TRANSPORTATION ENGINEERING

Lecture notes

UNIT I : HIGHWAY ENGINEERING

1.1 Importance of transportation:: Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure. A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption. Transportation fulfils these basic needs of humanity. Transportation plays a major role in the development of the human civilization. For instance, one could easily observe the strong correlation between the evolution of human settlement and the proximity of transport facilities. Also, there is a strong correlation between the quality of transport facilities and standard of living, because of which society places a great expectation from transportation facilities. In other words, the solution to transportation problems must be analytically based, economically sound, socially credible, environmentally sensitive, practically acceptable and sustainable. Alternatively, the transportation solution should be safe, rapid, comfortable, convenient, economical, and eco friendly for both men and material.

In the last couple of decades transportation systems analysis has emerged as a recognized profession. More and more government organizations, universities, researchers, consultants, and private industrial groups around the world are becoming truly multi-modal in their orientation and are opting a systematic approach to transportation problems.

1.2 Modes of transportation:: We find that basically transport is possible through land, air or water, which are called the different modes of transport. On land we use trucks, tractors, etc., to carry goods; train, bus, cars etc. to carry passengers. In air, we find aeroplanes, helicopters to carry passengers as well as goods. Similarly in water we find ships, steamers, etc., to carry goods and passengers. All these are known as various means of transport.

Land Transport:

Land transport refers to activities of physical movement of goods and passengers on land. This movement takes place on road, rail, rope or pipe. So land transport may further be divided into Road transport, Rail transport, Ropeway transport, pipeline transport.

a) **Road Transport**

Roads are the means that connect one place to another on the surface of the land. You must have seen roads in your village, in towns and cities. Not all of them look alike. Some of them are made of sand and some may be of chips and cement or coaltar. You find different vehicles plying on roads like bullock carts, cycles, motorcycles, cars, truck, buses, etc. All of these constitute different means of road transport.

b) Rail transport

Transportation of goods and passengers on rail lines through trains is called rail transport. It occupies an important place in land transport system of our country and is the most dependable mode of transport to carry goods and passengers over a long distance. Besides long distance, local transport of passengers is also provided by local trains or metro-rail in some metropolitan cities. Rail transport is available throughout the country except some hilly or mountainous regions. In India two types of trains are found. One is passenger train and other is goods train. While passenger trains carry both human beings and a limited quantity of goods, the goods trains are exclusively used for carrying goods from one place to another. These trains are driven by rail engines and they use steam, diesel or electric power to move.

c) Pipelines transport

In modern times, pipelines are used for various purposes. Water supply to residential and commercial areas is carried on with the help of pipeline. Petroleum and natural gas are also transported from one place to another through pipelines. This is the most convenient as well as economical mode of transport for petroleum as well as natural gas in comparison to road and rail transport, provided the volume to be transported is large. But the cost of installation and maintenance requires large capital investment.

d) Ropeway transport

Ropeway refers to a mode of transport, which connects two places on the hills, or across a valley or river. In the hilly areas, trolleys move on wheels connected to a rope and are used for carrying passengers or goods, especially building materials, food, etc. The famous “Uran Katella Jagdamba” in Gujarat that carries pilgrims to the temple is an example of ropeway transport, which carries more than 100 passengers at a time.

Water transport

Water transport refers to movement of goods and passengers on waterways by using various means like boats, steamers, launches, ships, etc. With the help of these means goods and passengers are carried to different places, both within as well as outside the country. Within the country, rivers and canals facilitate the movement of boats, launches, etc. Since the goods and passengers move inside the country, this type of transport is called inland water transport. When the different means of transport are used to carry goods and passengers on the sea route it is termed as ocean transport.

a) Inland water transport

Inland water transport use boats, launches, barges, streamers, etc., to carry goods and Passengers on river and canal routes. These routes are called inland waterways and are used in domestic or home trade to carry bulky goods. Passenger transport through Waterways is not so popular in our country. Inland water transport system exists only in few states like. West Bengal, Andhra Pradesh, Assam, Tamil Nadu, etc.

b) Ocean transport

Ocean transport refers to movement of goods and passengers with the help of ships Through sea or ocean waterways. It plays an important role in the development of International trade. It is also used for transporting goods and passengers in the coastal Areas. Ocean transport has its fixed route, which links almost all the countries of the world. Sea transport may be of the following two types.

Air transport

This is the fastest mode of transport. It carries goods and passengers through airways by using different aircrafts like passenger aircraft, cargo aircraft, helicopters, etc. Besides passengers it generally carries goods that are less bulky or of high value. In hilly and mountainous areas where other mode of transport is not accessible, air transport is an important as well as convenient mode. It is mostly used for transporting goods and passengers during natural calamities like earthquake and floods, etc. During war, air transport plays an important role in carrying soldiers as well as supplies to the required areas.

1.3 Characteristics of road transport ::

In India About 65% of freight and 80% passenger traffic is carried by the roads.

- National Highways constitute only about 1.7% of the road network but carry about 40% of the total road traffic.
- Number of vehicles has been growing at an average pace of 10.16% per annum over the last five years. About 65% of freight and 80% passenger traffic is carried by the roads.

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India has the second largest road network in the world, with over **3.314** million kms of roadways spread across the length and breadth of the country. The roads are primarily made of bitumen, with some Indian National Highways having concrete roads. The concept of expressway roads is also catching up in India, and the **Mumbai – Pune expressway** and **Delhi Gurgaon expressway** are the finest examples. **Yamuna-expressway** which connects **Delhi to Agra** is also good.

1.4.Classification of roads:: (PPT Enclosed)

1.5. Highway alignment:: The highway alignment can be either horizontal or vertical

The position or the layout of the central line of the highway on the ground is called the alignment. Horizontal alignment includes straight and curved paths. Vertical alignment includes level and gradients.

Alignment decision is important because a bad alignment will increase the construction, maintenance and vehicle operating costs. Once an alignment is fixed and constructed, it is not easy to change it due to increase in cost of adjoining land and construction of costly structures by the roadside.

Requirements of an ideal Alignment:

There are some basic requirements of the highway alignment in the plain and hill roads which must be fulfilled. In general the basic requirements are
(1) Short: The alignment must be the shortest of the various alternatives available. Of course the shortest path between any two points is a straight line but the topography of the area or other factors may necessitate it do divert and take some other route, but as far as possible it should be kept minimum.
(2) Easy: Alignment should be such that the road must be easy to construct and easy to maintain or repair.
(3) Safe: Safety is again the basic requirement of the highway alignment and special care must be taken to align the road in such a way that it must have the safe or minimum Sight distances.
(4) Economical: Road alignment must be designed to have the initial cost of construction,

maintenance cost and the vehicle operation cost to a minimum. Also the locally available materials .

Hill roads have some other basic requirements also which govern the alignment of the hill roads:
(1) Drainage: Drainage of the road must be kept in mind and it must be insured that enough drainage structures can be built on the route. As far as possible alignment must avoid the drainage works means it must have the minimum numbers of the drainage works.
(2) Economy: Economy is governed by the numbers of the drainage works, cutting filling and the gradient.
(3) Safety: Safety is governed by the sight distance, super-elevation and the design radius of the curves. It must be kept in mind that gradient must be kept below the ruling gradient. In hill roads special attention must be given to the side slopes, and thorough geological surveys must be carried out to ensure the safety while construction as well as while traffic movement.
(4) Minimum resisting length: The un-necessary rise and fall of the gradient must be minimized to reduce the cost and length of road.

Factors Governing Alignment:: The various factors that control the alignment are as follows:

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

Some of the examples are:

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

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

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

ENGINEERING SURVEYS FOR HIGHWAY LOCATION:

Before a highway alignment is finalised in highway project, the engineering surveys are to be carried out. The survey may be completed in four stages i.e.

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

(a) **Map study:** With the help of topographic map it is possible to suggest the likely routes of the road. In India, topographic maps are available from the survey of India with 15 of 30 m contour interval. The main features like rivers, hills, valleys, etc., are also shown on these maps.

(b) **Reconnaissance:** It is a rapid and rough survey. During the survey, the physical characteristics of the areal are inspected and the proposed route is thoroughly examined. it is done without accurate instruments. Clinometers are used to determine the slopes of the ground. It provides additional information not available in top sheets.

Objects: -

i). To study the feasibility or practicability of the proposed route

ii). To reduce the number of alternative routes to the minimum to select the best 2 or 3 routes.

iii) Source of construction materials, water and location of stone quarries.

iv) Number and type of cross drainage structure, maximum flood level and natural ground water level along the probable routes.

(c) **Preliminary Survey**: This survey can be started on the basis of reconnaissance. It consists of detailed survey of the alternative routes selected. After reconnaissance. It is done by using the instruments such as chain, compass, tape, level & theodolite.

Objects: -

a. To select the best route.

b. To determine the centre line to be followed

c. To collect are additional information found necessary after reconnaissance.

d. To estimate quantity of earthwork materials and other construction aspects and to work out the cost of alternate proposals

(d) **Final Location and Detailed Survey**: The alignment finalized after the preliminary survey is to be first located on the field by established the centre line.

This is done accurately by using instruments. The final route selected after the preliminary survey is surveyed and located on the ground.

Objects:-

1. To establish temporary bench marks
2. To collect information required for
3. The preparation of working drawings
4. The preparation of detailed estimates
5. The design of road & bridges
6. Preparing specifications
7. Land acquisition

UNIT II

HIGHWAY GEOMETRIC DESIGN

The geometric design of highways deals with the dimensions and layout of visible features of the highway. The emphasis of the geometric design is to address the requirement of the driver and the vehicle such as safety, comfort, efficiency, etc. The features normally considered are the cross section elements, sight distance consideration, horizontal curvature, gradients, and intersection. The design of these features is to a great extend influenced by driver behavior and psychology, vehicle characteristics, traffic characteristics such as speed and volume. Proper geometric design will help in the reduction of accidents and their severity. Therefore, the objective of geometric design is to provide optimum efficiency in traffic operation and maximum safety at reasonable cost. The planning cannot be done stage wise like that of a pavement, but has to be done well in advance. The main components that will be discussed are:

1. Factors affecting the geometric design,

2. Highway alignment, road classification,

3. Pavement surface characteristics,

4. Cross-section elements including cross slope, various widths of roads and features in the road margins.

5. Sight distance elements including cross slope, various widths and features in the road margins.

6. Horizontal alignment which includes features like super elevation, transition curve, extra widening and setback distance.

7. Vertical alignment and its components like gradient, sight distance and design of length of curves.

1.1. Factors affecting geometric design

- Design speed
- Topography
- Other factors

1.1.1. Design speed

Design speed is the single most important factor that affects the geometric design. It directly affects the sight distance, horizontal curve, and the length of vertical curves. Since the speed of vehicles vary with driver, terrain etc, a design speed is adopted for all the geometric design.

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

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

1.1.2. Topography

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

1.1.3. Other factors

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

- Vehicle: The dimensions, weight of the axle and operating characteristics of a vehicle influence the design aspects such as width of the pavement, radii of the curve, clearances, parking geometrics etc. affects the design. A design vehicle which has standard weight, dimensions and operating characteristics are used to establish highway design controls to accommodate vehicles of a designated type.
- Human: The important human factors that influence geometric design are the physical, mental and psychological characteristics of the driver and pedestrians like the reaction time.
- Traffic: It will be uneconomical to design the road for peak traffic flow. Therefore a reasonable value of traffic volume is selected as the design hourly volume which is

determined from the various traffic data collected. The geometric design is thus based on this design volume, capacity etc.

- Environmental: Factors like air pollution, noise pollution etc. should be given due consideration in the geometric design of roads.
- Economy: The design adopted should be economical as far as possible. It should match with the funds allotted for capital cost and maintenance cost.
- Others: Geometric design should be such that the aesthetics of the region is not affected.

1.2. Highway Cross Section Elements

1.2.1. Pavement Surface characteristics

For a safe and comfortable driving four aspects of the pavement surface are important; the friction between the wheels and the pavement surface, smoothness of the road surface, the light reflection characteristics of the top of pavement surface, and drainage to water.

1.2.1.1. Friction

Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed. Further, it also affect the acceleration and deceleration ability of vehicles. Lack of adequate friction can cause skidding or slipping of vehicles.

• Skidding happens when the path traveled along the road surface is more than the circumferential movement of the wheels due to friction

• Slip occurs when the wheel revolves more than the corresponding longitudinal movement along the road.

Various factors that affect friction are:

1. Type of the pavement (like bituminous, concrete, or gravel),
2. Condition of the pavement (dry or wet, hot or cold, etc),
3. Condition of the tyre (new or old), and
4. Speed and load of the vehicle.

The frictional force that develops between the wheel and the pavement is the load acting multiplied by a factor called the coefficient of friction and denoted as f. The choice of the value of f is a very complicated issue since it depends on many variables. IRC suggests the coefficient of longitudinal friction as 0.35-0.4 depending on the speed and coefficient of later friction as 0.15. The former is useful in sight distance calculation and the latter in horizontal curve design.

1.2.1.2. Unevenness

It is always desirable to have an even surface, but it is seldom possible to have such one. Even if a road is constructed with high quality pavers, it is possible to develop unevenness due to pavement failures. Unevenness affects the vehicle operating cost, speed, riding comfort, safety, fuel consumption and wear and tear of tires.

Unevenness index is a measure of unevenness which is the cumulative measure of vertical undulation of the pavement surface recorded per unit horizontal length of the road. An unevenness index value less than 1500 mm/km is considered as good, a value less than 2500 mm.km is satisfactory up to speed of 100 kmph and values greater than 3200 mm/km is considered as uncomfortable even for 55 kmph.

1.2.1.3. Light reflection

- White roads have good visibility at night, but caused glare during day time
- Black roads has no glare during day, but has poor visibility at night
- Concrete roads has better visibility and less glare

It is necessary that the road surface should be visible at night and reflection of light is the factor that answers it.

1.2.1.4. Drainage

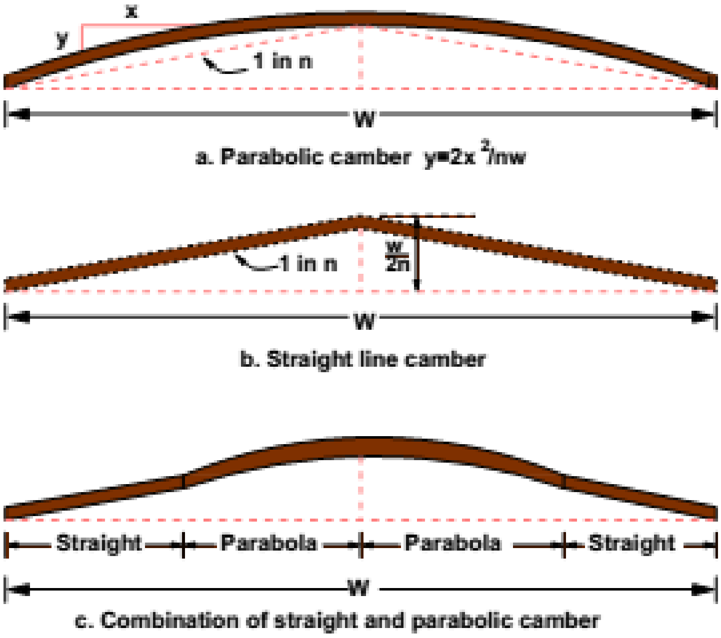
The pavement surface should be absolutely impermeable to prevent seepage of water into the pavement layers. Further, both the geometry and texture of pavement surface should help in draining out the water from the surface in less time.

1.2.2. Camber

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

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

Too steep slope is undesirable for it will erode the surface. Camber is measured in 1 in n or n% (Eg. 1 in 50 or 2%) and the value depends on the type of pavement surface. The common types of camber are parabolic, straight, or combination of them.



Types of camber

Surface Type	Heavy Rain	Light Rain
Concrete/ Bituminous	2%	1.7%
Gravel/ W.B.M	3%	2.5%
Earthen	4%	3%

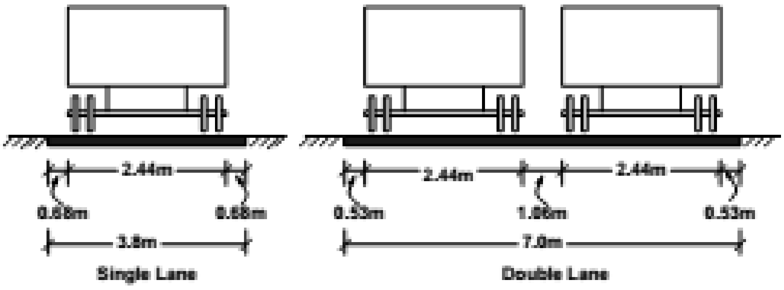
IRC values for camber

1.2.3. Width of Carriageway

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

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

IRC Specification for carriage way width



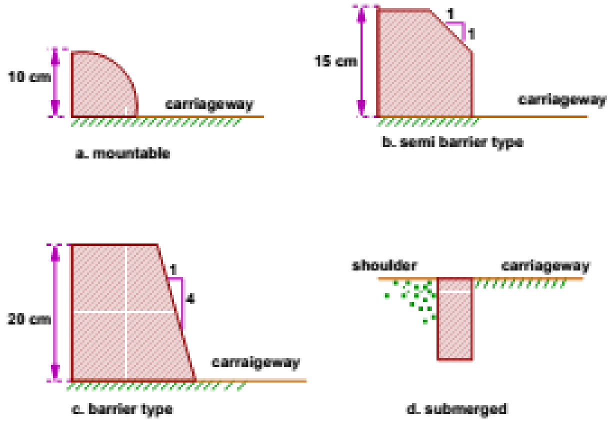
Lane width for single and two lane roads

1.2.4. Kerbs

Kerbs indicate the boundary between the carriage way and the shoulder or islands or footpaths. Different types of kerbs are-

- Low or mountable kerbs: Thesetype of kerbs are provided such that they encourage the traffic to remain in the through traffic lanes and also allow the driver to enter the shoulder area with little difficulty. The height of this kerb is about 10 cm above the pavement edge with a slope which allows the vehicle to climb easily. This is usually provided at medians and channelization schemes and also helps in longitudinal drainage.
- Semi-barrier type kerbs: When the pedestrian traffic is high, these kerbs are provided. Their height is 15 cm above the pavement edge. This type of kerb prevents encroachment of parking vehicles, but at acute emergency it is possible to drive over this kerb with some difficulty.

- Barrier type kerbs: They are designed to discourage vehicles from leaving the pavement. They are provided when there is considerable amount of pedestrian traffic. They are placed at a height of 20 cm above the pavement edge with a steep batter.
- Submerged kerbs: They are used in rural roads. The kerbs are provided at pavement edges between the pavement edge and shoulders. They provide lateral confinement and stability to the pavement.



Different types of Kerbs

1.2.5. 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.

1.2.5.1. Shoulders

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

1.2.5.2. 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.

1.2.5.3. 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.

1.2.5.4. 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.

1.2.5.5. Cycle tracks

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.

1.2.5.6. Footpaths

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

1.2.5.7. Guard rails

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. Various designs of guard rails are there. Guard stones painted in alternate black and white are usually used. They also give better visibility of curves at night under headlights of vehicles.

1.2.6. Width of formation

Width of formation or roadway width is the sum of the widths of pavements or carriage way including separators and shoulders. This does not include the extra land in formation/cutting.

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

Width of formation for various classes of roads

1.2.7. Right of way

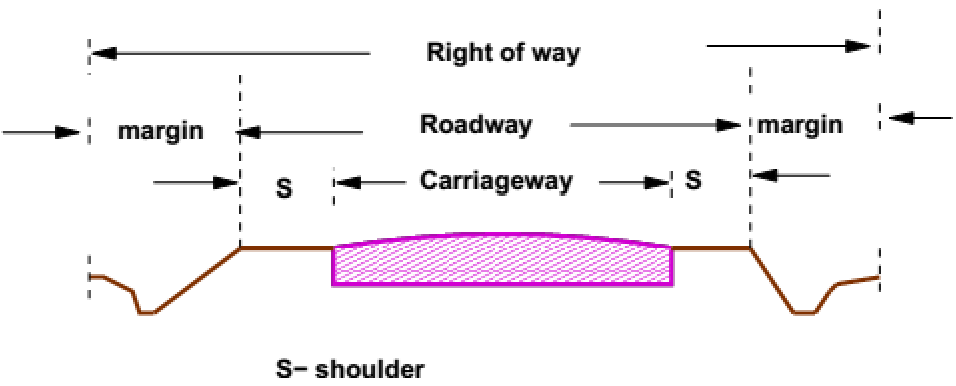
Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. It should be adequate to accommodate all the cross-sectional elements of the highway and may reasonably provide for future development. To prevent ribbon development along highways, control lines and building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

- Width of formation: It depends on the category of the highway and width of roadway and road margins.
- Height of embankment or depth of cutting: It is governed by the topography and the vertical alignment.
- Side slopes of embankment or cutting: It depends on the height of the slope, soil type etc.
- Drainage system and their size which depends on rainfall, topography etc.

- Sight distance considerations: On curves etc. there is restriction to the visibility on the inner side of the curve due to the presence of some obstructions like building structures etc.
  - Reserve land for future widening: Some land has to be acquired in advance anticipating future developmentslike widening of the road.

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

Normal right of way for open areas



A typical Right of Way

1.3. 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.

1.3.1. 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 the 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 light

• Safe sight distance to enter into an intersection

1.3.2. Factors affecting Sight Distance

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

The computation of sight distance depends on:

Reaction time of the driver

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

Speed of the vehicle

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

Efficiency of brakes

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

Frictional resistance between the tire and the road

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

Gradient of the road

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

1.3.3. Stopping Sight Distance

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

There is a term called safe stopping distance and is one of the important measures in traffic engineering. It is the distance a vehicle travels from the point at which a situation is first perceived to the time the deceleration is complete. Drivers must have adequate time if they are to suddenly respond to a situation. Thus in a highway design, a sight distance atleast equal to the safe stopping distance should be provided. The stopping sight distance is the sum of lag distance and the braking distance. Lag distance is the distance the vehicle traveled during the reaction time t and is given by vt, where v is the velocity in m/sec2 . Braking distance is the distance traveled by the vehicle during braking operation. For a level road this is obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle. If F is the maximum frictional force developed and the braking distance is l, then work done against friction in stopping the vehicle is Fl = fWl where W is the total weight of the vehicle. The kinetic energy at the design speed is

$$\begin{aligned} \frac{1}{2}mv^2 &= \frac{1}{2}\frac{Wv^2}{g} \\ fWl &= \frac{Wv^2}{2g} \\ l &= \frac{v^2}{2gf} \end{aligned}$$

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

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

where v is the design speed in m/sec2 , t is the reaction time in sec, g is the acceleration due to gravity and f is the coefficient of friction. The coefficient of friction f is given below for various design speed. When there is an ascending gradient of say +n%, the component of gravity adds to braking action and hence braking distance is decreased. The component of gravity acting parallel to the surface which adds to the the braking force is equal to W sin α = W tan α = Wn/100. Equating kinetic energy and work done:

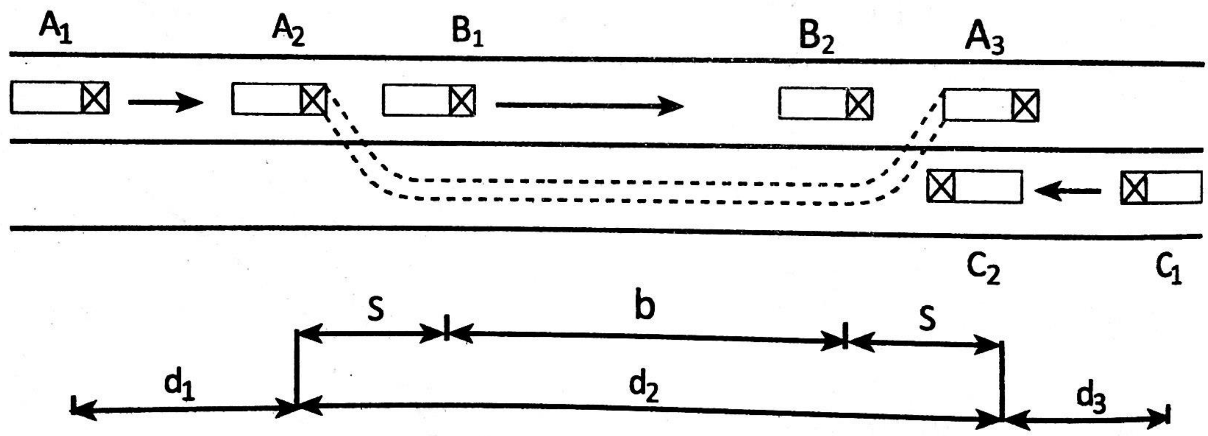
$$\begin{aligned} \left(fW + \frac{Wn}{100}\right)l &= \frac{Wv^2}{2g} \\ l &= \frac{v^2}{2g\left(f + \frac{n}{100}\right)} \end{aligned}$$

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

1.3.4. Overtaking Sight distance

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

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



d_1 the distance traveled by overtaking vehicle A during the reaction time t = t1 - t0

d_2 the distance traveled by the vehicle during the actual overtaking operation T = t3 - t1

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

Therefore:

OSD = d1 + d2 + d3

It is assumed that the vehicle A is forced to reduce its speed to vb, the speed of the slow moving vehicle B and travels behind it during the reaction time t of the driver. So d1 is given by:

$$d_1 = v_b t$$

Then the vehicle A starts to accelerate, shifts the lane, overtake and shift back to the original lane. The vehicle

A maintains the spacing s before and after overtaking. The spacing s in m is given by:

$$s = 0.7v_b + 6$$

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

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

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

d3 = vT

The overtaking sight distance is

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

where vb is the velocity of the slow moving vehicle in m/sec2, t the reaction time of the driver in sec, s is the spacing between the two vehicle in m given by equation 13.3 and a is the overtaking vehicles acceleration in m/sec2. In case the speed of the overtaken vehicle is not given, it can be assumed that it moves 16 kmph slower than the design speed.The acceleration values of the fast vehicle depends on its speed.

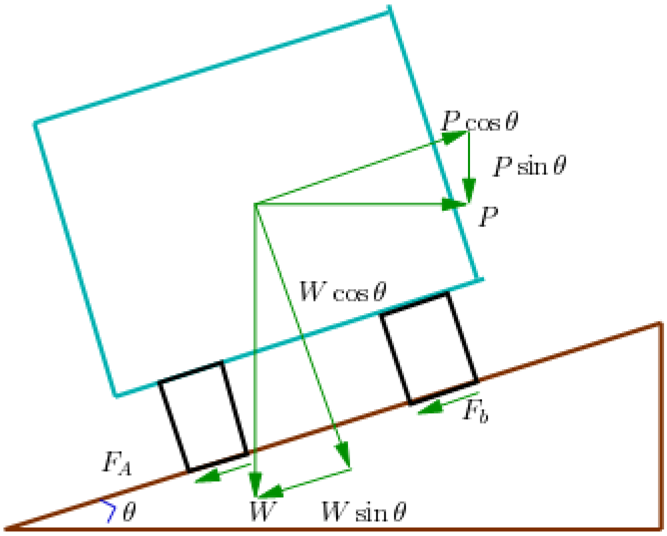
Note that:

- On divided highways, d3 need not be considered
- On divided highways with four or more lanes, IRC suggests that it is not necessary to provide the OSD,but only SSD is sufficient.

1.4. Horizontal Alignment

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

1.4.1. Super elevation



Super-elevation or cant or banking is the transverse slope provided at horizontal curve to counteract the centrifugal force, by raising the outer edge of the pavement with respect to the inner edge, throughout the length of the horizontal curve. When the outer edge is raised, a component of the curve weight will be complimented in counteracting the effect of centrifugal force. In order to find out how much this raising should be, the following analysis may be done. The forces acting on a vehicle while taking a horizontal curve with superelevation is shown in figure. Forces acting on a vehicle on horizontal curve of radius R m at a speed of v m/sec2 are:

- P the centrifugal force acting horizontally out-wards through the center of gravity
- W the weight of the vehicle acting down-wards through the center of gravity and
- F the friction force between the wheels and the pavement, along the surface inward.

At equilibrium, by resolving the forces parallel to the surface of the pavement we get,

$$\begin{aligned} P\cos\theta &= W\sin\theta + F_A + F_B \\ &= W\sin\theta + f(R_A + R_B) \\ &= W\sin\theta + f(W\cos\theta + P\sin\theta) \end{aligned}$$

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

$$\begin{aligned} \frac{P\cos\theta}{W\cos\theta} &= \frac{W\sin\theta}{W\cos\theta} + \frac{fW\cos\theta}{W\cos\theta} + \frac{fPsin\theta}{W\cos\theta} \\ \frac{P}{W} &= \tan\theta + f + f\frac{P}{W}\tan\theta \\ \frac{P}{W}(1 - f\tan\theta) &= \tan\theta + f \\ \frac{P}{W} &= \frac{\tan\theta + f}{1 - f\tan\theta} \end{aligned}$$

We have already derived an expression for P/W.By substituting this in equation

$$\frac{v^2}{gR} = \frac{\tan\theta + f}{1 - f\tan\theta}$$

This is an exact expression for superelevation. But normally, f = 0.15 and θ < 4 o , 1 − f tan θ ≈ 1 and for small θ, tan θ ≈ sin θ = E/B = e, then equation becomes:

$$e + f = \frac{v^2}{gR}$$

where, e is the rate of super elevation, f the coefficient of lateral friction 0.15, v the speed of the vehicle in m/sec2, R the radius of the curve in m and g = 9.8m/sec2

Three specific cases that can arise from equation 14.7 are as follows:

1 If there is no friction due to some practical reasons, then $f = 0$ and equation 14.7 becomes $e = \frac{v^2}{gR}$. This results in the situation where the pressure on the outer and inner wheels are same; requiring very high super-elevation e.

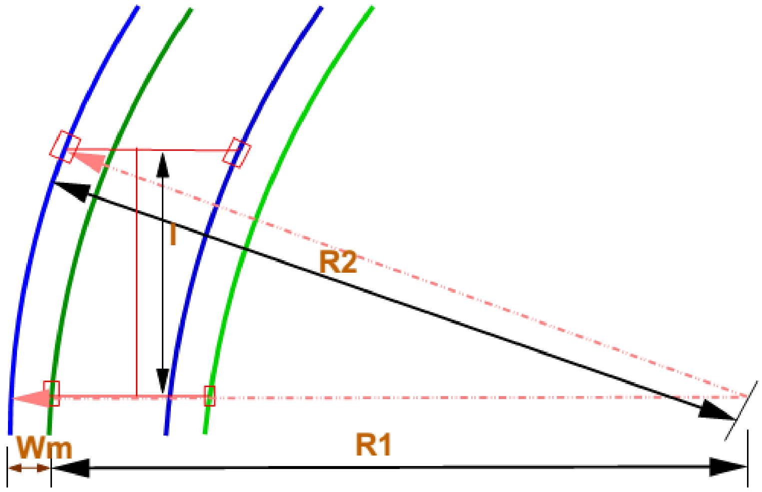
2 If there is no super-elevation provided due to some practical reasons, then $e = 0$ and equation 14.7 becomes $f = \frac{v^2}{gR}$. This results in a very high coefficient of friction.

3 If $e = 0$ and $f = 0.15$ then for safe traveling speed from equation 14.7 is given by $v_b = \sqrt{fgR}$ where v_b is the restricted speed.

1.4.2. Extra widening

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

1.4.2.1. Mechanical Widening



The reasons for the mechanical widening are: When a vehicle negotiates a horizontal curve, the rear wheels follow a path of shorter radius than the front wheels as shown in. 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 traveling in opposite direction on curved roads as is provided on straight sections, there must be extra width of carriageway available. This is an important factor when high proportion of vehicles 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 15.5. Let R1 is the radius of the outer track line of the rear wheel, R2 is the radius of the outer track line of the front wheel l is the distance between the front and rear wheel, n is the number of lanes, and then the mechanical widening Wmis derived below

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

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

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

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

Please note that for large radius, R2 ≈ R, which is the mean radius of the curve, then Wm is given by:

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

1.4.2.2. Psychological Widening

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

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

Therefore, the total widening needed at a horizontal curve We is:

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

1.4.3. Horizontal Transition curve

Transition curve is provided to change the horizontal alignment from straight to circular curve gradually and has a radius which decreases from infinity at the straight end (tangent point) to the desired radius of the circular curve at the other end (curve point) There are five objectives for providing transition curve and are given below:

- To introduce gradually the centrifugal force between the tangent point and the beginning of the circular curve, avoiding sudden jerk on the vehicle.This increases the comfort of passengers.
- To enable the driver turn the steering gradually for his own comfort and security,
- To provide gradual introduction of super elevation, and
- To provide gradual introduction of extra widening.
- To enhance the aesthetic appearance of the road

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

1.4.3.1. Rate of change of centrifugal acceleration

At the tangent point, radius is infinity and hence centrifugal acceleration is zero. At the end of the transition, the radius R has minimum value R. The rate of change of centrifugal acceleration should be adopted such that the design should not cause discomfort to the drivers. If c is the rate of change of centrifugal acceleration, it can be written as

$$\begin{aligned} c &= \frac{\frac{v^2}{R} - 0}{t}, \\ &= \frac{\frac{v^2}{R}}{\frac{L_s}{v}}, \\ &= \frac{v^3}{L_s R}. \end{aligned}$$

Therefore, the length of the transition curve Ls1 in m is

$$L_{s_1} = \frac{v^3}{cR}$$

where c is the rate of change of centrifugal acceleration given by an empirical formula suggested by by IRC as below

$$c = \frac{80}{75 + 3.6v}$$

$$\begin{aligned} c_{\min} &= 0.5, \\ c_{\max} &= 0.8. \end{aligned}$$

1.4.3.2. Rate of introduction of super-elevation

Raise (E) of the outer edge with respect to inner edge is given by E = eB = e(W + We). The rate of change of this raise from 0 to E is achieved gradually with a gradient of 1 in N over the length of the transition curve (typical range of N is 60-150). Therefore, the length of the transition curve Ls2 is:

$$L_{s_2} = Ne(W + W_e)$$

1.4.3.3. By empirical formula

IRC suggest the length of the transition curve is minimum for a plain and rolling terrain:

$$L_{s_3} = \frac{35v^2}{R}$$

and for steep and hilly terrain is:

$$L_{s_3} = \frac{12.96v^2}{R}$$

and the shift s as:

$$s = \frac{L_s^2}{24R}$$

1.5. Vertical Alignment

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

1.5.1. Types of gradients

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 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. Usually steep gradients are avoided as far as possible because of the difficulty to climb and increase in the construction cost. More about gradients are discussed below.

Ruling gradient

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

Limiting gradient

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

Exceptional gradient

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

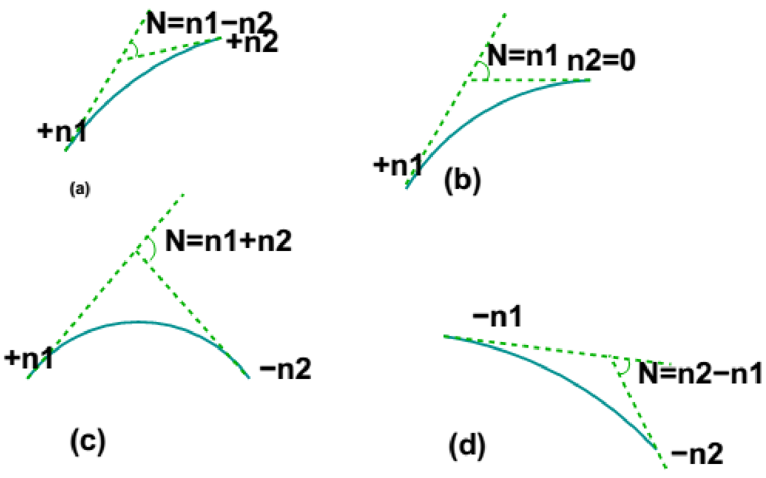
Minimum gradient

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

1.5.2. Summit curve

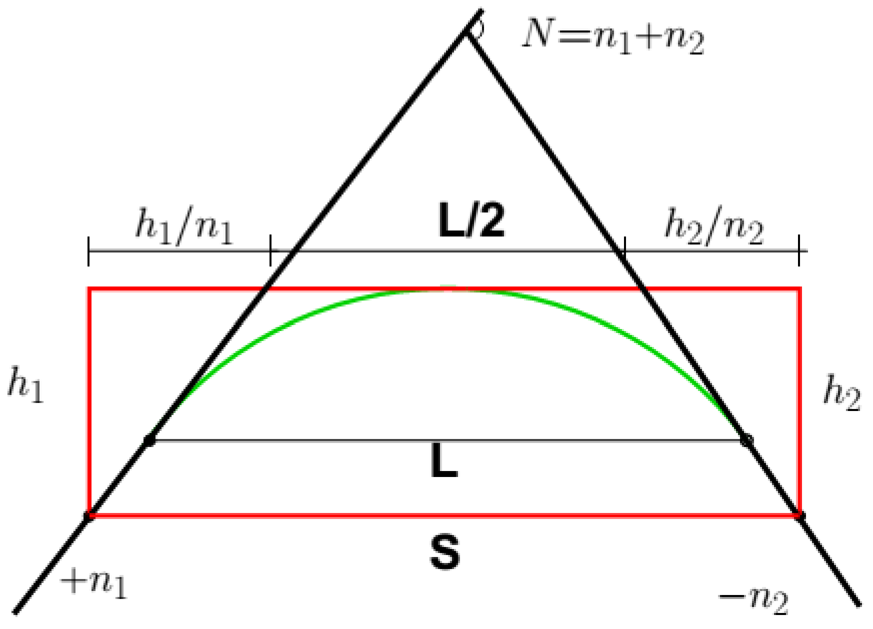
Summit curves are vertical curves with gradient upwards. They are formed when two gradients meet as illustrated in the figure in any of the following four ways:

- when a positive gradient meets another positive gradient
- when positive gradient meets a flat gradient
- when an ascending gradient meets a descending gradient
- when a descending gradient meets another descending gradient



Length of the summit curve

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration. That is, a driver should be able to stop his vehicle safely if there is an obstruction on the other side of the road. Equation of the parabola is given by $y = ax^2$, where 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. The length of the summit curve can be derived from the simple geometry as shown below:



Case a. Length of summit curve greater than sight distance

The situation when the sight distance is less than the length of the curve is shown in figure 17:3.

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

Case b. Length of summit curve less than sight distance

The second case is illustrated in figure 17:4 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,

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

$$n_1 = \frac{N\sqrt{h_1 h_2} - h_1 N}{h_2 - h_1}$$

Now we can substitute n back to get the value of minimum value of L for a given n1, n2, h1 and h2. Therefore,

$$S=\frac{L}{2}+\frac{h_1}{\frac{N\sqrt{h_1h_2}-h_1N}{h_2-h_1}}+\frac{h_2}{N-\frac{N\sqrt{h_1h_2}-h_1N}{h_2-h_1}}$$

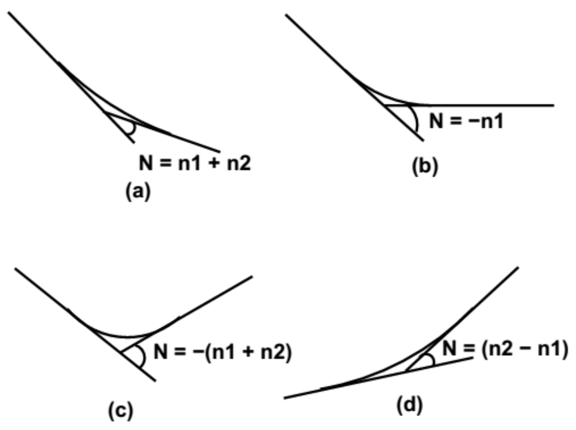
$$L=2S-\frac{\left(\sqrt{2h_1}+\sqrt{2h_2}\right)^2}{N}$$

When stopping sight distance is considered the height of driver's eye above the road surface (h1) is taken as 1.2 metres, and height of object above the pavement surface (h2) is taken as 0.15 metres. 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.

1.5.3. Valley Curves

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

1. when a descending gradient meets another descending gradient
2. when a descending gradient meets a flat gradient
3. when a descending gradient meets an ascending gradient
4. when an ascending gradient meets another ascending gradient



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:

1. comfort criteria; that is allowable rate of change of centrifugal acceleration is limited to a comfortable level of about 0.6m/sec3 .
2. 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:

$$L = 2\sqrt[2]{\frac{Nv^3}{c}}$$

where L is the total length of valley curve, N is the deviation angle in radians or tangent of the deviation angle or the algebraic difference in grades, and c is the allowable rate of change of centrifugal acceleration which may be taken as 0.6m/sec^3.

Safety criteria

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

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.

$$L = \frac{NS^2}{2h_1 + 2S\tan\alpha}$$

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.

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.

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

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 have to be calculated and the one which satisfies the condition is adopted.

UNIT III

HIGHWAY MATERIALS

3.1. Road 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 requirements of the aggregates in pavement are also discussed in this chapter.

3.1.1. Desirable properties of aggregates

Strength

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

Hardness

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

Toughness

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

Shape of aggregates

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

Adhesion with bitumen

The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped 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, chert, silt and other organic impurities.

3.1.2. Aggregate tests

In order to decide the suitability of the aggregate for use in pavement construction, following tests are carried out:

Crushing test

Abrasion test

Impact test

Soundness test

Shape test

Specific gravity and water absorption test

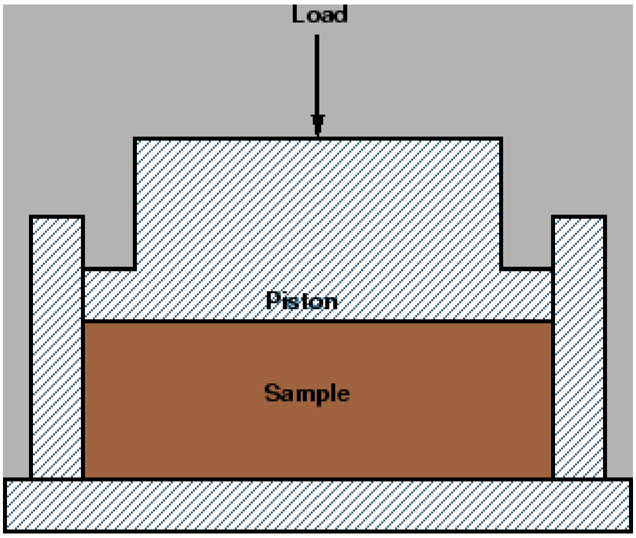
Bitumen adhesion test

3.1.2.1. Crushing test

One of the model in which pavement material can fail is by crushing under compressive stress. A test is standardized by IS:2386 part-IV and used to determine the crushing strength of aggregates. The aggregate crushing value provides a relative measure of resistance to crushing under gradually applied crushing load. The test consists of subjecting the specimen of aggregate in standard mould to a compression test under standard load conditions. Dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves are filled in a cylindrical measure of 11.5 mm diameter and 18 cm height in three layers. Each layer is tampered 25 times with at standard tamping rod. The test sample is weighed and placed in the test cylinder in three layers each layer being tampered again. The specimen is subjected to a compressive load of 40 tonnes gradually applied at the rate of 4 tonnes per minute. Then crushed aggregates are then sieved through 2.36 mm sieve and weight of passing material (W2) is expressed as percentage of the weight of the total sample (W1) which is the aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W_1}{W_2} \times 100$$

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



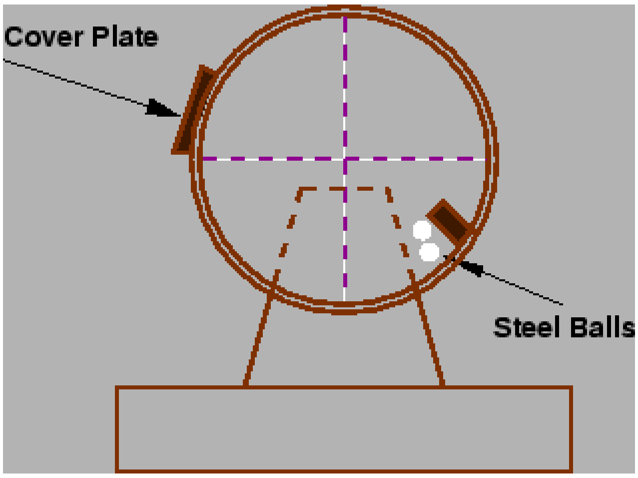
3.1.2.2. Abrasion test

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

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

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

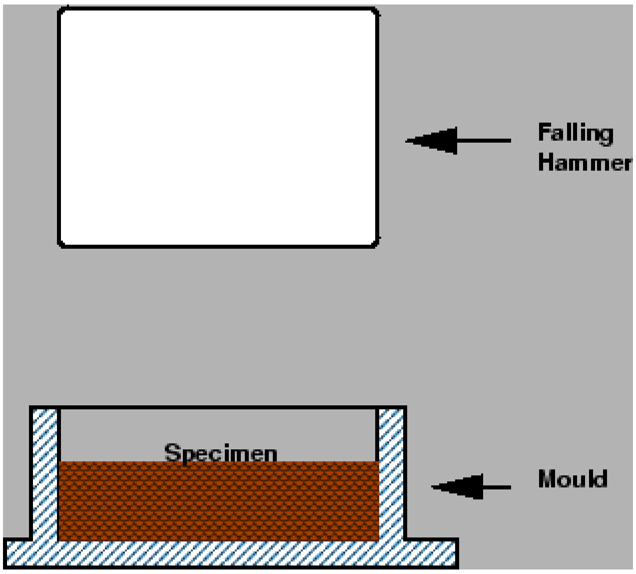
A maximum value of 40 percent is allowed for WBM base course in Indian conditions. For bituminous concrete, a maximum value of 35 is specified.



3.1.2.3. Impact test

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup of internal dia 10.2 mm and depth 5 cm which is attached to a metal base of impact testing machine. The material is filled in 3 layers where each layer is tamped for 25 number of blows. Metal hammer of weight 13.5 to 14 Kg is arranged to drop with a free fall of 38.0 cm by vertical guides and the test specimen is subjected to 15 numbers of blows. The crushed aggregate is allowed to pass through 2.36 mm IS sieve. And the impact value is measured as percentage of aggregates passing sieve (W2) to the total weight of the sample (W1).

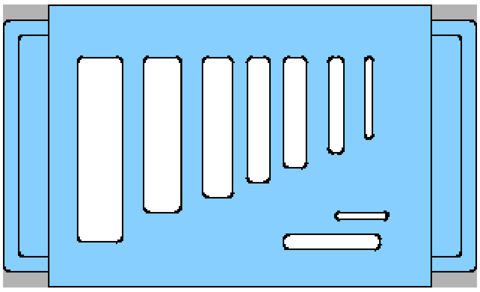
$$\text{Aggregate impact value} = \frac{W_1}{W_2} \times 100$$



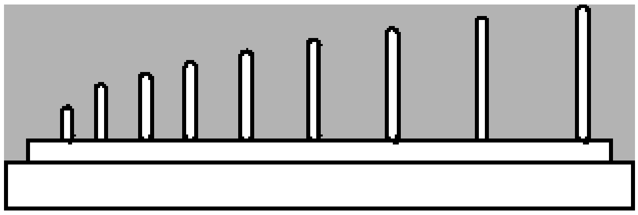
3.1.2.4. Shape tests

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

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



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



3.2. Pavement Bitumen

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. Bituminous materials consists of bitumen which is a black or dark coloured solid or viscous cementitious substances consists chiefly high molecular weight hydrocarbons derived from distillation of petroleum or natural asphalt, has adhesive properties, and is soluble in carbon di sulphide. Tars are residues from the destructive distillation of organic substances such as coal, wood, or petroleum and are temperature sensitive than bitumen. Bitumen will be dissolved in petroleum oils where unlike tar.

3.2.1. Different forms of bitumen

Cutback bitumen

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

Bitumen Emulsion

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

Bituminous primers

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

Modified Bitumen

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

- Lower susceptibility to daily and seasonal temperature variations
- Higher resistance to deformation at high pavement temperature
- Better age resistance properties
- Higher fatigue life for mixes
- Better adhesion between aggregates and binder
- Prevention of cracking and reflective cracking

3.2.2. Requirements of Bitumen

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

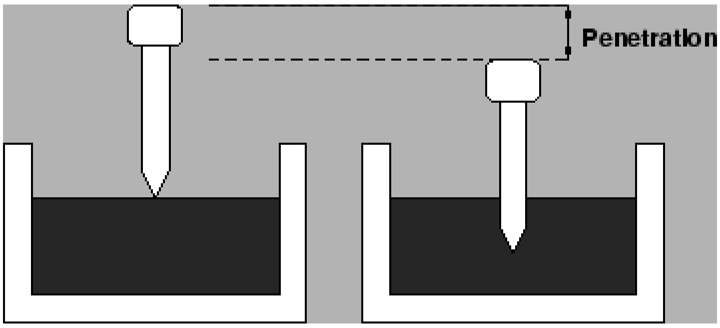
3.2.3. Tests on bitumen

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

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

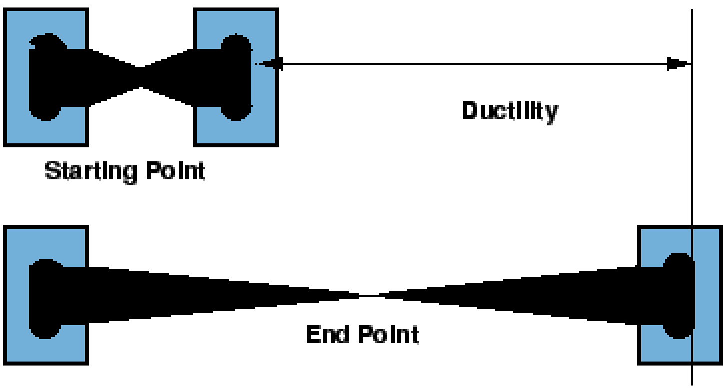
3.2.3.1. Penetration test

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



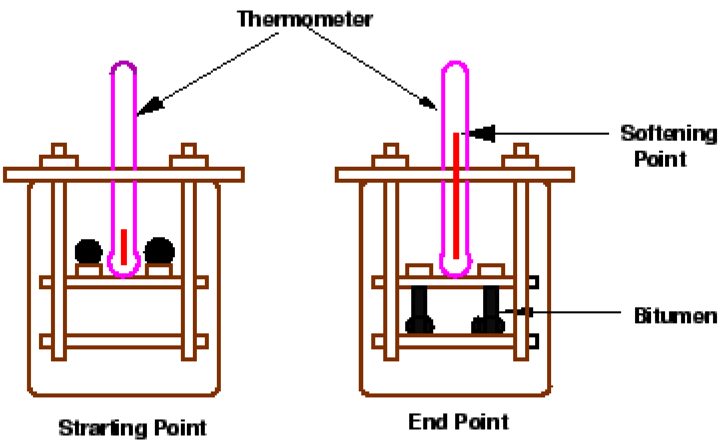
3.2.3.2. Ductility test

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



3.2.3.3. Softening point test

Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. The test is conducted by using Ring and Ball apparatus. A brass ring containing test sample of bitumen is suspended in liquid like water or glycerin at a given temperature. A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5^o C per minute. Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates.



3.2.3.4. Specific gravity test

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

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

3.2.3.5. Flash and fire point test

At high temperatures depending upon the grades of bitumen materials leave out volatiles. And these volatiles catch fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade. BIS defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions. The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.

3.3. Bituminous Aggregate Mix

The bituminous mix determines the proportion of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, strong, durable and economical.

3.3.1. Requirements of Bituminous mixes

Stability

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

Durability

Durability is defined as the resistance of the mix against weathering and abrasive actions. Weathering causes hardening due to loss of volatiles in the bitumen. Abrasion is due to wheel loads which causes tensile strains. Typical examples of failure are (i) *pot-holes,* -

deterioration of pavements locally and (ii) *stripping*, loss of binder from the aggregates and aggregates are exposed. Disintegration is minimized by high binder content because the mix to be air and waterproof and the bitumen film is more resistant to hardening.

Flexibility

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

Skid resistance

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

Workability

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

3.3.2. Desirable properties

The desirable properties of a bituminous mix can be summarized as follows:

- Stability to meet traffic demand
- Bitumen content to ensure proper binding and water proofing

- Voids to accommodate compaction due to traffic
- Flexibility to meet traffic loads, esp. in cold season
- Sufficient workability for construction
- Economical mix

UNIT IV

PAVEMENT DESIGN

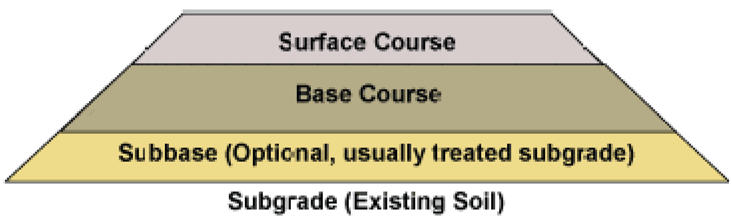
The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts like a flexible sheet (e.g. bituminous road). On the contrary, in rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads). In addition to these, composite pavements are also available. A thin layer of flexible pavement over rigid pavement is an ideal pavement with most desirable characteristics. However, such pavements are rarely used in new construction because of high cost and complex analysis required

TYPES OF PAVEMENTS

Flexible Pavements:

Flexible pavement can be defined as the one consisting of a mixture of asphaltic or bituminous material and aggregates placed on a bed of compacted granular material of appropriate quality in layers over the subgrade. Water bound macadam roads and stabilized soil roads with or without asphaltic toppings are examples of flexible pavements.

The **design of flexible pavement** is based on the principle that for a load of any magnitude, the intensity of a load diminishes as the load is transmitted downwards from the surface by virtue of spreading over an increasingly larger area, by carrying it deep enough into the ground through successive layers of granular material.



Rigid Pavements:

A rigid pavement is constructed from cement concrete or reinforced concrete slabs. Grouted concrete roads are in the category of semi-rigid pavements.

The design of rigid pavement is based on providing a structural cement concrete slab of sufficient strength to resists the loads from traffic. The rigid pavement has rigidity and high modulus of elasticity to distribute the load over a relatively wide area of soil.

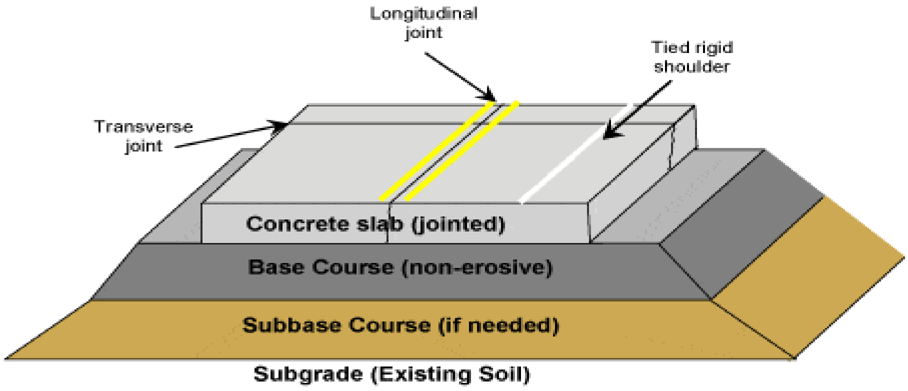


Fig: Rigid Pavement Cross-Section

Minor variations in subgrade strength have little influence on the structural capacity of a rigid pavement. In the design of a rigid pavement, the flexural strength of concrete is the major factor and not the strength of subgrade. Due to this property of pavement, when the subgrade deflects beneath the rigid pavement, the concrete slab is able to bridge over the localized failures and areas of inadequate support from subgrade because of slab action.

Difference between Flexible Pavements and Rigid Pavements:

	Flexible Pavement	**Rigid Pavement**
1.	It consists of a series of layers with the highest quality materials at or near the surface of pavement.	It consists of one layer Portland cement concrete slab or relatively high flexural strength.
2.	It reflects the deformations of subgrade and subsequent layers on the surface.	It is able to bridge over localized failures and area of inadequate support.

3.	Its stability depends upon the aggregate interlock, particle friction and cohesion.	Its structural strength is provided by the pavement slab itself by its beam action.
4.	Pavement design is greatly influenced by the subgrade strength.	Flexural strength of concrete is a major factor for design.
5.	It functions by a way of load distribution through the component layers	It distributes load over a wide area of subgrade because of its rigidity and high modulus of elasticity.
6.	Temperature variations due to change in atmospheric conditions do not produce stresses in flexible pavements.	Temperature changes induce heavy stresses in rigid pavements.
7.	Flexible pavements have self healing properties due to heavier wheel loads are recoverable due to some extent.	Any excessive deformations occurring due to heavier wheel loads are not recoverable, i.e. settlements are permanent.

Introduction to pavement design

Overview

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub-grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the riding quality.

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, environment.

Traffic and loading

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

Contact pressure:

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

Wheel load:

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

Axle configuration:

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

Moving loads:

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

Repetition of Loads:

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

Environmental factors

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

Temperature

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

Precipitation

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

Flexible pavement design

Overview

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

Design procedures

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

Empirical design

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

Mechanistic-Empirical Design

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

Traffic and Loading

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

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

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

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

Equivalent single wheel load

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

equalancy concept is based on equal stress;

contact area is circular;

influence angle is 45 $^{\circ}$; and

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

The ESWL is given by:

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

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

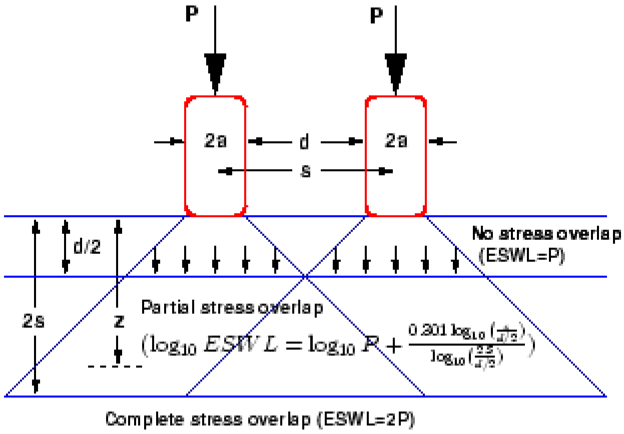


Figure 1: ESWL-Equal stress concept

Example 1

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

Solution

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

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

$$\log_{10} ESWL = \log_{10} 2044 + \frac{0.301 \log_{10}\left(\frac{20}{10/2}\right)}{\log_{10}\left(\frac{2 \times 20}{10/2}\right)}$$

=3.511. Therefore, ESWL = antilog(3.511)= 3244.49 kN

Equivalent single axle load

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

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

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

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

where, N_f is the number of load repetition for a certain percentage of cracking, ϵ_t is the tensile strain at the bottom of the binder course, E is the modulus of elasticity, and f_1, f_2, f_3 are constants. If we consider fatigue cracking as failure criteria, and a typical value of 4 for f_2, then:

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

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

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

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

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

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

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

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

Example 1

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

Solution:

Refer the Table 1. The ESAL is given as $\sum F_i n_i = 3225\ kN$

Table 1: Example 1 Solution

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

IRC 37:2001) Design of flexible pavements

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

Scope

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

Design criteria

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

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

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

pavement deformation within the bituminous layer.

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

Failure Criteria

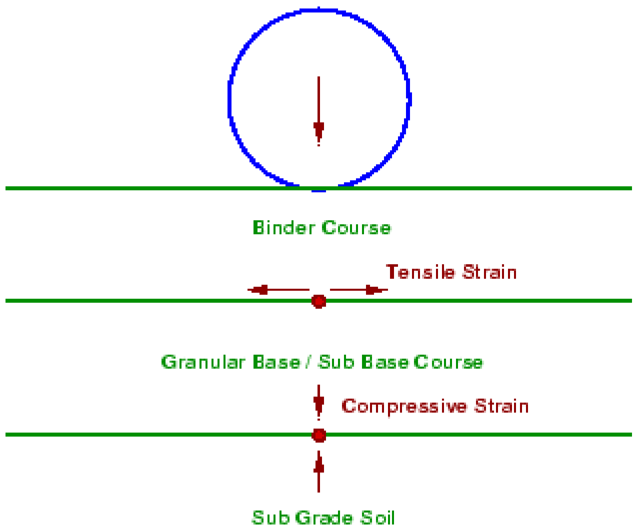


Figure: Critical Locations in Pavement

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

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

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

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

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

Design procedure

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

Design traffic in terms of cumulative number of standard axles; and

CBR value of subgrade.

Design traffic

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

Initial traffic in terms of CVPD

Traffic growth rate during the design life

Design life in number of years

Vehicle damage factor (VDF)

Distribution of commercial traffic over the carriage way.

Initial traffic

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

Traffic growth rate

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

Design life

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

Vehicle Damage Factor

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

Vehicle distribution

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

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

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

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

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

Pavement thickness design charts

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

Pavement composition

Sub-base

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

Base

The recommended designs are for unbounded granular bases which comprise conventional water bound macadam (WBM) or wet mix macadam (WMM) or equivalent confirming to MOST specifications. The materials should be of good quality with minimum thickness of 225 mm for traffic upto2msaan150mmfortrafficexceeding2msa.

Bituminoussurfacing

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

Numerical example

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

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 subgrade soil = 4%.

Solution

Distribution factor = 0.75

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

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

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

Bituminous surfacing = 25 mm SDBC + 70 mm DBM

Road-base = 250 mm WBM

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

Rigid pavement design

Overview

As the name implies, rigid pavements are rigid i.e, 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 considered the pioneer in providing the rational treatment of the rigid pavement analysis.

Modulus of sub-grade reaction

Westergaard 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 $K = \frac{p}{\Delta}$ where Δ is the displacement level taken as 0.125 cm and 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 1.

$$l = \sqrt[4]{\frac{Eh^3}{12K(1-\mu^2)}} \qquad (1)$$

where E is the modulus of elasticity of cement concrete in kg/cm ^{2} (3.0 $\times$ 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's gives a relation for equivalent radius of the resisting section in cm in the equation 1.

$$b = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675\ h & \text{if a} < 1.724\text{ h} \\ a & \text{otherwise} \end{cases} \qquad (1)$$

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 as $\sigma_i,\ \sigma_e,\ \sigma_c$ in kg/cm ^{2} respectively and given by the equation 1-3.

$$\sigma_i = \frac{0.316\ P}{h^2}\left[4\ \log_{10}\left(\frac{l}{b}\right) + 1.069\right] \tag{1}$$

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

$$\sigma_c = \frac{3\ P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right] \tag{3}$$

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

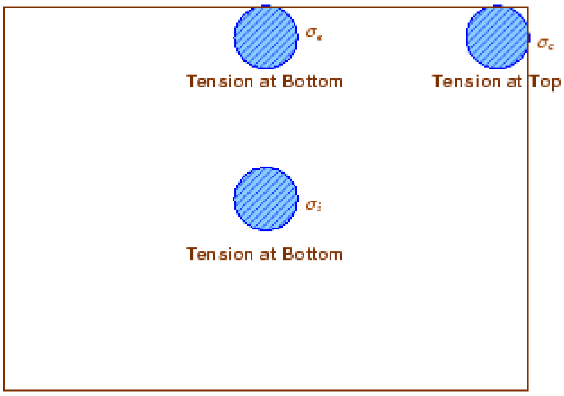


Figure 1: Critical stress locations

Temperature stresses

Temperature stresses 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 results in warping stresses and the later in frictional stresses.

Warping stress

The warping stress at the interior, edge and corner regions, denoted as $\sigma_{t_i}, \sigma_{t_e}, \sigma_{t_c}$ in kg/cm ^{2} respectively and given by the equation 2-3.

$$\sigma_{t_i} = \frac{E\epsilon t}{2}\left(\frac{C_x + \mu C_y}{1-\mu^2}\right) \qquad (1)$$

$$\sigma_{t_e} = \mathrm{Max}\left(\frac{\mathrm{C_x E\epsilon t}}{2}, \frac{\mathrm{C_y E\epsilon t}}{2}\right) \qquad (2)$$

$$\sigma_{t_c} = \frac{E\epsilon t}{3(1-\mu)}\sqrt{\frac{a}{l}} \qquad (3)$$

where E is the modulus of elasticity of concrete in kg/cm ^{2} (3×10^5), ϵ is the thermal coefficient of concrete per $^\circ$C (1×10^{-7}) t is the temperature difference between the top and bottom of the slab, C_x and C_y are the coefficient based on L_x/l in the desired direction and 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.

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 $36\ cmi\ @\ 55\ cm\ c/c$

Problems

Design size and spacing of dowel bars at an expansion joint of concrete pavement of thickness 20 cm. Given the radius of relative stiffness of 90 cm. design wheel load 4000 kg. Load capacity of the dowel system is 40 percent of design wheel load. Joint width is 3.0 cm and the permissible stress in shear, bending and bearing stress in dowel bars are 1000,1500 and 100 kg/cm^2 respectively.

Design the length and spacing of tie bars given that the pavement thickness is 20cm and width of the road is 7m with one longitudinal joint. The unit weight of concrete is 2400 kg/m^3, the coefficient of friction is 1.5, allowable working tensile stress in steel is 1750 kg/cm^2, and bond stress of deformed bars is 24.6 kg/cm^2

UNIT V

HIGHWAY CONSTRUCTION

Highway construction is generally preceded by detailed surveys and subgrade preparation.[3] The methods and technology for constructing highways has evolved over time and become increasingly sophisticated. This advancement in technology has raised the level of skill sets required to manage highway construction projects. This skill varies from project to project, depending on factors such as the project's complexity and nature, the contrasts between new construction and reconstruction, and differences between urban region and rural region projects.

1.Construction of W.B.M Roads

WBM Stands for Water Bound Macadam which is the most commonly used road construction procedure for over more than 190 years.Pioneered by Scottish Engineer John Loudon McAdam around 1820 Macadam is a type of Road Construction. The broken stones of base and surface course,if any are bound by the stone dust is presence of moisture is called WBM Roads. Macadam means the 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 may be used as a sub-base,base or a surface course.The thickness of each compacted layer of WBM ranges from 10cm to 7.5cm depending on size and the gradation of aggregate used.

ConstructionProcedure:
1.PreparethefoundationforreceivingtheWBMcourse.
2.Lateral confinement may be done by compacting the shoulder to advance,to a thickness equal to that of the compacted WBM layer and by trimming the inner side vertically.
3.Spreading of Coarse Aggregate

4.Compaction of coarse aggregate is done by wheeled power roller of capacity 6 to 10 tonnes or alternately by an equivalent vibratory roller.

5.Dry screening is applied gradually over the surface to fill the interstices in these.
6.Thesurfaceissprinkledwithwater,sweptandrolled.
7.Binding material is applied at a uniform and slow rate at two and more layers.
8.WBM Coarse is allowed to set overnight.

2.CONSTRUCTION OF BITUMEN MACADAM

Sub-grade act as a cushion for other layers i.e. In order to achieve durable road sub-grade should be strong. Sub-grade is provided by digging up the sub-soil and the level of the sub-grade is decided by subtracting the total thickness of the pavement from the finished level of the road pavement. The sub-grade is thoroughly compacted by rollers weighing 8 tonnes by sprinkling water one night before. Low spots which develop during rolling must be made up and brought to the grades as required. In rocky regions the sub-grades are not rolled whereas in region of clay soils, a layer to natural sand, moorum or gravel, is provided over sub-grade and is duly packed.

On a well compacted sub-grade, spread 10 to 20 cm size boulders or broken stones, or over burnt bricks in layers of 15 cm thickness and total width of the sub-base to be kept 60 cm wider than pavement width, projecting 30 cm on each side. The sub-base should be compacted by a roller to provide an even surface.

On the prepared sub-base or directly on the sub-grade, as the case may be, the specified materials of the base course is spread and proper grade, thickness and cross sections maintained as per design shown on the supplied drawings.

This course may be laid in one or two layers according to the total designed thickness and the thickness of each layer should not exceed 10 cm. this component being very important, the following steps may be taken systematically.

Check the defective portions/patches of the newly laid base course i.e. soling and rectify them

Provide either bricks on end edging or earthen kerbs strong enough to prevent the new road material from spreading outward and also to retain water used in consolidation of the wearing course.

Spread the road metal evenly over the prepared base to the specified thickness and hand pack them so that the finished surface is brought to the required camber.

Spread the coarse aggregate over the surface and roll it dry with a suitable roller till interlocking of the aggregate is achieved with sufficient void space. The rolling is started from the edges and gradually shifted towards the centre.

After dry rolling, spread the screening materials (stones upto 12 mm size) with uniform rate so that voids of coarse aggregates get filled properly. This is achieved by dry rolling and brooming alternatively, till the voids of the coarse aggregates are filled.

After spreading the screening material, sprinkle sufficient quantity of water, sweep the surface and roll it with roller again.

Now apply the binding material in two to three thick layers at a slow and uniform rate. Each layer of binding material is rolled after adding sufficient water. The slurry is swept in with brooms to fill the void properly. The moving wheel of the roller should be cleaned with water. Continue the operations of spreading of binder, sprinkling of water, sweeping with brooms and rolling till the voids get filled and slurry forms a wave before the moving wheel of the roller.

After proper compacting allow it to dry over night. Spread a layer of sand or earth, about 6 mm thick and roll the surface again after sprinkling water lightly.

The surface may be allowed for 7 to 10 days of curing.

While curing the pavement surface, prepare the shoulders by filling earth to the specified cross slope and compact them properly by rolling or by tamping. Width and thickness of the shoulder should be as per specification.

After properly drying, the road pavement may now be opened to traffic, ensuring that the traffic is distributed uniformly over the full width of the pavement.

1. Preparation of the existing base course layer

The existing surface is prepared by removing the pot holes or rust if any. The irregularities are filled in with premix chippings at least a week before laying surface course. If the existing pavement is extremely way, a bituminous leveling course of adequate thickness is provided to lay a bituminous concrete surface course on a binder course instead of directly laying it on a WBM.

2. Application of Tack Coat

It is desirable to lay AC layer over a bituminous base or binder course. A tack coat of bitumen is applied at 6.0 to 7.5 kg per 10 sq.m area, this quantity may be increased to 7.5 to 10 kg for non-bituminous base.

Bitumen bound macadam (BBM) and compares its performance with that of water bound macadam (WBM) and BUSG, a specification used by the Indian Ministry of Surface Transport. The BBM advantages of the BBM method include: (1) rapid construction; (2) less disturbance to traffic; and (3) relatively low cost. It has already been used successfully at several sites in India. BBM is similar to WBM, except that key aggregates and bitumen are used as binder, instead of screenings and water. The BBM layer can conventionally be laid over an existing bitumen layer, after applying a tack coat. The construction techniques for a layer of BBM are like those for a layer of WBM. BBM was found to be a suitable alternative treatment to WBM and BUSG, and it has a relatively dustproof surface. When overlaid by a hot mix paver treatment, a BBM layer has still better performance and riding conditions. It is predicted that precoating of 12mm size aggregates, in future forms of BBM, will improve the performance of the top layer, and reduce metal 'fly-off' due to traffic. One appendix gives the specification of BBM; the other compares the specifications for BBM, WBM and BUSG.

CONCRETE PAVEMENT CONSTRUCTION PROCESS

The construction of concrete pavement involves sequential construction of subgrade, sub-base/ base and the concrete slab. These are discussed in the following.

Subgrade preparation

Subgrade preparation involves cleaning, earthwork (excavation or filling of soil, replacement of weak soil, soil stabilization etc.) and compaction.

Where the concrete layer is laid directly over the subgrade, the subgrade is moist at the time concrete is placed. If the sub grade is dry, water could be sprinkled over the surface before laying any concrete course, however, care should taken so that soft patches or water pools are not formed at the surface (IRC:15-2002, Chakroborty and Das 2003). As an alternative arrangement, concreting could be done over a water proof polyethylene sheet, and in that case moistening the subgrade surface becomes redundant. This polyethylene sheet acts as a capillary cut-off layer (IRC:15 2002). Figure-31 presents a photograph of subgrade construction in progress.

Construction of Base/ Sub-base

A base/ sub-base to the concrete pavement provides uniform and reasonably firm support, prevents mud-pumping , and acts as capillary cut-off. Sub-base for concrete pavement could be constituted with brick flat soling, WBM, granular aggregates, crushed concrete, slag, stabilized soil etc. As per IRC: 15 (2002), sub-base could be of three types with (i) Granular material (for example, brick soling with one layer of sand under it, WBM, well graded granular materials etc.) (ii) Stabilized soil (iii) Semi-rigid material, (for example, lime burnt clay puzzolana concrete, lime fly-ash concrete, lean cement concrete roller compacted concrete etc.). Following contains a brief discussion on dry lean cement (DLC) concrete as sub-base, which is popularly being adopted for the current concrete pavement construction in India.

Dry lean cement concrete as sub-base

The thickness of DLC, generally recommended is 100mm or 150mm (IRC:SP-49 1998). The maximum aggregate to cement ratio is 15:1. The average compressive strength of DLC cubes at 7 days, as recommended by Indian guidelines (IRC:SP-49 1998) should not be less than 10 MPa, tested on 5 samples and individual compressive strength should not be less than 7.5 MPa, at 7 days (MORT&H 2001, IRC:SP-49 1998).

Before construction of DLC sub-base, the prepared subgrade is sprinkled with water to moisten the surface. The material is to be laid uniformly by a paver without any segregation . The paving machine should have high amplitude paving bars. The curing of DLC can be done by spraying liquid curing compound, or by covering the surface by gunny bags. As per Indian guidelines, the construction of cement concrete pavement can only start after 7 days of DLC construction (MORT&H 2001, IRC:SP-49 1998).

Figure-32 presents a schematic diagram of the sequence of rolling for DLC construction, and Figure-33 presents a photograph of DLC construction.

Construction of concrete slab

General

The concrete surfacing could be made up of plain concrete or reinforced concrete. Reinforced concrete has been discussed later in a different lecture. The proportions between cement, aggregate and water is determined by standard concrete mix design technique.

Premature setting and segregation is to be avoided while transporting the concrete mix through the access haul road and continuous stirring may be helpful in such a case. The spreading of concrete should be done uniformly such that no segregation of materials takes place. A separation membrane, made up of impermeable plastic/ polyethylene sheet (of thickness of the order of 150 micron) is sometimes laid over the sub-base, without creases, on to which concrete slab is laid (IRC:15 2002). Figure-34 presents a photograph of laying polyethylene sheet over DLC.

Compaction and surface finishing

Concrete is spread evenly and is rodded with suitable equipment such that formation of honey-combing or voids can be avoided. At the same time, over-compacting needs to be avoided, which can cause segregation and loss of entrained air (Swampland and Vanikar 2002). The working of fixed form and slip form pavers are different - and have been discussed briefly in the following:

Fixed form paving system

In fixed-form paver system, generally, separate powered machines for spreading, compacting and finishing are used. The spreader spreads concrete evenly through reversible auger to the desired surcharge level (O'Flaherty 2002). The rotary strike-off paddles trim minor irregularities in the surface of the surcharge concrete and adjusts with the carriage-way cross-slope . The compaction beam applies vibration to the concrete with pre-designed amplitude and frequency (O'Flaherty 2002). This vibration also helps to put the dowel and tie bars at their desired positions (for a single layer construction).

The wet formed joint groove is made by introducing vertical cut immediately after compaction is over and inserting a preformed cellular permanent strip . As an alternative, saw joint groove can be made after the concrete is sufficiently hardened and can maintain the sharp edge itself (O'Flaherty 2002).

The finishing of the surface is made, generally, with a pair of finishing beams . The leading beam vibrates and smoothens the surface, and the rear beam acts as float . The beams are oriented obliquely so that it causes less damage to the joints (O'Flaherty 2002).

Slip form paving system

Slip-form paving machine is a self-propelled system that can automatically spread, trim, compact and finish the surface in a synchronized manner through its feedback sensors. Placing of dowel/ tie bars at their pre-designed locations are done by the slip-form pavers. The introduction of joint grooves, surfacing texturing and spraying of curing compound etc. are done by the equipment those follow the paver (O'Flaherty 2002).

Slip-form paver requires guide-wires, parallel to edge of construction and maintained at fixed height, installed on the both side. The alignment of the slip-form paver is controlled automatically with respect to the guide-wires. Correct and precise alignment of the guide-wires is therefore extremely important. The hopper/ spreader maintains a constant surcharge of the concrete above the conforming plate level. The conforming plate, vibrators, strike off paddles and the finishing screed gives the final shape of the concrete pavement (O'Flaherty 2002). Figure-35 explains schematically the operation of a typical slip-form paver, and Figure-36 a photograph of concrete pavement construction by a slip form paver.

Texturing

Finished concrete has a smooth surface; texturing of concrete surface is done to impart required skid resistance to the concrete surface. The texturing is done by means of wire brushing or grooving along the transverse direction. Initial texturing may be done at the time of construction of the paver itself (refer Figure 37). Final texturing is done no sooner the sheen of the concrete surface goes off (Swanlund and Vanikar 2002).

Concrete curing

Curing is a process in which requisite moisture content and temperature is maintained so that concrete achieves its design strength through hydration of cement. For initial curing, curing compound with high water retentivity may be spread over the finished surface to prevent rapid drying of water. For final curing, continuous ponding or moistened hessain/ gunny bags should be kept for about a fortnight (refer Figure 38). As an alternative arrangement to ponding, impervious liquid maybe spread over the surface so as to restrict evaporation of water from the laid concrete. Forms are removed from the freshly prepared concrete layer after about curing of fourteen hours (IRC:15 2002, Chakroborty and Das 2003).

Opening to traffic

After curing period is over, and before opening the road to traffic, the temporary seal material is to be removed, and the joints are to filled with recommended joint sealing compound. The pouring of sealing material is monitored carefully such that it is not spilled over the pavement surface. Construction of joints and joint sealing have been discussed separately (IRC:15 2002,Chakorborty and Das 2003).

Highway maintenance

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. Defects differ 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

Through routine maintenance practices, highway systems and all of their components can be maintained to their original, as-built condition.

Necessity of road maintenance

Roads are among the most important public assets in many countries. Road improvements bring immediate and sometimes dramatic benefits to road users through improved access to hospitals, schools, and markets; improved comfort, speed, and safety; and lower vehicle operating costs. For these benefits to be sustained, road improvements must be followed by a well-planned program of maintenance. Without regular maintenance, roads can rapidly fall into disrepair, preventing realization of the longer term impacts of road improvements on development, such as increased agricultural production and growth in school enrolment

Postponing road maintenance results in high direct and indirect costs. If road defects are repaired promptly, the cost is usually modest. If defects are neglected, an entire road section may fail completely, requiring full reconstruction at three times or more the cost, on average, of maintenance costs. The South African National Road Agency Ltd. (SANRAL) estimates that repair costs rise to six times maintenance costs after three years of neglect and to 18 times after five years of neglect.

To avoid such escalating costs, SANRAL first “allocate its available funding resources to ideal maintenance actions (e.g., reseals and overlays), and thereafter to more extensive maintenance actions (e.g., rehabilitation), and finally to new construction”

Delayed maintenance has indirect costs as well. Neglected roads steadily become more difficult to use, resulting in increased vehicle operating costs (more frequent repairs, more fuel use) and a reluctance by transport operators to use the roads. This imposes a heavy burden on the economy: as passenger and freight services are curtailed, there is a consequent loss of economic and social development opportunities

Countries need a core road network that carries about 80 percent of national traffic, including key roads in urban areas and roads providing sufficient access to rural areas. Some part of the overall road budget thus has to be spent on construction and some part on maintaining the core network. But many countries have tended to favor new construction, rehabilitation, or reconstruction of roads over maintenance. This has led to a steady increase in the backlog of road repairs and a loss of development impact. In Sub-Saharan Africa for every kilometer of road rehabilitated, an estimated three kilometers of road fall into disrepair, leading to a net deterioration in the total road network (World Bank 2003). The situation is similar in many other developing country regions. Much of the capital cost of road construction is financed by donor funds, with low perceived cost to the country but high real costs, while maintenance is funded locally, requiring difficult and unpopular tax mobilization.

Scope of maintenance

The goal of maintenance is to preserve the asset, not to upgrade it. Unlike major road works, maintenance must be done regularly. Road maintenance comprises "activities to keep pavement, shoulders, slopes, drainage facilities and all other structures and property within the Page 2 Transport Note No. TRN-4 June 2005 road margins as near as possible to their as-constructed or renewed condition" (PIARC 1994). It includes minor repairs and improvements to eliminate the cause of defects and to avoid excessive repetition of maintenance efforts. For management and operational convenience, road maintenance is categorized as routine, periodic, and urgent.

- **Routine maintenance** which comprises small-scale works conducted regularly, aims "to ensure the daily passability and safety of existing roads in the short-run and to prevent premature deterioration of the roads" (PIARC 1994). Frequency of activities varies but is generally once or more a week or month. Typical activities include roadside verge clearing and grass cutting, cleaning of silted ditches and culverts, patching, and pothole repair. For gravel roads it may include regrading every six months.
- **Periodic maintenance** which covers activities on a section of road at regular and relatively long intervals, aims "to preserve the structural integrity of the road" (WB Maintenance website). These operations tend to be large scale, requiring specialized equipment and skilled personnel. They cost more than routine maintenance works and require specific identification and planning for implementation and often even design. Activities can be classified as preventive, resurfacing, overlay, and pavement reconstruction. Resealing and overlay works are generally undertaken in response to measured deterioration in road conditions. For a paved road repaving is needed about every eight years; for a gravel road re-graveling is needed about every three years.
- **Urgent maintenance** is undertaken for repairs that cannot be foreseen but require immediate attention, such as collapsed culverts or landslides that block a road.

HIGHWAY DRAINAGE

INTRODUCTION:

Highway drainage is the process of removing and controlling excess surface and sub-surface water within the right way. This includes interception and diversion of water from the road surface and sub-grade. The installation of suitable surface and sub-surface drainage system is an essential part of highway design and construction. During rain, part of the rain water flows on surface and part of it percolates through the soil. mass as gravitational water until it reaches the ground water below the water table. Removal and diversion of surface water from the roadway and adjoining land is termed as surface drainage, while the removal of excess soil-water from the sub-grade is termed as sub-surface water.

NECESSITY OF HIGHWAY DRAINAGE

Highway drainage is important from various view points:

- Excess moisture in soil sub-grade causes instability under the road surface. The pavement may fail due to sub-grade failure. In some clayey soil variation in moisture content causes considerable variation in volume of sub-grade. This sometimes contributes to pavement failure.
- The waves and corrugations formed in case of flexible pavements also play an important role in pavement failure.
- Sustained contact of water with bituminous pavements causes failure due stripping bitumen from the aggregates like loosening of some of the bituminous pavement layer and formation of pot holes.
- The prime cause of failures in rigid pavements by mud pumping is due to the presence of water in fine sub-grade soil.
- Excess water on shoulders and pavement edge causes considerable damage.
- Excess moisture causes increase in weight and thus increase in stress and simultaneous reduction in strength in soil mass. This is one of the main reasons of failure of earth slope and embankment foundations.
- In place where freezing temperatures are prevalent in winter, the presence of water in sub-grade and a continuous supply of water from the ground water can cause considerable damage to the pavement due to in frost action.
- Erosion of soil from top of un-surface roads and slopes of embankment, cut and hill side is also due to surface water.
- Failure due to hydraulic pressure and failure due to binder stripping can be avoided with the help of proper drainage on roads

ROAD DRAINAGE- importance

Well designed and well maintained road drainage is important in order to:

- Minimize the environmental impact of road runoff on the receiving water environment.
- Ensure the speedy removal of surface water to enhance safety and minimize disruption to road users.
- Maximize the longevity of the road surface and associated infrastructures.

There are many different types of drainage systems with different design features and attributes that can be used to manage flows and treat water quality. Drainage which is needed on the Highways Agency network depends not just on any flood risks and pollution risks identified but the characteristics of the natural water catchment area in which the network is based. The size, shape, gradient and geology of a catchment area are all factors which can influence the type of drainage methods used.

SURFACE DRAINAGE

The surface water is to be collected and then disposed off. The water on the surface is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course. For the preparation of surface drainage, we should keep in mind various things like

COLLECTION OF SURFACE WATER

Seeing the amount of rainfall and slope a suitable camber is to be provided for collection of surface water. The shoulders of rural roads are constructed with suitable cross slopes so that the water is drained across the shoulders to the side drains. These side drains of rural roads are generally Open (kutcha) drains of trapezoidal shape, cut to suitable cross-section and longitudinal slopes. These sides are provided parallel to the road alignment and hence these are also known as longitudinal drains. In embankments the longitudinal drains are provided on one or both sides beyond the toe; in cutting, drains are installed on either side of the formation. In urban roads because of the limitation of land width and also due to the presence of footpath, diving island and other road facilities, it is necessary to provide underground longitudinal drains. Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb and the pavement for short distances which may be collected in catch pits at suitable intervals and lead through underground pipes. Drainage of surface water is all the more important in hill roads. In hill roads disposal of water is also very important. Certain maintenance problems may arise due to faulty hill road construction.

CROSS DRAINAGE

For streams crossing the runways, drainage needs to be provided. Also often the water from the side drain is taken across by these cross drains in order to divert the water away from the road, to a water course or valley in the form of culverts or bridges. When a small stream crosses a road with linear water way less than amount six meter, the cross drainage structure provided is called culvert; for higher value of linear waterway, the structure is called bridge.

SUB-SURFACE DRAIN

Change in moisture content of sub-grade are caused by fluctuations in ground water table seepage flow, percolation of rain water and movement of capillary water and even water vapour. Although sub-surface drainage helps in removal of gravitational water, it is designed to keep minimum moisture in sub-grade.

LOWERING OF WATER TABLE

he 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.

UNIT VI: TRAFFIC ENGINEERING

The Road User and the Vehicle

Road user behaviour :

Broadly considered as two groups

1) Physiological
   a. Vision
   b. Hearing
2) Psychological
   a. Perception
   b. Intellection
   c. Emotion
   d. Volition

Vision:

Vision is most one or the important factor. The Human eye is the sensory organ that enables one to see.

- Evaluate the size, shape and color of objects.
- Estimate distance and speed of bodies.

a. Acute vison (sharp extremely):
   Formed by a cone whose angle is 3^o about Centre of retina. However, vision is till satisfactory when angle of cone is 10^o or 12^o. This is important locating traffic signs and signals.

b. Peripheral Vision:
   The angle of peripheral vision is about 160^o in the horizontal 115^o in the vertical direction. If detailed attention of the eye is needed driver has to turns his head so that the object now comes within the cone of clear vision.

c. Color vision:
   It is important for having the traffic lights and color schemes in traffic signs. But color blindness need not be of serious concern.

d. Driver eye should adopt to glare due to head-lights or to variations in the lighting conditions is an important factor.
   Glare recovery time varies from 3 to 6 seconds.

Hearing:

Hearing should be of service to the road -user. The sound of horn or the sound of the hearing vehicle itself can alert a pedestrian to safety. He has to design, operate, traffic facilities which will be useful.

PIEV theory or PIEV time:

Time taken for the process of perception, intellection, emotion and volition called it as PEIV time.

<u>Perception:</u>

Perception is the process of perceiving the sensations received through the eyes, ear's, nervous system and the brain. The exact time required for this dependent upon the individuals psychological and physiological build-up

<u>Intellection:</u>

Intellection is the identification of the event by the development of new thoughts of idea's may form leading to better understand of the event.

<u>Emotion:</u>

Emotion is the personal trait of the individual that governs this decision-making process, after perception and intellection of the event.

<u>Volition:</u> volition is the will to react a situation.

Total PIEV time is **2.5** sec.

Vehicular characteristics:

i. **Dimension and weight**:

Dimension and operating of a vehicle influence the geometric design aspects such as radii, width of pavement, clearness, parking geometric etc. The weight of the axels and the weight of the vehicle affect the structural design of pavement and structures. Because of its crucial important. The standardization of the dimension and weight of design vehicle is the first step in formulating geometric design standards

ii. **Braking system:**

Breaks are need to bring the vehicle to a safe stop whenever a immediate danger. So safe stopping distance is composed of the distance travelled by the vehicle during the perception and brake reaction time and the distance required to stop the vehicle after the brakes are applied if f is coefficient friction between tyre and pavement.

iii. Acceleration and Deceleration:

Acceleration characteristics of a vehicle need to be understood when designing te intellection element and overtaking sight distance. Acceleration rate is governed by the vehicle transmission system weight and horsepower. It is also changed with speed, being high at lower speeds and low at higher speeds.

Medium passenger cars	: 3-8 KPH/second
Trucks and buses	: 1-4 KPH/second

(when driver applies the brakes, vehicle decelerates)

Only in an emergency does the driver attempt to fully utilize the maximum deceleration. The maximum deceleration related to coefficient friction between tyre and the pavement.

Force required to deceleration a vehicle is

$$\mathbf{F = md}$$

m = mass of the vehicle

d = deceleration in m/sec^2 = F/m

but f = F/mg

$m = \frac{F}{fg}$

therefore, $d = f.g = 9.81f$

iv. Vehicle lighting system:

- Lighting system of the vehicle consist of head lights, dipper beam, side lamps, parking lights, rear lights, direction indicator's and stop lamps. An efficient and reliable system of lighting the vehicle is desirable for averting accidents.
- The headlight should perform 2 functions to provide main beam for the driver to see the road for sufficient long distance and to provide a dipper beam.
- Rear lamps give indication to the driver following a vehicle about the presence of a vehicle in front of him.
- Direction indication give adequate notice of the intension of the driver to turn or stop direct indications are usually amber in color and preferably they should be mounted at the side of the vehicle approximate at the level of the driver eye.

Features of vehicular body:

Factors needed to be considered are

1. The shape and dimension of the driver's seat
2. Arrangement of dials on the dash board
3. Positioning of controls in relation to the driver's seat

4. Visibility of the drivers from the seat
5. Noise levels in the vehicle
6. Concentration of carbon monoxide inside the vehicle.
   (high horse power, proper secure locks to door's)

Tyres:

- The performance of tyres relative to puncture, blowouts, vulnerability to damage by sharp objects, braking and road surface characteristics are areas where considerable research has taken place because of safety.
- Skidding is a phenomenon which is governed by the interaction of the tyre, brakes, road surface, speed and the wetness of road surface.
- It has extreme important in traffic accident prevention.

Power Performance of Vehicles:

- It is necessary to determine the vehicle costs and the geometric design elements.

Resistance to motion of a vehicle:

- Power developed by (vehicle) engine (Pp) should be sufficient to overcome all resistance to motion at the desires speed and to accelerate at any desired rate to desired speed.

Rolling resistance:

- When the vehicle wheels roll over the road surface the irregularities and the roughness of the surface cause deformation of the tyres road surface itself may undergoes deform. So rolling resistance varies with the type of surface

  Rolling resistance to friction

  $$P_f = m\,f\,g$$

  m = mass of vehicle in kg
  f = coefficient of rolling resistance
  P_f = rolling resistance in N
  g =acceleration due to gravity m/sec^2

Air resistance:

- Air has density, it exerts a reaction pressure against the front of the vehicle when it moves at speed.
- The friction of the air against the sides of the vehicle body causes the resistance.
- Eddying of the air stream behind the vehicle, under the body and around causes power loss.
- The flow of air through the vehicle for ventilating and cooling causes resistance to motion.

$$P_a = C_a\,AV^2$$

V = Speed of the vehicle relative to air m/sec

C_a = Coefficients of air resistance

A = Projected front area of the vehicle in sq.m on a plane at right angles to the tyre of motion

P_a = Air resistance N

Grade resistance (P_i) :

- when vehicle moving up an incline, an additional work has to be done in keeping the vehicle at the same speed.
- The additions work is equal to the works that will be needed to lift the vehicle through a height respectively by the vehicle.

$\pm Pi = mg/100$

-ve represent reduction in the force to move the vehicle .

Inertia forces during acceleration and deceleration:

when the speed of moving vehicle needs to be increased some additional power is needed to accelerate. Similarly if the vehicle has to gather a desired speed from a stopped position addition force is needed to accelerate.

Additional force P_j = Mass . acceleration

$\pm P_j = ma$

Transmission:

Low speed high gear transmission losses high.

Losses in power occur to the mode of power transmission from the engine to the gear system. The vehicle has system of gear such that the speed of the vehicle can be altered relative to the engine speed at the start of the vehicle as well as while climbing uptill we need high engine power movement along good road where the resistance to motion will be small.

The highest forward will generally 1:1

Speed, Journey Time and Delay surveys

Spot speed : Instantaneous speed at a specified location.

Running speed : Average speed by a vehicle over a given course while vehicle in motion.

Journey speed : Also Overall travel speed; is the effect speed of a vehicle between 2 points.

Time mean speed: Average of speed measurement at 1 point in space over a period of time. i.e., average of number of spot speed measure.

Space mean speed: average of speed measurement at an instant of time over a space.

<u>Uses of speed, journey time and delay those vehicles are time any:</u>

a. Spot speed:
    i. For geometric design of roads: design speed.
    ii. Regulation and control of traffic operation: Traffic signal design required specified data.
    iii. For analysis, the causes of accidents and identify any relation between speed and accidents.
    iv. Before and after road improvement schemes it is necessary to have spot speed data.
    v. Determine problem of congestion.
b. Journey speed and Delay speed:
    i. Cost of journey depends upon the speed. In all economic studies journey speed and delay are highly important.
    ii. To determine travel time to carry out the trip assignment. Also travel time and delay are some of the factors affecting modal choice.
    iii. Before and after studies.
    iv. Delay studies of intersection provide data for the design and installation of appropriate traffic control device.

<u>Methods of measuring spot speed:</u>

a. (req. observation of the) time taken by a vehicle to cover a known distance.
    i. Those vehicles are timed over a long distance
        a. Direct timing procedure:
            - Accurate stop watch as a vehicle crosses these 2 marks.
            - Known distance and measured time interval speed are calculated.

- Skilled observed can read stop watch to an accuracy 0.2 second.
- Disadvantage is large errors are likely to be happened because of the parallax effect.

Advanced method: 2 observers. One at the vehicle pass first signals that a vehicle to be timed is passing the point. Second observed starts the stop watch and stops watch when same vehicle passes terminal. Disadvantage is reaction time of two individual observers.

b. Enoscope:
   - Also, called Mirror-box.
   - It eliminates parallax error when direct readings are taken by one observer.
   - Mirror box is L shaped box.
   - Method can be done 1 Enoscope or 2 Enoscopes.
   - If one Enoscope is used it is directly placed opposite the first reference point and observer at another reference point.
   - Stop watch start as soon as vehicle passes the first reference point and stopped as soon as it passes the observer.
   - If 2 Enoscopes are used observer station will be midway between 2 reference points.

c. Pressure contact tube:
   - Detectors are used. (pneumatic tube) to indicate time entering and leaving the base length. When vehicle passes time over the tube laid at first reference point air impulse is sent, which activates the electromagnetically.
   - Controlled stopwatch in the hands of observer.
   - Alternatively, readings can be observed by automatic data recorders.
   - Disadvantage pressure contact tubes can be seen by driver and this may affect their behavior.

d. Short distance method:
   - Measuring speeds very short say 2m.

- Instrument are electronic and are used in conjunction with pneumatic tubes or electric detectors laid across the pavement.
- Recording can be manual being noted by the observers or can be automatic with or electronic system.

b. Radar speed meter:

- It works on doppler principle (change frequency of wave)
- Speed of moving body and change in frequency between radio wave transmitted for the moving body and received back.
- This instrument directly measures the speed and accuracy of atleast $\pm$1.5 to 3 KPH
- Instrument is portable and battery operated.
- Within 20° instrument is set up near the edge of carriage way at height about 1m speed and directions both can be measured.
- Method is used for traffic engineering studies as well as enforcement by traffic police.

c. Photographic method:

- It is used in crowded streets.
- In this pic are taken as fixed in travels of time.
- On special camera (say one second per frame).
- By projecting the film on the screen.
- The passage of any vehicle can be traced with reference to time.
- Images by video camera can also use.

Delay studies:

- Best are done by moving observer method; delays occurring due to stopping can be conveniently recorded by separate stopwatch.
- Special watches which can be found convenient for the purpose of which can accumulate delay time as operated by observer.

Two types of delays:

- **Stopped or fixed delay**: at intersection, railway crossing, stop signs.
- **Congestion delay or operational delay**: inadequate carriage way width, mixed traffic conditions, parked cars and heavy pedestrians.

Methods for measure running speed and journey speed:

i. Moving observer method:

Uses:

- Un biased estimate and neglisable error.
- Economical in man power.
- Speed and flow calculation as well as.
- Spot speed so that time mean speed.
- Additional information stops at intersection, delays, parked vehicles.

ii. Registration number method:

- Two observers in one direction with stop watch.
- 1 at entrance and 2 observer at terminal. Distance between 2 observer stations 0.5m- 1m.

iii. Elevated observer method:

- Observer stationed on top of the elevated building select vehicles at random and follow their course along the road, nothing the time of entering the test second, duration and nature of delay suffered and the time of leaving.

Needs of volume count:

- Volume of traffic using road in a given interval of time. Volume = vehicle/ hr or vehicle/day
- Traffic is composed of no. of types of vehicle. So we converting the flow into equivalent passenger car unit PCUs using certain equivalent factors. Now the flow expressed as PCU per hr or PCU per day.
- By knowing flow clearance. We can determine whether the particular section of road handling traffic much or below it capacity.
- If traffic is heavy road suffer because of congestion. Therefore, volume counts are necessary to improve traffic facilities.
- Structural design of road pavement we need to know no. pf commercial vehicle flow. It will good guide to pavement design.
- Maintenance of road also decided by no. of commercial vehicle per day.
- More people are involved in travelling useful for transport.

Types of counts:

1) Average annual flow, vehicle/year
2) Annual average flow, vehicle/day
3) Hourly flow, vehicle/day

Volume

Needs for volume, classification and counts

- Volume of traffic (or) flow is expressed as vehicles/hr (or) vehicle/day.
- Traffic is composed of no of vehicles it is normal practice to convert the flow into equivalent passenger car unit (PCUs), by using certain equivalency factors.

  3rTherefore, Flow is expressed as PCUs/hr (or) PCU/day.
- Knowing the flow char. We can determine whether particular sec of mad is handling traffic much above (or) below its capacity.
- If the traffic is heavy, road suffers from congestion with consequent loss in journey speeds &
- Lower speeds cause economic loss to the community due to time lost by the occupation of the vehicles & higher operational cost of vehicles.

  Therefore, Volumes counts are indicators of the needs to improve the transport facilities.
- If traffic flow data are available over the past no of years, the rate at which traffic flow can be increased in the past can be easily determined. Extrapolating the past trend into the future, future rate of growth of traffic is made possible.
- No of commercial are using the road will its self will be a good guide in pavement design.
- Maintain needs of a highways is often based using road. Moreover no of commercial vehicles/day.
- Traffic regulatory & control systems are designed on the basis of accurate flow data.
- Evaluating the financial validity of private financed toll roads, the important consideration is volume of both present future volume data are collected very carefully for such projects
- The ultimate aim of travel is to transport men & goods.so we have to take no of occupants (or) people traveling in vehicle. If vehicle count puts available & the advantage occupancy of each type of vehicle is know the total no of persons easily calculated.

Types of Counts:

1. Level of measurements of flow
   i. Average Annual flow, expressed in vehicle/year.

ii. Annual Average Daily Traffic (AADT), vehicle/day.

iii. Hourly flow, vehicle/hr.

AADT = 1/365 of total annual flow

If the flow is not measured for all 365 days. only for few days the average flow is known as Average Daily Traffic.

2. Short term and long term counts:

Duration of the counts depends upon the purpose for which the data are needed and financial and man-power resources at the command of the traffic engineer.

TYPES OF COUNTS:

The following are types of flows along with its purpose and use.

Short term counts;say 1hr, 2hr	1. flow in peak hr.
	2.To measure stiuation flow at signalised intersection.
	3.Used in intersection counts during morning and evening peaks.
Counts for full day	1. Hourly fluctuations.
	2.Used in intersection counts.
	3. Used in cordon line and screen line counts as part of trasport survey.
Counts for a full week	1. hourly and daily fluctations
	2.USed in developing countries.
	3. Used in cordon line and screen line as a part of urban transport survey.
Continous counts	1. To determine fluctuations of flow daily, weekly, seasonly and yearly.
	2. To know annual rate of growth of traffic.
	3. Used in generally developed countries at selection no. of stations for continuous monitoring of tarffic flow.

Methods Available For traffic count:

1. Manual
2. Combination of manual and mechanical
3. Automatic devices
4. Moving Observer
5. Photographic method

Manual Method:

No. of observers and No. of lanes in the highway.

Road features and Counting Required	No. of vehicle/hr by 1 trained observer
1. 2-lane 2-way road, separate observer for each direction and classified.	500 vehicle/hr one direction
2. 2- lane 2-way road, 1 observer for both direction. Counted and Classified	200 vehicle/hr both direction
3. 2-lane 2-way-road 1-observer for both direction. Simply counting.	800 vehicle/hr both direction

- Observer should be literate and can be trained suitable for purpose with preferably middle or matriculation level qualification.
- For all day counts, work in 3 shifts of 8 hours each.

Equipment Method:

1. A watch
2. Pencils, Eraser and Sharpener
3. Supply of blank field data sheets
4. Clip board.

If 5 types of vehicles are to be counted the multi bank hand fall should have 5 counters, with a label stuck on each pressing knob indicates vehicle type. Pressing knob operates the counter and records the vehicle. This is additional equipment which is very handily.

Field data sheets and summery sheets:

- `Multibank hand tally is not available, data is recorded conveniently by the fire-dash system.
- Field data sheet by IRC. This form is intended for last 4hrs.
- Data can be summarized for each hour of the day in the form prescribed by IRC.

For Example:

Types of vehicles ⇨ Hour count ⇩	Cars, jeeps, vans, 3wheels (2)	Buses (3)	Trucks (4)	Motor-cycles (5)	Animal drawn Vehicle (6)	Cycles (7)	Other specify (8)	Total flow (9)	Remark

1. Manual counts at intersections:

   Field data sheets can be modified to suit the particular requirement of any intersection. Observer needs to be posted on each arm of intersection at four arm intersection. Count at each arm of the traffic entering the intersection can be broken down into three categories left turning, right and straight ahead. Above field data sheets can be modified to suit.

2. Combination of manual and mechanical counts:

   Example for this is multi pen recorder. A chart moves continuously at the speed of clock. Different pens record the occurrence of different event on the chart. The actuations of each event recorder pen is by pressing the electric switch associated with each pen recorder.

   Advantages:

   (i) Permanent record is kept for each class of vehicle, classifications and count performed simultaneously.

   (ii) Additional information such as time -headways between successive vehicles and arrival per unit time is available.

3. Automatic Devices:
   - This device contains detecting the passage or presence of a vehicle called sensor or detectors and another for recording the count.

- The sensor usually transmitted some of Electric impulse which activates the accumulating register or recording chart.

SENSORS

1. Pneumatic tube
   Flexible tube with one end sealed is clamped to the road surface right angles to the pavement. Other end of tube is connected to a diaphragm actuated switch. When axel of vehicle cross the tube, a volume of air gets displaced thus creating a pressure which instant closes the electrical contact through the switch. Two such contacts result in one count being registered thus represented two axles in a vehicle.
   - Inaccuracies are caused when vehicles with more than two axles.
   - Because of simplicity and their cheapness pneumatic tubes are very popular.
   - Difficulty may be caused in in fixing them to gravel surfaces and they are easily pilfered by vandals.
   - Easily damaged by tractors*tire chains*snow ploughs and similar equipment.

2. Electric contact
   - A pair of steel strips are contained in a rubber pad which is buried beneath the surface.
   - On being pressed by vehicles weight steel strips come into contact with each other and causes electric current to flow.
3. Coaxial cable:
   - Coaxial cable is clamped across the road surface, with capability of generating signals with the passage of axles. These signals actuate a transistorized counter.
   - Advantage better reliability and less susceptibility to damage.
4. Photo electric:
   - One end of road is source light which emits a beam across a road.at other end photocell passage of vehicles in the path of the light beam and causes a detection by a photo cell.

   Disadvantage

   Abstractions may can be caused by pedestrians and more than one vehicle in different traffic lane will be registered only vehicles.
5. Radars:
   - Doppler effect is a well-known. when a moving object approach or recedes from a source of signal, the frequency of signals received by the back from the moving object will be different two frequencies causes detection of a moving object. Initial cost is high but its accuracy, reliability and not damaged by the traffic.
6. Infrared and ultrasonic:
   - Infrared sensors can detect heat radiated from a vehicle or can react to a reflection from the vehicle of infrared radiation emitted by sensor. Ultrasonic is also used for vehicles detection. Both the types have same advent and equally expensive as a radar.
7. Magnetic:

- Disturbance caused in a magnetic field by a passing vehicle as a basic of sensing. The magnetic field itself provided by a wire coil buried beneath the road surface.

Recording mechanism

i. Counting resistors: This is simply accumulating counter indicating directly the number of vehicles on a meter. Readings must be taken before and after the period.
ii. Printed output: This device prints accumulated total at regular intervals of time on a roll of a paper, resting the counting register to zero at the end of the each time interval. Time of the day and number of the vehicles are printed side by side*time interval 1hour, 30min,15min.
iii. electronic systems: Hard disks, floppies, discs

Maintenance of automatic devices

- For accuracy and reliability proper maintenance is necessity.
- Accuracy of clockwork mechanism needs to be check periodically.
- Recording devices used to work 6volts batteries, which need to be charged at regular intervals.
- All automatic devices mentioned above need attention.

Parking

Problems

- Not only vehicles need street space to move, but also need space to park where the occupants can be loaded and unloaded.
- Every vehicle owner would wish to park vehicle as closely as possible to his destination so as to minimize his walking.

Ill effects of parking

1. Congestion:

Capacity of street is reduced, journey speed decreases and the journey time and delay increases.

2. Accidents:

Careless opening of doors of parked vehicles, moving out of a parked position and bringing a car to the parking location from the main stream of traffic are some common causes of accidents.

3. Obstruction to firefighting operations:

Parked cars obstruct the movement of fire fighting vehicles. They block access to hydrant s and access to buildings.

4. Environment:

Stopping and starting of vehicles result in nose and fumes. Cars are parked into every little available space debase the visual aesthetics and " buildings seem to rise from a plinth of cars".

5. Zoning and parking space requirement standards:

- On street parking and its regulation will be an important aspect of the overall parking policy of a town.
- New or remolded buildings will be requirements to have within enclosed land around house
- Advantage of zoning and land use controls for steering safe and efficient traffic have been well recognized.

Sl no.	Land use	Parking space

1	Residential i)Detached and semi-detached row houses Plots areas: Up to 100sq.m 101 - 200sq.m 201 - 300sq.m 301 - 500sq.m 501 - 1000sq.m ≥1000sq.m ii)Flats iii)Special or costly developed area iv)multi storied	No space required Only community parking space is Required Min 1/3 rd for open area. Min ¼ th for open area. Min 1’6 th for open area. Open space for every 2 flats 50-99sq.m or more floor area. Open space for every 50-100sq.m. one and half space for every flat of 100 to 150sq.m of floor area. 2 spaces >150sq.m. One space for every four dwellings except cities where demand may be more.
2	offices	1 space for 70sq.m of floor area
3	Industrial premises	1 space for up to 200sq.m of initial floor area
4	Shops and markets	1 space for every 20sq.m of floor area.
5	Restaurants	1 space for every 10 seats.
6	Theaters and cinemas	1 space for every 20 seats
7	Hotels and motels i. 5 or 4 star ii. 3 star iii. 2 star iv. Motels	 1 space for every 4 guestrooms. 1 space for every 8 guestrooms. 1 space for every 10 guestrooms. 1 space for every guest room.
8	Hospitals	1 space for every 10 beds.

<u>Design standards for on-street parking facilities</u>:

Common methods of on street parking:

- **i.** Parallel parking
- **ii.** 30^o angle parking
- **iii.** 45^o angle parking
- **iv.** 60^o angle parking
- **v.** Right angle or 90^o angle parking

Regulatory measures for on street parking:

- On street parking is extravagant or excessive use of precious street space.
- A judicious application of approximate traffic management measure will help extent some of ill effects of on street parking.

2 types of regulatory measures use

1. Use of parking space is authorized for certain periods free or for payment.
2. Where parking prohibited but which for picking up or setting down goods and passengers.

<u>Prohibited parking:</u>

i. Near intersections:
    - 50 m away from intersection
    - Visibility adversely affected and safety is reduced; capacity intersection reduced.

ii. Narrow streets:
    - two way streets <5.75m wide & one way street <4cm prohibited.

iii. Pedestrian crossing:
    - Pedestrian crossing are worst suffering. parked cars obstruct visibility at pedestrian crossing. 8m from pedestrian crossing, parking prohibited.

iv. structures:
    - Bridges, tunnels & under passage gently have roadways width so durable to prohibit parking on them.

v. Entrance drive ways:
    - Houses & buildings in front of these structures prohibited. Normally period 8am (or) 9am to 6pm (or) 9pm. Prohibited & relaxation in Sunday's.

<u>Free parking limited period:</u>

- Free parking is allowed designated stalls on limited period. Adoption of these scheme are availability sufficient parking spaces to meet the demand. Parker's should leave their vehicle for a time which is less than a posted limit.

<u>Parking meters:</u>

These are two types:

- <u>Manual meter</u>: Manual meter is operated by inserting appropriate coin and working handle (or) lever. This activate clockwork mechanism of meter.
- <u>Automatic meter</u>: Automatic meter wound up periodically (once in a week) attendant upon insertion of coin needle shows time and it will start moving across time scale on the face of the meter until the period of time brought has expired.

Generally, Meter can be two types:

- <u>Canceling (or) non-cumulative</u>:
    - Unexpired time remaining on meter it canceled out by insertion of next coin.
    - Next motorist gets more time than he actually pays.
- <u>Cumulative</u>:
    - Unexpired time is added to time period of next motorist.
- Metering plan is reverent to favor shot time parameter and to parking turnover.
- Time limit judiciously selected.1hr is satisfactory limit for central area of the city.
- Near post office, bankers and public utility off 15-30 minutes should be sufficient for motorist to finish their work.

<u>Advantages of parking meter:</u>

i. 4 (or) 5 cars can use single parking in a day out provides short term Parker.
ii. Time check is very accurate and easy to violators.
iii. Dangerous parking is avoided because park bays are process precisely.
iv. Parking inform of important buildings and near ingest avoided.

<u>Disadvantages:</u>

i. Strick enforcement is necessary for its success.
ii. Bay are uniformly marked with reference to largest car operating in the country.
iii. If_we want to park long term.
iv. Meter scheme is a solution to only a part of park.

<u>Parking discs:</u>

- Disc is displaced by motorist on wind-screen, showing time of arrival and time by which the vehicle has to leave the parking space.
- No fee is charged and promotes short-term parking.
- Enforcement more attentive than meter systems. Since abuses may be more common.
- Setting and displacing the disc correctly is motorist responsibility.

Off- street Parking: (consideration locating off-street parking)

i. Surface car parking
ii. Multi-storied car
iii. Roof parks
iv. Mechanical car parks
v. Underground car parks

Primary consideration should be nearness to the place of usage by the 30 prospective customers. Proposed facility should be close to major parking generators.

<u>Surface car parks:</u>

- Located and developed on a piece of vacant land or surrounding an office complex or supermarket are very popular with the motorists.
- Great care is needed in their design and operation.
- A stall size 2.5m × 2.5m is probably adequate for Indian condition predominated by small size cars.
- Type of layouts depending on area.
- If it is fee-charging system, there should be arrangement for collecting the money.
- That can be either manually by stationing an attendant at entrance who cells parking tickets or by installing an automatic ticket vending machine which can be designed to raise a barrier rail upon insertion of coin.

<u>Multi-storied car parks(MSC):</u>

- Surface parks consume too much of the precious land in heart of city.
- One of the alternatives when land is costly is to provide multi storied car parks such facilities became common and popular in many cities.
- MSC are designed for a capacity of about 400 to 500 cars.
- Large capacity tends to increase the time for un parking a car.

Design standards for designing of multi-storied park:

i. Gradient of the ramp: 1 in 10 generally and 1 in 8 for every short ramp.
ii. Clear height b/w floors 2.1m
iii. Parking stall dimensions 2.5m × 5 m
iv. Inside radius of curve 7m.
v. Width of traffic lane on ramps and entrances 3.5m.
vi. Gradient of sloping floors: Not steeper than 1 in 20
vii. Loading standards 400kg/m^2.

- Arrangement of the floors and the access ramps needs careful thought and large no. of alternatives are available.
- Ramps are preferably made one day.
- If two way they should be divided.
- Continuously sloping to gain access from one level to another.
- Horizontal floor with separate helical entrance and exit ramps have been found efficient.
- Car parking floors, the ramps, Entrances and exits should be well lighted.
- Operation of multi storey car parks can be with customer or attendant parking or a combination of the two.

<u>Roof parks:</u>

- Very popular methods of solving parking problems adopted in many cities is to park vehicles on roof tops.
- Access ramp mechanical lifts provide necessary access to the roofs.
- To economize, many roofs may be linked together sensed by a single access ramp.

- In addition to ramps extra cost is involved in designing the roof tops and structural elements for parking.

<u>Mechanical car parks:</u>

- Provided for lifting of the cars from floor to floor by means of lift.
- Transfer of cars to and from the parking stall by means of wheeling or mechanically operated transfer dollies or cradles.
- Since ramp and aisles are estimated.
- If is more economical compared to ramped system multi stories system.

<u>Disadvantages:</u>

Higher maintenance cost and possibility of breakdown due to mechanical or power failure.

<u>Underground car parks:</u>

- Great advantages of underground car parks are least intrusion they cause to the aesthetics of a place.
- These can be built in the basement of any multi storied building or below open spaces.
- Work involves large quantities of excavation, construction of retaining walls ventilation and lighting such a car parking tends very costly.
- Underground car parking can be single storied or multi storied.

Peripheral parking schemes:

- Center of town is the worst hit by the parking problem.
- It is natural to think in terms of providing parking facilities at periphery of the town.
- Induce motorists to park there and travel to the busy town center by some other mode.

i. <u>Park and walk:</u>
   - Park at outskirts of town and walk down to town.
   - Inducement is in the form of lower parking charges at the periphery than at town center or no parking charges.

ii. <u>Park and ride:</u>
   - This scheme provides parking facilities and public transport side to the destinations in the town center.
   - Attractive scheme has been tried with success in many towns.
   - Since motorist voluntary park his car.

     Total travel time including parking time waiting time at the bus stop and travel time by bus should not be excessively high to make him look at it with disfavor.

- Cost peripheral parking charge + charge for to and fro journey by bus < cost of travel by his car + charges for parking in(cities) town center.

iii. Kiss and ride:

- Dropping her husband in the car in the morning near a bus stop from where the husband goes to work in a bus.
- The reverse operation takes place in the evening.
- Adequate space for parking of cars near the bus stops where the husbands can be dropped off or their arrivals awaited is an essential prerequisite for the success of the scheme.

Loading and unloading facilities:

1. Bus-Bays:
   - Bus bays recessed into the curb, facilitate loading and unloading of passengers without vehicle blocking the stream of traffic on carriage way.

   Guidelines for location of bus bays:

   i. Bus stop should not be located too close to intersect minimum distance 75m from intersection for urban 300m for rural desirable.
   ii. Bus stop located as to set down the passengers at safe places such as curbs.
   iii. Intending to turn right at an intersection, stop should be sufficiently away.
   iv. Length of recess should be 12-15m for single bus for every additional bus 12-15m left. Taper on either side should be about 8:1, the maximum valve being 6:1.
2. Commercial traffic:
   - Loading and unloading of goods by trucks on the roadside demands upon the space reserved for pedestrians as well as for moving vehicle.
   - Problem can be controlled by permitting loading and unloading only b/w 6pm to 8 pm or by permitting Loading and unloading at specified location.
     ie., providing (long-term) adequately designed truck terminals outside the cities.
3. Truck terminals:
   - Parking of trucks in the streets and upon spaces of the towns and cities has many adverse effects.
   - Pre-most is the degradation of environment and hazard to traffic.

- Security of the goods contained in the parked vehicle can also serious problem.
- Truck drivers who have often to drive for long hours and consequently need rest, toilet facilities and food deserve careful consideration.
- Right approach is to provide well designed truck terminal at outskirts of cities.
- Length of truck berths depends on type of trucks to handle.
- Truck trailer combination obviously need longer than single unit trucks.
- Alternatively, pre-quad questionnaire may be distributed to person residing at stations outside the survey area and are collected at station inside the survey area.

Presentation of Results:

- Origin and destination survey yields a vast amount of data. To understand them it is necessary to present them in convenient tabular or pictorial form.
- The most convenient form is origin and destination matrix. Origin zones and destination zones are represented.
- Most popular pictorial representation is by means of a desire line chart i.e., trips b/w any pair of zones are by straight line connecting the centroid of the two zones and having band width drawn to a suitable scale to represent the actual volume of trips.

Parking surveys

Need for parking surveys:

- It is one of the serious problem that deals with urban planner and traffic engineering available parking space, Extent of its usage and parking demand are essential.
- If it is proposed to implement a system of parking charges it will also be necessary to know how much to charge and what will be the effect of pricing policy on parking.
- Parking survey needs all this kind of information.

COMMON TERMS:

Parking Accumulation: Total no. of vehicle parked on an area at a specified moment.

Parking volume: No. of vehicles parking in a particular area over a given period of time measured in vehicle/day.

Parking load: The area under parking accumulation curve during a specified period.

Parking index: Percentage of parking bays actually occupied by parked vehicle as compared to the theoretical number available.

P.I = No. of bays occupied × 100 ÷ Theoretical no. of bays available

Parking turn-over: Rate of usage the available parking space.

10 parking space used by 100 vehicles in a period of 12hrs.

Therefore, parking turn over = (100÷10) vehicle / space in a period of 12 hrs.

Types of Parking surveys:

1. Parking space inventory
2. Parking usage survey by patrol
3. Questionnaire type parking usage survey
4. Cordon count

Parking space inventory:

- Central business district is usually the area where parking survey in needed and area surrounding central business districts where the parking spills over should also be included in survey.

- The survey area is them subdivided into street by street basis and sub-divisions marked on a map. Then sketch marks are prepared in advance.

Items should be recorded as follows:

a. Total length of curb, and length governed by no waiting and limited waiting restriction.
b. No. of parking space provided in street.
c. Street width
d. Location of bus stop, bus bays, pedestrian crossings, fire hydrants, loading zones, taxi stands and other features will affect because using street parking.
e. No. of types of traffic signs for regulation of parking.
f. Vacant or unused land suitable for temporary or permanent parking space.

For single unit truck space of 3.75m × 7.5m per vehicle is adequate

For truck trailer combination 15m may be needed.

Width of loading platform should be 3.5 to 4.5m.

Long distance bus terminals:

- In towns, it is desirable to design bus terminals to handle exclusively long distance bus traffic.
- Such terminals should preferably be outside the congested portion of the town.
- If a town has ring road the ideal location in many cases is the ring road itself.
- Terminal should be planned such that one-way circulation of buses is achieved.
- Pedestrian movement will be heavy in a terminal and should as far as possible, not conflict with vehicular movements.
- Platform where pedestrian wait should raise.
- Parking facilities for car, scooter, cycle, taxis etc. should be provided.
- Terminal should be planed for anticipated future traffic in the design year.
- Bus width generally 2.5m and it is desirable have 3.3- 3.75m wide lanes. Length of bus about commercial vertical clearance 3.75m.
- Passenger platform should have minimum width of 2.5m.

Parking Usage Survey by Patrol:

Purpose:

- Survey is to obtained data on the extent of usage of parking spaces.
- Survey counts parked vehicle at regular intervals through a period, covering both morning and evening peak period and parking accumulation and turn-over.
- Survey can be on-street or off-street parking.
- Methods for both the surveys similar. Some minor difference will be there.
- Method consist of making periodic observations of parked vehicle on each patrol.
- Off-street observations the entire parking space can be patrolled on entrance and exit may be observed continuously.

Mapping street system:

Steps:

1. Preparing map of street system that will be covered by patrol it has to show its sub-division into sections.
2. Street junctions make convenient points for determining the sections
3. Recording can be for both side of roads or smooth for each other.
4. Map and forms should clearly show the direction of travel by patrol ma and the side or sides where observations are to be side or sides.

The length of streets to be covered by a patrol is

1. Speed of walking while noting the registration number.
2. Frequency of patrol.

A speed 900m in half an hour is useful guide.

Frequency of patrol:

- More frequent patrols result in more accurate data filed work and subsequent become more tedious.
- A frequency of ½ hr considered to be satisfactory for on-street parking. For off-street 1 hr patrol used.

- A frequency ½ hr may miss short term street parkers. This makes it necessary to have more frequently patrols in selected areas where short-term parking may be significant.

  Ex: near banks, post office.

Methods of observation:

Usually patrols are by foot, if vehicles are not parked too close to one another a moving car also used. A tape recorder may be used to record the registration number of vehicle.

Timing of survey:

Done in week days. Period of survey 10-12 hrs so to cover the arrival and departure of customers and shoppers.

Traffic signs

Importance:

- Timely warning of hazardous.
- Regulating traffic by imparting messages to the drivers about need to shop give way and limit their speeds.
- They give information as to highway routes, directions and points of interest.

General Principles of traffic signing:

i. Traffic signing should be installed only by authority of law. Unofficial and Non-Essential signs should not permit.
ii. For imparting a sense of respect towards signs, proper enforcement measures should be taken.
iii. Excessive use of signs shouldn't be more. Conservative use of warning and regularly signs is recommended.
iv. Signs should be put up only after traffic engineering studies.
v. High visibility, both during night and day.
vi. Lettering or symbols of adequate size for being read from far way.
vii. Simplicity and uniformity in design, position and application.
viii. Location at conspicuous position to be able to be seen by drivers.
ix. It is desirable that there should be two sizes for types of sign.

(a) Standard size (b) a reduced size.

Where conditions do not permit in the safety of road users doesn't require the erection of the standard size.

Types of Traffic signs (3 types):

1. Danger signs or warnings signs or Cautionary signs:
   - Necessary to warn traffic of existing or potentially hazardous conditions on or adjacent to a highway or steel.
   - Warning signs are of great help in ensuring safety of traffic.
   - Should be keep minimum because their unnecessary use tends disrespect for all signs.
   - IRC standard 900mm for a standard size, 600mm for a reduced size.
   - Signal have red border and symbols are black in color with white background.

2. Regulatory signs:
   - Signs giving definite instruction sub divided into

   i. Prohibitory signs:
      - To inform the highway users of traffic laws or regulations.
      - This signs gives definite negative instructions prohibiting the motorist from making particular manoeuvres.

      Types:

      i. Movement Prohibition: Examples-certain turns, prohibited of entry, prohibited overtaking, One-way Traffic.
      ii. Waiting restrictions signs, such as prohibited waiting.
      iii. Restrictions on dimension, weight or speed of vehicle.
      - According IRC these signs are circular shape of 0.6m dia standard 0.4m for reduced size.
      - Signs have red border, white color background for speed control, blue for waiting and parking restrictions and direction control also. Symbols are black in color per prohibited and white in color for direction control signs.

   ii. Mandatory signs:
      - These are intended to convey definite positive instructions when it is desired that motorists take some positive action.
      - 2 important mandatory signs are (i) stop (ii) Yield or Give way

      STOP:

      - These signs require all vehicles to come to half before the stop line.
      - Because it causes substantial inconvenience to motorists.
      - It is generally used at intersections should be used follows
        a. Intersection of less important roads with a main road.
        b. Street entering a through highway or street.
        c. Un signalized intersect in a signalized.

d. Where combination of high speed, restricted view and serious accident record indicates a need for control by stop sign.

Shouldn’t be used:

a. On through roadways or expressways.
b. For speed control
c. At signalized intersection.

- IRC octagon with white border and red background and sides of octagon being 900mm for stand and 600mm for smaller size.
- Combination with a definition plate carrying message stop.

Yield or Give way:

- Used to assign right of way to traffic on certain approaches to an intersect.
- Vehicle controlled by yield sign need to stop only when necessary to avoid interference with other traffic that is given the right of way.

They are used in under following conditions:

i. On a minor road at the entrance to an intersection where it is necessary to assign right of way to major road where stop is not necessary at all times.
ii. Entrance ramp to an express-way when acceleration lane is not provided.
iii. If there is separate or channelized left-turn lane without adequate acceleration lane.
iv. Within intersection with a divided highway where entrance stop sign is present at entrance to 1st road way and where median width b/w two road ways exceeds 9m.
v. Where special problem exists at any intersections.

Shouldn’t be used:

i. Control the major flow of traffic at intersection.
ii. On the through roadways or expressways.

iii. On the approaches of more than 1 of the intersection streets or highways or at any intersection where there are stop signs on one or more of the approaches, except under special circumstances, to provide minor movement control within complex intersection.

- IRC downward pointing equilateral triangle red border and white background. 900mm standard triangle 600mm long smaller size.
- Shall be used in combination with a definition plate carrying massage "GIVE WAY".

3. Information signs: (3 types)
   - Intended to guide motorist along street and highways to inform him of intersecting routes, to direct him to cities, towns. Villages or other important destination to identify nearby rivers and streams, parks, forests generally to give him such information as will help him.
   - Signs not lose their effectiveness by over-use.
   - Important dealing with provision of informatory signs is the size of lettering.
   - Letters should be of such size as can be easily read when the vehicle are moving at speed.

     i. Indication signs:
        - Provide information of facilities such as hospitals, filling station, telephone, eating place, first aid etc.
        - Generally required shape 600mm × 450mm with black symbol, blue background and white rectangle.
        - Information regarding parking facilities are frequently needed.

     ii. Direction signs, Advanced direction signs and place identification:
        - Sign indicate name of the place and rectangular in shape, terminating in the form of an arrow head.
        - Advanced direction signs are necessary at intersection of roads. They are Rectangle in shape.
        - Reassurance sign reassures the traveler about the places ahead and the direction.

Overhead signs:

Used to provide following consider exist

i. Traffic volume at or near capacity
ii. Complex interchange
iii. 3 or more lanes in each direction
iv. Restrict sight distance
v. Closely spaced interchanges
vi. Multi-lane exists
vii. Large percent of trucks
viii. Street lighting background
ix. High speed traffic
x. Right exist ramps

Existence of any or more of the conditions listed doesn't automatically justify the use of overhead signs.

Height of the panel ranges from 125cm to 305cm, depending on no. of line sand messages. Letter size range 25-30cm. Vertical clearance needed in India 5.5m.

Types of Supporting Systems:

1. Cantilever with one post
2. Butterfly with one post
3. Two post unit

Route Marker signs:

RMS for national highways has been standardized in India by IRC. It consists of shield painted on a rectangle plate 450mm × 600mm. Sign has yellow background and lettering and border are in black.

Location, height and maintenance of traffic signs:

- Located at left side of road. Repeated on other side of carriage on multiple line carriage ways.
- On wide expressways, overhead signs may also necessary.
- On hill road, they are normally fixed valley side of road.
- IRC not less than 60cmaway from edge of kerb in case of kerbed roads and distance 2-3m from carriage way edge in unkerbed roads.

- Stop sign located at point where vehicle has to stop or near there to say 1.5 to 3m if there is pedestrian crossing stop shall be 1.2m in advance of pedestrian cross stop line.
- Give way sign located at near to point where the vehicle is to stop say distance 1.5 to 3m it should be erected 1.2m in advance of marking.
- Warning sign: to be located at the following distance in advance hazard warned against,

Non-Urban locations	Plain and rolling terrain	Hilly or mountainous terrain
National Highways and State Highways	120m	60m
Major District Roads	90m	50m
Other District Roads	60m	40m
Village Roads	40m	30m

For urban location: 50m

- Sign post should be maintaining proper position.
- Damaged signs should be removed and replaced immediately.
- Periodic painting of signs should be routine part of maintenance.

Variable Message Signs or Dynamic Message Signs:

- Which can be changed whenever need by means of remote control at a centralized location.
- Information such as severe weather conditions, incident notification (accident, road closure) congestion, travel time b/w distance.
- UMS display board uses high intensity LED’s generally yellow color size of letter 380-400mm.

Traffic signals

1. Advantages:
   - Orderly movement of Traffic flow.
   - Because of proper layouts and control measures, they can increase the traffic-handling capacity of intersection.
   - Reduce frequency of certain types of accident.
   - Under favorable condition, they can be coordinated to provide for continuous or nearly continuous movement of traffic at definite speed along given route.
   - Used to interrupt heavy traffic at intervals to permit other vehicular or pedestrian to cross.
   - Traffic signals dispense with police control and can thus be economical.

   Disadvantages:

   - Excessive delays to vehicle may be caused, particularly during indication.
   - Unwarranted signal installation tends to encourage the disobedience of signals.
   - Driver may use less adequate and less safe routes to avoid delays at signals.
   - Accident frequency, especially of rear end type may increase.
   - When installation breakdown, total and widespread confusion and difficulties can result.

2. Signal Indication:
   - Indian practice:
     - Amber period 2 seconds as transition interval b/w termination of related green movement and exhibition of indication or b/w termination of red indication and commence of green movement.

     Pedestrian Signal indication: Red standing man represents don't cross and green walking man represents indication cross.

     Flashing amber: Signal is a hazard identification beacon is normally used to warn of obstruction and intersections to supplement regulatory signs and to warn of mid block cross walks.

3. Signal Face:
   - Minimum number of senses in a signal face is 3- red, amber, green. Maximum no. of American practice is 5.
   - Lenses in a signal face can be arranged in a vertical or horizontal straight line.
   - Relative position top to bottom or left to right are red, amber, green.
   - Lenses normally of 2 sizes 200mm and 300mm dia.
   - Large size used where 85% approach speeds exceed 65 KPH; for special problem. Location, for all arrow indication, for intersection where signalization unexpected and for intersection where drivers may view both traffic control and lane direction signs simultaneously.

- IRC recommended size 200mm for light signals intended for drive, 300mm for green arrow signals and 300mm for signals intended for pedestrians.
- Arrow pointed vertically upward to indicate a straight through movement and in horizontal direction to indicate a turn at approximately.

4. Illumination of Signals:
   - Illumination of signals as to be visible for a distance of atleast 0.4km under normal atmospheric conditions.
5. Number and location of signals faces:
   - <u>American practice</u>: Minimum of 2 signals faces to be provided and be visible from a point atleast. Normally one primary signal is installed at 0.9m from the stop line and secondary signal is commonly installed diagonally opposite the 1st primary signal on the back, on the back of the primary signal intended for opposite traffic.
   - <u>Indian practice</u>: When erected the center of the amber signals shall not be less than 2.4m nor more than 4m above carriageway level.

Amber period:

<u>Indian practice:</u> Amber interval is a transition interval b/w termination of related green movement and exhibition of a red indication or wise versa b/w termination of red and commencement of related green movement.

1st case it is called "Clearance Amber" and 2nd case "Initial Amber". Amber period is 2 seconds.

- Cycle length is time required for one complete sequence of signal indications phase is defined as sequence of condition applied to one or more streams of traffic.

Fixed Time Signals and Vehicle actuated Signals:

1. Which the green periods, hence the cycle length is predetermined and of fixed duration.
2. Vehicle actuated signals, are which the green period varies and are related to the actual demands made by traffic. Popular in U.K.
3. Intermediate type semi-vehicle actuated on all the available i.e., right of way normally rests with the main road and detections are located only on side roads.

Type	Advantages	Disadvantages
Fixed time	i) Simple in construction ii)Relatively in expensive iii)Most successfully used in linked system required fixed cycle length for a given pattern.	i)Inflexible cause avoidable delay ii)Required careful setting
Vehicle-actuated	i)Flexible and able to adjust to change in traffic	i)costly equipment ii)Can't provide signal

	condition automatically ii)Delay held minimum and maximum traffic capacity achieved	coordination
Semi-vehicle actuated	Useful for junction of a side street having low traffic volume with main street having flow	Cause high accident rates at times of light traffic.

Determination of Optimum cycle length and signal setting for intersection with time signals:

- Important step in fixed time signals system is to determine the cycle time.
- Main consideration is selecting the cycle time should be outlined that the least delay is caused to the traffic passing through the intersection.
- In selecting a cycle time other guiding factor is proportion of the time lost (in the inter green period and starting delay) to the cycle time.
- If the cycle time is small, the proportion of the time lost to the cycle time will be high resulting in large, proportion of time lost to the cycle time will be small and signal operation will be more efficient.
- If the cycle time is too large, there is danger that a good portion of green time will be used by unsaturated flow of traffic which again leads inefficiency.
- For each traffic flows, there is an optimum cycle time which results minimum delay to the vehicle.
- From graph traffic flows, there is an optimum valve the delay is never more than 10-20% above that the given optimum cycle time.
- Result could be used in determining the comprise cycle time that would suit variation inflow during the delay.

Total delay for intersection w.r.t cycle time for the optimum cycle time,

$C_o = \frac{1.5L+5}{1-Y}$ seconds

C_o = optimum cycle time

L = total lost time per cycle

$Y = y_1+y_2+y_3+\dots\dots +y_n$;

$y_1, y_2, y_3, \dots\dots$ are the maximum ratios of flow to saturation flow for phase.

- Fig 1 shows that as soon as green signal is given, rate of discharge begins to pick up and some time is lost before the flow reaches maximum value.
- Similarly, termination of green phase, flow tends to taper off further lost time

Lost time L = K + a – g

For phase K = green time for phase

a = Amber time for phase

g = Effective green time = b/s ; s=saturation flow

therefore, b = No. of vehicle discharge on the average during a saturation flow

- Total lost time due to delays per cycle will be l, if there are n phases in cycle.

  In addition to this lost time, time R during each cycle, when all signals display red simultaneously is also lost to the total traffic.

  Therefore, Total lost L = nl + R

- Value Y sum of y values for each phase will handle one or more intersection, each approach having its own traffic flow and saturation flow.

  y, value taken a s highest ratio of traffic flow to saturation flow.

- Effective green available in a cycle can be apportioned to the difference phases as

  g1:g2:g3:……:gn = y1:y2:…..:yn

  = effective green time allotted to phases = 1,2,3,4,….,n respectively

From practical consideration, tower limit of the cycle time may be taken as 25 second upper limit may be regarded as 2 minutes.

Saturation Flow:

Determine y values, saturation flow should be measured rather than estimated value. For designing new signal installation. Following form devised by Road Research Laboratory.

S = 525 w PCU/hr

S = Saturation flow

W= width of approach road in meter measured kerb to inside of pedestrian or center line, whichever is nearer or to the inside of central reserve refuse in case of dual carriage way.

- When approaches are in gradient, saturation flow needs some adjustment approx. This can be done by decreasing the saturation flow by 3% for each 1% uphill gradient and increase in saturation flow by 3% for each 1% of downhill gradient.

Effect of Right – turning traffic on the saturation flow accounted as follows:

i. No opposing flow, no exclusive right turning lanes

   For this calculation using above eq S = 525w PCU/hr

ii. No opposing flow, exclusive right turning lanes

   Saturation flow of right turning stream through a right angle should be obtained separately.

   $S = \frac{1800}{1+\left(\frac{1.52}{r}\right)}$ PCU/hr for single file streams.

$S = \frac{3000}{1+\left(\frac{1.52}{r}\right)}$ PCU/hr for Double file stream file stream

R = radius of curvature of right turning stream

iii. Opposing flow, no exclusive right turning lanes:

Effects are possible under these circumstances.

1. Opposing traffic, the right turning are delayed themselves and consequently delay.

   Non- right turning vehicle in the same stream.

2. Their presence tends to inhibit the use of off-side lane by straight ahead vehicle.

These two effects can be allowed by assuming that on the average. Each right turning vehicle is equivalent to 1.75 straight ahead vehicle.

3. It pertains to the discharge of right turners through suitable gaps in the opposing (flow) stream.

   ∴ maximum no. of right turn vehicle $n_r = S_r \times \frac{gs-qc}{s-q}$

   S_r = right turning saturation flow
   g = green time
   c = cycles time
   q = flow in opposing arm
   S = saturation flow for opposing arm

Average no of right turning lanes per cycle is > n_r, then difference b/w two n_w will have to wait at the intersection at the terminating of green time. For allowing all these n_w vehicle to clear the intersection, inter green time can be made equal to $2\frac{1}{2}$ n_w sec, assuming each vehicle takes $2\frac{1}{2}$ sec to clear.

iv. Opposing flow, Excessive turning lanes:

- There is no delay to straight ahead traffic using the same approach as the right turners.
- But there will be effect on the cross phase and this should be calculated.as outlines
- If % of left turner is <10. Then it is degraded.
- If >10% then corrections are made.

  Assuming Each left turner is equivalent to 1.25 straight ahead vehicles.

IRC laid these 4 warrants, one or more of which must be met with before signal can be installed.

Warrants for signals:

<u>IRC warrants 1:</u> Minimum vehicle volume

Traffic volume on major streets and the higher volume minor street for each of any 8hr of an average day. Should be equal to values

No. of lanes		Vehicle/hour on major street (both approaches)	Vehicle/hour on minor street (one direction only)
Major	Minor		
1	1	650	200
2 or more	1	800	200
2 or more	2 or more	800	250
1	2 or more	650	250

<u>Warrant 2</u>: Interruption of continuous Traffic.

Traffic volume on major street and higher volume minor street for each street of average day

No. of lanes on each approach		Vehicle/hour on major street (both approaches)	Vehicle/hour on minor street (one direction only)
Major street	Minor street		
1	1	1000	100
2 or more	1	1200	100
2 or more	2 or more	1200	150
1	2 or more	1000	150

<u>Warrant 3:</u> Min pedestrian volume

For each of any hour of any 8hr of average day following traffic must exists

i. On the major streets, 600 or more vehicles/hour enter the intersection (both approaches) or there is a raised median island 1.2 m or more in width, 1000 or more vehicle/hr both direction enter intersection.
ii. During same 8hr, there are 150 or more pedestrians/hr on the highest volume cross=walk crossing major street.

Warrant 4: Accident experience

i. Adequate trail of less restrictive remedies with satisfactory observance and enforcement have failed to reduce the accident frequency.
ii. 5 or more reported accidents, of types susceptible of correction by traffic signal have occurred within period of 12 months.
iii. Signal installation will not seriously make a break in traffic flow.

Coordination control of signals:

Need:

- Desirable to reduce delays and avoid main traffic from having to stop at every junction.
- Signal indicates a stop aspect at a junction, a queue of vehicle is formed behind stop line. When signal changes to green, vehicle start moving in platform.
- If this platoon in made to meet a green aspect at the next junction no delay is caused to vehicle.
- This principle of linking adjacent signals so as to secure maximum benefits to flow of traffic is called coordinates of signals.

Objects of coordinates:

i. To pass maximum amount of traffic without enforced halts.
ii. Have minimum overall delay t traffic streams both in main and side roads.
iii. Prevent queue of vehicle at one intersection from extending and reaching next intersection.

Off set:

Difference b/w the start of green time at successive upstream and downstream signal.

- It is important consideration planning coordinates system.
- If start of green at downstream signal is offset at particular value such that platoon, which starts at upstream signal upon green indication there arrives at downstream signal just time for green signal platoon has Unhindered movement.

Time and Distance diagram:

- Planning as system of coordinates signal control, indication the system diagrammatically known as "Time and Distance" diagram.
- Time and signal settings are indicated along the horizontal axis suitable scale.
- Distance travelled along the major rote is plotted vertically to suitable scale.

Types and Coordinates signal system: 4 systems

i. Simultaneous system or synchronized system:

- Signals along this street always display same indication to the same traffic stream at the same time.
- Division of cycle time is the same at all intersection.
- A master controller is employed to keep the series of signals in step.

Disadvantages:

1. It is not conductive to give continuous movement of all vehicles.
2. It encourages spending of drivers between stops.
3. Overall speed is often reduced.
4. Because the division of cycle time is same all the intersections, inefficiency is inevitable at same intersection.
5. Simultaneously stoppage continuous line of traffic at all intersections often results in difficulty for the side street vehicles in turning or crossing main side street.

ii. Alternative System: (limited progressive system)

- In this consecutive signal installation along a given road show contrary indications at same time.
- This permits vehicle to travel one block in half the cycle time.
- It is very efficient when blocks are equal lengths.

Disadvantages:

1. Green times for both main and side streets have o substantially equal resulting inefficiency at most of the intersection.
2. If blocks length is unequal, the system is not well suited.
3. Adjustments are difficult for changing traffic condition.

iii. Simple progressive system:

- In these various signals along a street display green aspects in accordance with a time schedule to permit as nearly as possible, continuous operation of platoons of vehicle along the street at a planned rate of motion.
- Offset at each installation is determined so as to secure the best continuous movement of platoons in both directions.
- These offsets are fixed and can't be altered at different periods of the day.
- Each signal installation had a cycle division different from the others but division remains fixed throughout the day.

iv. Flexible progressive system:

This is improving over simple progressive system with follow provision.

1. It is possible to vary the cycle time and division at each signal depend on traffic.
2. Possible to vary the offset.
3. Possible the introduce flashing or shut down during off peak hours.

Signal Approach Dimensions:

- Approach dimension have an influence on the design and perform of intersection.
- Modify the approach dimensions. We can improve the efficiency of signalized intersection.
- Signal permit traffic movement from any approach for only a proportion of the time reason that is approach roads in immediate vicinity of the intersection should have wider roadway than the normal.
- These when planning or improvement in the geometric layout of existing intersection or planning for new facilities, it helps to keep in view the improvement in flow conditions for new achieved with wider approaches.
- Webster and Newby have produced the following rules for determine approach
  - For 2 phase cross roads the approach widths should be proportion to the square roots of the flows.
  - q1 and q2 are maximum flows on phase1 and 2 respectively, green times g1 and g2 length widened d1 & d2 , width w1 & w2 are related as

    $$\frac{w1}{w2} = \frac{g1}{g2} = \frac{d1}{d2} = \sqrt{\frac{q1}{q2}}$$

  - if approach width deduced from the above rule is less than of feeder road, it should be made equal to that of feeder road and the green time made corresponding less.
  - Extra green time thus allocated to other phase results in less widening being necessary.
  - Flow used should be the maximum flow on the 2 or more arms of the same phase.
    1. With multiple phase intersection

       w1:w2:w3:…….:wn $= \sqrt{q1}:\sqrt{q2}:\sqrt{q3}:\ldots:\sqrt{qn}$

       = g1:g2:……:gn =d1:d2:…….:dn
    2. T – junctions with 2 phase control,

$$\frac{w1}{w2} = \sqrt{\frac{q1}{2\,q2}} \quad ; \frac{g1}{g2} = \frac{d1}{d2} = \sqrt{\frac{2\,q1}{q2}}$$

2 refers to stem of T-junction.

Area Traffic Control:

Introduction:

- Area traffic control is futhur extension of coordinated signal systems. Description of simple linked system along a single road.
- If works on same principle of coordination to include signals in a sustainable area.
- Area Traffic Control is technique through for a centralized control of numerous signal installation distributed through an urban area, such that there is a planned coordination b/w signals at different junctions. Technique invariable employs digital computers for achieving the desired.

Objectives:

- Minimizing journey time for vehicle.
- Reducing accidents
- Minimizing person time
- Minimizing vehicle stops, resulting less noise, less pollution and less consumption of fuel.
- Discouraging use of certain areas.

Traffic Control Methods:

1. Fixed time plans based on historical data and calculation off line by a computerized optimizing technique. Information movement is obtained manually on through detectors and fed to the computed which then determine the signal.
2. Coordinated system will response from at each signal,
   Example: FLEXIPROG (Flexible Progressive) and EQUISAT (Equally Saturated).

Fully responsive system such as S.P.G (Signal Plan Generation).