review key design parameters.



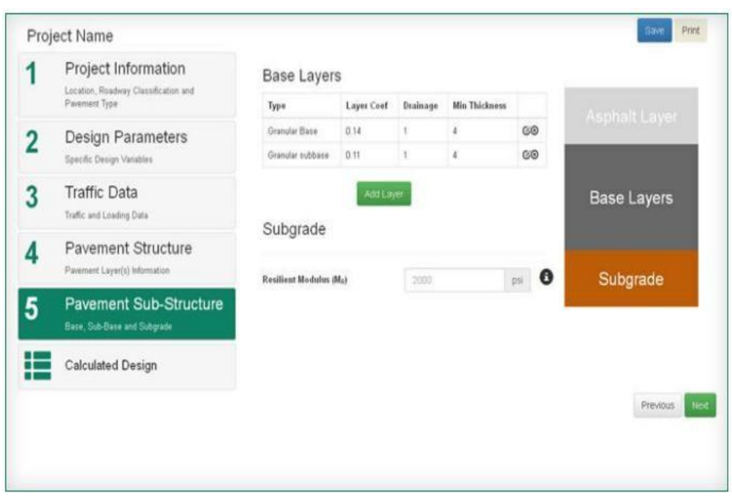
**Step 3 -** Enter data on traffic counts and load distributions to calculate total design ESALs.




**Step 4 -** Define the number and types of layers in the pavement structure.




**Step 5 -** The PaveXpress Scoping Tool generates a recommended pavement design and links to related design resources.



**Calculated Design -** View your AASHTO 93/98 pavement design and layer thickness calculations.


**FAARFIELD**

FAARFIELD is a computer program for airport pavement thickness design. It implements both layered elastic based and three-dimensional finite element-based design procedures developed by the Federal Aviation Administration (FAA) for new and overlay design of flexible and rigid pavements. The thickness design procedures implemented in the program are the FAA airport pavement thickness design standards referenced in Advisory Circular (AC) 150/5320-6E.

**PCASE**

It is software for the design and evaluation of airfields and roadways according to Tri-Service Criteria.

http://softadvice.informer.com/Pavement_Design_So
ftware.html Main features are:

- Pavement Design using empirical or layered elastic methodology
- Pavement Evaluation
- Evaluation Equipment Support Software
- Dynamic Cone Penetrometer (DCP)
- Non-Destructive Testing (NDT) using Falling Weight Deflectometer (FWD) data

**HIPAVE**

HIPAVE (Heavy Industrial PAVEment design) is a program for the mechanistic analysis and design of flexible pavements subjected to the extremely heavy wheel loads associated with freight handling vehicles in industrial facilities, in particular, intermodal container terminals. It is designed to conveniently model each combination of vehicle type and container load and to combine the damage using the Cumulative Damage Factor concept.

**EverStressFE**

It is a user-friendly 3D finite-element analysis tool for simulating the response of flexible asphalt pavement systems subjected to wheel loads. EverStressFE is useful for both flexible pavement researchers and designers who must perform complex analyses of flexible asphalt pavement systems.

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

HIGHWAY ENGINEERING

# UNIT – V – PAVEMENT EVALUATION AND MANAGEMENT SCIA1304

## INTRODUCTION

The overall purpose of highway maintenance is to fix defects and preserve the pavement's structure and serviceability. Defects must be defined, understood, and recorded in order to select an appropriate maintenance plan. The Defects varies between flexible and rigid pavements.

There are four main objectives of highway maintenance:

- Repair of functional pavement defects
- Extend the functional and structural service life of the pavement
- Maintain road safety and signage
- Keep road reserve in acceptable condition

The maintenance activities include:

- Identification of defects and their possible causes
- Determine appropriate remedial measures
- Implementations of remedial measures in the field
- Monitoring of results

## CAUSES OF FAILURES IN FLEXIBLE PAVEMENTS

This may be due to settlement of any one of the components of the pavement.

**Causes of Failure in subgrade soil:**

- Excessive settlement of the subgrade of soil in the form of excessive undulations or waves or corrugations on the pavement surface.
- Inadequate stability is due to excessive moisture, improper compaction and inherent weakness of the soil
- Excessive stress application causes the deformation of the subgrade to be plastic and unrecoverable resulting in subsidence of the subgrade

**Causes of Failure of sub-base or base course:**

- Settlement of layers due to internal readjustment of aggregates and movement of wheel loads which results in loosening of compacted layer.
- Lack of stability due to inadequate thickness or poor mix of base or sub-base course.
- Loss of base course materials

**Causes of Failure of wearing course:**

- Inferior or improper mix design
- Inadequate binder cement and Inferior quality of binder

## TYPES OF FLEXIBLE PAVEMENT FAILURES

### Alligator cracking or Map cracking (Fatigue)

This is a common type of failure of flexible pavements. This is also known as atigue failure. Followings are the primary causes of this type of failure.

- Relative movement of pavement layer material
- Repeated application of heavy wheel loads
- Swelling or shrinkage of subgrade or other layers due to moisture variation

**FIG.1 ALLIGATORS ON ROAD SURFACE**

**Consolidation of pavement layers (Rutting)**

Formation of ruts falls in this type of failure. A rut is a depression or groove worn into a road by the travel of wheels.

This type of failure is caused due to following reasons.

- Repeated application of load along the same wheel path resulting longitudinal ruts.
- Wearing of the surface course along the wheel path resulting shallow ruts.

**FIG.2 RUTTING ON ROAD SURFACE**

**Shear failure cracking**

Shear failure causes upheaval of pavement material by forming a fracture or cracking. Followings are the primary causes of shear failure cracking.

- Excessive wheel loading
- Low shearing resistance of pavement mixture

**FIG.3 SHEAR FAIL ON ROAD SURFACE**

**Longitudinal cracking**

This types of cracks extents to the full thickness of pavement. The following are the primary causes of longitudinal cracking.

- Differential volume changes in subgrade soil
- Settlement of fill materials
- Sliding of side slopes

**FIG.4. LONGITUDINAL CRACK ON ROAD SURFACE**

## Frost heaving

Frost heaving causes upheaval of localized portion of a pavement. The extent of frost heaving depends upon the ground water table and climatic condition.

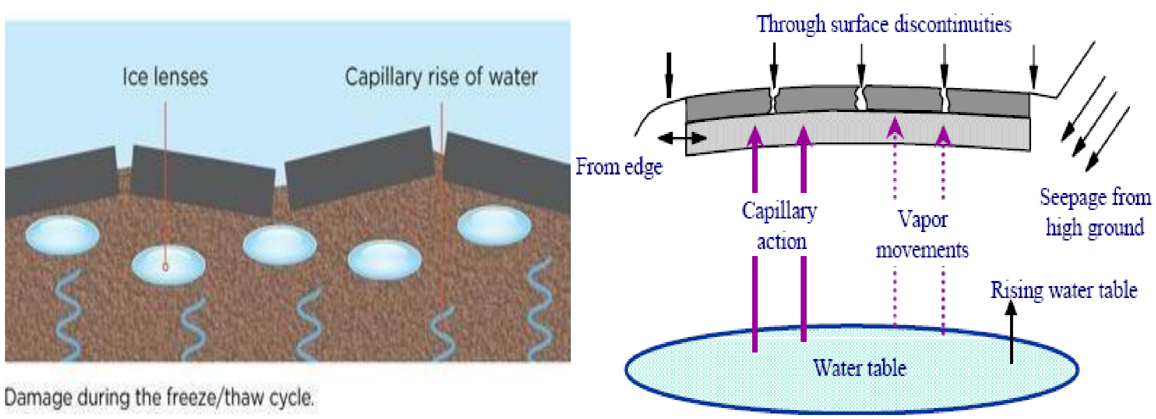


**FIG.5. FROST CRACK ON ROAD SURFACE**

**Lack of binding to the lower course**

When there is lack of binding between surface course and underlying layer, some portion of surface course looses up materials creating patches and potholes. Slippage cracking is one form of this type of failure. Lack of prime coat or tack coat in between two layers is the primary reason behind this type of failure.

**FIG.6 ROAD FAILURE DUE TO LACK OF BINDING**

**Reflection cracking**

This type of failure occurs, when bituminous surface course is laid over the existing cement concrete pavement with some cracks. This crack is reflected in the same pattern on bituminous surface.

**FIG.7 REFLECTION CRACK ON ROAD SURFACE**

## Formation of waves and corrugation

Transverse undulations appear at regular intervals due to the unstable surface course caused by stop- and-go traffic.

**FIG.8 WAVE FAILURE ON ROAD SURFACE**

## Bleeding

Excess bituminous binder occurring on the pavement surface causes bleeding. Bleeding causes a shiny, glass-like, reflective surface that may be tacky to the touch. Usually found in the wheel paths.

**FIG.9 BLEEDING FAILURE ON ROAD SURFACE**

**Pumping**

Seeping or ejection of water and fines from beneath the pavement through cracks is called pumping.

**FIG.9 MUD PUMPING ON ROAD SURFACE**

**CAUSES OF FAILURES OF RIGID PAVEMENTS**

- Deficiencies in Pavement materials
- Structural Inadequacy
- Improper Construction and Maintenance

**Deficiencies in Pavement materials**

Causes are;

- Soft aggregates
- Dirty aggregates with silt and clay
- Low quality joint filler
- Poor sealer material
- Poor quality steel
- Improper use of cement for the specific region

**Structural Inadequacy**

Causes are;

- Poor subgrade soil and improper assessment of its strength
- Improper mix design approach
- Inadequate pavement thickness
- Incorrect spacing of joints
- Incorrect design of load transfer devices
- Absence of longitudinal hinge joints
- Long length of slab
- Non-existence of temperature steel
- Deep foundation movements

**Improper Construction and Maintenance**

Causes:

- Poor workmanship in pavement and joint construction
- Poor surface finish
- Improper and insufficient curing
- Use of concrete mixes which are wet

**TYPICAL RIGID PAVEMENT FAILURES**

- Scaling of Cement Concrete
- Shrinkage Cracks
- Warping Cracks
- Spalling of Joints

**Scaling of cement concrete**

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. This may be due to the following reasons

- Improper mix design
- Excessive vibration during compaction of concrete
- Performing finishing operation while bleed water is on surface

**Shrinkage cracks**

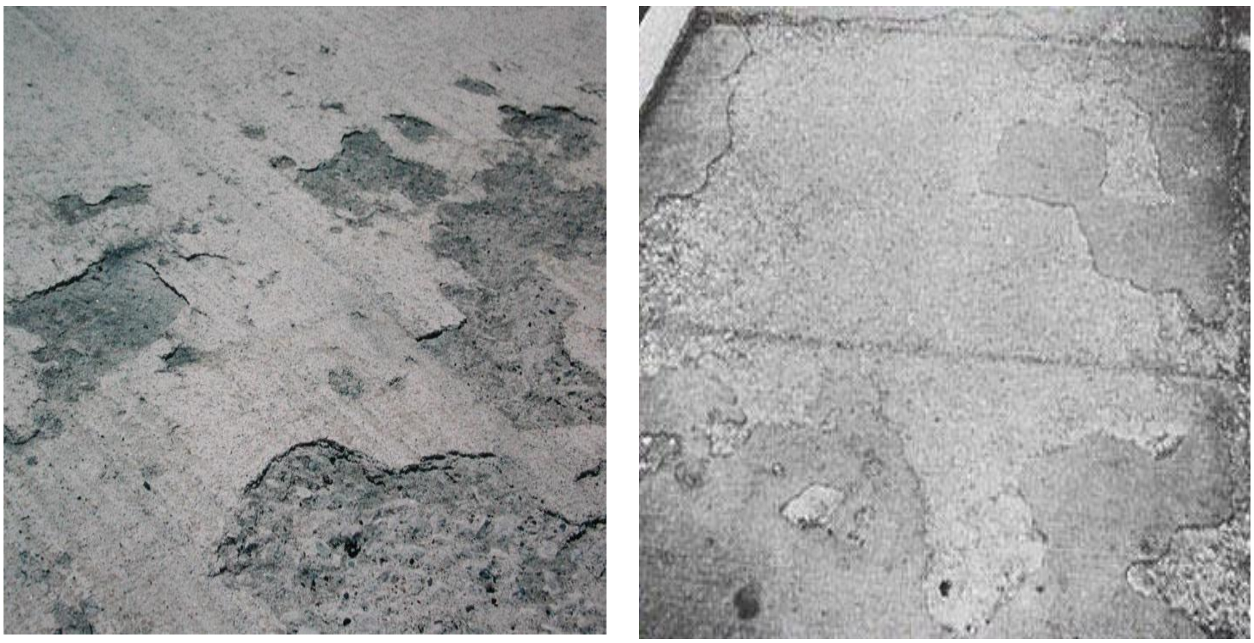


**FIG.10 SHRINKAGE CRACK ON ROAD SURFACE (a)**

Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks. Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.

**FIG.11 SHRINKAGE CRACK ON ROAD SURFACE (b)**

## Joint spalling

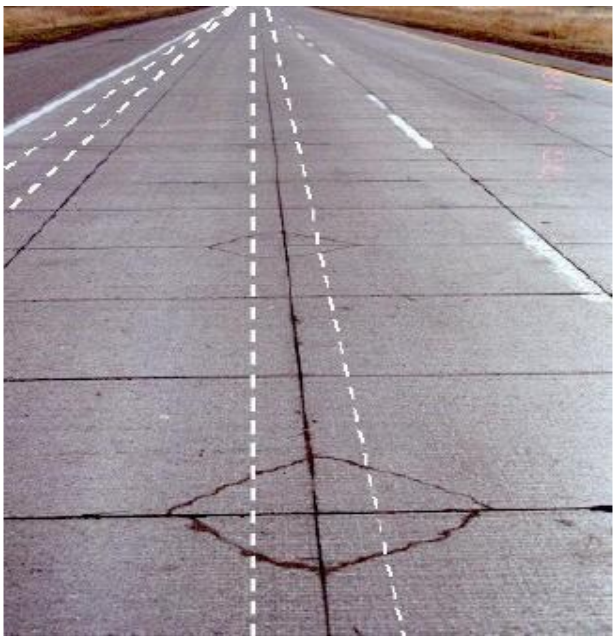
Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- Faulty alignment of incompressible material below concrete slab
- Insufficient strength of concrete slab near joints
- Freeze-thaw cycle
- Excessive stress at joint due to wheel load

**FIG.12 JOINT SPALLING CRACK ON ROAD SURFACE**

## Warping cracks

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause formation of warping cracks of the concrete slab near the joint edge. This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.



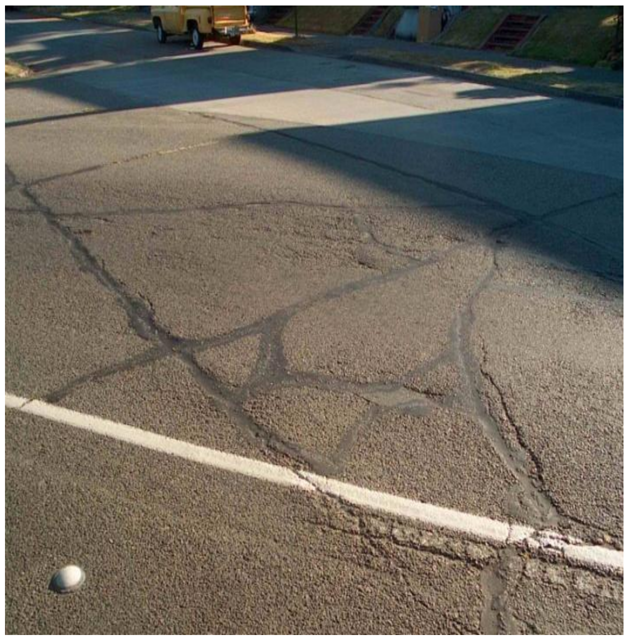


**FIG.13 WARPING CRACK ON ROAD SURFACE**

## Pumping

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping.

The common reasons for this defect are

- Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.
- When there is void space between slab and the underlying base of sub-grade layer
- Poor joint sealer allowing infiltration of water
- Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support. When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks.

This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.

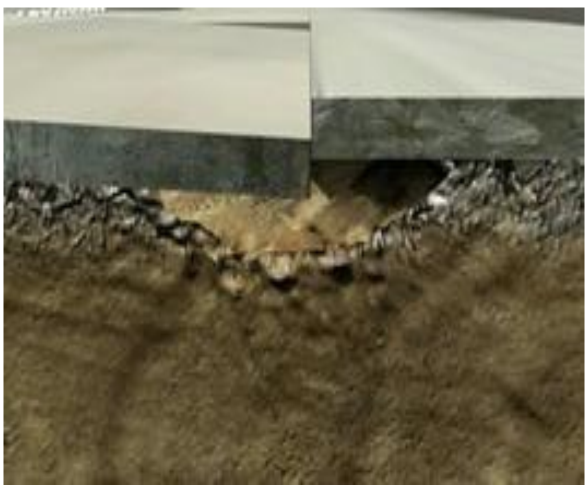



**FIG.14 JOINT SOIL SPILLAGE ON ROAD SURFACE**

## PAVEMENT EVALUATION

It is the study of various factors pertaining to pavement, such as subgrade support, pavement composition and its thickness, traffic loading and environmental condition.

The main aim:

- To assess as to whether and to what extent the pavement fulfills the design requirements.
- To investigate the structural inadequacy of pavements and also the requirements for providing safe and comfortable traffic operations.

**Methods of Evaluation of Pavements:**

- Structural Evaluation
- Evaluation of Pavement Surface Condition

## STRUCTURAL EVALUATION

- Plate bearing test can be conducted for both flexible and rigid pavements to assess the structural capacity.
- The assessment may be made by
    - The load carried at a specified deflection at a place or
    - The amount of deflection at a specified load on the plate
- The performance of a flexible pavement is closely related to the elastic deformation under loads or its rebound deformation.

## EVALUATION OF PAVEMENT SURFACE CONDITION

- Surface conditions of flexible pavements may be determined by their unevenness, patches, ruts and cracks. These surface conditions affect the riding quality of the pavements.
- Unevenness of the pavements may be measured using unevenness indicator, profilograph, profilometer or roughometer.

**Unevenness Index:**

It is the index by adding the unevenness of the surface on a cumulative scale represented as cm/km length of road.

**TABLE 1 NUEVENNESS WITH RIDE QUALITY**

| **Unevenness Index, Cm/Km** | **Riding Quality** |
|---|---|
| Below 95<br>95 to 119<br>120 to 144<br>145 to 240 | Excellent<br>Good<br>Fair<br>Poor |
| Above 240 | Very poor (Resurfacing is required) |
| **In new pavements**<br>Below 120<br>120 to 145<br>Above 145 | <br>Good<br>Fair<br>Poor |

## STRENGTHENING OF EXISTING PAVEMENTS

- A highway is expected to have adequate stability to withstand the design traffic under prevailing climate and subgrade conditions.
- Only solution to manage the increased traffic is either to direct the traffic on some adjacent roads or to strengthen the existing pavements.
- Strengthening may be done by providing additional thickness of pavement provided the subgrade is strong enough.

## OVERLAY

Construction of one or more layers over the existing pavement

**Types of overlay:**

- Flexible overlays are bituminous surfaces constructed over existing flexible pavements or existing concrete pavements.
- Rigid overlays consists of plain, simply reinforced or continuously reinforced concrete pavements.

**Combination of Overlays:**

**TABLE 2TYPES OF OVERLAY**

| Existing pavement | Overlay |
|---|---|
| Cement concrete | Cement concrete |
| Cement concrete | bituminous |
| Bituminous or flexible | Cement concrete |
| Bituminous or flexible | Bituminous or flexible |

The choice of overlay depends on various factors,

- Total thickness of overlay required
- Wheel load
- Subgrade strength, etc.

## BENKELMANN BEAM DEFLECTION METHOD FOR STRUCTURAL EVALUATION OF PAVEMENT

Benkalmann Beam is a device used to measure the rebound deflection of a pavement.

**Principle:**

A well designed and constructed flexible pavement which has been well conditioned also deforms elastically under the design wheel load i.e. there is an elastic recovery or rebound of the deformed pavement surface. This is the basic principle of deflection method of pavement which is used to design the overlay thickness.

**Equipment:**

Benkelmann beam consists of a slender beam 3.66 m long pivoted at a distance of 2.44 m from the tip. The tip is a probe end. The datum frame rests on a pair of front leveling legs and a rear leg with adjustable height.

By suitably placing the probe between the dual wheels of a loaded trucks, it is possible to measure the rebound and the residual deflection of the pavement structure. Rebound deflection is used for overlay design and the residual deflection may be used attributed to non-recoverable deflection of the pavement.

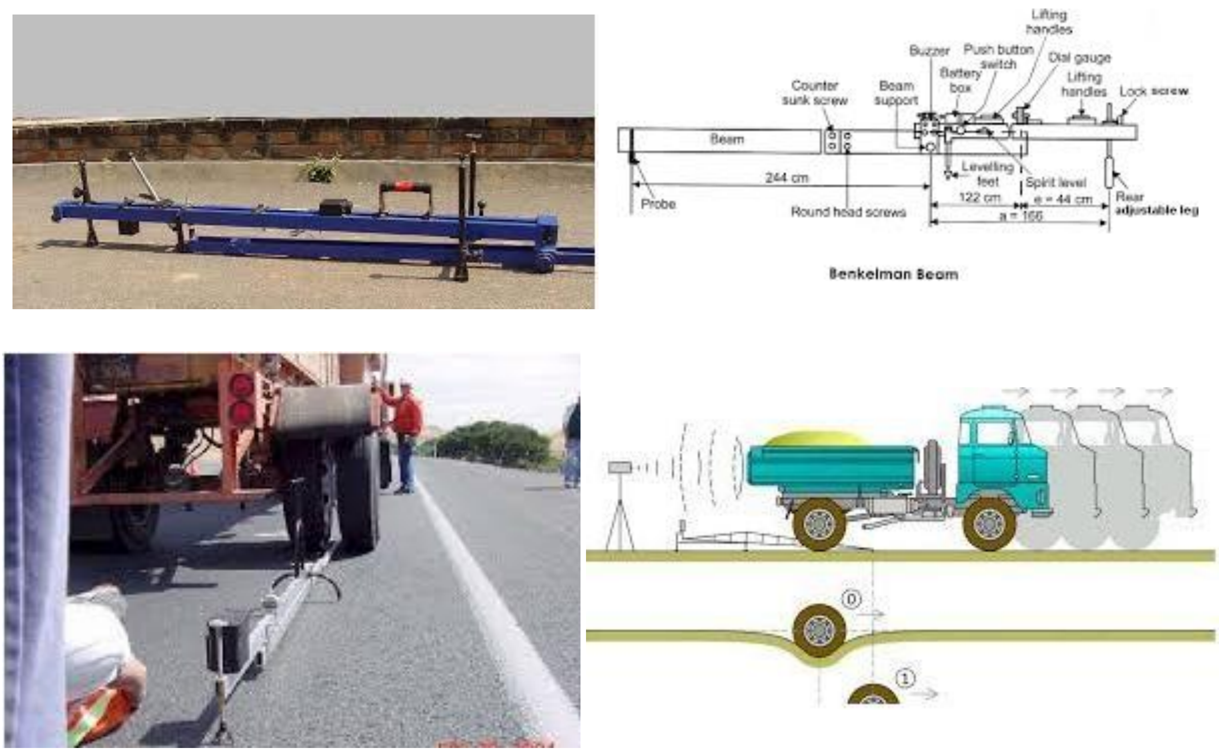



**FIG.15 DEFLECTION TEST ON ROAD SURFACE**

**Procedure**

- The road to be evaluated is first surveyed to assess the general conditions of the pavement.
- The pavement stretches of length not less than 500 m are classified and grouped on to different classes of length, viz., good, fair and poor for the purpose of studies.
- Loading points for deflection measurements are located along the wheel paths.
- A minimum of 10 deflection observation points may be selected and its may be staggered if necessary.

- The truck is stopped in such a way that the left side rear dual wheel is centrally placed over the first point for deflection measurement.
- The probe end of the benkelmann beam is inserted between the gap and positioned exactly over the deflection observation point.
- The initial dial gauge reading, $D_o$ is noted.
- The truck is moved forward through a distance of 207 m from the point and stopped. The intermediate dial gauge reading $D_i$ is noted.
- The truck is then moved further forward 9.0 m. The final dial reading, $D_f$ is recorded.
- These three deflection dial readings, $D_o$, $D_i$ and $D_f$ form one set of readings at one deflection point.
- Temperature at intervals of one hour are taken on the pavement surface.

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

a. If $(D_i - D_f) < 0.025$ mm, then $D = 2 (D_o – D_f) = 0.02 (D_o - D_f)$ mm

b. If $(D_i - D_f) > 2.5$ division of dial gauge. A correction has to be applied for the vertical movement of the front legs.

$D = 2 (D_o – D_f) + 2 K (D_i - D_f)$ division

The value of

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

Where $d$ = distance between the bearing of the beam and the rear adjusting leg

e = distance between the dial gauge and the rear adjusting leg

f = distance between the front and rear legs

The value of K depends on the type of equipment. The value of K for the equipment available in India is 2.91.3

$$D = 0.02\ (D_o - D_f) + 0.0582\ (D_i - D_f)\ \text{mm}$$

The mean value of deflection at n points is given by

$$D = \frac{D}{n}\ mm$$

The standard deviation of the deflection value is given by, Characteristics deflection $D_c$ is given by

$$D_c = D + t\,\sigma$$

Where t is to be chosen upon the percentage of the deflection values to be covered in the design.

When t = 10,

$D_c = D + \sigma$ covers about 84 % of the cases of deflection values on the pavement When t = 2.0,

$D_c = D + 2\sigma$ covers about 97.7 % of the cases of deflection values on the pavement IRC recommends $D_c = D + \sigma$

**Thickness Design of Overlay**

Based on the allowable deflection $D_a$ in the pavement, the overlay thickness $h_o$ required may be determined.

According to Ruiz's equation, in cm is given by,

Where

R = deflection reduction factor, is a function of overlay material varies from 10 to 15 for bituminous overlays. An average value of 12 is used generally.

$D_a$ = allowable deflection which depends upon the pavement type and the desired design life. For flexible pavements for overlay design it varies from 0.75 to 1.25 mm

Where = thickness of granular or WBH overlay in mm

$h_o$

$D_c = D + \sigma$

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

A = design traffic

$A = D [ 1 + r ]^{n+10}$

For bituminous concrete or bituminous macadam with bituminous surface course, then the thickness is reduced by an equivalence factor of 2.0

## PAVEMENT MANAGEMENT SYSTEM

**Pavement management** is the process of planning the maintenance and repair of a network of roadways or other paved facilities in order to optimize pavement conditions over the entire network.

A pavement management system (PMS) is a planning tool used to aid pavement management decisions. PMS software programs model future pavement deterioration due to traffic and weather, and recommend maintenance and repairs to the road's pavement based on the type and age of the pavement and various measures of existing pavement quality. Measurements can be made by persons on the ground, visually from a moving vehicle, or using automated sensors mounted to a vehicle. PMS software often helps the user create composite pavement quality rankings based on pavement quality measures on roads or road sections. Recommendations are usually biased towards predictive maintenance, rather than allowing a road to deteriorate until it needs more extensive reconstruction.

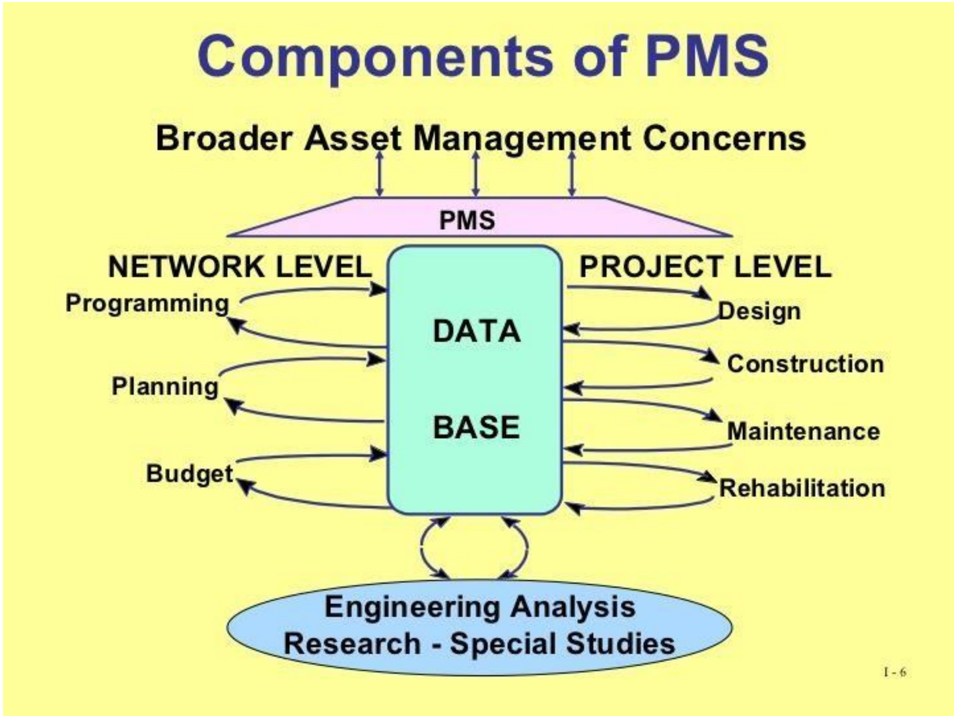



**FIG.16 COMPONENTS OF PMS (a)**

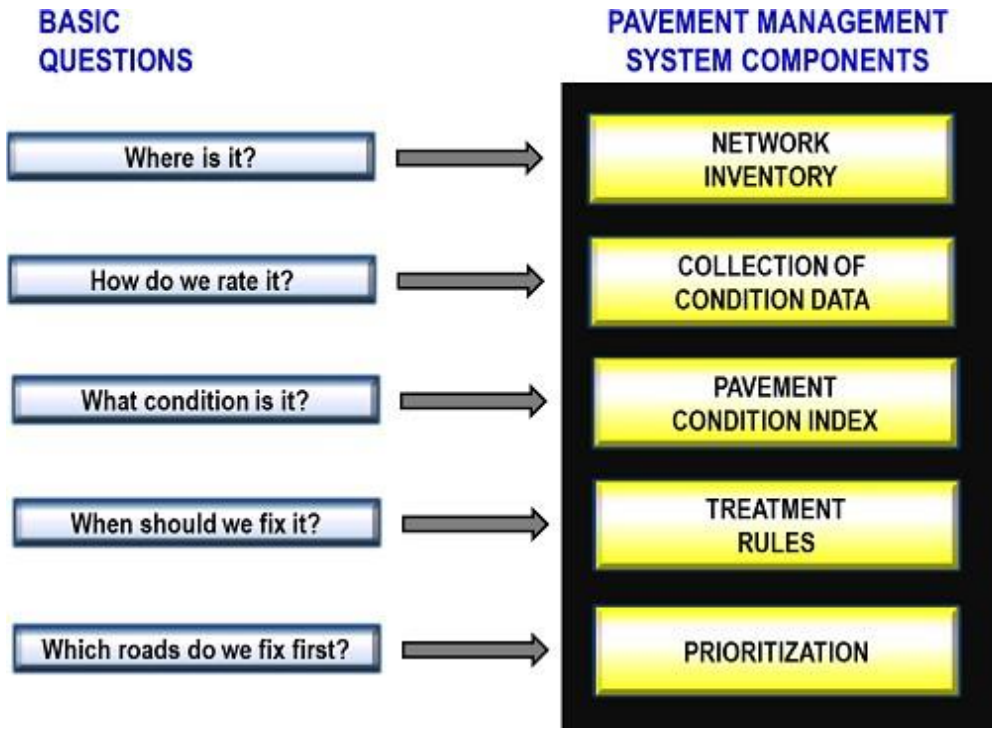



**FIG.17 COMPONENTS OF PMS (b)**

Typical tasks performed by pavement management systems include:

- Inventory pavement conditions, identifying good, fair and poor pavements.
- Assign importance ratings for road segments, based on traffic volumes, road functional class, and community demand.
- Schedule maintenance of good roads to keep them in good condition.[6]
- Schedule repairs of poor and fair pavements as remaining available funding allows.

## HIGHWAY DRAINAGE

Highway drainage may be defined as the process of interception and removal of water from over, under and the vicinity of the road surface. Road drainage is very important for safe and efficient design of the road way.

**Function of Highway Drainage:**

- Remove water from the road surface
- Prevent ingress of water into the pavement
- Pass water across the road, either under or over
- Prevent scour and/ or washout of the pavement, shoulder, batter slopes, water courses and drainage structures

## EFFECTS OF IMPROPER DRAINAGE

One of the major causes of road failure is its improper drainage. Improper drainage of the road causes destruction in the following ways:

- Road surface if made of soil, gravel or water bound macadam, it will becomes soft and losses strength.
- The road sub-grade may be softened and its bearing capacity reduced.
- Variation in moisture content in expensive soils, causes variation in the volume of sub-grade and thus causes failureof roads.
- Failure of formation slopes is also attributed to poor drainage.
- If rain water is not properly drained and allowed to flow along the road side for long distances, slip and land slides may occur causing road failures.

- Erosion of side slopes, side drains, formation of gullies may result if proper drainage conditions are not maintained.
- Flexible pavement’s failure by formation of waves and corrugations is due to poor drainage.
- Continuous contact of water, with bituminous pavements causes failures due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.
- Rigid pavement’s prime cause of failure in by mud pumping which occurs due to water in fine sub-grade soil.
- Excess moisture causes increase in weight and thus increase in stress and simultaneous reduction in strength of the soil mass. This main reason of failure of earth slopes and embankment foundation.
- Erosion of soil from the top of un-surfaced roads and embankment slopes in also due to surface water

## TYPES OF DRAINAGE SYSTEM

- A part of rainwater falling on road surface and adjoining area is lost by evaporation and percolation. The remaining water known as surface water , either remains on the surface of the road and adjoining area, or flows away from it, depending upon the topography and general slope of the area. Removal and diversion of this surface water from highway and adjoining land is known as **surface drainage.**
- Due to percolation, if water table does not rise near of the road sub-grade, it does not create any problem as it does not affect the road sub-grade. If water table rises to the vicinity of road sub-grade, it requires to be lowered as it will definitely affect road sub-grade. Measures adopted to lower the subsoil water table are called **sub surface drainage.**

## SURFACE DRAINAGE SYSTEM

### Kerb and Gullies:

- Road gullies generally discharge to longitudinal carrier pipes
- They are safety hazard for high speed vehicles and are generally not suitable on trunk roads
- One advantage of kerb and gullies is that its ability to carry road surface runoff to outfall is not dependent upon the longitudinal gradient of the roads itself

### Surface Water Channel:


**FIG.18 ROAD SURFACE DRINAGE CHANNEL**

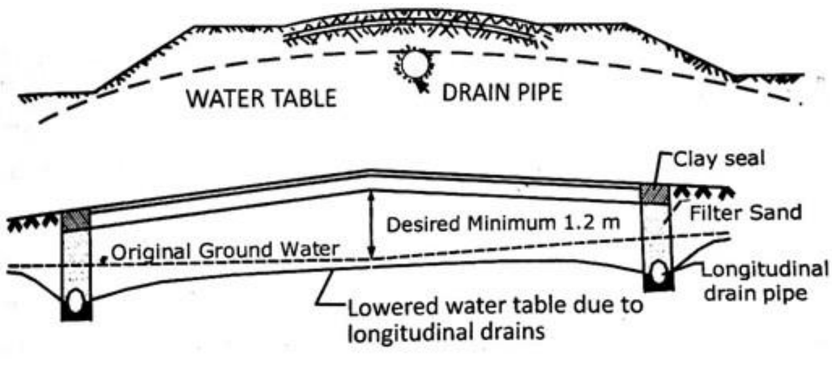
- Normally of triangular or trapezoidal concrete section, usually slip-formed, set at the edge of hard strip or hard shoulder and flush with the road surface.
- They may not be appropriate for roads with long stretches of zero longitudinal gradients.
- Can be constructed quickly
- Comparatively less maintenance
- Potentially less hazardous
- Give Less chance of surface water entering the road foundation and causing premature failure

**SUB-SURFACE DRAINAGE SYSTEM**

Subgrade may be damaged by sub soil water. Sub soil water as free water, when water table is high or it may come up by capillary action to the subgrade when water table is low. Subgrade should be of self draining material so that it may pass off the percolation water that comes to it to remain dry and stable. But if subgrade is of soft and retentive soil, or there are underground springs bringing free water to the subgrade for that reason subsurface drains should be constructed about 1
½' to 2' below the formation level to carry away water from the subgrade and thus keep it dry.

Cross-drains may be in the form of trapezoidal trenches filled with selected rubble called rubbled drains or trench drains. Depth is not much and the discharge is small. The pipes are surrounded by filler material and the remaining of the cross trench is filled with graded rubble, the bigger size rubble being nearer to the pipe. Water of wet subgrade passes through the open joint of pipes and enter the lateral drain which discharge into the longitudinal drain pipe in the two longitudinal side trenches. Longitudinal drain carry water to the nearby stream. Cross-drains, staggered in herring bone fashion. Spacing of lateral drains is less in impermeable soil and more in permeable soil.

**DRAINAGE OF SUB-SURFACE WATER**




**Lowering of Water Table**

**FIG.19 LOWERING OF WATER TABLE**

The highest level of water table should be fairly below the level of sub grade, in order that the sub grade and pavements layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 meter below the sub grade. In place where water table is high (almost at ground level at times) the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 meter. When the formation is to be at or below the general ground level, it would be necessary to lower the water table. If the soil is relatively permeable, it may be possible to lower the high water table merely construction of longitudinal drainage trenches with drain pipe and filter sand. If the soil is relatively less permeable, the lowering of ground water level may not be adequate at the center of the pavement or in between the two longitudinal drainage trenches. Hence in addition, transverse drainage may have to provide in order to effectively drain off the water and thus lower the water table up to the level of transverse drains.

**Control of Seepage Flow**

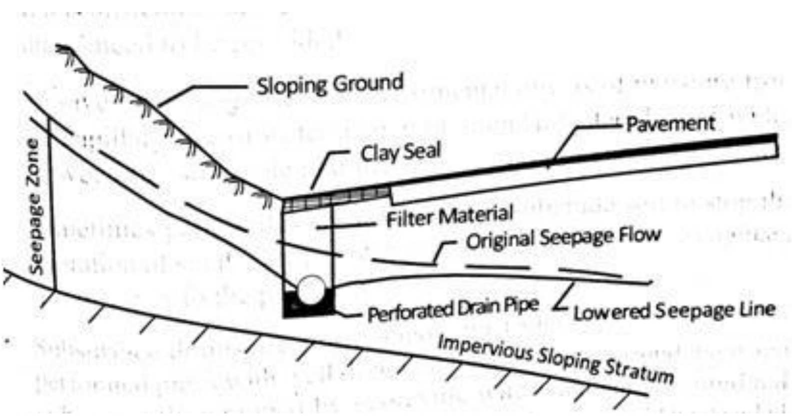



**FIG.20 LOWERING OF DRAIN WATER**

When the general ground and impervious strata below are slopping, seepage flow is likely to exist. If the seepage zone is at depth less than 0.6 to 0.9 meter from the sub grade level, longitudinal pipe drain in trench filled with filler material and clay seal may be constructed to intercept the seepage flow.

**Control of Capillary Rise**

If the water reaches the sub grade due to capillary rise is likely to be detrimental, it is possible to solve the problem by arresting the capillary rise instead of lowering the water table. The capillary rise may be checked either by capillary cut-off of any one of the following two types:-

- A layer of granular material of suitable thickness is provided during the construction of embankment, between the sub grade and the highest level of sub surface water table. The thickness of the granular capillary cut-off layer should be sufficiently higher than the anticipated capillary rise with in the granular layer so that the capillary water cannot rise above the cutoff layer.

- Another method of providing capillary cut-off is by inserting an impermeable or Bituminous layer in the place of granular blanket.

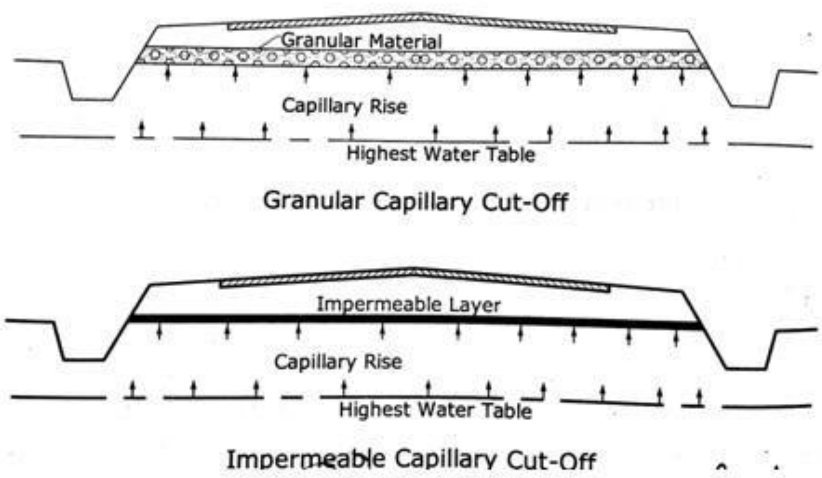



**FIG.21 CAPILARY CUT-OFF TO DRAIN WATER**

## DRAINAGE OF SLOPES AND EROSION CONTROL

Drainage of slopes of embankment, cutting and hill side are of utmost importance to prevent the instability of slopes and slides.

- Soaking of slopes causes increase in stress and reduction in strength. Hence an efficient network of surface drainage system consisting of intercepting drains and sloping drains to keep the slopes properly drained.
- The sloping drains may be provided with lining or pitching or may be filled with gravel.
- The water from the sloping drains is collected in catch pits and diverted across through the culverts at suitable intervals.
- The flow of surface water also frequently causes erosion of soil. This may occur on earth roads if the cross slope is too steep and also on earth shoulders.
    - Surface treatment and stabilization of these surfaces are useful for the control of erosion.
    - Erosion of soil from the slopes of cut and embankment is detrimental to the slope stability.

The erosion depends on several factors such as,

- Intensity and duration of rainfall
- Type and conditions of soil
- Height and angle of slope
- Climatic conditions

## FORMULATION OF HIGHWAY PROJECT REPORT

Refer detailed project report on Bruhat Bengaluru Mahanagara Palike 2017 report which is uploaded in LMS