A LECTURE NOTE

ON

HIGHWAY ENGINEERING

(TH-4)

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INTRODUCTION

Importance of transportation

Transportation contributes to the economic, industrial, social and cultural development of any country.
Transportation is vital for the economic development of any region since every commodity produced, whether it is agricultural or industrial product needs to be transported at various stages from production to distribution. At the production stage, transportation is required for carrying raw materials like seeds, manure, coal, steel, machines, component parts, etc. At the distribution stage, transportation is required from the production centres like the farms & factories to the marketing centres and later to the retailers and to the consumers.
Inadequate transportation facilities retard the process of socio-economic & cultural development of the country. Development of adequate transportation system in a country indicates its economic growth and progress in social development.
The main objective of a good transportation system is to provide safe, economical, efficient transportation facility for the travel of passengers and transportation goods.

Different modes of transportation

1. Land
2. Water
3. Air

1. Land : Transportation by roads and railways.
   (i) Roads / highways : Urban arterials & city streets, feeder roads, village roads, pedestrians
   (ii) Railways :
2. Waterways : Transportation by oceans, rivers, canals & lakes for the movement of ships & boats.
3. Airways :- Transportation by aircrafts & carriers.
4. Other : Pipe lines, elevators, belt conveyers, cable cars & aerial ropeway.

Characteristics of road transport

(i) Roads are used by various types of road vehicles like passenger cars, buses, trucks, two & three wheeled automobiles, pedal cycles and animal drawn vehicles and also the pedestrians.

(ii) Road transport infrastructure requires the lowest initial investment.

(iii) Roads offer complete freedom to the road users to make use of the roadway facilities at any time they feel convenient to them or to move the vehicle from a lane of the road to the adjoining one and from

one road to another, according to the need and convenience. The flexibility of changes in location, direction, speed and timings of travel is not available to other modes of transport.

(iv) It is possible to travel directly from the respective places of origin to the destination by road vehicles. For short distances, it saves time and is most convenient.

(v) Road transport is the only mode that offers the facilities to the whole section of society.

Road Development in India

Jayakar Committee

It was a Road Development Committee appointed by the Govt: in 1927, with M.R. Jayakar as the chairman.

Recommendations:

(a) The road development in the country should be considered as a national interest as this has become beyond the capacity of provincial governments and local bodies.

(b) An extra tax should be levied on petrol from the road users to develop a road development fund called 'Central Road fund'.

(c) A semi-official technical body should be formed to pool technical knowledge from various parts of the country & to act as an advisory body on various aspects of roads.

(d) A research organisation should be constituted to carry out research and development work pertaining to roads & to be available for consultations.

Important Organisations

1. Indian Roads Congress (IRC)
2. Central Road Research Institute (CRRI)
3. Highway Research Board (HRB)
4. Central Road Fund (CRF)
5. Ministry of Surface Transport
6. National Transport Policy Committee (NTPC)

Indian Roads Congress

It was a semi-official technical body of central government formed in 1934.

→ IRC was constituted to provide a forum for regular pooling of experience, technical knowledge and ideas on all matters related to planning, construction and maintenance of roads in India.

→ IRC will prepare standard specifications & provide a platform for the expression of professional opinion on matters relating to road engg. including those of organisation & administration.

→ It will formulate all development plans in India.

→ IRC controls specifications, standards and guidelines on materials, design and construction of roads and bridges.

→ IRC publishes journals, research publications, standards, specifications, guidelines & other special publications on various aspects of Highway Engg.

Road Development Plan

1. Nagpur Road Plan

→ First 20-year Road Development Plan.
→ Period: 1943 - 63
→ Target road length: 16 Km per 100 sq. Km area of the country.

2. Bombay Road Plan

→ Second 20-year Road Development Plan
→ Period: 1961 - 81
→ Target road length: 32 Km per 100 Km^2 area.

3. Lucknow Road Plan

→ Third 20-year Road Development Plan
→ Period: 1981 - 2001
→ Target Road Length: 46 Km to 82 Km per 100 sq. km

Highway planning

Objective:

(a) To plan overall road network for efficient and safe traffic operation, but at minimum cost.
(b) To arrive at the road system and the lengths of different categories of roads which could provide maximum utility and could be constructed within the available resources during the plan period under consideration.
(c) To divide the overall plan into phases and to decide priorities.

(d) To fix up date-wise priorities for development of each road link based on utility as the main criterion for phasing the road development programme.

(e) To plan for future development, requirements and improvements of roads in view of anticipated developments.

(f) To workout suitable financial system.

Classification of Roads

Types of roads based on seasons:

(i) All-weather roads : negotiable during all seasons

(ii) Fair-weather roads: interrupted during monsoon.

Types of roads based on carriageway:

(i) Paved roads : Roads with a hard pavement surface

(ii) Un-paved roads: Roads without a hard pavement

Types of roads based on pavement surface:

(i) Surface roads: Road pavements with any type of bituminous surface or cement concrete

(ii) Un-surfaced roads: Roads not provided with any surface.

Road classification as per Nagpur road plan

Based on the location & function:

(i) National Highways (NH)
(ii) State Highways (SH)
(iii) Major District Roads (MDR)
(iv) Other District Roads (ODR)
(v) Village Roads (VR)

NHs (National Highways)

NHs are the main highways running through the length & breadth of India connecting major ports, foreign highways, capital of large states & large industrial & tourist centres including roads required for strategic movements for the defence of India.

SHs (State Highways)

SHs are the arterial roads of a state, connecting the national highways of adjacent state, district head quarters & important cities within the state & serve as the main arteries for traffic to & from district roads.

MDR (Major District Roads)

MDR are imp. roads within a district serving areas of production & markets & connecting with other major roads or main highways of a district.

ODR (Other District Roads)

ODR are the roads serving rural areas of production and providing them with outlet to market centres, taluk head quarters, block development head quarters or other main roads.

VR (Village Roads)

VR are roads connecting villages or groups of villages with each other to the nearest road of a higher category.

Road classification based on Lucknow plan

Based on transport planning, functional identification earmarking administrative jurisdictions & assigning priorities on a road network:

1. Primary system : (a) Expressways
   (b) National Highways
2. Secondary system : (a) State Highways
   (b) Major District Roads
3. Tertiary system : (a) Other District Roads
   (b) Village Roads

Expressways:

These are a separate class of highways with superior facilities & design standards & are meant as through routes having very high volume of traffic. These are to be provided with divided carriageways, controlled access, grade separations at cross roads & fencing. These highways should permit only fast moving vehicles.

ROAD GEOMETRIC

Geometric design of a highways deals with the dimension and layout of visible features of the highway such as horizontal and vertical alignments, sight distances and intersections.

Geometric design of highways deals with the following elements:

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

(A) Cross section elements:

1. Pavement surface characteristics:
   (i) friction
   (ii) Levenness
   (iii) Light reflecting characteristics
   (iv) Drainage of surface water

friction:

The friction or skid resistance between vehicle type and pavement surface is one of the factors determining the operating speed and the minimum distance required for stopping the vehicles.

When a vehicle negotiates a horizontal curve, the lateral friction developed counteracts the centrifugal force & thus governs the safe operating speed.

Frictional force is an imp. factor in the acceleration & retardation abilities of vehicles.

→ 'skid' occurs when the wheels slide without revolving or rotating or when the wheels partially revolve i.e. when the path travelled along the road surface is more than the circumferential movements of the wheels due to their rotation. when the brakes are applied, the wheels are locked partially or fully, and if the vehicle moves forward, the longitudinal skidding takes place which may vary from 0 to 100%. while a vehicle negotiates a horizontal curve, if the centrifugal force is greater than counteracting forces, lateral skidding takes place.

→ 'slip' occurs when a wheel revolves more than the corresponding longitudinal movement along the roads. slipping occurs in the driving wheel of a vehicle when the vehicle rapidly accelerates from stationary position or from slow speed on pavement surface which is either slippery and wet or when the road surface is loose with mud.

→ For the calculation of stopping distance, the longitudinal friction coefficient value of 0.35 to 0.40 have been recommended by the IRC.

→ In case of horizontal curve design, IRC has recommended the lateral coefficient of friction of 0.15.

→ For high speed for design speeds of 120 & 100 kmph are 0.10 & 0.11 respectively.

Pavement unevenness:

The Longitudinal profile of the road pavement has to be even in order to provide good riding comfort to fast moving vehicles and to minimize the vehicle operation cost.

→ Presence of undulations on the pavement surface is called pavement unevenness which results in:

(i) increase in discomfort & fatigue to road users
(ii) increase in fuel consumption & tyre wear
(iii) increase in vehicle maintenance cost.
(iv) reduction in vehicle operating speed.
(v) increase in accident rate.

Light reflecting characteristics:

Night visibility depends upon the colour & light reflecting characteristics of the pavement surface. Light coloured or white pavement surface give good visibility at night particularly during rains, however it may produces glare and eye strain during bright sunlight.

2. Cross slope or Camber

It is the slope provided to the road surface in the transverse direction to drain off the rain water from the road surface.

Purposes:

(i) To prevent the entry of surface water into the pavement layers and the subgrade soil through pavement; the stability, surface condition and

the life of the pavement get adversely affected if the water enters into the subgrade and the soil gets soaked.

(ii) To prevent the entry of water into the bituminous pavement layers, as continued contact with water causes stripping of bitumen from the aggregates and results in deterioration of the pavement layers.

(iii) To remove the rain water from the pavement surface as quickly as possible and to allow the pavement to get dry soon after the rain. The skid resistance of the pavement decreases considerably when the pavement surface is wet. Presence of a thin layer of water on the pavement surface renders the surface very slippery at high running speeds & it becomes unsafe or dangerous during sudden application of brakes.

→ Usually the camber is provided on the straight roads by raising the centre of the carriageway w.r.t the edges, forming a crown or highest point along the centre line.

→ The rate of camber is designated by 1 in 'n' (i.e. it may also be expressed as a % of camber is x%. the cross slope is 'x' in 100.

→ The required camber of a pavement depends on :
(i) type of pavement surface
(ii) amount of rainfall.

IRC recommended values of camber:

Sl. No.	Type of road surface	Range of camber in areas of	
		heavy rainfall	Low rainfall
1.	Cement concrete & high-type bituminous surface	1 in 50 or 2.0%	1 in 60 or 1.7%
2.	Thin bituminous surface	1 in 40 or 2.5%	1 in 50 or 2.0%
3.	Water bound Macadam & gravel pavement	1 in 33 or 3.0%	1 in 40 or 2.5%
4.	Earth road	1 in 25 or 4.0%	1 in 33 or 3.0%

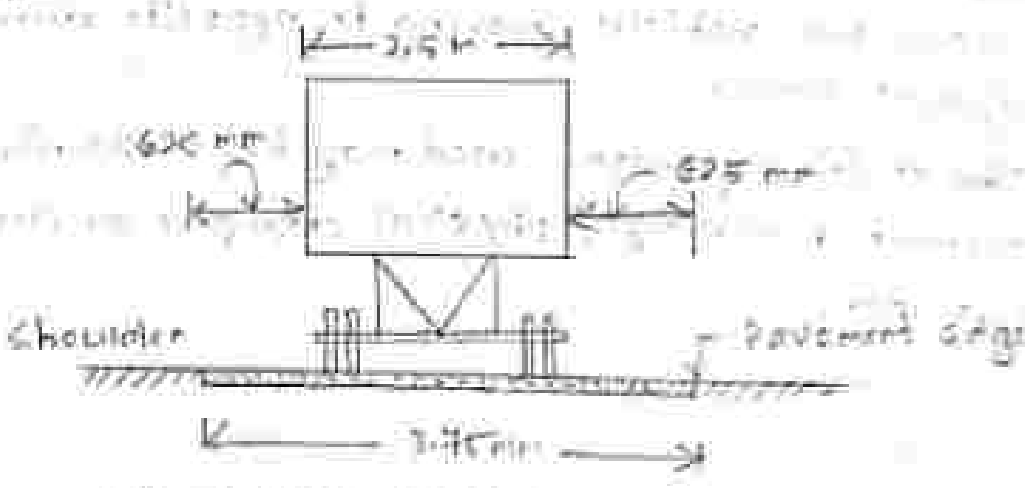
→ The cross slope for shoulders should be 0.5% steeper than the cross slope of adjoining pavement subject to a minimum of 2.0% & a maximum value of 5.0% for earth shoulders.

3. Width of pavement or Carriageway

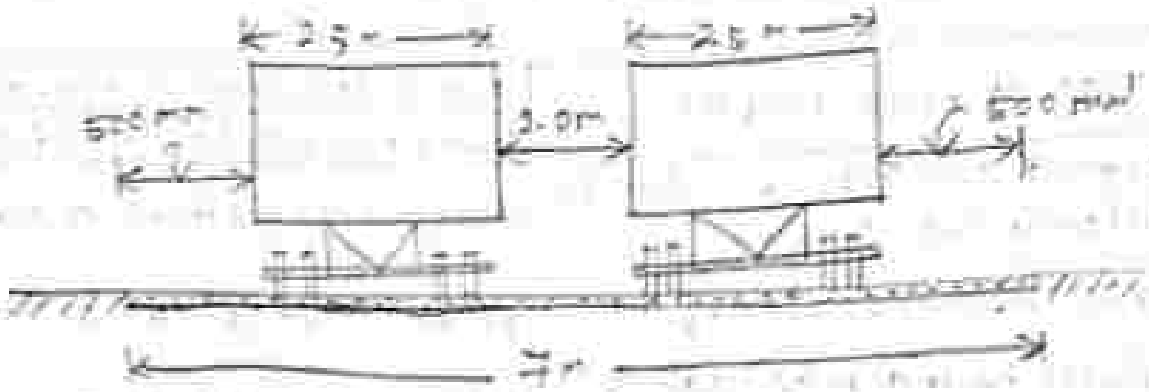
The width of pavement depends on (i) width of traffic lane (ii) no. of lanes.

→ Carriageway extends for one line of traffic movement.

→ The portion of CW intended for one line of traffic movement is called a traffic lane.



(a) SINGLE LANE PAVEMENT



Width of CW recommended by IRC :

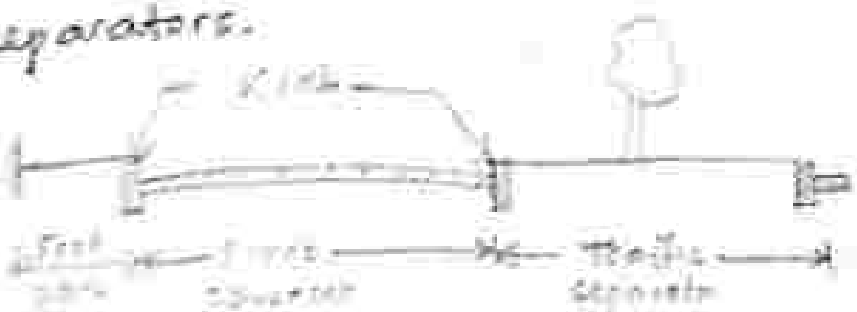
Class of road	Width of CW, m
(i) Single lane road	3.75
(ii) Two lanes, without raised Kerbs	7.0
(iii) Two lanes, with raised Kerbs	7.5
(iv) Intermediate carriageway	5.5
(v) Cycle lane pavements	2.5 per lane

4. Median / Traffic separators:

In highway with divided CW, a median is provided between two sets of traffic lanes intended to divide the traffic moving in opposite directions.

→ The main function of median is to prevent head-on collision between vehicles moving in opposite directions or adjacent lanes.

→ The traffic separators used may be in the form of pavement marking, physical dividers or area separators.



→ A min. of 6m is required to reduce head light glare due to vehicles moving in opposite direction on either side of the median at night.

→ IRC recommends a min. width of 5.0m for medians of rural highways, which can be reduced to 3.0m where land is restricted.

→ On long bridges width of median may be 1.2 to 1.5m.

→ At intersection of urban roads : 1.2m for pedestrian refuge, 4.0 to 7.5m for protection of vehicles making right turn & 9.0 to 12m for protection vehicles crossing at grade.

→ In urban area : 1.2m absolute min. width
& 5.0m desirable " "

→ of median barriers are provided, the width of median is 4.5m.

5. Kerbs

Kerb indicates the boundary between the pavement and median or footpath or island or shoulder.

→ 3 groups : (a) Low Kerb or mountable type kerb
(b) Semi-barrier type kerb
(c) Barrier type kerb

→ (a) Low Kerb : 100mm above the pavement edge.

(b) Semi-barrier Kerb : 150mm above pavement edge

(c) Barrier Kerb : 200mm above pavement edge.

6. Road margins:

Various elements included in the road margins are shoulder, guard rail, foot path, drive way, cycle track, parking lane, bus bay, lay-bye, frontage road and embankment slope.

Shoulders:

→ Provided on both sides of the pavement all along the road in case of undivided carriageway.

→ Provided along the outer edge of the cw in case of divided cw.

→ Width, width (IRC) : 2.5m

Guard rails:

→ Provided at the edge of the shoulder when the road is constructed on a fill.

Footpath / side walk:

→ Provided in urban roads to provide safe facility to pedestrians to walk along the roadway.

→ Min. width: 1.5m & desirable: 2.0m.

Drive ways:

→ Connect the highway with commercial establishments like fuel stations, service stations etc.

Cycle track: width 2m.

* Parking lane:

→ Provided on urban roads to allow kerb parking.

→ For parallel parking, lane width : 2.0m.

Bus bays:

→ Provided by recessing the kerb to avoid conflict with moving traffic.

→ Should be located at least 75m away from the intersections.

Lay-byes:

→ Provided near public conveniences with a wide margin to enable drivers to stop clear off the carriageway.

→ Width : 3.0m
Length : 30m with 15m end tapers on both sides.

Frontage roads:

→ Provided to give access to properties along an imp. highway with controlled access to express way or free way.

7. Width of formation or Roadway:

It is the sum of widths of pavement or carriageway including separators, if any and shoulders.

→ It is the top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

8. Right of way & Land Width:

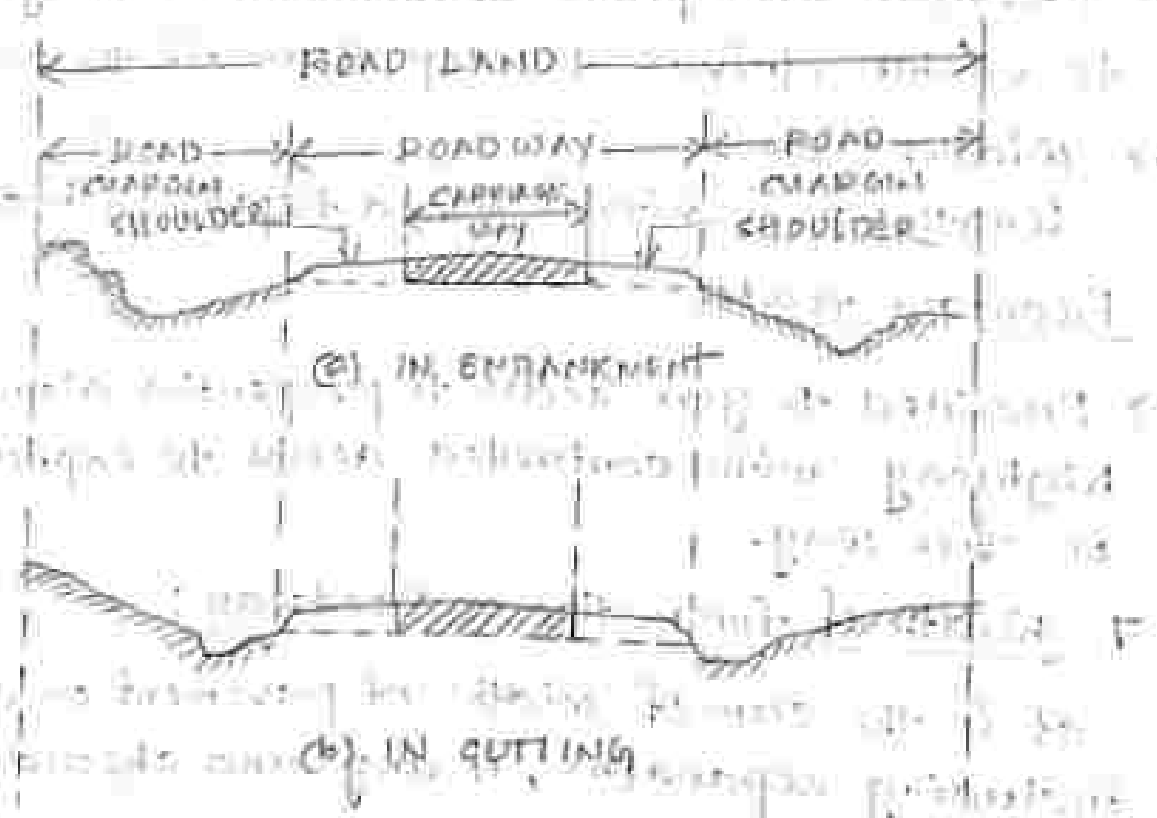
It is the area of land acquired for the road along its alignment. The width of land is known as land width & it depends on the importance of road & possible future development.

Notes:

→ NH & SH : width of roadway - 12 m (single lane & two lane)

→ The min. roadway width on single lane bridge is 4.25 m.

Cross-section details of road :



(B) Sight distance

It is the length of road visible ahead to the driver at any instance. Sight distance available at any location of the carriageway is the actual distance a driver with his eye level at a specified height above the pavement surface has visibility of any stationary or moving object of specified height which is on the carriageway ahead.

Type of sight distance

(a) Stopping sight distance (SSD) or absolute minimum sight distance :

(b) Safe overtaking sight distance (OSD) or passing sight distance :

(c) Safe sight distance for entering into uncontrolled intersections

Apart from the three, sight distances considered by the IRC in highway design :

(i) Intermediate sight distance (ISD) :

It is twice the SSD. When OSD cannot be provided, ISD is provided to give limited overtaking opportunities to fast vehicle.

(ii) Head light sight distance :

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

Stopping Sight Distance (SSD)

It is the minimum distance visible to a driver ahead or the sight distance available on a highway at any spot to safely stop a vehicle travelling at design speed, without collision with any other obstruction.

→ This is also called as non-passing sight distance

→ The SD depends on the following factors:

(a) features of the road ahead.

(b) height of the driver's eye above the road surface

(c) height of the object above the road surface.

→ IRC has suggested the height of eye level of driver as 1.2 m and the height of the object as 0.15 m above the road surface.

Factors affecting SSD :-

(i) Total reaction time of the driver

(ii) Speed of vehicle

(iii) efficiency of brakes

(iv) Frictional resistance between the road & the tyres.

(v) Gradient of the road.

. Total reaction time :-

Reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied. The stopping distance increases with increase in reaction time of the driver.

→ The total reaction time, t may be split up into two parts : (i) perception time
(ii) brake reaction time

→ Perception time is the time required for a driver to realise that brakes must be applied. It is the time from the instant the object comes on the line of sight of the driver to the instant he realises that the vehicle needs to be stopped.

→ Brake reaction time is the time required for the application of brakes.

The total reaction time may be explained with the help of 'PIEV' theory.

Acc. to PIEV theory, the total reaction time of the driver is split into four parts i.e. time taken by the driver for : (i) perception (P)
(ii) Intellection (I)
(iii) Emotion (E)
(iv) Volition (V)

→ Perception time is time reqd for the sensations received by the eyes or ears of the driver to be transmitted to the brain through the nervous system

and spinal cord. It is the time required to perceive an object or situation.

→ Intellection time is the time reqd. for the driver to understand the situation.

→ Emotion time is the time elapsed during emotional sensations and other mental disturbances such as fear, anger or emotional feelings like superstition etc, with reference to the situation.

→ Volition time is the time taken by the driver for the final action, such as brake application.

The total reaction time of an average driver may vary from 0.5 second for simple situations to as much as 3 to 4 seconds in complex situations.

Speed of vehicle :-

Higher the speed of the vehicle, higher will be the stopping distance.

Efficiency of brakes :-

The braking efficiency is said to be 100% if the wheels are fully locked preventing them from rotating on application of the brake.

Frictional resistance :-

The frictional resistance developed betn road & tyre depends upon the 'skid resistance' or coeff. of friction 'f' betn the road surface & the tyre of the vehicle. This depends on the type & condn of both road & tyre.

→ IRC values of 'f' : 0.35 to 0.40 !

Analysis of SSD

The SD of a vehicle is the sum of

(a) the distance travelled by the vehicle at uniform speed during the total reaction time, t, which is known as 'lag distance'

(b) the distance travelled by the vehicle after the application of the brakes, until the vehicle comes to a dead stop, which is known as 'braking distance'

Lag distance:

During the total reaction time, t sec the vehicle may be assumed to move forward with a uniform speed at which the vehicle has been moving & this speed may be taken as design speed. If 'v' is the design speed in m/sec and 't' is the total reaction time of the driver in seconds, then

$$\text{Lag distance} = vt, \text{ m}$$

If V kmph, then lag distance $= 0.278 Vt$ m.

→ IRC has recommended the value of reaction time t as 2.5 sec for the calculation of SD.

Braking distance:

Assuming a level surface of road, the braking distance may be obtained by equating the work done in stopping the vehicle and the kinetic energy of the vehicle moving at design speed.

of the maximum frictional force developed is F (kg) and the braking distance is l (m), then work done against friction force to stop the vehicle is given by :

$F \times l = W f l$, where W is the total weight of the vehicle in kg, f is the coeff. of friction & l is the braking distance in metres.

The kinetic energy of the vehicle of weight W moving at the design speed of V m/sec is $= \frac{WV^2}{2g}$

Hence, $W f l = \frac{WV^2}{2g}$

Therefore braking distance, $l = \frac{V^2}{2gf}$

→ Stopping distance on level road :

SD = Lag distance + braking distance

i.e, $SD, m = Vt + \frac{V^2}{2gf}$

If speed is V Kmph,

$SD, m = 0.278 Vt + \frac{V^2}{254f}$

⇒ Stopping distance at slopes:

When there is an ascending gradient of +n%, the component of gravity adds to the braking action & hence the braking distance is decreased.

$$l = \frac{v^2}{2g(f + n\%)}$$

On descending gradient of -n%, the braking distance increases, as the component of gravity now opposes the braking force.

$$l = \frac{v^2}{2g(f - n\%)}$$

Hence, $SD, m = vt_m + \frac{v^2}{2g(f \pm n\%)}$

If speed is V Kmph

$$SD = 0.278Vt + \frac{V^2}{254(f \pm n\%)}$$

Notes:

→ The min. SD read. should be equal to the SSD in one way traffic lanes & also in two-way traffic roads with two lanes or more traffic lanes.

→ On roads with restricted width or on single lane roads with two-way traffic, the min. SD should be equal to twice the SSD to enable both vehicles coming from opposite directions to stop.

Overtaking sight Distance (OSD)

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

→ The OSD is the distance measured along the centre of the road which a driver with his eye level at 1.2 m above the road surface can see the top of an object 1.2 m above the road surface.

Factors affecting OSD:

(i) Speeds of (a) overtaking vehicle (b) overtaken vehicle & (c) the vehicle coming from opposite direction

(ii) Distance between the overtaking & overtaken vehicle the min. spacing between vehicles depends on the speeds.

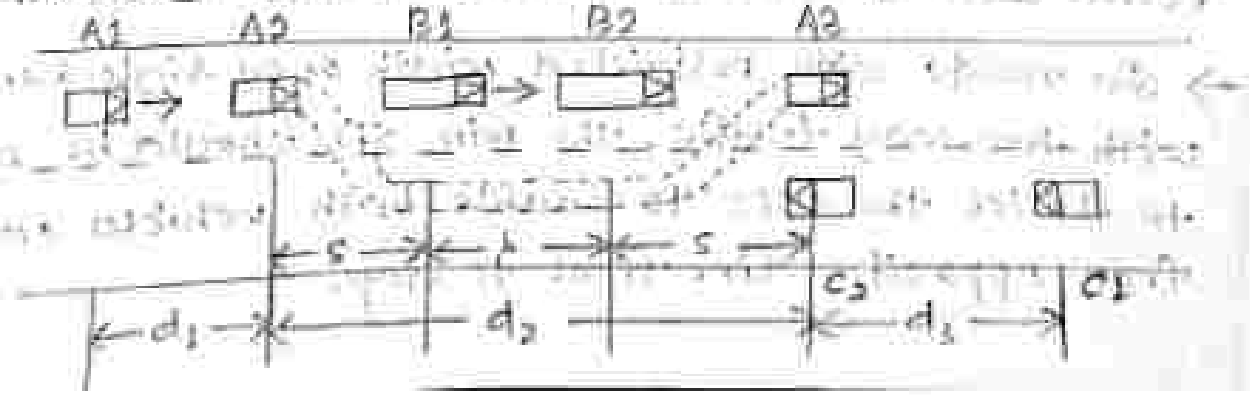
(iii) Skill and reaction time of the driver.

(iv) Rate of acceleration of overtaking vehicle.

(v) Gradient of the road.

Analysis of OSD

Simple overtaking process on a two-lane highway with two-way traffic movement :-



veh. A travelling at the design speed v m/sec or V Kmph desires to overtake another slower, veh. B moving at a speed of v_b m/s or V_b kmph. The veh. A has to accelerate, shift to the adjacent right side lane, complete the overtaking manoeuvre & return to the left lane, before the on-coming vehicle C approaches the overtaking stretch.

The overtaking manoeuvre may be split up into three operations, thus dividing the OSD into three parts, d_1, d_2 & d_3.

→ d_1 is the distance (m) travelled by the overtaking vehicle A during the reaction t (sec) of the driver from posn A_1 to A_2 before starting to overtake the slow veh. B.

→ d_2 is the distance (m) travelled by the veh. A during the actual overtaking operation during T (sec) from posn A_2 to A_3

→ d_3 is the distance (m) travelled by on-coming vehicle C during the actual overtaking operation of A during T (sec) from posn C_1 to C_2.

Thus, on a 2-Lane road with two-way traffic the OSD = $d_1 + d_2 + d_3$ (m).

Assumptions:

1. The overtaking veh. A is forced to reduce its speed from the design speed v to v_b of the slow veh. B & move behind it, allowing a space 's', till there is an opportunity for safe overtaking operation.

→ When the driver of veh. A finds sufficient clear gap ahead, decides within a reaction time 't' to accelerate & overtake the veh. B, during which the veh. A moves at speed v_b through a distance d_1, from pos^n A_1 to A_2.

→ The veh. A accelerates & overtakes the slow veh. B within a distance d_2 during the overtaking time, T between the position A_2 to A_3.

→ The distance d_2 is split up into three parts :
(i) spacing 's' betn A_2 & B_1 (ii) distance 'b' travelled by slow veh. B betn B_1 & B_2 during the overtaking manoeuvre of A & (iii) spacing 's' between B_2 & A_3.

→ During this overtaking time T, the veh. C coming from opposite dirn travels through a distance d_3 from position C_1 to C_2.

Determination of the components of OSD :-

(a) From pos^n A_1 to A_2, the distance travelled by overtaking veh. A, at the reduced speed v_b during the reaction time $t' = v_b t$

IRC suggests on the value of reaction time $t' = 2''$

$\therefore d_1 = 2 v_b$ (m).

(b) From pos^n A_2, the veh. A starts accelerating, shifts to the adjoining lane, overtakes the veh. B, & shifts back to its original lane ahead of B in pos^n A_3 during the overtaking time, T sec. The straight distance betn pos^n A_2 & A_3 is taken as d_2, which is further split into three parts, i.e.

$d_2 = s + b + s$

$\therefore d_2 = b + 2s$

(c) The min. distance betn posn A_2 & B_1 may be taken as the min. spacing 's' betn two vehicles while moving with the speed v_b. The min. spacing betn vehicles depends on their speed & is given by empirical formula, $s = (0.7v_b + 6)$, m.

(d) The min. distance betn B_2 & A_2 may also be assumed equal to 's'. If the overtaking time by veh. A for the overtaking operation from posn A_2 to A_3 is T, the distance covered by the slow vehicle B travelling at a speed of v_b, $= b = v_bT$.

$$\therefore d_2 = b + 2s$$

$$d_2 = v_bT + 2s$$

$$d_2 = v_bT + 2(0.7v_b + 6)$$

(e) Now the time T depends on speed of overtaken veh B & the average acceleration 'a' (m/sec^2) of overtaking veh. A. The overtaking time T (sec) may be calculated by equating the distance d_2 to $(v_bT + \frac{1}{2}aT^2)$, using the general formula for the distance travelled by an uniformly accelerating body with initial speed v_b m/sec & 'a' is the average acceleration during overtaking in m/sec^2.

$$d_2 = (b + 2s) = v_bT + \frac{1}{2}aT^2$$

$\therefore b = v_bT$ & $\therefore 2s = \frac{1}{2}aT^2$

Therefore, $T = \sqrt{\frac{4s}{a}}$ sec, where $s = (0.7v_b + 6)$ m

Hence, $d_2 = (v_bT + 2s)$, m

(3) The distance travelled by veh. C moving at design speed v during the overtaking operation of veh. A i.e during time T is the distance d_2 betn positions C_1 to C_2, Hence,

$$d_2 = vT \quad (m)$$

Thus, $OSD = d_1 + d_2 + d_3$

$$OSD = (v_b t + v_b T + 2s + vT) \text{ m}$$

In Kmph units,

$$OSD = 0.278 V_b t + 0.278 V_b T + 2s + 0.278 VT$$

Here,

V_b = Initial speed of overtaking vehicle, Kmph

t = reaction time of driver = 2 sec

V = Speed of overtaking vehicle or design speed (Kmph)

$$T = \sqrt{\frac{14.4 s}{A}}$$

S = spacing of vehicles

$= (0.7 V_b + 6)$ m

$= (0.2 V_b + 6)$ m

A = average acceleration during overtaking, Kmph/sec.

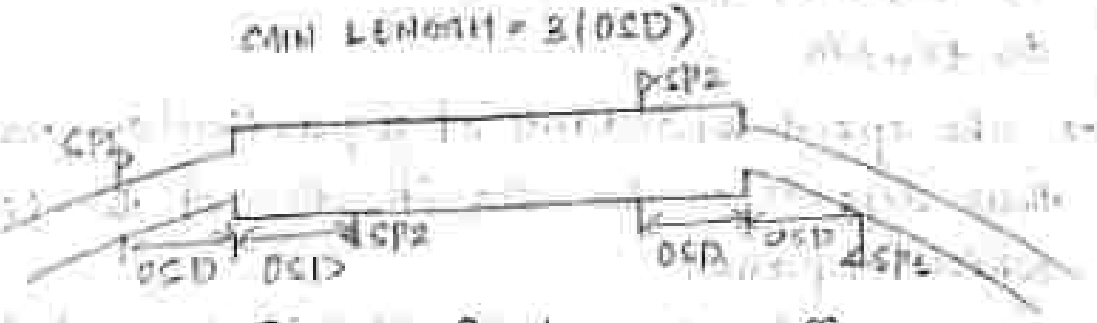
→ In case of speed of overtaken vehicle (v_b or V_b) is not given, the same may be assumed as 4.5 m/sec or 16 Kmph less than the design speed of highway.

$\therefore v_b = v - 4.5$ (m/sec) ; v = design speed in m/s.

or $V_b = V - 16$ (Kmph), V = design speed in Kmph

Overtaking zones:

It is desirable to construct highways in such a way that the length of road visible ahead at every point is sufficient for safe overtaking. This is seldom practicable & there may be stretches where the safe overtaking distance cannot be provided. In such zones where overtaking or passing is not safe or is not possible, sign posts should be installed indicating "No Passing" or "Overtaking Prohibited" before such restricted zones start. These zones which are meant for overtaking are called "overtaking zones".



OSD = $(d_1 + d_2)$ for one way traffic

OSD = $(d_1 + d_2 + d_3)$ for two way traffic

SP1 = Sign post "overtaking zone ahead"

SP2 = Sign Post "end of overtaking zone"

→ The min. length of overtaking zone should be three times the safe OSD. i.e 3(OSD).

→ It is desirable that the length of overtaking zones is kept five times the OSD, i.e 5(OSD).

Intermediate sight Distance:-

$$\boxed{ISD = 2SSD}$$

(C) Design of Horizontal Alignment

Various design elements to be considered in the horizontal alignment are design speed, radius of circular curve, type & length of transition curves, superelevation, widening of pavement on curves & required set-back distance for fulfilling sight distance requirement.

1. Design Speed

The geometric details of a highway mainly depend on the design speed.

The design speed of roads depends upon:

a) class of the road &

b) terrain.

→ The speed standards of a particular class of road thus depends on the classification of the terrain through which it passes.

→ The terrains have been classified as plain, rolling, mountainous and steep, depending on the cross slope of the country:

Terrain classification	Cross slope of the country, %
Plain	0 - 10
Rolling	10 - 25
Mountainous	25 - 60
Steep	> 60

→ Two values of design speeds are considered at the design stage of highway geometrics,

(i) Ruling design speed

(ii) Minimum design speed.

→ Ruling design speeds are the guiding criteria for the geometric design of highway.

→ Min. design speeds may be accepted where site conditions or economic considerations warrant.

→ The ruling design speeds suggested for the NHs & SHs in India passing through plain terrain is "100 Kmph" & through rolling terrain is "80 Kmph".

→ The min. design speeds for NHs & SHs in India passing through plain terrain is "80 Kmph" & through rolling terrain is "65 Kmph".

→ Recommended design speeds:

(i) Arterial roads: 80 Kmph

(ii) Sub-arterial " : 60 Kmph

(iii) Collector streets: 50 Kmph

(iv) Local streets: 30 Kmph.

2. Horizontal Curves:

A hz. curve is a curve in plan to provide change in direction to the centre line of a road.

→ A simple circular curve may be designated by either the radius, R of the curve in metres or the degree, D of the curve.

→ The degree of curve, (D°) is the central angle subtended by an arc of length 30 m & is given by

the relation, $\frac{RDT}{180} = 30$, Therefore the relation betwn the radius & degree of circular curve is given by,

$$R = \frac{1720}{D}$$

When a vehicle traverses a hz. curve, the centrifugal force acts horizontally outwards through the centre of gravity of the vehicle. The centrifugal force developed depends on the radius of the hz. curve & the speed of the vehicle negotiating the curve. This centrifugal force is counteracted by the transverse frictional resistance developed betwn the tyres & the pavement which enables the vehicle to change the direction along the curve & to maintain the stability of the vehicle. Centrifugal force, P is given by eqn:

$$P = \frac{Wv^2}{gR}$$

→ The ratio of centrifugal force to the wt. of the vehicle, P/W is known as 'centrifugal ratio' or the 'impact factor'. Therefore, C.R, $\frac{P}{W} = \frac{v^2}{gR}$

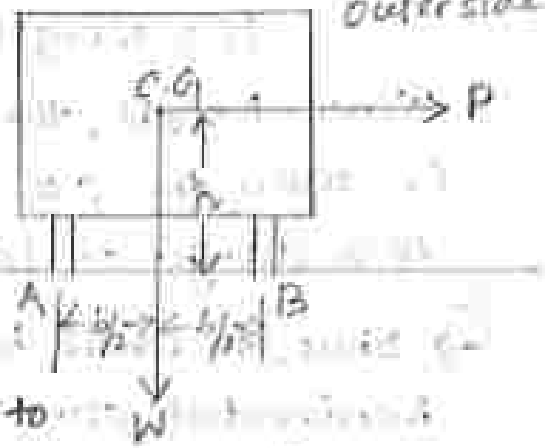
⇒ The centrifugal force acting on a vehicle negotiating a hz. curve has two effects:

(i) Tendency to overturn the vehicle outwards about the outer wheels &

(ii) Tendency to skid the vehicle laterally outwards

(i) Overturning effect :-

Let 'h' be the height of the centre of gravity of the vehicle above the road surface & 'b' be the width of the wheel base of the wheel track of the vehicle.



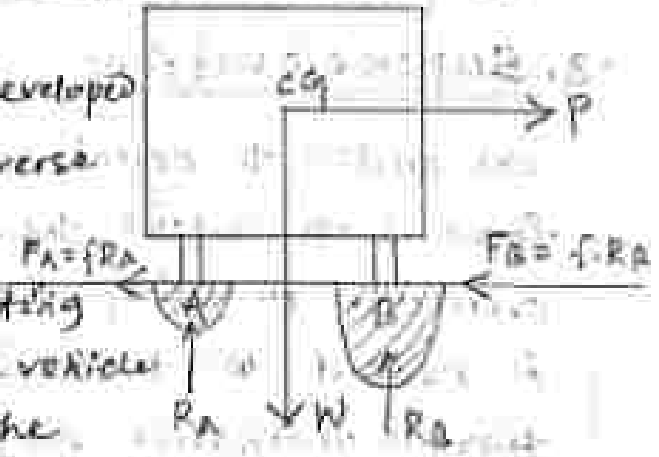
The overturning moment due to centrifugal force, P = P.h

This is resisted by the restoring moment due to weight of the vehicle W & is equal to $(Wb/2)$.

→ The equilibrium condn for overturning will occur when $Ph = Wb/2$ or when $\frac{P}{W} = \left(\frac{b}{2h}\right)$. It means that there is danger of overturning when the centrifugal ratio P/W or $\frac{V^2}{gR}$ attains a value of $b/2h$.

(ii) Transverse skidding effect :-

If the centrifugal force developed exceeds the maximum transverse friction force or transverse skid resistance counteracting the centrifugal force, the vehicle will start skidding in the transverse direction.



→ The equilibrium condn for the transverse skid resistance developed is given by :

$$P = F_A + F_B = f(R_A + R_B)$$

$$\Rightarrow P = fW$$

Where, f = coeff of friction

R_A & R_B = normal reactions at the wheels

W = weight of the vehicle

Since $P = fW$, the centrifugal ratio P/W is equal to f; i.e. when the C.R attains a value equal to f, there is a danger of Lateral skidding.

→ Thus, to avoid both overturning & skidding on a horizontal curve, the C.R should always be less than $(b/2h)$ & also transverse friction coeff f.

→ If the pavement is kept horizontal across the alignment, the pressure on the outer wheels will be higher due to the centrifugal force acting outwards & hence the reaction R_B at the outer wheel would be higher. The difference in pressure distribution at inner & outer wheels has been indicated in the figure. When the limiting eqlm cond^n for overturning occurs the pressure at the inner wheels becomes equal to zero.

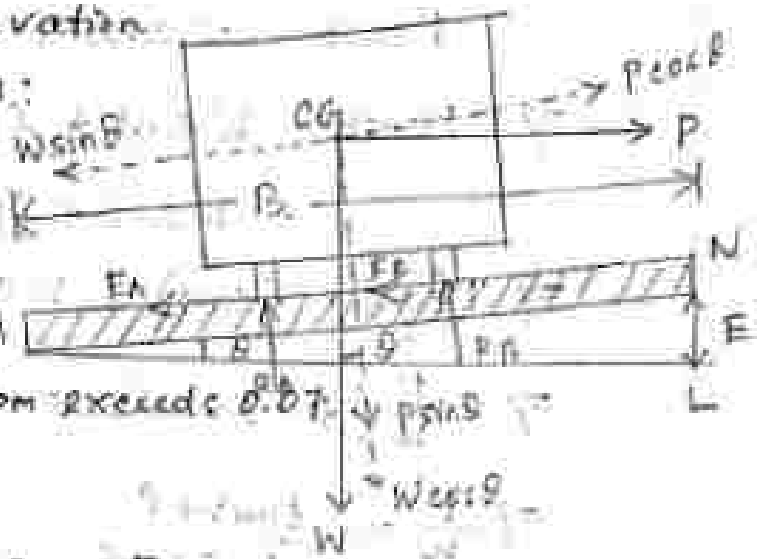
3. Superelevation

In order to counteract the effect of centrifugal force & to reduce the tendency of the vehicles to overturn or skid, the outer edge of the pavement is raised w.r.t the inner edge, thus providing a transverse transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as 'superelevation' or 'cant' or banking.

→ The rate of superelevation 'e' is expressed as the ratio of height of outer edge w.r.t the hz. width.

The outer edge of pavement is raised by NL = E & the rate of superelevation e, may be expressed as:

$$e = \frac{NL}{ML} = \tan\theta$$



→ θ is very small & the value of tanθ seldom exceeds 0.07

$\therefore \theta \simeq \sin\theta$

Hence, $e = \tan\theta \simeq \sin\theta = \frac{E}{B}$

where, E = total superelevated height

B = width of pavement

The total rise in outer edge w.r.t inner edge, NL,

$E = eB$.

Analysis of superelevation

The forces acting on the vehicle while moving on a circular curve of radius R metres at speed of v m/s are:

(a) the centrifugal force, $P = \frac{Wv^2}{gR}$ acting horizontally outwards through the c.g.

(b) weight of the vehicle acting vertically downwards

(c) the frictional force developed betn the wheels & the pavement counteracting transversely along the pavement surface surface towards the centre of the curve.

For equilibrium condition,

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

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

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

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

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

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

→ The value of coefficient of lateral friction, 'f' is taken as 0.15 for the design of hz. curves.

→ $\tan\theta \leq 0.07$ or about 1/15. Hence the value of ($f\tan\theta$) is about 0.01.

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

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

∴ The general eqn for design of superelevation is,

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

Here,

e = rate of superelevation = $\tan\theta$

f = design value of lateral friction coefficient = 0.15

v = speed of vehicle, m/sec

R = Radius of hz. curve, m

g = acceleration due to gravity = 9.8 m/sec²

If, the speed V in Kmph,

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

→ The maximum value of 'e' is limited to 7% or 0.07 & the min. value of 'f' is 0.15.

→ At some intersections it is not possible to provide super-elevation & in such cases the friction counteracts the centrifugal force fully.

$$f = \frac{V^2}{9R} \text{ i.e. } \frac{V^2}{127R}$$

$$\Rightarrow V = \sqrt{127fR}$$

→ Thus without 'e', the allowable speed of vehicle negotiating a curve should be restricted.

→ Max. 'e' in plain & rolling terrains, & snow bound area: 7%.
- → Hill roads: 10%.
- → Urban road with intersection: 4%.

Design of superelevation:

Steps

1. The superelevation is calculated for 75% of design speed ($0.75v$ m/sec or $0.75V$ kmph), neglecting the friction.

$$e = \frac{(0.75V)^2}{9R} \text{ or } e = \frac{(0.75V)^2}{127R}$$

$$\Rightarrow e = \frac{V^2}{225R}$$

2. If the calculated value of 'e' is less than 7% or 0.07 the value so obtained is provided. If it exceeds 0.07, then provide the max. 'e' equal to 0.07 & proceed with steps (iii) & (iv)

3. Check the coeff of friction developed for the max. value of e = 0.07 at the full value of design spd, v m/sec or V Kmph.

$$f = \frac{v^2}{9R} - 0.07 \quad \text{or} \quad f = \frac{V^2}{127R} - 0.07$$

If the value of 'f' calculated is less than 0.15, the superelevation of 0.07 is safe for the design spd & this is accepted as the design superelevation. If not, either the radius of the hz. curve has to be increased or the spd has to be restricted to the safe value which will be less than the design spd.

4. The restricted spd or allowable spd (i.e. V_a or v_a) at the curve is calculated by considering the design coeff. of lateral friction & the max. superelevation.

$$e + f = 0.07 + 0.15$$

$$= 0.22 = \frac{v_a^2}{9R} \quad \text{or} \quad 0.22 = \frac{V_a^2}{127R}$$

$$\Rightarrow v_a = \sqrt{0.729R} \quad \text{or} \quad V_a = \sqrt{27.94R} \text{ Kmph.}$$

$$\Rightarrow v_a = \sqrt{2.156R} \text{ m/s}$$

If the v_a is higher than the design spd, then the design is adequate & provide a 'e' equal to 0.07. If v_a is less than design spd, the spd is limited to the allowable spd V_a calculated above.

Attainment of superelevation in the field

The attainment of superelevation may be split up into 2 parts:

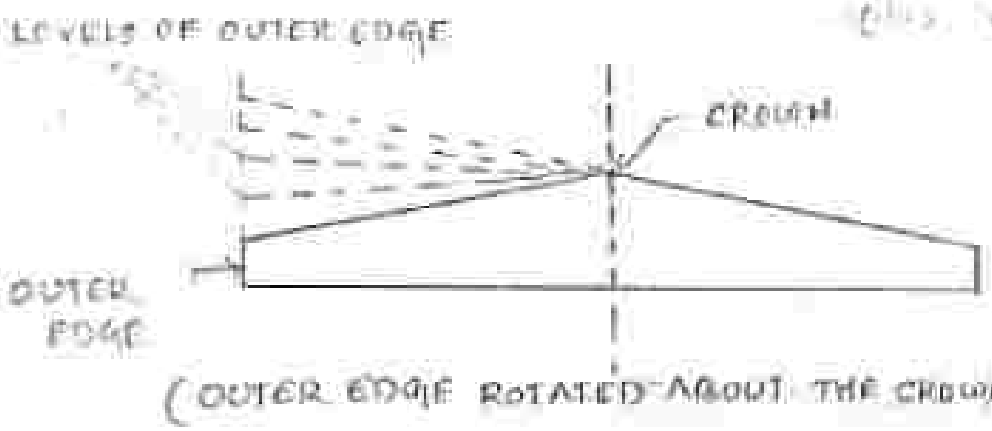
(a) Elimination of crown of the cambered section.

(b) Rotation of pavement to attain full superelevation.

(a) Elimination of the crown of the camber:

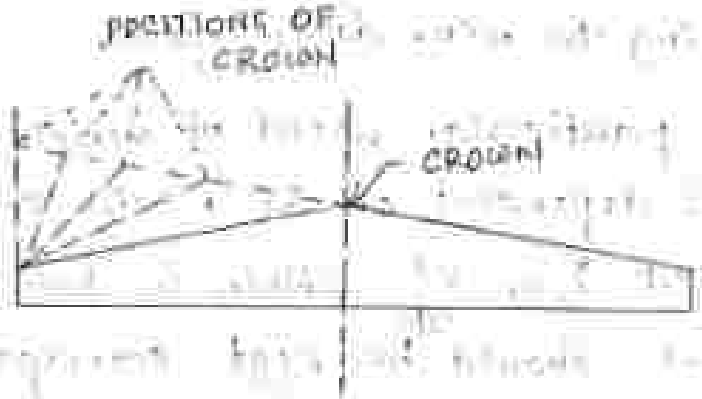
This may be done by 2 methods:

(i) The outer half of the cross slope is rotated about the crown at a desired rate such that the surface falls on the same plane as the inner half & the elevation of the centre line is not altered.



(OUTER EDGE ROTATED ABOUT THE CROWN)

(ii) Diagonal crown method: The crown is progressively shifted outwards, thus increasing the width of the inner half of cross section progressively.



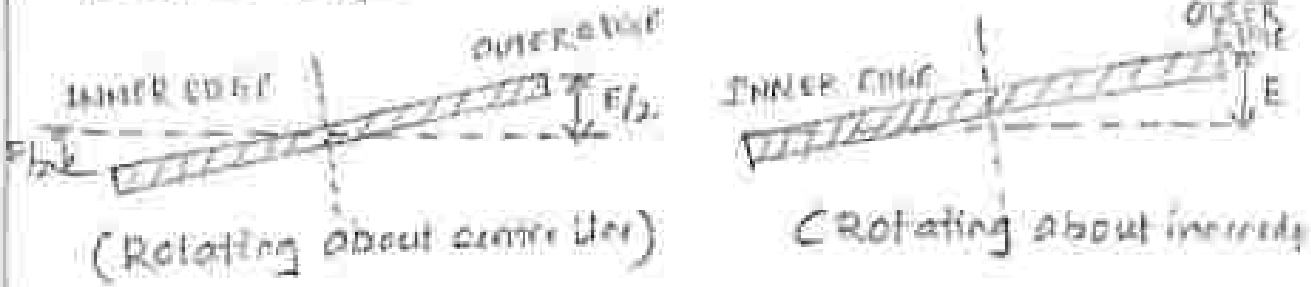
(CROWN SHIFTED OUTWARDS)

(b) Rotation of pavement to attain full superelevation :-

2 methods :

(i) By rotating the pavement cross section about the centre line, depressing the inner edge & raising the outer edge by half the total amount of superelevation i.e. by $\frac{E}{2}$ w.r.t the centre.

(ii) By rotating the pavement about the inner edge of the pavement section raising both the centre as well as outeredge of the pavement, such that the outer edge is raised by full amount of superelevation, E w.r.t the inner edge.



(Rotating about centre line) (Rotating about inner edge)

4. Radius of Horizontal curve

Hz. curves of highways are designed for the specified trailing design speed of highway. If this is not possible due to site restriction, the hz curves may be designed considering the min. design speed.

→ For a particular speed of vehicle the centrifugal force is dependent on the radius of the hx. curve. To the e+f $\frac{P}{D}$ or $\frac{V^2}{gR}$ within in two limit, the radius of curve should be kept correspondingly high.

$$e+f = \frac{V^2}{gR} \text{ or } \frac{V^2}{127R}$$

$$\Rightarrow 0.07+0.15 = \frac{V^2}{gR} \text{ or } \frac{V^2}{127R} \Rightarrow 0.22 = \frac{V^2}{gR} \text{ or } \frac{V^2}{127R}$$

Thus, the ruling min. radius of the curve, R_{ruling} for ruling design speed v m/sec or V Kmph is given by:

$$R_{ruling} = \frac{v^2}{(e+f)g}$$

or $$R_{ruling} = \frac{V^2}{127(e+f)}$$

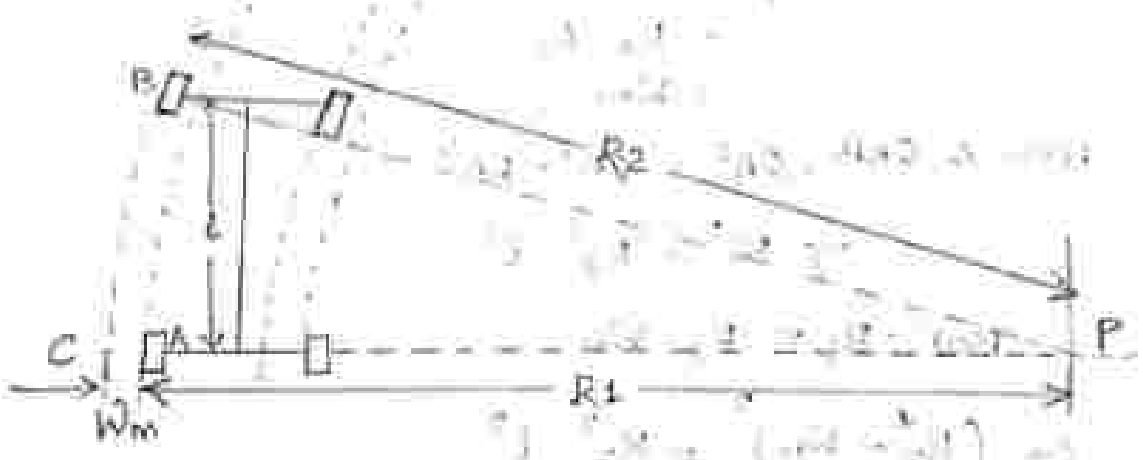
If the min. design speed is V' Kmph, the absolute min. radius of hz. curve R_{min} is given by:

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

e = 0.07 at all the region except on hill roads without snow where max. e is taken as 0.1.

5. Widening of pavement on horizontal curves

On hz curves, especially when they are not of very large radii, it is a practice to widen the pavement slightly more than the normal width.



The reqd extra widening of the pavement at the h2. curves, We depends on :

(i) the length of wheel base of the vehicle, l ;

(ii) radius of the curve negotiated R ;

(iii) the psychological factor which is a function of the speed of the vehicle and the radius of the curve

→ Extra width is provided when the radius is less than about 300 m.

→ The extra widening of pavement on h2. curves is divided into two parts :

(i) mechanical widening,

(ii) psychological widening

Mechanical widening :-

The widening reqd. to account for the off tracking due to the gravity of rigidity of wheel base is called mechanical widening (Wm).

From figure,

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

from ΔOAB, $OA^2 = OB^2 - BA^2$

$$\Rightarrow R_1^2 = R_2^2 - l^2$$

But $R_1 = R_2 - W_m$

i.e. $(R_2 - W_m)^2 = R_2^2 - l^2$

$$\Rightarrow R_2^2 - 2R_2 W_m + W_m^2 = R_2^2 - l^2$$

$$\Rightarrow l^2 = W_m (2R_2 - W_m)$$

$$\Rightarrow W_m = \frac{l^2}{2R_a - W_m}$$

Therefore, $W_m = \frac{l^2}{2R}$ (approx.)

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

Here, n = no. of traffic lanes, as n vehicles.

Psychological widening:-

$$W_{ps} = \frac{V}{9.5\sqrt{R}}$$

Hence, the total widening 'We' reqd. on a hz. curve,

$$W_e = W_m + W_{ps}$$

$$\Rightarrow \boxed{W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}}$$

where,

n = no. of traffic lanes

l = Length of wheel base of longest vehicle, m.

= 6.1 or 6.0 m for commercial vehicles

V = design speed, Kmph

R = radius of hz. curve, m.

6. Horizontal transition curves

A transition curve is introduced between the straight and a circular curve which will help in gradually introducing the designed - superelevation and the extra widening necessary.

Functions:-

→ to introduce gradually the centrifugal force between the tangent point & the begining of the circular curve, avoiding a sudden jerk on the vehicle.

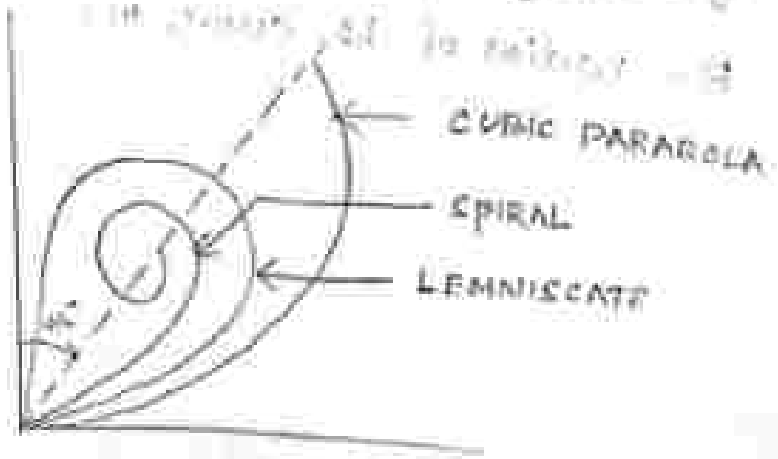
→ to enable the driver turn the steering gradually for his own comfort and safety.

→ to enable gradual introduction of the designed superelevation & extra widening of pavement at the start of the circular curve.

→ to improve the aesthetic appearance of the road.

· Different types of transition curves :-

(a) Spiral
(b) Lemniscate
(c) Cubic parabola



All the three curves follow almost the same path up to deflection angle of 4°, & practically there is no significant difference even up-to 9°. In all these curves, the radius decreases as the length increases. But the the rate of change of radius & hence the rate of change of centrifugal acceleration is not constant in case of lemniscate & cubic parabola, especially at deflection angles highter than 4°.

→ In spiral curve the radius is inversely proportional to the length and the rate of change of centrifugal acceleration is uniform throughout the length of the curve. Thus, the spiral curve fulfills the condition of an ideal transverse curve.

→ IRC recommends the use of the spiral as transition curve in the hz. alignment of highways. Because:

(i) It satisfies the requirements of an ideal transition.

(ii) The geometric property of spiral is such that the calculations & setting out the curve in the field is simple & easy.

The eqn. of the spiral may be written as:

$$LR = L_c R_c = \text{constant}$$

Therefore, $L = m\sqrt{\theta}$

Here, m is a constant equal to $\sqrt{2RL_c}$ & θ is the tangent deflection angle in radius.

(D) Design of vertical alignment

The vertical alignment is the elevation or profile of the centre line of the road. It consists of grades and vertical curves.

→ The vertical alignment of a highway influences:

(i) vehicle speed
(ii) acceleration & deceleration
(iii) stopping distance
(iv) sight distance
(v) comfort while travelling at high speeds
(vi) vehicle operation cost.

1. Gradient :

It is the rate of rise or fall along the length of the road w.r.t the horizontal. It is expressed as a ratio of 1 in x (1V : xH)

→ It is also expressed as a percentage, n%.

→ The ascending gradients are given +ve signs, +n1, +n2

& descending gradients are given -ve signs, -n1, -n2.

→ The angle which measures the change of direction at the intersection of two grades is called the deviation angle 'N which is equal to the algebraic difference betn the two grades.

$$N = \angle DBC = \angle BAC + \angle BCA$$

$$= +n_1 - (-n_2) = n_1 + n_2$$

where, $+n_1$ or n_1 is the ascending gradient of AB and

$-n_2$, the descending gradient of BC.

Types of gradient :

(i) Ruling gradient : It is the maximum gradient within which the designer attempt to design vertical profile of a road. It is the design gradient.

IRC value : Plain & rolling terrain : 1 in 30

Mountainous " : 1 in 20

Steep " : 1 in 16.7

(ii) Limiting gradient : where topography of a place compels adopted steeper gradient than the ruling gradient Limiting gradient is used.

(iii) Exceptional gradient : In some extra ordinary situations it may be unavoidable to provide still steeper gradients than limiting gradient at least for short stretches & In such cases the steeper gradient upto 'exceptional gradient' may be provided.

(iii) Minimum gradient :- From drainage point of view it is desirable to have a certain 'min. gradient' on roads.

→ 1 in 500 may be sufficient to drain water in concrete drain or gutters.

Grade compensation :-

$$G.C, \% = \frac{30+R}{R}$$ where, R = Radius of curve.

→ max. value : $\frac{75}{R}$

→ IRC value : not necessary for gradients flatter than 4%

→ Compensated gradient = Ruling Gradient − G.C

2. Vertical Curves

Due to changes in grade in the vertical alignment of highway, it is necessary to introduce vertical curves at the intersections of different grades to smoothen out the vertical profile & thus ease off the changes in gradients for the fast moving vehicles.

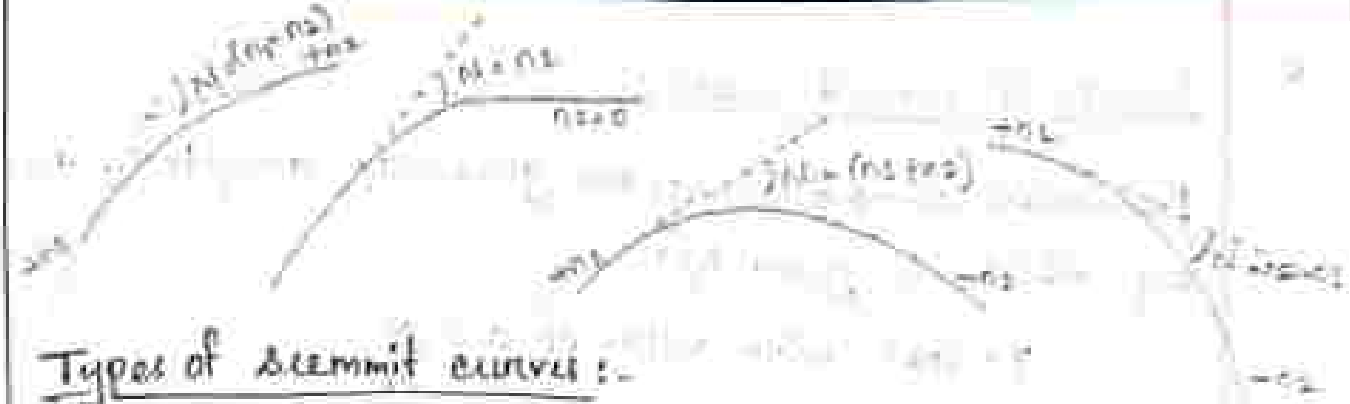
These can be classified into two types:

(a) Summit curves or crest curves with convexity upwards.

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

Summit curves :-

Summit curves with convexity upwards are formed in any one of the cases:



Types of summit curves :-

The design of summit curves are governed only by considerations of sight distance & therefore, transition curves are not necessary.

→ Circular summit curve is ideal as the sight distance available throughout the length of circular curve is constant.

Road humps :-

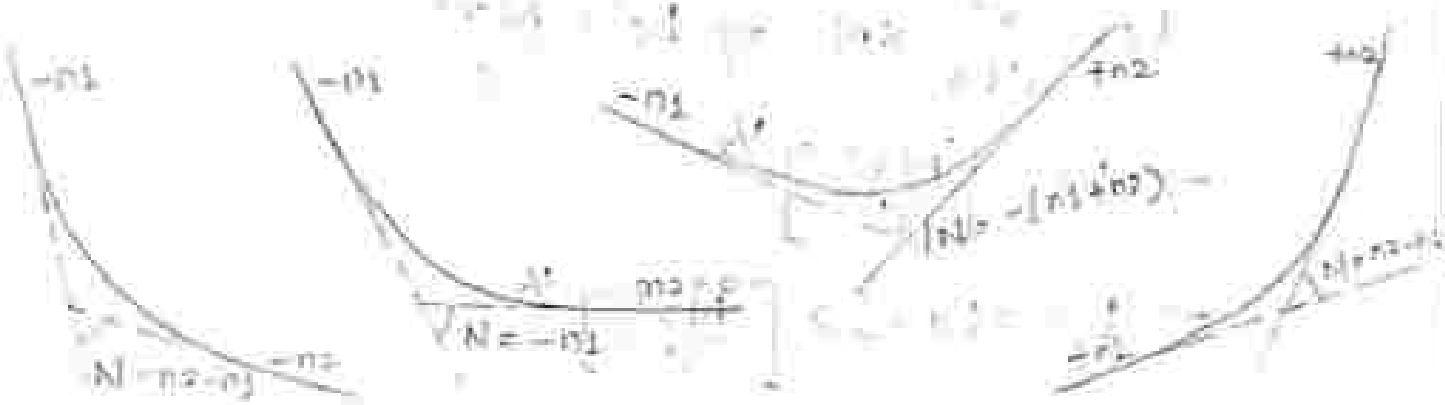
→ When a hump may be introduced on a road is due to the presence of a culvert, the top of which is above the general level of the road by less than about a metre, thus causing a sharp but relatively small summit or hump on the road profile.

→ For proper design of humps, the vertical profile should consist of two transition curves each on either side of the hump with a level strip in between, over the culvert.

→ Road humps are also introduced as speed breakers on certain roads. These are low humps of 900mm height & width greater than the wheel base of common vehicles, laid across the roadway with specified rounded shapes.

Valley curves :

Valley curves or sag curves with convexity downwards are formed in any one of the cases.



As fast moving vehicles negotiate valley curves, the centrifugal force developed acts downward in addition to the self weight, thus adding additional pressure on the suspension system of the vehicle & discomfort to passengers due to impact.

ROAD MATERIALS

Highway structures are generally constructed above or below the general ground level with the following components:

(a) Embankment or fill / prepared cutting
(b) Subgrade
(c) Pavement layers of flexible or rigid pavement structure.

Materials for highway embankment:

→ Locally available soils excavated from near by borrow pits
→ Locally available 'waste materials' such as fly-ash, construction debris, etc.

Materials for highway cutting:

→ Local materials

Subgrade material:

→ Superior soils of specified properties.

Materials for pavement layers:

Flexible pavement:

→ Selected granular soils or crushed aggregates or soil aggregates mixes with adequate permeability in the drainage layer.
→ Stone agg. & fine agg. in granular base course.
→ CA, FA & bitumen binder in the bituminous pavement layers used in base course or binder course & the surface course.

Rigid Pavement :-

→ Selected granular soils or crushed agg. or soil agg. mixes with adequate permeability in drainage layer

→ CA, FA & Portland cement for the lean cement concrete in sub-base course

→ CA, FA & Portland cement in cement concrete pavement slab, in both base course & surface course.

Highway materials :

(a) Soil
(b) Stone aggregates
(c) Bituminous binders
(d) Bituminous mixes
(e) Portland cement and cement concrete

1. Soil

Soil subgrade is an integral part of road pavement structure as it provides the support to the pavement.

→ The function of subgrade is to provide adequate support to the pavement even under adverse climatic & loading conditions.

→ The formation of waves, corrugations, rutting & shoving in flexible pavements & phenomenon of pumping, blowing & consequent cracking of cement concrete pavements are attributed due to the poor subgrade conditions.

Characteristics of soil:

Soils consist of mineral matter formed by the disintegration of rocks, by the action of water, frost, temperature, pressure or by plant or animal life.

→ Based on the individual grain size of soil, soils are classified as gravel, sand, silt & clay.

→ The characteristics of soil depend on the size, shape, surface texture, chemical composition & electrical charges on the surface of fine soil particles.

→ Moisture & dry density influence the engg. behaviour of a soil mass.

Desirable properties of soil :-

(a) Stability
(b) Incompressibility
(c) Permanency of strength
(d) Minimum changes in volume & stability under adverse condition of weather and ground water.
(e) Good drainage
(f) Ease of compaction.

Tests on soil :

1. Shear tests → Direct shear test
   → Triaxial compression test
   → Unconfined compression test
2. Bearing tests : Plate bearing test
3. Penetration tests

California Bearing Ratio (CBR)

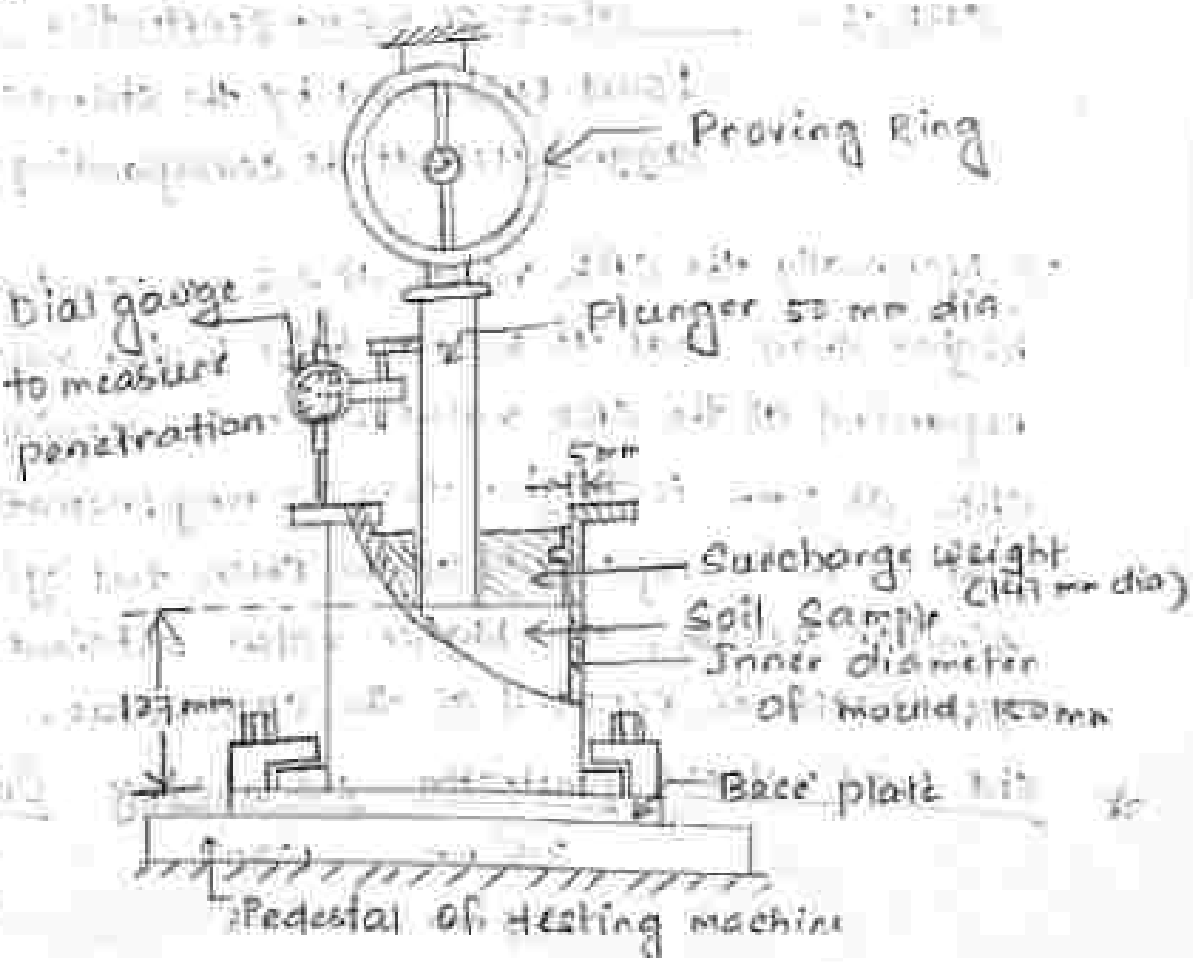
→ Developed by the California State Highway Dept. as a method of evaluating the strength of subgrade soil & other pavement materials for design & construction of flexible pavements.

→ CBR test denotes a measure of resistance to penetration of a soil or flexible pavement material.

→ Test may be conducted in lab. on re-moulded specimens or may be conducted on undisturbed soil specimens.

Test Apparatus

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



The specimen in the mould is compacted to a dry density corresponding to the minimum state of compaction likely to be achieved in practice. The specimen is subjected to 4 days soaking and the swelling & water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould & the assembly is placed under the plunger of the loading frame. The load values are noted corresponding to penetration values of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 & 12.5 mm.

The load-penetration graph is plotted. The load values corresponding to 2.5 & 5.0 mm penetration values are noted.

The CBR value is calculated using the relation:

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

→ Normally the CBR value at 2.5 mm penetration is higher than that at 5.0 mm & the higher value is reported as the CBR value of the material. If the CBR at 5mm is higher than 2.5 mm penetration, then the test is to be repeated. If the check test gives again similar results, the higher value obtained at 5.0 mm penetration is reported as the CBR value.

★ Std. load values:

Penetration	Std. load, kg	Unit std. load, kg
2.5 mm	1370	70
5.0 mm	2055	105

→ The CBR test is an arbitary strength test & cannot be used to evaluate the soil properties like cohesion or angle of internal friction or shearing resistance.

→ Presence of coarse grained particles results in poor reproducibility of CBR test results.

→ Material passing 20 mm sieve is only used in the test.

2. Aggregates

Aggregates form the prime materials used in the construction of different pavement layers.

→ The aggregates of the pavement surface course have to resist: (i) the wear due to abrasive action of traffic
(ii) deterioration due to weathering
(iii) the highest magnitude of wheel load stresses.

→ Stone aggregates are used as:
(i) bituminous pavement layers of flexible pavements
(ii) cement concrete mixes used for CC pavement slab & for other cross drainage structures.
(iii) granular base course
(iv) granular sub-base course or lean cement concrete sub-base
(v) drainage layer.

→ Types of aggregates:
(i) Coarse aggregates: Gravel
(ii) fine aggregates: Sand

→ Based on strength property, the CA may be divided as hard aggregates & soft aggregates.

→ For the wearing course of superior pavement type, hard aggregates are preferred.

→ Soft aggregates such as moorum, kankar, laterite brick agg. & slag are used in lower layer of road pavement. & in case of low-volume roads.

Desirable properties

(i) Resistance to impact due to heavy wheel loads. (toughness property).

(ii) Resistance to wear & tear or abrasion (Hardness property).

(iii) Resistance to crushing & to retain strength. (Strength & durability)

(iv) Resistance to weathering.

(v) Resistance from getting polished or smooth / slipping

(vi) Good adhesion or affinity with bituminous material in presence of water or less stripping of bitumen coating from the aggregates.

Tests on aggregates

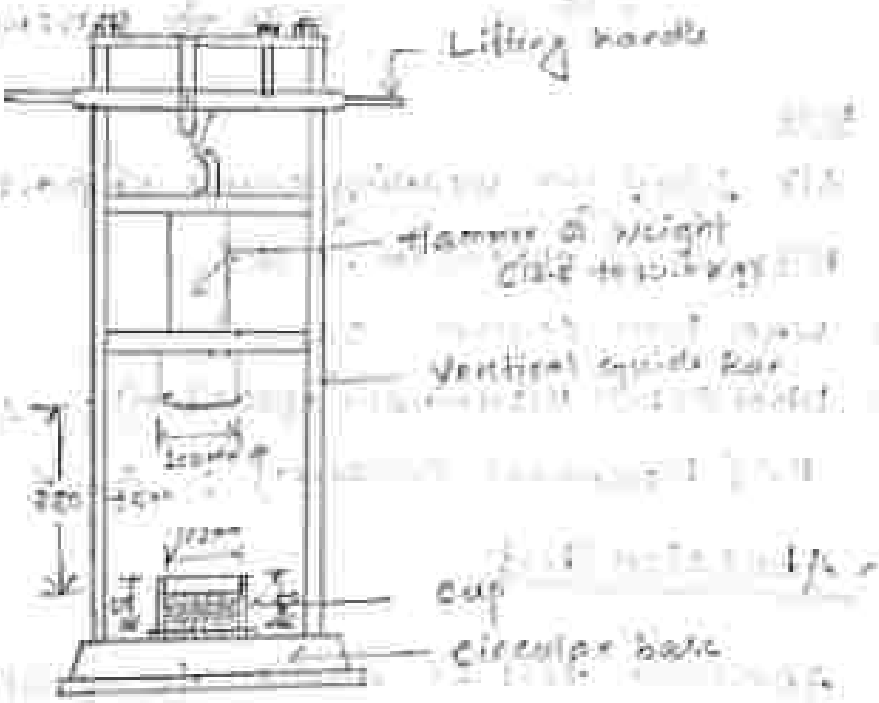
(a) Agg. impact test
(b) Los Angeles abrasion test
(c) Crushing test
(d) Shape tests : Flakiness index, elongation index, Angularity
(e) Soundness test
(f) Specific gravity & water absorption test
(g) Bitumen adhesion or stripping value test.

Aggregate Impact Test

This test is carried out to evaluate the resistance to impact of aggregates to fracture under repeated impact.

Test apparatus:

Agg. impact testing machine consists of a metal base & a cylindrical steel cup of internal dia. 102 mm & depth 50 mm in which the agg. specimen is placed. A cylindrical metal hammer of weight 13.5 to 14.0 kg having a free fall from a height of 380mm is arranged to drop through vertical guides.



Aggregate passing 12.5 mm sieve & retained on 10 mm sieve is filled in the cylindrical measure in 3 layers by tamping each layer by 25 blows by the tamping rod. The sample is weighed & transferred from the measure to the cup of the agg. impact testing machine & compacted by tamping 25 times. The hammer is raised to a height

of 380 mm above the upper surface of the aggregate in the cup and it allowed to fall freely on the specimen. After subjecting the test specimen to 15 blows, the crushed agg. is sieved on 2.36 mm sieve. The aggregate impact value is expressed as the percentage of the fines passing 2.36 mm sieve formed in terms of the total weight of the sample.

AIV, %	Toughness property
≤ 10	exceptionally tough / strong
10 - 20	very tough / strong.
20 - 30	good for pavement surface course
> 35	weak for pavement

Note

AIV ≤ 30% → wearing course of pavement

Bituminous macadam : ≤ 35%

WBM base courses : ≤ 40%

DBM (Dense Bituminous Macadam) : ≤ 27%

BC (Bituminous Concrete) : ≤ 24%

Abrasion Test

Abrasion test is carried to evaluate the resistance to wear or hardness due to traffic.

methods :

(i) Los Angeles abrasion test

(ii) Deval abrasion test

(iii) Dorry abrasion test

Los Angeles abrasion test

The principle of Los Angeles abrasion test is to find the percentage wear due to the relative rubbing action between the aggregates and steel balls used as abrasive charge.

Apparatus:

The Los Angeles machine consist of a hollow cylinder closed at both ends, having inside dia. 700 mm & length 500mm, & mounted so as to rotate about its horizontal axis. A removable steel shelf projecting radially 89 mm into the cylinder & extending to the full length of it is mounted on the interior surface of the cylinder rigidly parallel to the axis. The abrasive charge consisting of cast iron spheres of approx. dia 48 mm & each of weight 390 to 445 g is placed in the machine. The no. of spheres to be used as abrasive charge & their total weight have been specified based on grading of the selected aggregate sample.

Test:

The specified weight of aggregate specimen of desired grading is taken (5 to 10 kg depending on gradation) and placed in the machine along with the specified abrasive charge. The machine is rotated at a speed of 30 to 33 rpm for the specified no. of revolutions (500 to 1000 depending on gradation). The abraded aggregate is then sieve on 1.7 mm IS sieve, and the

weight of powdered aggregate passing this sieve is found. The result of abrasion test is expressed as the percentage wear or the percentage passing the sieve expressed in terms of the original weight of the sample.

Note:

B.C & high quality pavement : $\leq 30\%$
cement concrete pavement & DBM binder course : $\leq 35\%$
Granular base course (WBM, BM) : $\leq 40\%$

Aggregate Crushing Value test

The aggregate crushing value provides a measure of resistance to crushing under gradually applied compressive load.

Agg. possessing high resistance to crushing or low ACV are preferred for use in high quality pavement.

Apparatus

The apparatus consists of a steel cylinder 152 mm dia with a base plate and a plunger, compression testing machine, cylindrical measure of dia 11.5 mm and height 180 mm, tamping rod and sieves.

Test

Dry aggregates passing 12.5 mm IS sieve and retained on 10 mm sieve is filled in the cylindrical measure in 3 equal layers, each layer being rammed 25 times by the tamper. The test sample is weighed (equal to W1) and placed in the test cylinder in 3 equal layers, tamping each layer 25 times. The plunger is placed

on the top of specimen & a load of 40 tonnes is applied at a rate of 4 tonnes per minute by the compression machine. The crushed aggregate is removed & sieve on 2.36 mm IS sieve. The crushed material which passes this sieve is weighed equal to W_2 g. The aggregate crushing value is the percentage of the crushed material passing 2.36 mm sieve in terms of original weight of the specimen.

$$ACV = \frac{100W_2}{W_1} \text{ percent}$$

Note:

Base course : 45%

surface course : 30%

Cement concrete pavement : $\leq$ 30%

Shape tests

The shape of agg. is determined by the % of flaky and elongated particles contained in it. In case of gravel the shape may be expressed in terms of angularity number.

Flakiness index (FI)

It is the % by weight of aggregate particles the least dimension of which is less than $\frac{3}{5}$th or 0.6 of their mean (thickness) dimension.

→ This test is applicable to sizes larger than 6.3 mm.

→ Standard thickness gauge is used to gauge the thickness of the agg. samples.

→ The flaky agg. are those which pass through the designated slots of the thickness gauge which has elongated slots with least dimension equal to 0.6 times of the mean dimension of

each size range, then flaky agg. are separated.

→ FI in BC & SD = ≤ 25%.

WBM & BM = ≤ 15%

Elongation Index

It is the % by weight of particles, the greatest dimension of which or its length is greater than one and four fifth or 1.8 times their mean dimension.

→ The E.I test is not applicable for sizes smaller than 6.3 mm.

→ Standard length gauge is used to gauge the greatest dimension or length of the agg. samples.

→ The elongated agg. are those which are 1.8 times of the respective mean size of the aggs; those elongate pieces of agg. are seperated.

→ F.I and E.I values in excess of 15% are generally considered undesirable.

→ CYORTH: Combined Index = 30% for wet mix Macadam base course, DBM binder course & BC surface course

Angularity Number

The degree of packing of particles of single sized agg. depends on the shape & angularity of the aggregate. A well compacted single sized rounded agg. is found to have a solid volume of 67% & void volume of 33%.

→ The angularity number of agg. is expressed in terms of the voids in a sample of single sized agg. compacted in a particular manner.

→ A.N is defined as (67 - percent solid volume of aggregate).

→ The solid volume of the agg. is found by filling it in a vessel in a specified manner. Thus, the angularity no. measures the voids in excess of 33%.

→ The higher the A.N, more angular is the aggregate.

→ The A.N for agg. used in construction = 0 to 11.

$$\therefore AN = 67 - \frac{100W}{C G_a}$$

where,

W = wt of agg. in the cylinder in gm.

C = wt of water filling the cylinder in gm.

G_a = Sp. gravity of the aggregate.

✓Water absorption & Specific Gravity test

The sp.gr of a stone agg. is measure of strength or quality of the material.

→ stones having Low sp.gr. are weaker than those with higher sp.gr. values.

→ Water absorption is an indicator for the strength of rock.

→ Stones having high water absorption are more porous & are unsuitable.

Tests:

About 2 kg of dry sample of coarse agg. is placed in wire basket and immersed in water for 24 hrs. The sample is weighed in water & the buoyant weight is found. The agg. are then taken out, surface dried well with absorbent cloth & weighed. The aggregate are then dried in an oven at a temp. 110°C for 24 hrs & then the oven dry weight is determined. The specific gravity is calculated by dividing the dry wt of agg. by wt. of equal volume of water.

→ The water absorption is expressed as the percent water absorbed in terms of oven dried wt. of the aggregate.

Note:

→ Sp. gr. for rocks = 2.6 to 2.9

→ Rock having > 0.6 % water absorption are considered unsatisfactory unless found acceptable based on strength tests.

✓ Soundness test

It is intended to study the resistance of aggregate to weathering action by conducting "accelerated weathering test cycles".

→ The resistance to disintegration of aggregate is determined by using saturated solution of sodium sulphate or magnesium sulphate.

Test

Clean, dry agg. of specified size range is weighed & the no. of pieces counted. The agg. sample is immersed in the saturated soln of sodium sulphate or magnesium sulphate for 16 to 18 hours. Then the specimen is dried in an oven at 105° to 110°C to a constant weight thus making one cycle of immersion & drying. The no. of such cycles is decided by prior agreement & then the specimen are tested. After completing the final cycle, the sample is washed & each fraction of the agg. is examined visually to see if there is any evidence of excessive splitting, crumbling or disintegration of the grains. Sieve analysis is carried out to note the variation in gradation from original.

Notes

→ The avg. loss in wt after 10 cycles : ≤ 12% (Na_2SO_4)
: ≤ 18% ($MgSO_4$)

→ IRC: After 5 cycles loss of wt. : ≤ 12% (Na_2SO_4)
≤ 18% ($MgSO_4$)
(Bituminous binder course & surface course of flexible pavement)

Stripping value test

The displacement of bituminous coating from the aggregates is known as stripping of aggregates.

→ Stripping is more when agg. have greater affinity towards water than with bituminous binders.

Test

200 g of dry Sirohan stone aggr. passing 20 mm IS sieve & retained on 12.5 mm sieve is heated upto 170°c. The heated aggr. is mixed with 5% by wt of bitumen binder heated to 160°c. The aggr. & binder are mixed thoroughly till they are completely coated & mixture is transferred to a 600 ml beaker & allowed to cool at room temperature for about 2 hr. Distilled water is then added to immerse the coated aggr. The beaker is covered & kept in a water bath maintained at 40°c, taking care that the level of water in the water-bath is at least half the height of the beaker. After 24 hrs, the beaker is taken out cooled at room temperature & the extent of stripping from the individual aggr. is estimated visually.

→ The stripping value is the ratio of the area uncovered or stripped area observed visually to the total area of aggregates in each test, expressed as a percentage.

Note:

→ TRC: SD, BM & Bitumen mastic = 25%

Open graded premix carpet = 10%

3. Bituminous binders

Bituminous binders used in pavement construction mixes are (a) bitumen & (b) tar.

→ Bitumen is a petroleum product obtained by the distillation of petroleum crude.

→ Coal tar is produced from coal as a by product of coke.

→ Both bitumen & tar have similar appearance as both are black in colour.

→ Bitumen is hydrocarbon material of either natural or pyrogenous origin found in gaseous, liquid, semisolid or solid form & is completely soluble in carbon disulphide & in carbon tetra chloride.

→ Tar is soluble in toluene only.

→ Tar has high temperature susceptibility than bitumen.

→ Tar has harmful effects of its fumes during heating.

The types of bituminous binders that are used in flexible pavement construction are :

(a) Paving grade bitumen

(b) Modified bituminous binders

(c) Cut-back bitumen

(d) Bitumen emulsion

Paving grade bitumen :-

The diff. grades of bitumen used for pavement construction work of roads & airfields are called paving grade bitumen & those used for water proofing of structures & industrial floors etc., are called industrial grade bitumen.

→ For the construction of bituminous pavements, the paving grade bitumen is heated to temperatures in the range of 130° to 175°C, depending upon the type & grade of bitumen selected & the type of the construction work.

Modified Bituminous binders :-

Bitumen modifier reduce the temperature susceptibility of the binder as well as that of bituminous mix with consequent improvement in pavement stability by imparting visco-elastic properties to the mix.

→ Modified bituminous binders offer better resistance to deformation at higher temperatures & remains flexible & elastic at low temperatures.

Desirable Properties of bitumen

→ The viscosity of bitumen at the time of mixing with agg. & compaction of the pre-mix should be adequate. This is achieved either by (i) heating the bitumen & agg. prior to mixing or (ii) by using in the form of cut-back or (iii) by using in the form of emulsion of suitable grade.

→ It should become sufficiently viscous on cooling that the compacted bituminous pavement layer can gain stability & resist deformation under traffic loads.

→ It should form ductile thin films around the agg. to serve as a satisfactory binder in improving the physical interlocking of the agg. The binder which does not possess sufficient ductility would crack & thus provide pervious pavement surface.

→ It should not be highly temp. susceptible.

→ It should have sufficient adhesion with the agg. in the mix in presence of water.

→ There should be adequate affinity & adhesion betn the bitumen & agg. used in the mix.

Cutback Bitumen :

Cutback bitumen is obtained by blending bitumen binder with suitable volatile diluents or solvents in the requ. proportion to reduce its viscosity to the desired range.

→ After the cutback mix is used in construction work, the volatile solvent gets evaporated, the binder starts hardening & develops the binding properties.

→ Cutback bitumen of appropriate grade is used as tack coat without heating & in sites at sub-zero temperatures & in regions of high altitude.

→ Also it is used for preparing bituminous mixes & for soil-bitumen stabilisation.

→ (In order to achieve fluid consistency of bitumen at relatively low temp. with normal heating, cutback bitumen has been developed. It is prepared by diluting a paving grade bitumen with a volatile solvent such as a light fuel oil or kerosene)

Types of cutback bitumen :-

(i) Rapid curing (RC)

(ii) Medium curing (MC)

(iii) Slow curing (SC)

This classification is based on the rate of curing or hardening after the application.

Rapid curing bitumen :-

→ classified by BIS, on the basis of initial kinematic viscosity into a 4 grades : RC-70, RC-250, RC-800, RC-3000. In increasing order of initial viscosity.

Medium curing bitumen :-

→ classified into 5 grades : MC-30, MC-70, MC-250, MC-800 & MC-3000.

→ of 30 is used as primer.

Slow-Curing bitumen :-

→ classified into 4 grades : SC-70, SC-250, SC-800, SC-3000

Bitumen Emulsion :-

A bitumen emulsion is liquid product in which a substantial amount of bitumen is suspended in a finely divided condⁿ in an aqueous medium & stabilized by means of one or more suitable materials.

→ An emulsion is a two phase-system consisting of two immiscible liquids, the one being dispersed as fine globules in the other.

Types of bitumen emulsion :-

(i) Rapid setting type : RS-1 & RS-2

(ii) Medium setting type : MS

(iii) Slow setting type : SS-1 & SS-2

Rapid setting emulsion:

→ Used in spray application like tack coat, for surface treatments, surface dressing & penetration macadam.

Medium-setting emulsion:

→ Used in cold bituminous mixes, surface dressing & penetration macadam (the % of CA are high).

Slow setting emulsions:

→ Used for prime coat, slurry seal treatments, recycling works, soil stabilization.

→ Used with well graded bituminous mixes.

Grading of Bitumen

Bitumen binders for pavement construction are classified into various penetration grades such as 80/100, 60/70, 30/40, based on the penetration test values determined at 25°C.

→ Method of grading paving bitumen is known as viscosity grading (VG), based on the absolute viscosity values determined at 60°C & kinematic viscosity values determined at 135°C.

→ Pavement service temp. is considered to be around 60°C & the laying temp. of hot bituminous mixes to be about 175°C.

12- Viscosity grades of bitumen for use in India :-

Sl. no	Viscosity grading	Absolute viscosity at 60°C, poise	Kinematic viscosity at 135°C, cSt	Range of penetration value at 25°C
1.	VG10	800	250	80-100
2.	VG20	1600	300	60-80
3.	VG30	2400	350	50-70
4.	VG40	3200	400	40-60

1. VG-40 : Use in high stressed areas like intersections, toll plazas, truck terminals, truck lay-byes in lieu of 30/40 penetration grade.

2. VG-30 : Paving applications for most part of India, in lieu of 60/70 penetration grade of bitumen.

3. VG-20 : Paving applications in cold climatic conditions of North India & in high altitude regions.

4. VG-10 : Spraying applications; paving applications in cold regions in lieu of 80/100 penetration grade.

Tests on Bitumen

(a) Penetration test
(b) Viscosity test
(c) Ductility test
(d) Softening point test
(e) Specific gravity test
(f) Flash and Fire point test
(g) Loss on heating test
(h) Solubility test

• Penetration test

It is one of test to determine the consistency of paving grade bitumen. It is used for classifying the bitumen into different grades.

→ It is the measurement of the penetration (in units of one tenth of a mm) of a standard needle in a bitumen sample maintained at 25°C during 5 seconds, the total weight of the needle assembly being 100g.

The penetrometer consists of a penetration needle which is attached to a calibrated dial. On release, the penetration needle penetrates into the bitumen specimen without appreciable friction. The bitumen is softened to a pouring consistency, stirred thoroughly & poured into containers to a depth at least 10 mm in excess of the expected penetration. The sample containers are then placed in a temp. controlled water bath at a temp. of 25°C for one hour. The sample with container is taken out, placed under the penetrometer & the needle is adjusted to make contact with the surface of the sample. The dial is set to zero or the initial reading is taken & the needle is released for 5 seconds. The final reading is taken on dial gauge.

Viscosity tests

Viscosity of a liquid is the property that retards its flow due to internal friction & it is a measure of resistance to flow of the liquid.

→ Higher the viscosity, slower will be its movement or rate of flow.

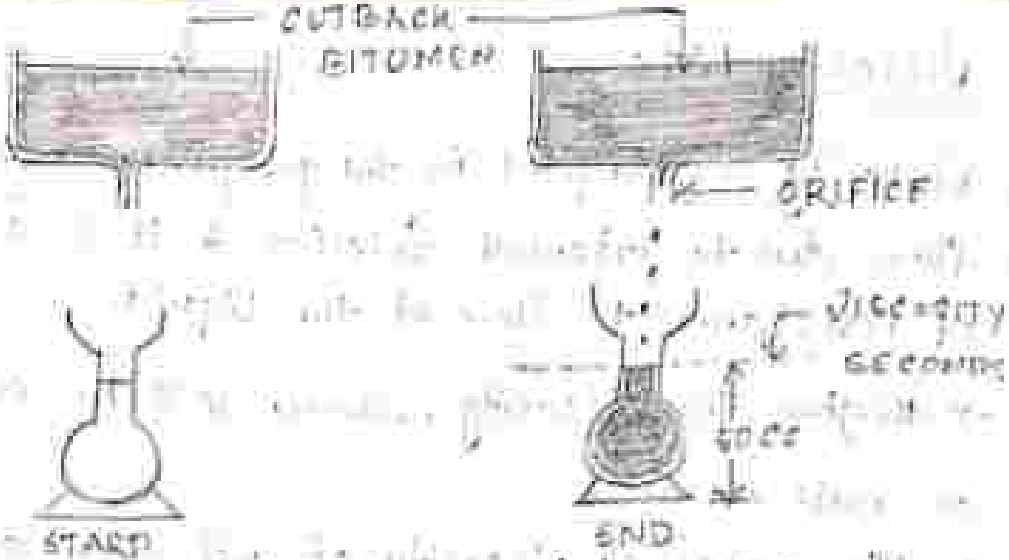
→ The range of viscosity of diff types of bituminous binders (such as hot bitumen, cutback bitumen or bitumen emulsion) depends on the type & grade of the binder & the temperature of application.

Determination of viscosity using orifice viscometer

Viscosity of liquid bituminous binders like bitumen emulsion & tar are determined by indirect method using orifice type viscometers. A specified quantity of the binder (50 ml) is allowed to flow through specified orifice size of the test cup at a given temperature & the time taken in seconds is recorded as the viscosity value.

→ As per BIS, the viscosity of bitumen emulsions is determined by 'Saybolt Furol' orifice viscometer at temp. of 25°C & 50°C.

→ The viscosity of tar is determined using orifice viscometer called 'Tar Viscometer' using either 10 mm or 4 mm size orifice.



Ductility test

On the flexible pavement constructions - where bitumen binders are used, it is Imp. that the binders form ductile thin films around the aggregate. It improves the physical interlocking of the aggregate - bitumen mixes.

→ Ductility test is carried out to test the adhesive property of bitumen & its ability to stretch.

→ Less ductile binder would crack & permit the surface-water to enter into the pavement.

→ The ductility value is expressed as the distance in cm to which the bitumen specimen of standard size can be stretched before the thread breaks.

→ The standard briquette specimen has a minimum cross-section of 10 mm x 10 mm.

→ The test is conducted at 27°C with a rate of pull 50 mm per minute, until the stretched specimen breaks.

→ The ductility machine functions as a constant temp. water bath with a pulling device at a pre-calibrated scale. Two clips are then pulled apart horizontally at a uniform speed of 50 mm per minute.

→ Ductility value range: 5 to 200

→ Min. ductility value of 50 to 75 cm is specified for pavement construction.

Softening point test

The softening point is the temp. at which the substance attains a particular degree of softening under specified cond^n of test.

→ It is determined by Ring and Ball test.

→ Higher softening point indicates lower temp. susceptibility & preferred in warm climates.

→ A brass ring containing test sample of bitumen is suspended in a beaker with liquid bath; water is used as the bath if softening point is less than 80°C. & glycerine is used for temp. exceeding 80°C. A steel ball is placed upon the bitumen sample

& the liquid medium is then heated at a rate of 5°C per minute. The temp. at which the softened bitumen touches the metal plate placed at a specified distance below the ring is recorded as the softening point of the bitumen.

→ Harder grade of bitumen possess higher softening point than soft grade bitumen.

→ For paving jobs softening point : 35° to 70°C.

ROAD PAVEMENTS

Objects of highway Pavements

→ To support the wheel loads & to transfer the load stresses through a wider area on the soil subgrade below.

→ To allow the heavy wheel loads of road traffic to move with least possible rolling resistance.

Types of Pavement structure

1. Flexible pavements
2. Rigid pavements
3. Semi-rigid or composite pavement
4. Interlocking cement concrete Block Pavement (ICBP)

Flexible Pavements

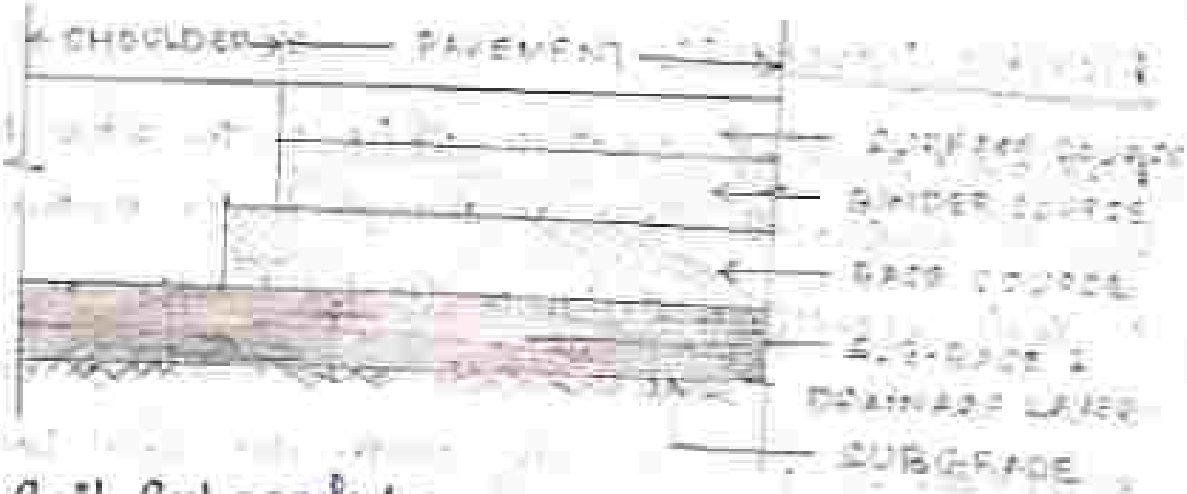
Flexible pavements are those, which on the whole have low or negligible flexural strength & are rather flexible in their structural action under the loads.

→ The vertical compressive stress is maximum on the pavement surface directly under the wheel load & is equal to the contact pressure under the wheel. Due to the ability of the flexible pavement layers to distribute the compressive stresses to a larger area in the shape of a truncated cone, the comp. stresses get decreased at the lower layers.

· Components of flexible pavements

(a) Prepared soil subgrade
(b) Granular sub-base course
(c) Granular base course
(d) Bituminous binder course or surface course

Flexible pavement consists of a wearing surface at the top, the base course followed by the sub-base course cum-drainage layer below. The lowest layer is the compacted soil subgrade which has the lowest stability among the four typical flexible pavement components.



Soil Subgrade :-

It is a layer of natural or selected soil from identified borrow pits fulfilling the specified requirements & well compacted in layers to the desired density to required thickness.

→ The subgrade is the lowest layer of the pavement layer system which supports all other pavement

component layers & the traffic loads.

→ The min. thickness of compacted subgrade is 500 mm on NH & SH & major arterial roads. & 300 mm for rural roads.

Granular Sub-base :-

It has to serve as an effective drainage layer of the pavements & has to sustain lower magnitudes of comp. stresses than base course.

→ Crushed stone aggregates are used in GSB layer. (With low percentage of fines < 5.0% finer than 0.075 mm size).

Granular Base Course :-

It sustains the wheel load stresses & disperses through larger area on to the GSB Layer below.

→ It enhances the load carrying capacity of the flexible pavement structure.

→ As per MORTH, the agg. used in the base course should have low agg. impact value (< 30%) & low Los Angeles abrasion value (< 40%).

Thin Bituminous Surface :-

It prevents the entry of surface water into the pavement layers during the rains & thus protects the base course & other pavement layers below.

→ Surface Dressing, 20 mm thick Pre-mixed Bituminous carpet with seal coat & 20 mm thick Mixed seal surface are adopted for the wearing course of roads with low vol. with less proportion of heavy vehicles.

a)

Thick Bituminous Binder & Surface Course :-

Thicker layers of dense graded bituminous surface course along with a dense graded bitumenous binder course are generally adopted on expressways, NH & SHs for heavy traffic volume with a high proportion of heavy commercial vehicles.

→ As per IRC : DBM binder course & BC surface cour

Rigid Pavements

Rigid pavements are those which possess noteworthy flexural strength or flexural rigidity.

→ These are made of Portland cement concrete (CC) & are called as CC pavements.

→ In rigid pavements the stresses are not transferred from grain to grain to the lower layers. It has the slab action & is capable of transmitting the wheel load stresses through a much wider area below the pavement slab.

→ The rigid pavement does not get deformed to the shape of the supporting layer below, as the pavement slab can bridge the gap or minor variations of the surface of the supporting layer below.

Components of Rigid Pavements

(a) Compacted soil subgrade at the bottom or lowest layer

(b) Granular sub-base course & drainage layer.

(c) Base course

(d) CC/ PQC (Pavement Quality concrete) pavement slab

→ The cc pavement is supported by a prepared soil subgrade, sub-base & a base-course. As the cc pavement slab has to withstand flexural stresses caused by moving traffic loads & warping action of the slab due to daily variation in temperatures, the cc slab is made of high quality cement concrete & is called pavement quality concrete (PQC). The cc pavement slab can serve as both the base course & surface course of pavements. A thin separation membrane is placed on the top of the base course before laying the PQC slab.

Soil subgrade: →

It consists of natural or selected soil from identified borrow pits fulfilling the specified requirements & well compacted in layers to the specified density & thickness. It is the lowest layer of the components of the cc pavement which supports all other component layers & the traffic loads.

Granular sub-base & drainage layer :-

It has to serve as an effective drainage layer of the rigid pavement to prevent early failures due to excessive moisture content in the subgrade soil.

→ crushed stone agg. with low % of fines.

Base course :-

It is provided under the cc pavement slab in low volume roads & in also roads with moderate traffic loads.

→ DLC (Dry lean concrete) are used in base course.

PQC pavement slab :-

→ As per IRC M-40 cement concrete mix with a min. flexural strength of 45 kg/cm² is used in cc pavements of highways with heavy to very heavy traffic loads.

→ The cc pavement slab is expected to withstand the flexural stresses caused by the heavy traffic loads & the warping effects in the cc slabs due to the temp. differentials betn the top & bottom of the slab caused by the daily variation in temp.

Comparison of Flexible & Rigid Pavements

Advantages of flexible pavements :-

(a) Design life is 15 years.

(b) A standard design wheel load is made use of for the design.

(c) The functional & structural evaluation studies can be carried out periodically & can be strengthened by laying an appropriately designed 'overlay'.

(d) It is possible to resort to 'milling & recycling' technique & thus utilise substantial portion of damaged bituminous pavement layers.

(e) The curing period for bituminous surface course is less & hence the surface can be opened to traffic within 24 hours.

Limitations of flexible pavements :-

→ It gets deteriorated when exposed to stagnant water due to poor drainage of surface & subsurface water. (Stripping of bitumen)

→ It is essential to carry out routine & periodic maintenance of drainage system, shoulders & pavement surface.

→ It is difficult or very expensive to carry out repairs of deteriorated bituminous pavements or patching of pot-holes during the rains or under wet weather conditions.

→ Total thickness & quantity of hard agg. req. are higher than cc pavements.

as

→ For longer service life, the life cycle cost are higher.

→ Night visibility of bituminous surface is very poor.

Advantages of rigid or cc pavements :-

(a) Do not get deteriorated under wet conditions.

(b) Service life is 30 years.

(c) Life cycle cost is lower.

(d) Total thickness & quantity of hard agg. reqd. are lower.

(e) Good night visibility under wet conditions.

Limitations of rigid pavements :-

→ The design wheel load is not equal to the standard wheel load.

→ It is not possible to restore a failed or badly cracked cc pavement.

→ Surface becomes too smooth & slippery during the long service life & re-texturing is difficult or too expensive.

→ A long curing period of 28 days is reqd. before opening to traffic.

HIGHWAY CONSTRUCTION

After the alignment is finalised & set-out for the construction of a new highway, the subsequent stages involve design of geometric features, choice of pavement type, soil investigations along the alignment, investigations & testing of construction materials, design of drainage system & structural design of pavements & other structures.

-Highway construction consists of :

(i) earth work for preparation of road formation
(ii) construction of road drainage facilities
(iii) construction of cross drainage structures
(iv) construction of pavement structure.

Earth work includes :

(a) construction of embankment using locally available soil.
(b) excavation for road stretches in cutting, grading & adequately compacting the bottom surface of the cutting; excavation of earth is also done for providing longitudinal road side drains & cross drainage structures
(c) construction of subgrade using selected soil before taking up construction of other layers of pavement

Q. Construction of embankment involves compaction of locally available soil in layers. Subgrade is also to be constructed by compacted selected soil in layers above the embankment or over the prepared cutting. Construction of drainage layer & other pavement layer is taken up after the subgrade is made ready to receive the pavement structure.

Steps for highway construction on embankment

(i) Clearing and grubbing to remove the vegetation, roots & other organic matter along the alignment upto the bottom width of the embankment & the side drains.

(ii) Re-compaction of ground that supports the embankment to the specified density.

(iii) Selected soil is spread & compacted in layers to form the embankment as specified.

(iv) Selected soil is spread & compacted in layers to form the subgrade.

(v) Excavation for the longitudinal side drains.

(vi) Construction of cross drainage structures.

(vii) Laying of drainage layer-cum-granular sub-base course in layers, over the subgrade.

(viii) Building up the shoulders in layers.

(ix) In case of flexible pavements, construction of base course in layers; in case of rigid pavements, construction of lean concrete base course.

(x) In the case of flexible pavement, construction of

bituminous binder & surface course layers; in the case of rigid pavement construction of cement concrete slab & the specified joints.

(x) Finishing works as specified.

Steps for highway construction in cutting

(i) Excavation of earth upto the desired width & depth with the cut slopes.

(ii) Compaction of the bottom of the cutting.

(iii) Excavation of longitudinal side drains.

(iv) Construction of subgrade.

(v) Construction of cross drainage structures.

(vi) Laying of drainage layer-cum-granular sub-base course over the subgrade.

(vii) Building up of shoulders in layers.

(viii) Construction of pavement layers.

(ix) Finishing works.

Construction of Highway embankment

1. Materials required:-

Materials suitable for construction of embankment are soil, moorum, gravel & a mixture of these which are free from organic matter such as stumps, roots, rubbish or such ingredients likely to decay or deteriorate.

The max. permissible size of CA is 75 mm.

Requirements of soil:

(i) Liquid limit = ≤ 70% (ii) Plasticity index = ≤ 45

(iii) Free swell index = ≤ 50%.

(iv) OMDD = ≥ 152 kg/m³ (upto 3.0m) & 160 kg/m³ (> 3.0m)

2. Construction method :-

→ The selected soil in loose condition is spread to uniform thickness using appropriate equipment over the prepared ground; the thickness of the loose soil is decided so as to obtain the specified compacted thickness of the layer (100 to 300 mm) determined during proof rolling.

→ Additional water as reqd. is sprayed so as to obtain the OMC of the soil determined from the lab. compaction test.

→ The soil with the added water is mixed thoroughly using appropriate equipment so that the water gets distributed in the soil layer uniformly; the mixed soil is spread again to uniform layer thickness.

→ The soil layer is compacted by rolling using the selected equipment so as to obtain the specified density.

→ After ensuring that the layer has been compacted to the desired density, the next layer of soil is spread over the already compacted layer, water added, mixed & compacted. The process is repeated until the desired height of the embankment is achieved.

→ Quantity control checks are done during construction of highway embankment.

Construction of Subgrade

1. Materials :-

Materials suitable for construction of subgrade & earth shoulders are selected soil, moorum, gravel & a mixture of these which are free from organic matter.

→ The max. permissible size of coarse material / stone agg. is 50 mm.

→ Liquid limit = ≤ 60 %

Plasticity index = ≤ 25

MDD = ≥ 175 kg/m³

2. Construction Method :-

→ Same as embankment construction.

→ The max. compacted thickness of layer is 200 mm as per MORTH.

Compaction of soil

By compacting the soil, the particles are mechanically constrained to be packed more closely, by expelling part of the air voids.

→ Compaction increases the density & stability, reduces settlement & lowers the adverse effects of moisture.

→ As per IRC, IS heavy compaction or modified Proctor compaction test is to be carried out on soil to be used in both embankment as well as in subgrade of all highways.

→ For low-volume roads, light compaction or Proctor test may be adopted to determine the OMC & MDD.

→ The MDD value of soils is made use of for specifying the DD to be achieved during field compaction in terms of a %, such as 95 or 97 of MDD value of respective soils for compacting the embankment & subgrade in the field.

→ As per IRC & MORTH, the max. thickness of each compacted layer shall not exceed 200 mm in construction of both embankment & subgrade.

→ The total compacted thickness of subgrade for highways is 500 mm. (in three layers).

Equipment for Compacting Soils

Soil compaction is achieved in the field either by tamping or ramming or by vibration.

→ Cohesion-less sand may be compacted by vibration, getting & ponding with water.

→ Compacting equipments:
- (i) Rollers
- (ii) Rammers
- (iii) Vibrators

(i) Rollers :-

The loose soil particles get packed closer during the rolling process, as part of the air voids get expelled due to compression & slight re-arrangement of the soil grains.

Types:

(a) Ordinary smooth wheel type rollers
(b) Vibratory rollers
(c) Pneumatic tyred rollers
(d) sheep-foot rollers

Smooth wheeled rollers :-

There are two types of smooth wheeled rollers;
(i) three-wheeled rollers (Macadam roller)
(ii) tandem rollers with two wheels of same width.

→ The gross weight of three-wheeled type rollers varies from 8 to 15 tonnes & that of the two-wheel tandem rollers varies from 3 to 14 tonnes.
→ These are suitable for compacting granular soils, aggregates & other pavement materials.
→ These are not suitable for cohesionless sand, non-plastic silts & clayey soils with high plasticity.

Vibratory rollers :-

In these, compaction is effected due to both the dynamic effect of the vibratory force & also the static weight of the roller.
→ These may be used for compacting a wide range of soils such granular soils & pavement layers with granular materials such as aggregates.
→ 2 types: (i) with two steel drums in tandem of the total static wt. of 8 to 12 tonnes.
(ii) single vibrating steel drum of static wt. 10 to 15 tonnes.

Pneumatic tyred rollers :-

A no. of pneumatic wheels are mounted on two or mor axles, under a loaded platform. The gross load of the rollers can be substantially increased by adding sand bags or any other load on the platform.

→ These may be of self propelled type or pulled by trac

→ These are suitable for compacting non-plastic silt & fine sands. It also used in compacting pavem layers consisting of bituminous mixes.

Sheep-foot roller :-

It consists of hollow steel cylinder with projecting fee

→ The wt. of the roller can be increased by filling the drum with wet soil.

→ These may be pulled by tractors.

→ These are suitable for compacting clayey soils.

(ii) Rammers :-

These are useful to compact relatively small areas & where the rollers cannot operate such as compactio of deep & narrow trenches, foundation of structures, & slopes of embankments & cuts.

→ The rate of output of rammer is lower than that of roller.

(iii) Plate vibrators :-

These are suitable for compacting layers of dry cohesionless granular material like sand.

→ Also these are used for compacting trenches, foundn & slop

Compaction of sand :

→ This can be densified by vibration technique. It can be compacted in wet sands by rolling the layer when it is saturated with water, the sand is watered heavily & rolled using a smooth wheeled roller or pneumatic tyred roller.

→ Jetting & ponding with water is the most effective method of compacting cohesion-less sands.

Excavation of Earth

Excavation is the process of cutting or loosening & removing earth including rock from its original position, transporting & dumping it as a fill or spoil bank.

→ Excavation may be needed in soil, soft rock or even in hard rock, before preparing the formation of a new highway.

Equipments for excavation

1) **Bull dozer :-**

It is a versatile earth moving equipment used for clearing site, opening up pilot roads, moving earth for short haul distances of about 100m & also in several other jobs.

→ It can be excavate even relatively stiff earth & some types of soft rock.

→ It can be used for shallow excavation work during highway construction.

→ Bull dozers with chain-drive are versatile machines that are mounted on crawler tracks & they can operate even in slushy & marshy ground & on steep slopes.

(ii) Scraper :-

It is one of the useful earth-moving equipment as it is self operating & can dig earth up to a shallow depth haul & discharge the material in layers of uniform thickness, where required.

→ The main advantage of scraper is that the depth of excavation of earth & the thickness of spreading the excavated earth at the desired stretch can be controlled precisely.

→ These are not capable of excavating stiff matrix

(iii) Power shovel :-

It is used to excavate earth of all classes except rock & to load it into wagons.

→ These may be mounted on crawler tracks & they are stable & can move at low speeds.

→ These include the mounting, cab, boom, dipper stick dipper & hoist line.

→ This can effectively operate to excavate earth from a lower level where it stands.

→ As the dipper moved upwards, the cutting edge can excavate even stiff earth; the bottom of the shovel can swing & the excavated material can be dumped into the wagon.

(iv) Hoe :-

It is an excavating equipment of power shovel family. It is meant to excavate below the natural surface where the machine stationed & is capable of having precise control of depth of excavation at close range work.

→ It can exert high tool pressure & hence can excavate stiff material which cannot be excavated by dragline.

(v) Dragline :-

It is used to excavate soft earth & to deposit in near-by banks or to load into wagons.

→ It may be mounted on crawler track.

→ The bucket is thrown out from the dragline on the top of the earth to be excavated & then pulled backtowards the base of the machine.

→ It can operate from natural ground while excavating earth with the bucket from a lower level or a pit.

(vi) Clam shell :-

It consists of a heavy bucket of two halves in the form of a shell, hinged together at top. The shells may be attached to the shovel-crane unit or at the boom of a dragline.

→ The open clam-shell bucket is thrown on the top of the loose material after the material is dug & as the bucket is lifted, the two halves close entrapping the material into the bucket.

→ It is useful for excavation of loose material at or below existing ground surface.

Construction of flexible pavements

Construction of Sub-base :-

A granular sub-base (GSB) course is laid in between the subgrade & the base course of all highway pavements, in one or more layers.

→ The GSB should be laid over the full width of the prepared subgrade, extending upto the side drains so to serve as a drainage layer of the pavement.

Materials :-

Materials used for GSB are (i) crushed stone aggregate (ii) gravel, (iii) coarse sand, (iv) selected soils such as moorum with less fines & very low plasticity.

As per MORTH :

→ Passing 425 μ sieve with $w_L < 25\%$ & $I_p < 6.0\%$

→ Fines passing 75 μ sieve : < 10%

→ CBR < 30%

Construction method :-

→ Spreading of material to desired thickness, grade & camber using a motor grader with hydraulic control of the blade.

→ Compaction of loose GSB layer by rolling for thickness > 100 mm & upto 225 mm.

→ Continuation of rolling till at least 98% of MDD is achieved.

Construction of Granular base course :-

The common types of base course materials used in India are 'Wet Mix Macadam' (WMM), Water Bound Macadam (WBM), soil agg. mixes & stabilized soil mixes.

Wet Mix Macadam (WMM) :-

WMM consists of a well graded hard crushed aggregate & adequate proportion of water mixed thoroughly in a mixing plant; the wet mix is spread over the prepared sub-base course with a mechanical paver & rolled to a dense mass.

→ The min. & max. thickness of each compacted layer have been specified as 75 and 200 mm respectively.

→ Crushed SA should fulfill the following properties:

Los Angeles Abrasion value = < 40%.

A.I.V = < 30%.

F.I & E.I = < 30%.

Ip = < 6.0.

Water Bound Macadam (WBM) :-

WBM is the construction of 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 sub-base, base course or even surface course of low volume roads.

→ The compacted thickness of each layer depends on size & gradation of the aggregates used.

→ 3 gradations, grading-1, grading-2, grading-3 are suggested by IRC & MORTH. Grading-1 contains the largest size of CA & grading-3 the smallest.

→ Grading-1 Layer of 100 mm thickness is to be used only to the sub-base course.

→ When used as a surfacing course, it is desirable to provide a bituminous surfacing course over the WBM layer.

→ materials: (i) CA : LAAV < 50% } → sub-base cours
AIV < 40 % }

LAAV < 40% } → base course.
AIV < 30% }

LAAV < 40% } → Surface cours
AIV < 30% }

→ Grading-1 : compacted thickness = 100mm → sub-b
Grading-2 & Grading-3 = 75 mm thickness
(sub-base or base course)

(ii) Screenings:- consist of same material as the CA, but of smaller size.

(iii) Binding material :- consist of fine grained mate passing 425 μ sieve.

→ Kankar nodules or lime stone dust

→ Ip = 4 to 8

Construction of Bituminous Pavement Layers

On roads with heavy traffic loads, additional bituminous pavement layers in the form of 'binder course' or base course & binder course' are laid before laying the bituminous surface course.

→ It is essential to provide an appropriate type of interface treatment before laying any type of bituminous layer over another layer. If the bituminous layer is to be laid over a granular or non-bituminous base or sub-base course, the interface treatment consists of application of both 'prime coat' and 'tack coat'. If the bituminous layer is to be laid over an existing bituminous surface, the interface treatment consists of application of only tack coat.

→ Different types of bituminous base course:

(i) Bituminous macadam
(ii) Penetration macadam
(iii) Built-up spray Grout

→ Different types of bituminous binder course:

(i) Bituminous macadam
(ii) Dence Bituminous macadam

→ Different types of thin bituminous surface course on roads with low to moderate traffic volume:

(i) Bituminous surface Dressing
(ii) Open-graded Premix carpet with seal coat
(iii) Closed Graded Premix Surfacing or Mixed seal surfacing

Interface treatment

Prime coat :-

Spraying of liquid bituminous binder of low viscosity over a granular or non-bituminous surface is called application of prime coat or priming.

Objectives of priming a granular surface :

(i) to penetrate deep into the surface & plug or seal the voids on the surface.

(ii) to coat & bond the loose particles on the surface.

(iii) to render the surface of the base course water resistant.

(iv) to permit the tack coat to be applied over the primed surface to provide proper adhesion between the base & the bituminous pavement layer constructed above the treated granular base.

Materials :-

→ Cationic bitumen emulsion of SS-1 grade or medium curing cutback bitumen may be used.

Tack coat :-

It is the application of a small quantity of liquid bituminous binder of low viscosity over either a primed granular surface or over an existing bituminous or cement concrete surface.

Objective :

→ to provide adequate interface bond between the receiving pavement surface & the new bituminous layer being overlaid.

materials:-

→ cationic bitumen emulsion of grade PS-1 or suitable paving bitumen of low viscosity such as VG-10 grade bitumen may be used.

→ For temp. below 0°c, cutback bitumen of RC-70 grade may be used.

Seal coat :-

Bituminous Base Course

Bituminous Macadam (BM) :-

It consists of crushed aggregate and bituminous binder heated and mixed in a hot mix plant at specified temperature, transported to the construction site, laid with a mechanical paver & compacted by rollers.

→ BM is laid in compacted thickness of 50 to 100 mm.

→ The BM layer should be covered by a suitable surfacing course before exposing to weather or traffic.

→ BM base course is considered superior than other types of base course materials such as penetration macadam, WMM or WBM w.r.t load dispersion characteristics & durability.

Materials :

→ Bitumen : VG-30 (60/70 penetration grade)
VG-20 (70/80 ") - Cold weather

→ Aggregates: Hard crushed rock retained on 2.36 mm

Penetration Macadam :-

It may be used as a base course of flexible pavements in small road projects where hot mix plant facility is not available.

→ The CA are first spread & compacted well in dry state, hot bituminous ~~bitumen~~ binder is sprayed in fairly large quantity on the top of this layer. The bitumen penetrates into the voids from the surface of the compacted aggregates, thus filling up a part of the

voids & binding more stone aggregate together.

→ The compacted thickness of each layer is 50mm or 75 mm.

Built-up spray grout (BUSG) :-

It consists of a two-layer composite construction of compacted crushed stone agg. with bituminous binder applied after each layer & key agg. placed on the top of the second layer. After the first layer of CA is compacted, the bitumen binder is sprayed which penetrates into the layer; then the second layer of CA is spread & compacted, binder sprayed, key agg. spread & compacted.

→ The compacted thickness of two layers of CA including the key agg. is 75 mm.

→ BUSG is used as a base course of flexible pavements in very small road projects.

Thin Bituminous Surfacing

Bituminous Surface Dressing (BSD) :-

It is provided over a prepared base course or existing pavement to serve as thin wearing coat.

→ SD consists of application of suitable grade of bitumen or emulsion by spraying over a prepared base course or existing pavement surface followed by spreading specified size of hard agg. at recommended rate & rolling.

→ BSD is a cost effective surface-treatment to provide a dust free & impermeable pavement surface.

→ IRC has provided two types of SD work:

(i) Single coat SD → It consists of application of bituminous binder material followed by spreading of aggregate cover and rolling. (Low vol. roads, in low rainfall)

(ii) Two-coat SD → It is formed by spraying the first layer of binder, spreading a layer of cover aggregates & rolling, which forms the first coat. Over the first compacted layer, the second layer of binder is sprayed, cover agg. is spread & rolled. The agg. size of the second layer is smaller than that of the first layer. (High vol. roads, in high rainfall)

Open graded premix carpet (PC):-

It consists of CA of nominal size 13.2 mm (passing 26.5 mm & retained on 11.2 mm) premixed with a suitable type & grade of bituminous binder, spread and compacted to a thickness of 20 mm followed by application of seal coat, to serve as a thin surface course of the pavement.

→ The PC mix may either be prepared in a hot mix plant using paving grade bitumen binder or as a cold mix using cationic bitumen emulsion.

→ The 20 mm PC with seal coat forms one of the thin bituminous surfacing that may be laid over a GSB or as a re-surfacing over an existing bituminous surface course.

SOIL STABILIZATION

Soil stabilization means, improvement of the stability or bearing power of the soil by the use of controlled compaction, proportioning & or the addition of suitable admixture or stabilizers.

→ It deals with physical, physio-chemical & chemical methods to ensure that the stabilized soil serves its intended purpose as pavement component material.

Effects of soil stabilization :-

→ Increase in the strength characteristics

→ Modification in some of the undesirable properties of the soil, such as high plasticity, swelling etc.

→ Change in chemical properties.

→ Retaining desired minimum strength even after subjecting the stabilized soil to soaked condition.

Soil stabilization Techniques

(a) Proportioning and mixing different materials :

→ The proportioning technique aims at achieving a well graded soil having coarse to fine soil, which can provide both the components of cohesion and friction.

→ Various locally available soils & aggregates are mixed in suitable proportions & compacted to serve the desired objective.

(b) Cementing agents :-

The strength of the stabilized soil can be increased by the addition of cementing agents like Portland cement, Lime, Lime-flyash or some of the chemical stabilizers.

→ Bituminous binders Impart binding effect to non-cohesive soils.

(c) Modifying agents :-

Modifiers modify the undesirable properties such as high plasticity, swelling of certain soils.

→ Lime is the most common modifier used for improving highly plastic clayey soils.

→ Portland cement acts as modifier.

(d) Water proofing agents :-

Absorption of water can be stopped or retarded by means of some water proofing agent.

→ Ex. use of bituminous binder.

(e) Water repelling agents :-

→ It retards the water absorption.

→ Ex. Dirsol resin, resinous materials.

(f) Water retaining agents :-

It is useful to retain some moisture or absorb moisture from the atmosphere & Imparts some apparent cohesion & retains the stability of soil.

→ Ex. Calcium chloride

(g) Heat treatment :- (thermal stabilization)

It results in some useful or desirable change in prop. of clayey soils, which depend on temperature & heating.

→ This include reduction in swelling properties.

→ Heat treated soil may be used as a soft aggregate in mechanical soil stabilization or as a pozzolanic additive in soil-lime stabilization.

(h) Chemical stabilization :-

→ Chemicals are used as additives in soil-cement and soil-lime stabilization.

→ These are used in very small proportion (< 0.5% by wt of soil).

→ These improve the strength and durability of soils.

Methods of Soil stabilization

(i) Mechanical soil stabilization :-

Correctly proportioned materials (aggregates & soils) when adequately compacted to get a mechanically stable layer, the method is called mechanical stabilization.

→ Two basic principles of this method are:

(a) Proportioning

(b) Compaction

→ If a granular soil containing negligible fines is mixed with a certain proportion of fine or binder soil, the stability can be increased & vice versa.

→ This method has been applied in the construction of sub-base & base courses of low volume roads & also used as surface course for low cost roads.

Properties of soil-aggregate mixtures

The desirable properties of soil-aggregate mixtures are strength, incompressibility, less changes in volume & stability with variation in moisture content, good drainage, less frost susceptibility & ease of compaction.

→ Compacted agg. without fines have no cohesion, high permeability, no frost action & no variation in volume or stability with moisture variations.

→ Compacted agg. with compacted fines just filling the voids, have cohesion, but less permeable, cause frost action & variation in volume & stability due to moisture variations.

→ Aggregates with excess fines have lost their contacts with each other & float in mix is less desirable with poor drainage, more variation in stability & volume with moisture variation & high frost susceptibility.

With proper proportioning it is possible to attain a mix with best combination of the desirable properties.

Factors affecting mechanical stability:-

(i) Mechanical strength of aggregates
(ii) Gradation
(iii) Properties of soil
(iv) Presence of salts, mica etc.
(v) Compaction

(ii) Soil-cement stabilization

Soil-cement is an intimate mix of soil, cement and water which is well compacted and cured to form a strong base course so as to fulfil the specified stability and durability.

→ Cement treated soil refers to the compacted mixes where cement is used in small proportions to impart some strength or to modify the properties of soil & these mixes do not fulfil the mix design requirements.

→ In granular soil the mechanism of stabilization is due to development of bond betn the hydrated cement & the compacted soil particles at the points of contact.

→ In fine grained soil, the stabilization is due to reduction in plasticity & formation of matrix enclosing small clay lumps.

Factors influencing properties of soil-cement :-

(a) Soil :-

→ The physical properties like particle size distribution, dry content, specific surface, liquid limit & plasticity index affect the properties of soil-cement.

(b) Cement :-

→ An increase in cement content generally causes increase in strength & durability.

→ The cement content reqd for stabilization of soils depends on the soil type.

→ Both normal & air entraining cement give almost the same results of stabilization.

(c) Pulverisation and mixing :-

→ Better pulverisation & degree of mixing result in higher strength.
→ Presence of unpulverised dry lumps of soil reduces the strength & durability of soil-cement.
→ The size of lump should be as small as possible.
→ Uniformity of mixing soil, cement & water is essential.
→ Increase in period of wet mixing & delay in compaction cause reduction in density, stability & durability of soil-cement.

(d) Compaction :-

The OMC for adequate compaction or to achieve MDD is enough for the purpose of hydration of cement
→ of the dry density is increased by increasing the amount of compaction, the strength & durability of the soil-cement also increase.

(e) Curing :-

During curing adequate moisture is to be retained.
→ High temp. of curing accelerates the rate of gain in strength. Because strength increase with curing period.

(f) Additives :-

→ Lime, is a useful additive when clayey soil or an organic soil is to be stabilized.
→ Sodium hydroxide, sodium carbonate & calcium chloride are chemical additives to soil-cement.

Application :-

→ Cement-treated soils form a strong & excellent subgra of all types of pavements.
→ Can be used as the sub-base course of both flexible & rigid pavements even for heavy traffic roads.
→ Can be used in the base course of low-volume roads

(iii) Soil-Lime Stabilization

When soils are treated with lime, either modification in soil properties or binding or both actions may take place.
→ In case of clayey soils, reduction in plasticity takes plac & volume change due to variation in moisture content
→ Soil-lime mixes become friable & easy to be pulverized having less affinity with water, there could be 'pozzolanic action' resulting in slow rate of increase in strength with curing period.
→ The MDD of soil-lime mix is decreased by 2 to 3% in term of untreated soils, however this decrease in DD with the addition of small proportion of lime does not cause reduction in strength.

Factors affecting properties of soil-lime :-

(a) Soil type :-

Properties of clay fraction in the soil affect the physical & other properties such as base exchange capacity & pozzolanic action.
→ Increase in strength in a soil-lime mix depends on the pozzolanic characteristics of the soil.

(b) Lime content :-

An increase in lime content causes a slight change in liquid limit & a considerable decrease in plastic limit resulting in reduction in plasticity index.

→ When lime content is increased in the mix, there is a high rate of increase in stability.

→ With proper lime treatment, it is possible to make the clay almost non-plastic with plasticity index reducing to practically zero.

→ There is also considerable reduction in swelling & increase in the shrinkage limit due to lime treatment of clayey soils.

(c) Types of lime:-

Quick lime or calcium oxide (CaO) is found to be more effective than hydrated lime [$Ca(OH)_2$]

→ Hydrated lime is commonly used in stabilization work, either as a dry powder or by mixing with water.

(d) Compaction :-

Compacted density is important as regards the strength of soil-lime is concerned. Compaction is carried out at once to attain MDD.

(e) Curing :-

The strength of soil-lime increases with curing period upto several years. The rate of increase in strength is rapid during the initial period of curing.

→ At low temp. the rate of strength decreases & below freezing point there is no gain in strength.

(f) Additives:-

→ Portland cement & pozzolanic materials like flyash & surkhi are most promising additives which increase the strength of soil-lime.

→ chemical additives like sodium meta-silicate, sodium hydroxide & sodium sulphate are also useful to soil-lime.

Applications:-

→ soil-lime is suitable as sub-base course for all type of pavements & base course for pavements with very low traffic.

→ soil-lime is suitable in warm regions.

(iv) Soil-bitumen stabilization

The basic principle is considered as water-proofing with some binding action. By water-proofing the inherent strength & other properties of soil could be retained.

→ In granular soils, the coarser grains may be individually coated & stuck together by a thin film of bituminous materials. But in fine grained soils bituminous materials plugs up the voids betn small soil clods, thus water proofing the compacted soil-bitumen.

→ Most commonly used bituminous materials are cutback and emulsion.

→ Emulsion is used, when there is scarcity of water for construction purposes.

Factors affecting properties of soil-bitumen:-

(a) Soil :-

The particle size & the gradation of soil influence the properties of the soil-bitumen mix.

→ A small proportion of fines in the soil are preferred.

→ The relative affinity of soil for water & bitumen depends on surface chemical factors.

(b) Type of bituminous binders:-

→ Cutbacks of highest grade can be mixed with soil at the time of construction.

→ Emulsion gives slightly inferior results than cutback.

(c) Amount of bituminous binders :-

→ Increasing proportion of bitumen causes a decrease in MDD of soil-bitumen, but the stability increases upto a certain value of optimum bituminous binder content & then rapidly decreases.

→ Water absorption decreases with increase in binder content

→ The optimum binder content for max^m stability ranges from 4 to 6% by weight of dry soil, depending upon the soil properties.

(d) Mixing:-

Improved type of mixing with low mixing period may be preferred.

→ The soil should made wet by mixing the soil with water before adding cutback.

→ Mixing temp. also affects the properties of mix, depending upon the type & grade of cutback used and the soil type.

(E) Compaction:-

Better the compaction, higher will be the stability and resistance to absorb water.

→ The OMC values corresponding to MDD, max. soaked stability & min. water absorption for a soil-bitumen mix may differ slightly depending on the proportions & properties of the mix constituents.

(F) Curing:-

By curing the soil-bitumen layer, the water & the volatiles are allowed to evaporate; there-by allowing the bitumen to be effective to impart the binding & water proofing actions.

→ It depends on curing temp., relative humidity & soil type.

(G) Additives:-

→ Anti-stripping & reactive chemical additives are added to improve the properties of soil-bitumen.

→ Portland cement is used to increase the stability of the mix.

Applications:-

→ Soil-bitumen may be used as a base course or sub-base course of low volume roads & even as surface course for roads with light vehicles in low rainfall regions.

HIGHWAY DRAINAGE

Highway drainage is the process of removing & controlling excess surface and sub-soil water within the roadway or right of way.

→ The highway drainage system consists of :

(i) Surface drainage system

(ii) Subsurface drainage system

1. Surface Drainage System

Removal and diversion of surface water from the roadway and adjoining land is known as surface drainage.

The various components of surface drainage system are :

(a) the cross-slope or camber of the pavement & the shoulders

(b) the road side drains

(c) cross drains

Camber or cross-slope :-

The water from the pavement surface and shoulders is first drained off to the road side drains with the help of the cross-slope or camber.

→ The rate of cross-slope depends on : (a) the type of pavement surface & (b) amount of rainfall in the region

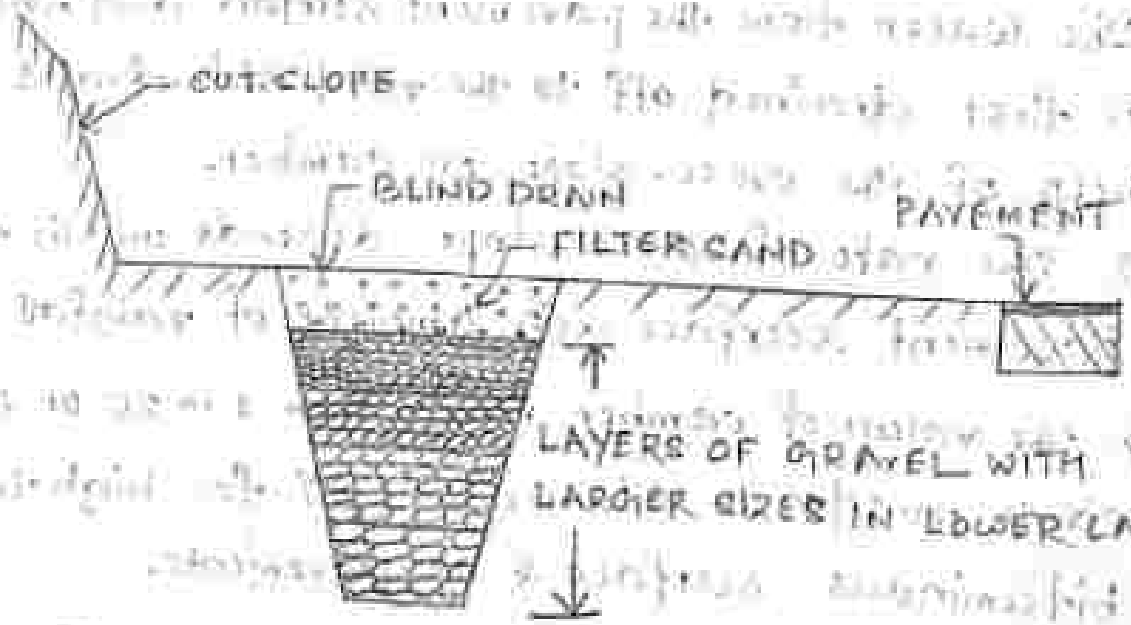
→ The value of camber range from 1 in 25 or 4.0% for earth roads to 1 in 60 or 1.7% for high type bituminous surface & cc pavements.

Road side drains :-

→ The road side drains of highways passing through rural areas generally open, unlined or 'kutcha' drains of trapezoidal shape, cut to suitable cross section and longitudinal slopes. These drains are provided parallel to the road alignment & hence known as longitudinal drains.

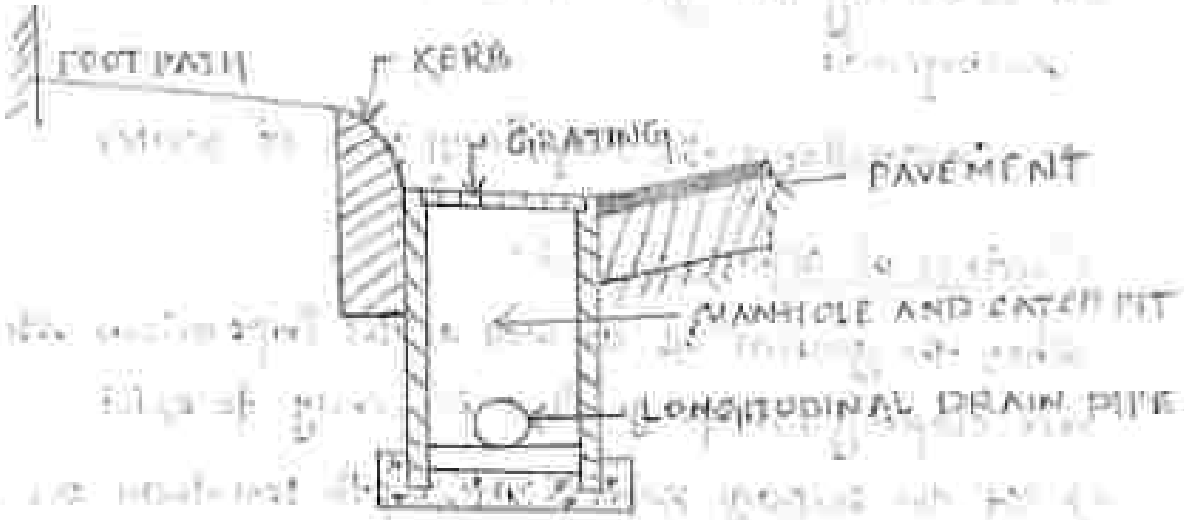
On plain terrain with embankments these are provided on both sides beyond the toe of embankment. But, on sloping terrain these are provided on one side only beyond the toe of embankment along the highest side of the slope.

→ On cutting, these drains are installed on either side of the formation. On places where there is restriction of space, construction of deep open drain may be undesirable. On such cases drainage trenches of suitable depth & cross-section are dug & properly filled with layers of filter material consisting of coarse sand & gravel to form the 'covered drain'.



(DRAINAGE TRENCH FILLED WITH FILTER MATERIAL)

→ On urban roads because of the limitation of land width under ground longitudinal drains are provided between the kerb and the pavement for short distances.
Water drained from the pavement can be carried forward along these drains & then may be collected in catch pits at suitable intervals & lead through under-ground drainage pipes.



Cross drains :-

On rural highways, the water flowing along the road side drains are collected by suitable cross drains through cross drainage structures (CD) at locations of natural valleys & streams & disposed off to the natural water course.

→ These CD structures may be a culvert, depending on the quantity of water to be carried across & the span.

→ Different types of culverts adopted on rural roads are slab, box or pipe culverts.

→ When the width of stream to be crossed is more than 6.0m, the CD is called minor bridge & when the total length of the bridge is more than 60m, it is known as major bridge.

2. Sub-surface drainage

Diversion or removal of excess soil-water from the subgrade is known as subsurface drainage.

The subsurface drainage system enables :

(a) intercepting the seepage flow of water & diverting away from the roadway to the nearest water course

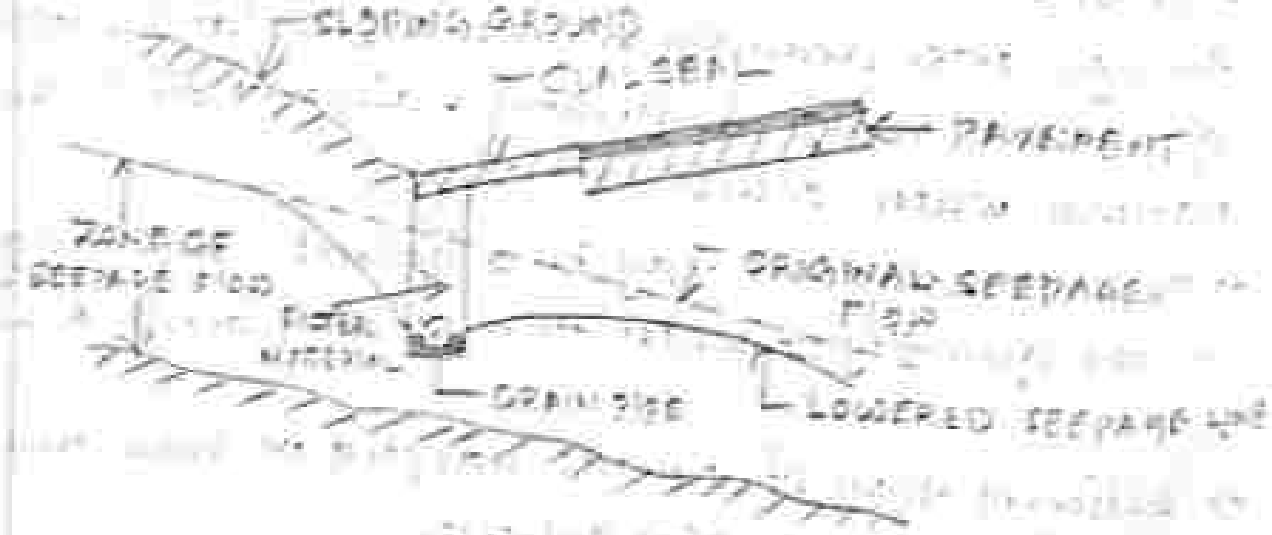
(b) Lowering the ground water level well below the subgrade.

(c) Controlling the capillary rise of water.

Control of seepage flow :-

When the ground GL as well as the impervious strata below are sloping, seepage flow is likely to exist.

→ If the seepage zone is at depth less than 0.6 to 0.9m from the subgrade level, longitudinal pipe drain in trench filled with filter material and clay seal may be constructed to intercept the seepage flow.



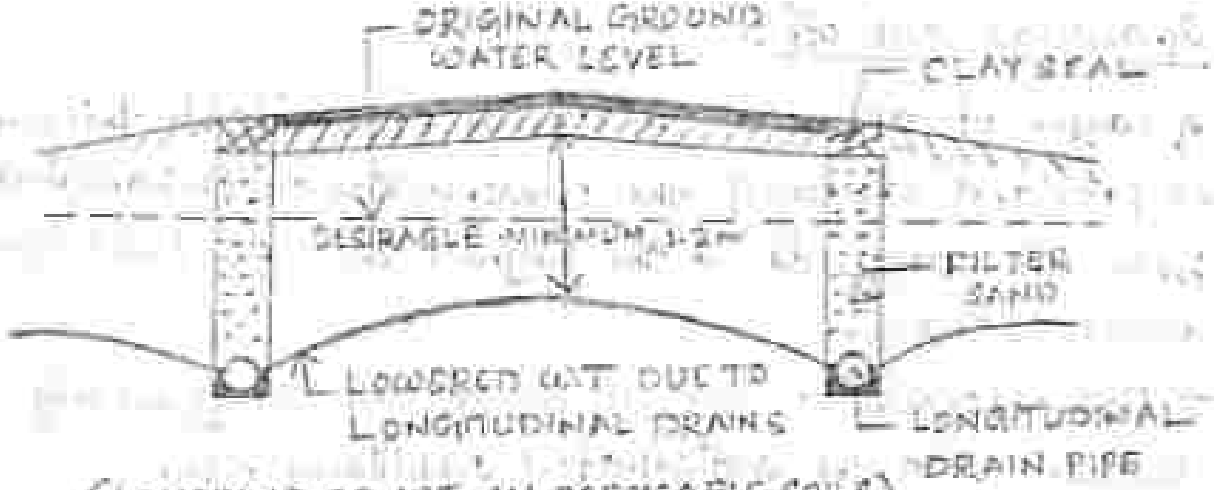
Lowering of water table:-

The highest level of WT should be fairly below the level of subgrade. The WT should be kept atleast 1.0 to 1.2 m below the subgrade.

→ On places where WT is high the best remedy is to take the road formation on embankment of height not less than 1.2 to 1.5 m above the G.L.

→ When the formation is to be at or below the G.L at cuttings, it is necessary to lower the WT so as to keep the subgrade as dry as possible.

→ On permeable soils, the high WT can be lowered by construction of longitudinal drainage trenches with drain pipe & filter sand.



(LOWERING OF WT IN PERMEABLE SOILS)

→ On impermeable or less permeable soils, in addition to longitudinal drain trenches, transverse drains have to be installed at suitable intervals in order to effectively drain off the water & thus to lower the WT upto the level of transverse drains consisting of perforated pipes.

Control of capillary rise:-

of the water reaching the subgrade due to capillary rise, it may be checked by providing a suitable capillary cut-off by one of the two methods:

(a) granular cut-off

(b) Impermeable capillary cut-off.

Granular cut-off:-

↑ layer of granular material of suitable thickness is provided during the construction of embankment, betn the subgrade & the highest level of subsurface water table.

→ The thickness of cut-off should be sufficiently higher than the anticipated capillary rise.

Impermeable capillary cut-off:-

In this method, an Impermeable membrane or a bituminous layer is inserted in place of granular blanket during the construction of the embankment

HILL ROADS

Hilly regions have steep topography, difficult and hazardous terrain, high altitude areas and extreme climatic conditions.

Roads paning through hilly terrain and leading to towns and villages located on hills are called hill roads.

→ Hill roads are also classified as National Highways (NH), State Highways (SH), Major District Roads (MDR), other District Roads (ODR) and Village Roads (VR) as in plain terrain.

→ | Terrain classification | Cross slope, % |
|---|---|
| (i) Plain | 0 to 10 |
| (ii) Rolling | 10 - 25 |
| (iii) Mountainous | 25 - 60 |
| (iv) Steep | 7 60 |

→ The Border Roads Organisation (BRO) (GOI) has classified hill roads as :

(a) National Highways
(b) Class 9 (6m wide for 3-tonne vehicles)
(c) Class 5 (4.9 m wide for 1-tonne vehicles)
(d) Class 3 (2.45 to 3.65 m wide for jeeps)

Different types of curves

(i) Hair-pin curves
(ii) Salient curves
(iii) Re-entrant curves.

Hair-pin curves:-

The curve in a hill road which changes its direction through an angle of 180° or so, down the hill on the same side is known as hair-pin curve.

→ This curve is so called because it confirms to the shape of a hair-pin. The bend to formed at the hair-pin curve in a hill road is known as hair-pin bend.

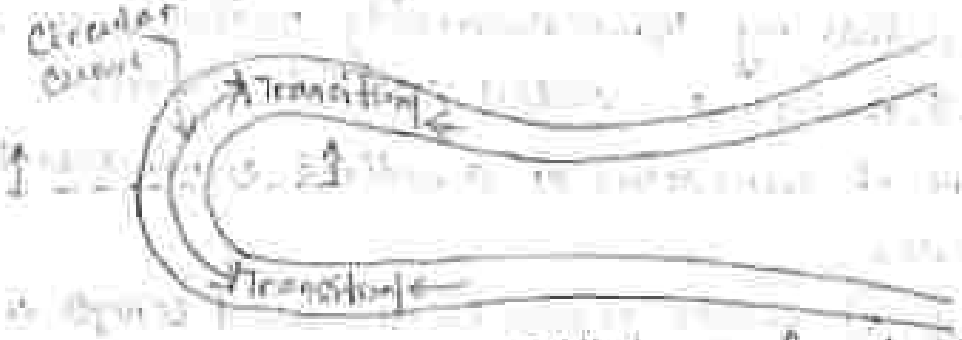
→ At sharp horizontal curves it becomes necessary to provide hair-pin bends, with increase in radius of the curve.

→ Because of precipitous rock, deep valley, steep ascents to obligatory points & presence of innumerable gorges, hair-pin bends are unavoidable on hill roads.

→ A hair pin bend is located on a hill ~~road~~ side having the minimum slope and maximum stability.

→ It must also be safe from view point of land-slides and ground water.

→ Hair-pin bends with long arms and farther spacing should be preferred. This will reduce construction problems and expensive protective works.



→ The full roadway width is surfaced at the hair-pin bends.
→ Approach gradients should not be steeper than 5%. for 40m.
→ The straight length betn two successive hair-pin bends should be minimum of 60m excluding the length of circular and transition curves.

Design criteria for planning hair-pin bends :-

(a) Min. design speed = 20 kmph.
(b) Min. radius of the inner curve = 14m.
(c) Min. length of transition = 15m.
(d) Superelevation in circular portion of the curve = 1 in 20.
(e) Min. width of carriageway at the apex of the curve are 11.5 & 9.0 m respectively for 2 lane & single lane pavements of NH & SH. For MDR & ODR it is 7.0m & for VR it is 6.5m.
(f) The maximum & minimum gradients are 1 in 40 & 1 in 200 respectively at the curve.
(g) Approach gradient should not be steeper than 1 in 20(5%) for a length of 40m & not steeper than 1 in 15 (6.67%)
(h) For good visibility at the hair-pin bend, the island portion shall be cleared of all obstructions including trees and shrubs.

Salient curves :-

The curves having their convexity on the outer edge of the hill road are called salient curves.

→ The centre of curvature of a salient curve lies towards the hill side.

→ This type of curve occurs in the road length contour on the ridge of a hill.

→ The bend so formed at the salient curve in a hill road is known as corner.

→ At such a curve or at corner bend, the portion of projecting hill side is usually cut down to improve the visibility.

→ The outer edge of the road at such a curve is essentially provided with a parapet wall for protection of vehicles from falling down the hill slope.

→ These are very dangerous for fast moving vehicles.

Re-entrant curves :-

The curves having their convexity on the inner side of a hill road are called re-entrant curves.

→ The centre of curvature lies away from the hill side.

→ This type of curve occurs in the road length constructed in the valley of a hill.

→ At such curves, the parapet wall is provided only for safety of fast moving traffic.

→ These are less dangerous as they provide adequate visibility to the fast moving traffic.

Retaining Walls

Retaining walls are most important structures in hill road construction to provide adequate stability to the roadway and to the slope.

→ These are constructed on the valley side of the roadway and also on the cut hill side to prevent land slide towards the roadway.

→ These are relatively rigid walls used for supporting soil laterally so that it can be retained at different levels on the two sides.

→ Generally, the back side of the wall is stepped while the face is kept vertical or inclined.

→ Sufficient no. of weep holes are provided all along the length as well as height of wall to drain off gravitational water of earth fill.

→ Dry stone masonry is preferd to masonry in mortar as the former permits easy drainage of seeping water.

→ The width at the base will depend upon the height of the earth to be retained as the more the height, the greater will be the pressure at the base and the top can be kept 2 bricks thick.

Definition

→ The walls constructed for retaining or supporting earth against their back are called retaining walls.

Breast walls :-

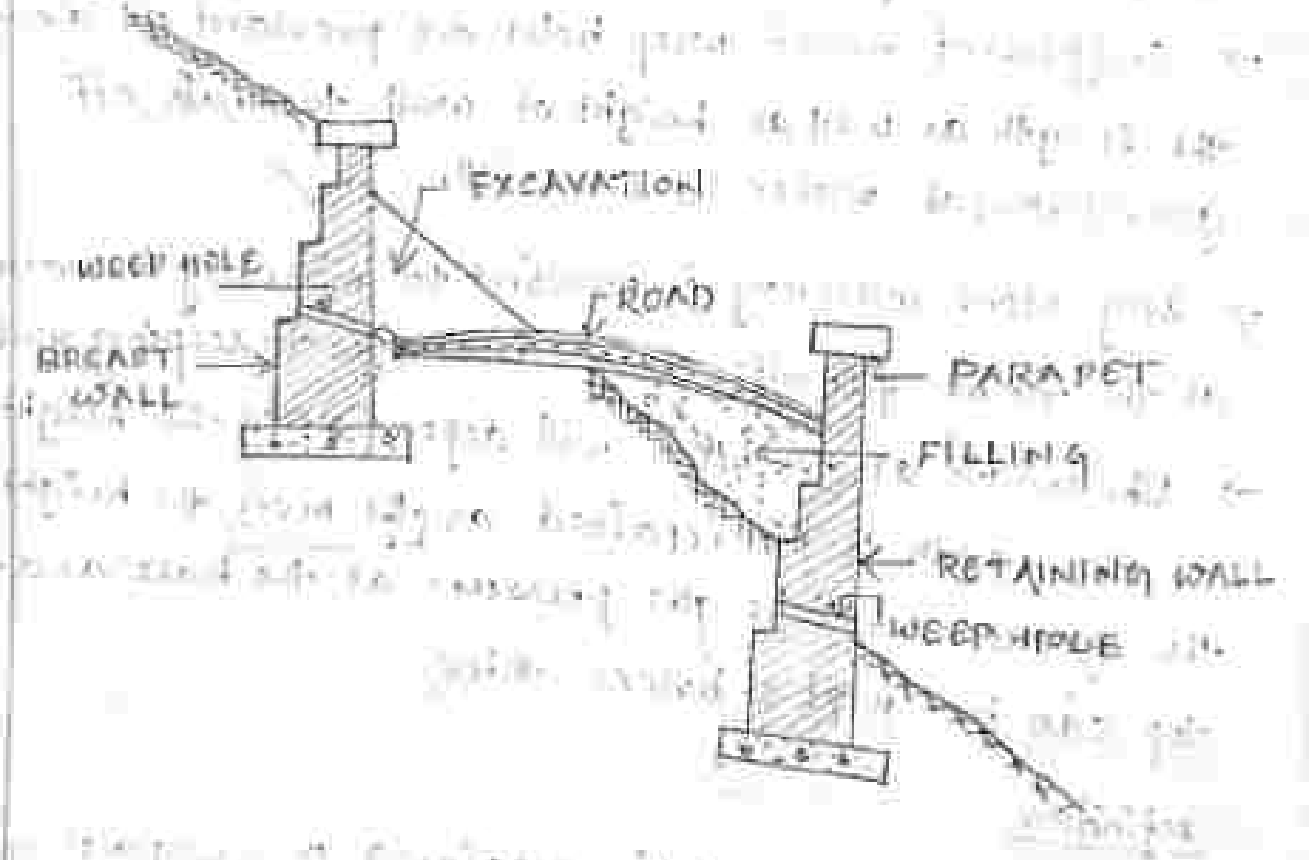
→ A breast wall is constructed to protect the natural sloping ground from the cutting action of natural agents.

→ Breast walls also prevent slides of unreliable soils.

→ These walls may be 0.6 m wide at the top.

→ Weep holes should be provided at regular intervals among the length of the wall to relieve the walls of saturated earth pressure.

→ These are so designed that their line of pressure should be normal to the earth pressure or thrust.



HIGHWAY MAINTENANCE

Objectives :-

The basic objectives of highway maintenance from time to time are to ensure to provide the following facilities:-

(a) continue to provide safe and convenient travel facilities to the road users.

(b) avoid detour, speed changes, due to failures in roadway facilities & to minimise the increase in road transportation cost.

(c) preserve the asset & investments made on the road infrastructure by taking appropriate maintenance measures at the right time.

(d) avoid rapid deterioration of the pavement structure leading to huge maintenance cost by carrying out timely preventive maintenance works.

(e) improve the pavement surface condition by providing resurfacing layer or strengthening layer, at the right time so as to extend the life of the existing pavement structure.

(f) to preserve the surrounding environment & natural aesthetics so that the travel by road is pleasant and comfortable.

General causes of damages to Roads

Causes of distress in flexible pavements :-

→ Ineffective road surface drainage system, which results in the stagnation of water on the shoulders or on the pavement surface on roads.

→ Blockages or silting up of longitudinal & cross drains resulting in stagnation of water on road.

→ Inadequate sub-surface drainage system or improper functioning of the DLSB layer, leading to stagnation of water on the subgrade & resultant damages to the pavement layers.

→ Environmental factors including heavy rainfall, soil erosion, high water table, snow fall, frost action etc.

→ Inadequate compaction of embankment, subgrade or any of the pavement layers or settlement of embankment foundation itself, which could result in settlement of the supporting layers of pavement resulting in damages to the roadway.

→ Defects in construction method and quality control during construction.

→ Defect in the quality of materials used in any of the pavement layers.

→ Increase in the magnitude of wheel loads & the no. of load repetitions or passage of excessively overloaded commercial vehicles, exceeding the design values.

General causes of distress in rigid pavements :-

→ Defective drainage system may lead to failures in rigid pavements such as mud pumping, unless preventive measures are taken up at the design & construction stages.

→ Use of non-durable materials which starts deteriorating during weathering cycles.

→ Improper alignment of dowel bars may lead to stress concentration & cracking near the joints.

→ Structural inadequacy of the pavement structure consisting of the cement concrete pavement slab, sub-base & subgrade, with respect to the actual loading conditions to which the pavement is being subjected to.

→ Inadequate compaction of embankment or subgrade or settlement of foundation itself, which would result in settlement of supporting layers of pavement.

Maintenance of bituminous road

Localised distresses :-

1. **Pot-holes :-**

These are small bowl shaped holes developed on the surface layer of flexible pavements after the rains.

Causes :-

(a) Stagnation of water on the pavement surface due to inadequate cross slope & stripping of bitumen binder from aggregates.

(b) Ingress of water into the pavement through surface & the shoulders.

(c) Lack of bond between the bituminous surface & base course due to improper application of prime coat / tack coat.
(d) Insufficient bitumen content at some locations.
(e) Segregation of bituminous mix during laying resulting the surface remaining permeable due to too less fines or excess CA at some location.

4) Patching of Pot-hole :-

Steps

(a) Cutting around the pot-hole area to rectangular shape with vertical edges upto max. depth & removing all the loose aggregates & dust.
(b) Application of tack coat of suitable bituminous binder at the bottom & all vertical edges using a sprayer.
(c) Filling up the prepared pot-hole with a dense bituminous premix.
(d) Compaction of patched mix using a roller & finishing level with the adjoining pavement surface.

2. Isolated cracked areas :-

Cracks are developed at isolated locations within a limited areas which may be considered as weak pockets within the paved area.

Causes :

→ Develop due to passage of heavy vehicles over the depressions that are formed due to localised settlement of pavement layers.

Remedy :

→ Patching. (same as pot hole repair).

3. Localised depression due to settlement :-

These are formed due to settlement of the lower layers of the pavement.

Causes :-

→ Inadequate compacted pockets of fill or subgrade or other pavement layers.
→ Laying of surfacing course by manual methods.

Remedy :-

→ Marking & clearing the affected area & removing the loose material & dust.
→ spraying tack coat
→ placing a pre-mix of dense graded bituminous mix using suitable aggregate sizes in depression.
→ Compacting well with a roller & finishing to a desired level.

General Distresses :-

1. Ravelling :-

The loosening of aggregates of the surface from the surface due to moving traffic, is known as ravelling. This occurs due to failure of binding bet^n bitumen binder and aggregates.

Causes :-

→ Construction during wet weather conditions which results in stripping of binder from aggregates.
→ Delayed rolling after the bituminous mix has cooled down resulting in porous surface.
→ Insufficient binder content in the mix.

→ Improper gradation of the aggregates or segregation of the mix during laying.
→ Over-heating of the binder or mix.

Remedial measures:-

Steps: (Initial stage of ravelling)
→ The surface is cleaned to remove loose particles & dust.
→ A suitable liquid seal coat or slurry seal is applied on the surface.

Steps: (progressed ravelling)
→ Removing the loose particles & dust.
→ Application of adequate quantity of tack coat.
→ Resurfacing with a bituminous premix of regd. thickness.

2. Rutting:-

Rutting is longitudinal deformation or depression of the pavement surface along the wheel paths of heavy vehicles.

Causes:-

→ Inadequate stability of subgrade or subbase or base course or surface course or a few of these pavement layers.
→ Inadequate compaction of subgrade or any of the pavement layers.
→ Channelized movement of heavy wheel loads causing significant vertical strain on the subgrade.
→ Improper specification or design of bituminous mix
→ Inadequate thickness of the flexible pavement or weak pavement structure.
→ Densification or consolidation deformation of the surface course material

Remedial measures :-

→ If inadequate thickness of the pavement structure is ruled out, then the remedy is :- steps:-

(i) cleaning the affected surface, (ii) application of tack coat covering the cuts (iii) filling the cuts using either a dense graded bituminous mix or open graded pre-mix followed by seal coat, (iv) compaction by rolling, (v) providing a thin bituminous resurfacing course to achieve good riding quality.

→ If weak pavement is indicated, it may be strengthened with an overlay of reqd. thickness.

→ If there is shear failure of subgrade, total reconstruction of pavement is done.

3. Corrugations :-

Corrugations are the shallow undulations in the form of ripples of depth upto 25 mm, across the road at about 2 to 3 m intervals. The defect is confined to bituminous surface course only.

Causes :-

→ Excess binder content in bituminous mix.
→ Excess proportion of fines in the mix.
→ Use of binder of low viscosity w.r.t temp. of the region.
→ Use of smooth textured or rounded gravel / coarse aggregates in the mix.
→ Initial undulations due to improper or faulty laying
→ The oscillations & impact caused by the traffic moving on the corrugated surface.

Remedial measures:-

→ In case of thin bituminous surface:-
- Removing the thin surfacing along with top portion of existing base source.
- Re-compacting the material
- Applying prime coat & tack coat
- Laying of another bituminous surface course.

→ In case of thick bituminous surface:-
- Cutting of the high spots using the blades of a drag spreader
- Applying a suitable levelling source of bitumino mix.
- Compacting thoroughly.

4. Edge breaking:-

The erosion of soil from the earth shoulders leads to edge drop or edge breaking of pavement.

Causes:-

→ Inadequate lateral support to the pavement edge.

→ Infiltration of water through the pavement edge.

Remedial measures:-

→ The affected portion are cut vertically upto the regd. width & depth of the pavement & the materials are removed. The adjoining earth shoulders are also cut & removed to suit the width of rollers & pavement machine. The pavement layers & shoulder are simultaneously laid using appropriate materials & compacted.

5. Alligator cracking :-

- An existing bituminous pavement surface that has developed extensive cracks which are interconnected forming a number of blocks, the crack pattern resembles the skin of an alligator; therefore such crack pattern of the pavement surface is called as 'alligator cracking' or 'map cracking'.

Causes :-

→ Higher deflection under wheel load.
→ Repeated application of wheel loads on weak pavements.

Remedial measure :-

→ The damaged bituminous pavement layer with extensive cracks is carefully removed without disturbing the base course underneath. Then prime coat or tack coat is applied, additional strengthening layers are applied such as a bituminous binder course and surface course are constructed, after designing the overlay thickness requirement.
→ Crack retarding layer such as a suitable geo-synthetic layer may be laid and a bituminous overlay is laid above.

6. Wavy surface :-

Large deformations formed along the road surface due to settlement or upheavals result in a wavy surface & the riding quality is adversely affected at high speeds.

Causes :-

→ Inadequate compaction of the fill.
→ Use of highly compressible soil in the fill or subgrade.
→ Presence of excessive moisture in the subgrade due to ineffective subsurface drainage system.
→ Frost heaving at frost susceptible regions.
→ Inadequate pavement thickness for the prevailing traffic loads.

Remedial measure :-

→ It is necessary to excavate & remove the pavement layers & then the defective fill up to the full depth. The embankment & subgrade soil shall be reconstructed using proper soils; the soil layers shall be compacted adequately under controlled conditions; the pavement layers are then reconstructed in a proper way using approved materials.
→ New sub-surface & surface drainage system have to be planned & constructed before re-constructing the pavement layers.
→ Suitable measures should be taken to resist the adverse effects of frost action before re-constructing the pavement layers.

→ It is necessary to remove all the existing pavement layers excluding the subgrade soil. The thickness requirement of the new pavement is designed & the new pavement layers are re-constructed starting from the subgrade.

7. Shear failures :-

Type(i) :- Shear failure of the pavement starting from the subgrade. (Total shear failure of pavement).

→ It is indicated by a deep and large depression or settlement & upheaval adjacent to the depression.

Causes :-

→ Laying of weak pavements on poor subgrade soil with high moisture content.

(may be seen along the wheel paths in the form of deep and wide rut)-

Remedial measures :-

→ Total reconstruction of the entire flexible pavement structure after designing the same to withstand the prevalent heavy traffic loading, soil & moisture condition & environmental factors.

→ The surface & sub-surface drainage system are constructed as per new design.

Type(ii) : Shear failure of the bituminous surface course only.

→ It is indicated by small size depression & similar small heaving of the surface, adjoining the depression.

Causes:

→ very heavy traffic loading, much higher than that expected at the time of design & construction.

Remedial measures:-

→ Milling & removing the defective bituminous concrete surfacing course up to the top of the DBM binder course.

→ Re-compacting the surface & finishing to required profile.

→ Application of tack coat.

→ Laying of a new layer of bituminous concrete surface course using revised mix design & binder specifications.

8. Reflection cracks :-

When the crack pattern on a bituminous surface course is almost of the same pattern and location as the cracks of the lower pavement layer, the cracks are known as 'reflection cracks' or 'sympathetic cracks'.

Causes:-

→ Construction of bituminous overlay above a rigid or semi-rigid pavement with cracks.

→ Delayed maintenance of cracked bituminous surface.

Remedial measures:-

→ If the pavement is structurally sound & fine cracks are formed only on the bituminous surface course, the treatment is 'crack sealing'. Fine cracks are sealed by applying bitumen emulsion or fog seal after cleaning the surface to remove loose particles & dust.

→ If the cracks of medium width are formed on the surface, the loose materials & dust are removed & the binder is poured through a pouring can & extra binder is pushed in with the help of brushes; a thin layer of sand/FA is spread over the binder covering the cracks; an additional thin surfacing course may also be laid as required.

→ If the pavement is structurally inadequate, a suitable overlay may be designed & constructed, after treating the cracks on the existing pavement surface.

Distress in cc pavements & maintenance measures

The types of distress in the cc pavements may be classified into two groups:

(i) Functional distresses

(ii) structural distresses

→ Functional deterioration include surface unevenness, scaling / travelling / spalling of joint, loss of sealant at joints, formation of fine shrinkage cracks & change in surface texture.

→ Structural distresses include development of structural cracks of depth more than half the thickness of the cc slab; also isolated failures in cc pavement slabs take place due to: settlement of embankment & subgrade at some locations.

Functional distresses:-

1. Surface unevenness or roughness :-

The surface condition of a cc pavement is considered to be 'good' if the value of unevenness index (UI) or roughness index determined using the bump integrator is < 2200 mm/km; 'average' if UI is 2200 to 3000 mm/km; 'poor' if > 3000 mm/km.

Causes:

→ Settlement of high embankments (results in formation of bumps & dips near the joints).

Remedy:-

→ The surface unevenness may be improved by 'diamond grinding' to partially remove the bumps; a thin layer of concrete is removed from the surface by the grinding process.

2. Scaling and ravelling :-

Scaling is the peeling off of part of the concrete surface to a depth of 5 to 15 mm.

Ravelling is the loss of hardened cement mortar from the surface;

Causes:-

→ Segregation of the concrete mix at the surface.
→ use of dirty or unclean aggregates.
→ use of excess water in the mix at a location.
→ use of excess fines in the mix
→ sawing the joints too early after concreting.

→ Improper curing
→ Excessive abrasion caused on the surface by the movement of crawler mounted machinery with steel chain drive.

Remedy :-

→ The damaged areas are marked out in rectangular shape by including extra 50 mm around the affected area. The disintegrated materials are chiselled & removed upto the affected depth. The area is patched up using a suitable mix of polymer concrete or by providing a bonded enlay
→ If the affected depth is > 25 mm, the slab is removed & reconstructed.

3. Spalling of joints :-

Spalling of joints occur due to cracking & breaking away part of the concrete near the joints of the cc slab.

Causes :-

→ Ingress of stones or grit into the gap of expansion joints
→ Failure or defects in load transfer dowel bar system on their placement at the concerned joint.
→ Use of weaker concrete or improperly compacted concrete when the work is stopped at the construction joint.

Remedy :-

→ If the affected width on either side of the joint is < 20 mm & affected length of spalled portion

is < 25% of joint length, epoxy resin mortar is applied.

→ If the width & length exceeds the above, partial depth repair is carried out.

4. Loss of joint sealant :-

The sealant at the joints of the cc pavement is subjected to very harsh conditions & therefore suffers distress over a period of time.

Remedy :-

→ The sealant material is removed, the joint groove is cleaned & the joint is re-sealed using appropriate type of sealant.

→ Polysulphide sealants are reported to perform well for 5 to 7 years; silicone sealants are reported to serve well for over 10 years.

5. Shrinkage cracks :-

(i) Plastic shrinkage cracks

(ii) Drying shrinkage cracks

Plastic shrinkage : Due to rapid drying of the fresh concrete caused by wind blowing at high speeds.

→ Formed at the time of mixing; 0.3 to 0.6 m in length to extend upto a depth of 20 to 30 mm.

Remedy :-

→ Can be prevented by taking suitable measures for curing of concrete.

→ Cracks can be sealed using epoxy resin of low viscosity.

Drying shrinkage:- Due to overall shrinking of the cc mix during the initial curing period, which is restrained by the interface friction betn the bottom of the cc slab & the supporting layer or the separation membrane.

Remedy:-

→ Cracks may be prevented by properly designing the spacing of the contraction joints & carrying out the joint cutting within the recommended period after laying the concrete.

6. Loss of surface texture:-

It result in smoothening of the cc pavement surface which may become slippery under wet conditions.

causes:

→ Poor texturing during construction.
→ Abrasion of the surface due to wear & tear caused by heavy traffic movements under wet conditions or when the surface is covered by sand particles.
→ Movement of construction traffic before the concrete gains strength.
→ Road stretches with frequent braking or turning movements of fast vehicles
→ Use of non-durable materials in the concrete.

Remedy:-

→ It may be restored by diamond grinding or groove cutting of the polished surface. Groove

ROAD-SIDE DEVELOPEMENT

Objects

Road side development deals with the planning and development of aesthetic measures and other amenities of road-side and the abutting land or the right of way.

→ Proper planning is needed for road-side development right from the stage of preliminary survey for highway alignment and during construction.

Points to be considered:-

(a) Consistent and smooth horizontal and vertical alignments.

(b) Wide right of way and shoulders in rural highways.

(c) Wide right of way in urban areas to screen adjoining property by plantation.

(d) Flat side slopes on embankment and cut, rounded to blend with original land.

(e) Suitable planning and plantation of road-side trees and shrubs and their proper maintenance.

(f) Turfing on side slopes and on edge of shoulders of highways passing through rural areas.

(g) Aesthetically developing pleasant views, parks and parking facilities.

Road Arboriculture

Planting of trees along the road-side land is also called as road arboriculture. This is one of the important aspects in road-side development.

Trees provided on both sides of urban and rural roads serve the following purposes:

→ to provide attractive landscape of road-sides.
→ to arrest environmental degradation due to infrastructure development.
→ to provide shade and pleasant drive to the road users.
→ to protect against moving sand in desert areas.
→ to provide fruit bearing trees and timber.
→ to intercept the annoying sound waves and fumes from road vehicles.

On urban areas the road-side planting is mainly for the beauty of the landscape and therefore, trees and shrubs of ornamental trees and flowering species are generally preferred.

On wide urban roads as well as on divided highway passing through rural areas, the planting of shrubs is done along the medians or separators, besides providing trees on road sides. These shrubs reduce the head light glare during night driving.

Choice based on the crown of tree :-

→ Wide crowned trees on road-sides are generally not preferred, because they obstruct the day light and make the roads appear dark and unsafe even with street lighting during night.

→ Due to high branches of the road-side trees which overhang on the carriageway is dripping of water from branches of these trees during the rains and consequent damages in the form of pitting and loss of fines caused to the flexible pavements.

→ It is desirable that the crowns of the trees planted on both sides of a road do not cover the carriageway.

→ The trees should be so planted on roadsides that the crown of trees do not extend beyond the pavement edges.

→ The trees should be at least 2.5 m away from edge of the carriageway and 12 m away from the centre of the road or carriageway.

Equipment for compacting soils

Soil compaction is achieved in the field either by rolling, ramming or by vibration.

→ Cohesion-less sand may be compacted by vibration, jetting & ponding with water.

→ Compacting equipments:

(i) Rollers
(ii) Rammers
(iii) Vibrators

(i) **Rollers**

The loose soil particles get packed closer during the rolling process as part of the air voids get expelled due to compression. A slight rearrangement of the soil grains

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Types :-

(a) Ordinary smooth wheel type rollers
(b) Vibratory rollers
(c) Pneumatic tyred rollers
(d) Sheep foot rollers

1. Smooth wheeled rollers :-

There are two types of smooth wheeled rollers,
(i) three wheeled rollers (Cycaedam roller)
(ii) tandem rollers with two wheels of same width.

→ The gross weight of three wheeled type rollers varies from 8 to 15 tonnes & that of the two wheeled tandem rollers varies from 3 to 14 tonnes.
→ These are suitable for compacting granular soils, aggregates & other pavement materials.
→ These are not suitable for cohesionless sand, non-plastic silts & clayey soils with high plasticity.

Vibratory rollers :-

In these, compaction is effected due to both the dynamic effect of the vibratory force & also the static weight of the roller.
→ These may be used for compacting a wide range of soils such granular soils & pavement layers with granular materials such as aggregates.
→ 2 types : (i) with two steel drums in tandem of the total static wt. of 8 to 12 tonnes.
(ii) single vibrating steel drum of static wt. 10 to 15 tonnes.

Pneumatic tyred rollers :-

→ no. of pneumatic wheels are mounted on two or more axles, under a loaded platform. The gross load of these rollers can be substantially increased by adding sand bags or any other load on the platform.

→ These may be of self propelled type or pulled by tractor.

→ These are suitable for compacting non-plastic silt & fine sands. Also used in compacting pavement layers consisting of bituminous mixes.

Sheep-foot rollers :-

→ It consists of hollow steel cylinder with projecting feet.

→ The wt. of the roller can be increased by filling the drum with wet soil.

→ These may be pulled by tractors.

→ These are suitable for compacting clayey soils.

(ii) Rammers :-

These are useful to compact relatively small areas & where the rollers cannot operate such as compaction of deep & narrow trenches, foundations of structures, & slopes of embankments & cuts.

→ The rate of output of rammer is lower than that of roller.

(iii) Plate vibrators :-

These are suitable for compacting layers of dry cohesionless granular material like sand.

→ Also these are used for compacting trenches, founds & slopes

4. Compaction of sand :

→ This can be densified by vibration techniques. It can be compacted in wet sands by rolling the layer when it is saturated with water, the sand is watered heavily & rolled using a smooth wheeled roller or pneumatic tyred roller.

→ Jetting & ponding with water is the most effective method of compacting cohesionless sands.

Excavation of earth

Excavation is the process of cutting or loosening & removing earth including rock from its original position, transporting & dumping it as a fill or spoil bank.

→ Excavation may be needed in soil, soft rock or even in hard rock before preparing the formation of a new highway.

Equipments for excavation

1. Bull dozer

It is a versatile earth moving equipment used for clearing site, opening up pilot roads, moving earth for short haul distance of about 100m & also in several other jobs.

→ It can be excavate even relatively stiff earth & some types of soft rock.

→ It can be used for shallow excavation works during highway construction.

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→ Bull dozers with chain-drive are versatile machines that are mounted on crawler tracks & they can operate even in slushy & marshy ground & on steep slopes.

(ii) Scraper :-

It is one of the useful earth moving equipment as it is self operating & can dig earth up to a shallow depth, haul & discharge the material in layers of uniform thickness, where required.

→ The main advantage of scrapers is that the depth of excavation of earth & the thickness of spreading the excavated earth at the desired stretch can be controlled precisely.

→ These are not capable of excavating stiff material

(iii) Power shovel :-

It is used to excavate earth of all classes except rock & to load it into wagons.

→ These may be mounted on crawler tracks & they are stable & can move at low speeds.

→ These include the mounting, cab, boom, dipper stick, dipper & hoist line.

→ This can effectively operate to excavate earth from a lower level where it stands.

→ As the dipper moved upwards, the cutting edge can excavate even stiff earth; the bottom of the shovel can swing & the excavated material can be dumped into the wagon.

106 (IV) Hoe :-

It is an excavating equipment of power shovel family. It is meant to excavate below the natural surface where the machine stationed & is capable of having precise control of depth of excavation at close range work.

→ It can exert high tooth pressure & hence can excavate stiff material which cannot be excavated by dragline.

(V) Dragline :-

It is used to excavate soft earth & to deposit in near-by banks or to load into wagons.

→ It may be mounted on crawler track.

→ The bucket is thrown out from the dragline on the top of the earth to be excavated & then pulled back towards the base of the machine.

→ It can operate from natural ground while excavating earth with the bucket from a lower level.

(VI) Clam shell :-

It consists of a heavy bucket of two halves in the form of a shell, hinged together at top. The shells may be attached to the shovel-crane unit or at the boom of a dragline.

→ The open clam-shell bucket is thrown on the top of the loose material after the material is dug & the bucket is lifted, the two halves close entrapping the material into the bucket.

→ It is useful for excavation of loose material at or below existing ground surface.

TRAFFIC ENGINEERING

Traffic engineering is that branch of engineering which deals with the improvement of traffic performance of road networks and terminals. It is that phase of engineering that deals with planning and geometric design of streets, highways, abutting lands and with traffic operation, as their use is related to the safe, convenient and economic transportation of persons and goods.

Traffic Control Devices

The various aids and devices used to control, regulate and guide traffic may be called as traffic control devices.

The most common are:

(a) Signs
(b) Signals
(c) Markings
(d) Islands.

→ Road lights are useful in guiding traffic during night.

Traffic signs

There have been divided into three categories according to Indian Motor Vehicle Act.

(i) Regulatory signs

(ii) Warning signs

(iii) Informatory signs.

→ In the case of roads with Kerbs, the edge of the sign adjacent to the road is not less than 0.6 m away from the edge of the Kerb.

→ On roads without Kerbs the nearest edge may be 2.0m to 3.0m from the edge of the carriageway

(i) Regulatory signs :-

Regulatory or mandatory signs are meant to inform the road users of certain laws, regulations and prohibitions.

These are classified under the following sub-heads:

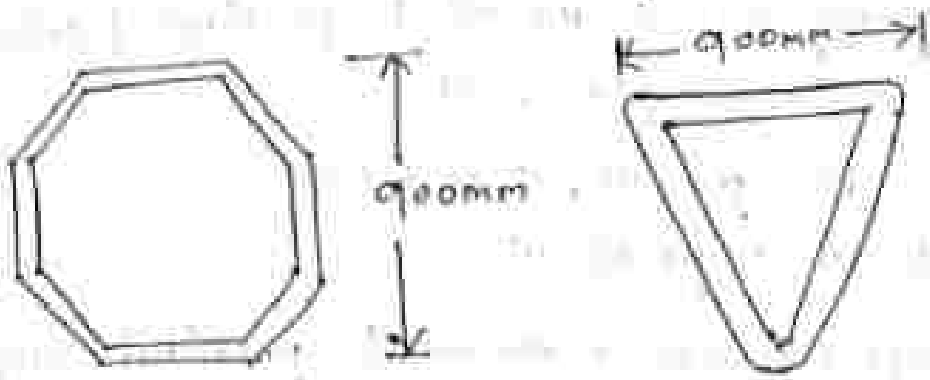
(a) Stop and Give-way signs :-

→ Stop sign is intended to stop the vehicles on a roadway.

→ Octagonal in shape, red in colour with a white border.

→ Give-way sign is used to control the vehicles on a road so as to assign right of way to traffic on other roadways.

→ It is triangular with the apex downwards, white in colour with a red border.



STOP

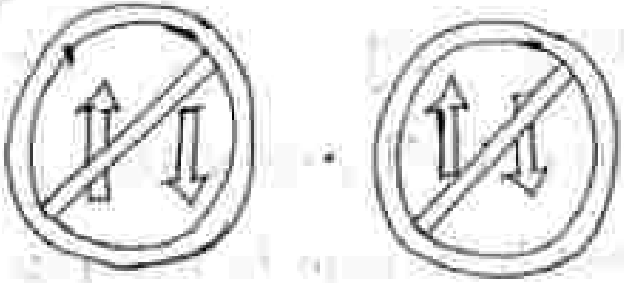
GIVE WAY

(b) Prohibitory signs :-

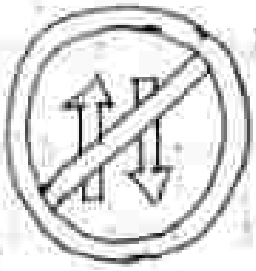
These are meant to prohibit certain traffic movements use of horns or, entry of certain vehicle class.

→ These are circular in shape, white in colour with red border.

Straight Prohibited or No Entry



One way signs



vehicles prohibited in both directions.

Right turn prohibited

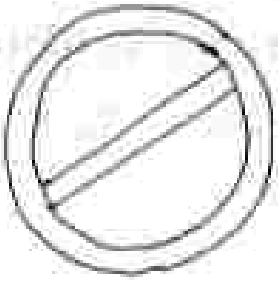
U-turn prohibited

overtaking Prohibited

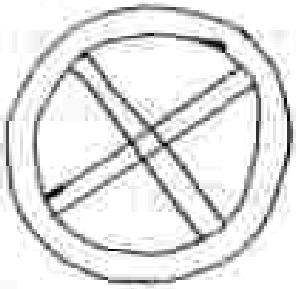
(c) No parking and No stopping signs :-

→ No parking sign is meant to prohibit parking of vehicles at that place. It is circular in shape with a blue background, a red border & an oblique red bar at an angle of 45°.

→ No stopping sign is meant to prohibit stopping of vehicles at that place. It is circular in shape with blue background, red border & two oblique red bars at 45° & right angle to each other.



No parking



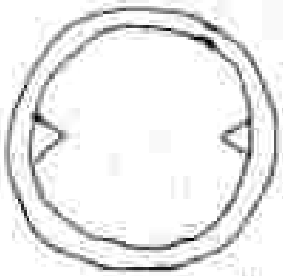
No stopping / standing

(d) Speed limit and vehicle control signs :-

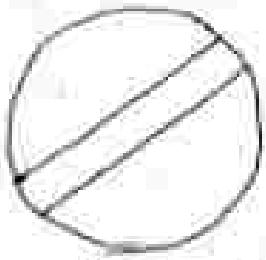
→ Speed limit sign is meant to restrict the speed of all or certain classes of vehicles on a particular stretch of a road. This is circular in shape, white background, red border & black numerals.

→ Vehicle control signs are similar to speed limit signs with black symbols instead of numerals. eg. Width limit, Height limit, Length limit, Load limit & Axle load limit.

Speed Limit



width limit



Restriction ends sign.

(e) Restriction Ends sign :-

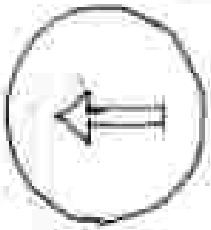
→ Indicates the point at which all prohibitions notified by prohibitory signs for moving vehicles cease to apply.

→ It is circular in shape with white background & a broad diagonal black band at 45°.

(f) Compulsory direction control signs :-

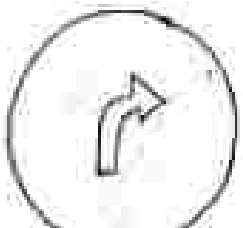
These signs indicate the appropriate directions in which the vehicles are obliged to proceed, or the only directions in which they are permitted to proceed.

→ These are circular in shape with a blue back ground and white direction arrows.



Compulsory turn left

Compulsory ahead only



Compulsory turn right ahead.

Compulsory ahead or turn right

Compulsory ahead or turn left

Compulsory keep left.

(ii) Warning Signs :-

Warning or cautionary signs are used to warn the road users of certain hazardous conditions that exist on or adjacent to the roadway.

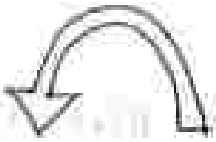
→ They are in the shape of equilateral triangle with the apex pointing upwards.

→ They have a white back ground, red border & black symbols.

→ Commonly used warning signs are : Right / Left Hand curve, Right / Left Hair pin bend, Narrow Bridge / Road ahead, Slippery road, Cycle crossing, Pedestrian crossing, school zone, cross road, side road, T- intersection, Y - intersection, Major Road ahead, Men at work, Round about, Hump, Railway crossing, Falling rock.

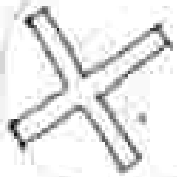
(Right Hand curve)

(Left Hand curve)



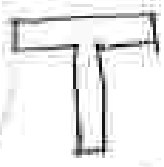
(Hair pin bend left)

(Reverse bend right)

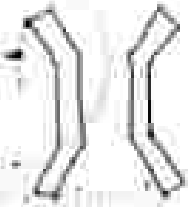


(cross road)

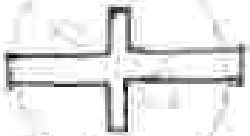
(side road right)



(T- intersection)



(Narrow bridg



(Major road ahead)

(iii) Informatory Signs :-

These signs are used to guide the road users along routes, inform them of destination and distance and provide with information to make travel easier, safe and pleasant.

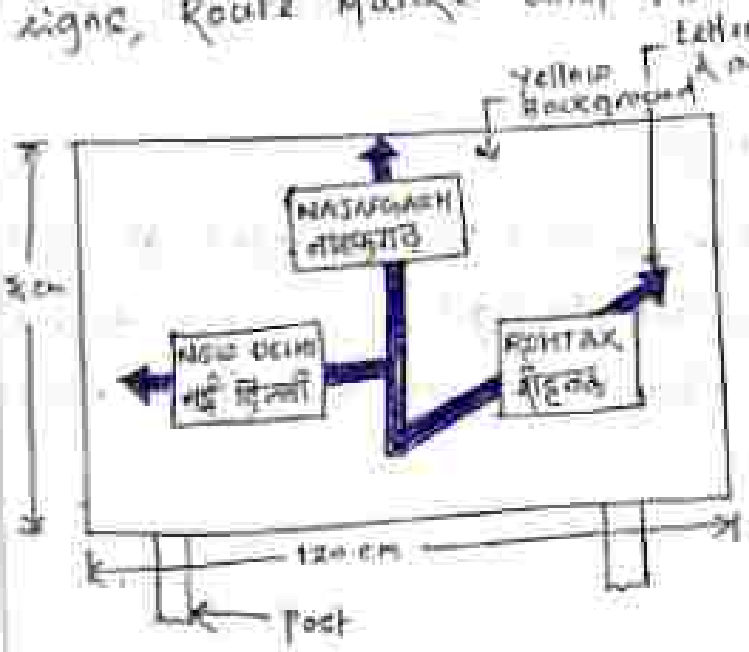
→ The information signs are grouped under the following sub-heads:

(a) Direction and Place identification signs :-

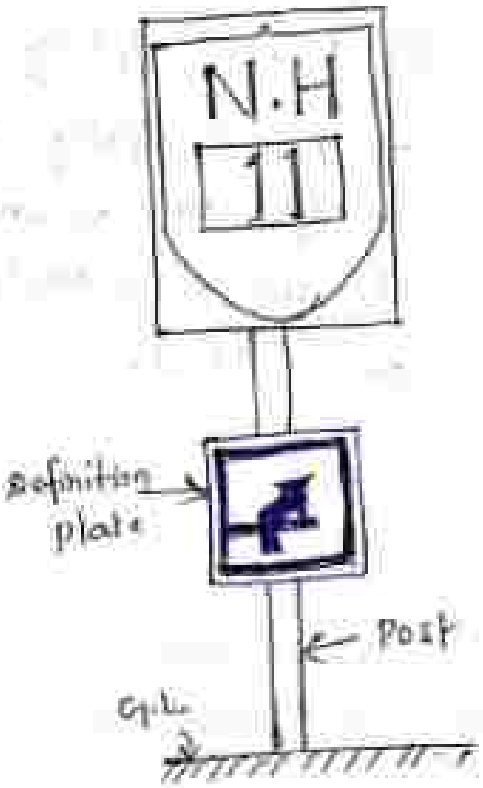
→ These are rectangular with white back ground, black border & black arrows and letters.

→ The descriptions should be in English & other languages as necessary.

→ Examples: Destination signs, Direction signs, Re-assurance signs, Route Marker and place identification signs.



(a) Road Junction Approach



(b) Route Marker Sign

(b) Facility information signs:-

→ These are rectangular with blue back ground & white / black letters / symbols.

→ Some of them are: Public Telephone, Petrol Pump, Hospital, First Aid Post, Eating Place & Resting Place.

(c) Other useful information signs:-

→ These include No Through Road, No Through Side Road etc.

(d) Parking signs:-

→ These are set up parallel to the road wing square sign board with blue ~~black~~ back ground and white coloured letter 'P'. Additional definition plate may be used to indicate category of vehicle for which parking space is reserved, direction of parking space etc.

(e) Flood Gauge sign:-

→ Flood Gauge sign should be installed at all cause ways and submersible bridges or culverts to indicate to the road users the height of the flood above road level.

Traffic Signals

Traffic signals are the control devices which could alternatively direct the traffic to stop and proceed at intersections using red and green traffic light signals automatically.

→ The main requirements of traffic signal are to draw attention, provide meaning and time to respond & to have minimum waste of time.

Advantages of traffic signals :-

→ They provide orderly movement of traffic and increase the traffic handling capacity of most of the intersections at grade.

→ They reduce certain types of accidents, notably the right angled collisions.

→ Pedestrians can cross the roads safely at the signalised intersection.

→ Signals allow crossing of the heavy traffic flow with safety.

→ Signals provide a chance to crossing traffic of minor road to cross the path of continuous flow of traffic stream at reasonable intervals of time.

Types of traffic signals :-

(i) Traffic control signals : (a) Fixed-time signal
(b) Manually operated signal
(c) Traffic actuated (automatic) signal.

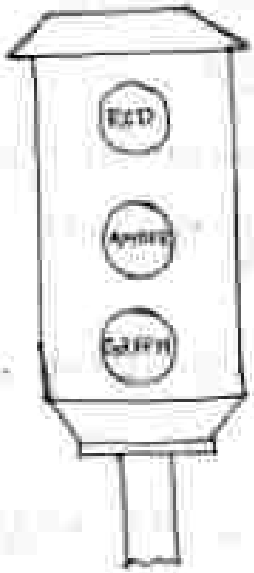
(ii) Pedestrian signal

(iii) Special traffic signal.

(i) Traffic control signals :-

There have three coloured light glows facing each direction of traffic flow.

→ The red light is meant for 'stop', the green light indicates 'Go' and the amber or yellow light allows the clearance time for the vehicles which enter the intersection area by the end of green time, to clear off.



STOP

CLEARANCE TIME

GO

(a) Fixed-time signal / Pre-timed signals :-

→ These are set to repeat regularly a cycle of red, amber and green lights.

→ The timing of each phase of the cycle is predetermined based on the traffic studies and they are the simplest type of automatic traffic signals which are electrically operated.

(b) Manually operated signals :-

→ In these types of signals, the traffic police watches the traffic demand from a suitable point during the peak hours at the intersection & varies the timings of these phases and cycle accordingly.

(c) Traffic actuated signals :-

→ In these signals the timings of the phase and cycle are changed according to traffic demand.

→ In semi-actuated signals, the normal green phase of a traffic stream may be extended upto a certain period of time for allowing the vehicles to clear off the intersection.

→ In fully-actuated signals, computers assign the right of way for the traffic movement on-term basis of traffic flow demand.

(ii) Pedestrian signals :-

→ When the vehicular traffic remains stopped by red or stop signal on the traffic signals of the road intersection, these signals give the right of way of pedestrians to cross a road during the walk period.

(iii) Special signals / Flashing beacons :-

→ These signals are used to warn the traffic.

→ When there is a red flashing signal, the drivers of vehicles must stop before entering the nearest cross walk at the intersection or at a stop line where marked.

→ Flashing of yellow signals are used to direct the drivers of the vehicular traffic to proceed with caution.

Road markings

Road or traffic markings are made of lines, patterns, words, symbols or reflectors or the pavement, kerb, sides of islands or on the fixed objects within or near the roadway.

→ Traffic markings may be called special signs intended to control, warn, guide or regulate the traffic.

→ The markings are made using paints in contrast with colour & brightness of the pavement or other back ground. Light reflecting paints are commonly used for traffic marking.

→ In order to ensure that the markings are seen by the road users, the Longitudinal lines should be atleast 10 cm thick & the transverse lines should be made in such a way that they are visible at sufficient distance in advance to give road users adequate time to respond.

The various types of markings may be classified as,

(i) Pavement markings

(ii) Kerb markings

(iii) Object markings

(iv) Reflector unit markings

Pavement Markings :-

These markings may be of white paint. Yellow colour markings are used to indicate parking ~~restrictions~~ restrictions & for the continuous centre line and barrier line markings.

→ Longitudinal solid lines are used as guiding or regulating lines.

→ Transverse lines indicate the position of stop lines for vehicular traffic.

→ Common types : Centre lines, Lane line, No parking zone marking, Turn markings, stop line, cross walk lines, Approach to obstructions, Parking space limit, Border or edge lines, Route direction arrows, Parking space limits, Bus stop.

Kerb markings :-

These markings indicate certain regulations like parking regulations.

→ These are marked with alternate black and white line which increase the visibility from a long distance.

Object markings :-

These include typical obstructions markings like supports for bridges, signs & signals, level crossing gates, traffic islands, narrow bridges, culvert head walls.

Reflector Unit Markings :-

These are used as hazard markers and guide markers for safe driving during night.

→ Hazard markers reflecting yellow light should be visible from a long distance of about 150 m.

Traffic Islands :-

Traffic islands are raised areas constructed within the roadway to establish physical channels through which the vehicular traffic may be guided.

→ Traffic islands may be classified based on the function as :

(i) Divisional islands

(ii) channelizing islands

(iii) Pedestrian loading islands

(iv) Rotary

Divisional islands :-

These are intended to separate opposing flow of traffic on a highway with four or more lanes.

→ By dividing the highways into two one-way roadways, the head-on-collisions are eliminated & other accidents are also reduced.

Channelizing islands :-

They are used to guide the traffic into proper channel through the intersection area.

→ They are very useful for intersection at grade, particularly when the area is large.

Pedestrian loading islands :-

They are provided at regular bus stops & similar places for the protection of passengers.

→ A pedestrian island at or near a cross walk to aid and protect pedestrian crossing the carriageway may be termed as pedestrian refuge islands.

Rotary island :-

It is the large central island of a rotary intersection. This island is much larger than the central island of channelized intersection.

→ It is an enlarged road intersection where all converging vehicles are forced to move around a large central island in one direction before they can weave out of traffic flow into their respective directions radiating from the central island.