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# Transportation Engineering – BCV403



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# Module – 1

## Transportation Engineering



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## **Introduction**

Mobility is a basic human need. From the times immemorial, everyone travels either for food or leisure.

A closely associated need is the transport of raw materials to a manufacturing unit or finished goods for consumption.

Transportation fulfils these basic needs of humanity. Transportation plays a major role in the development of the human civilization



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## **Different modes of transportation and comparison**

- Three basic modes of transport are by land, water and air.
- Land has given development of road and rail transport.
- Water and air have developed waterways and airways respectively.
- Other modes include pipelines, elevators, belt conveyors, cable cars, aerial ropeways and monorails. Pipe lines are used for the transportation of water, other fluids and even solid particles.



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## **Different modes of transportation and comparison**

The major modes of transportation are:

- Roadways or highways
- Railways
- Airways
- Waterways.
- Pipelines
- Rope ways
- Hyper loop



<b>Mode</b>	<b>Product Options</b>	<b>Speed</b>	<b>Accessibility</b>	<b>Cost</b>	<b>Capacity</b>	<b>Intermodal Capability</b>
<b>Road</b>	Very Broad	Moderate	High	Moderate	Low	Very High
<b>Railroad</b>	Broad	Slow	Moderate	Low	Moderate	Very High
<b>Air</b>	Narrow	Fast	Low	Very High	Very Low	Moderate
<b>Water</b>	Broad	Very Slow	Moderate	Very Low	Very High	Very High
<b>Pipeline</b>	Very Narrow	Very Slow	Low	Low	Very High	Very Low
<b>Digital</b>	Very Narrow	Very Fast	Very High	Very Low	Moderate	Very Low



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## Highway Development in India

### Jayakar committee recommendations

Over a period after the First World War, motor vehicles using the roads increased and this demanded a better road network which can carry mixed traffic conditions.

The existing roads when not capable to withstand the mixed traffic conditions. For the improvement of roads in India government of India appointed Mr. Jayakar Committee to study the situations and to recommend suitable measures for road improvement in 1927 and a report was submitted in 1928 with following recommendations:



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## **Jayakar committee recommendations**

1. Road development in the country should be considered as a national interest. As the provincial and local government do not have the financial and technical capacity for road development.
2. Extra tax to be levied from the road users as fund to develop road.
3. A Semi-official technical body has to be formed to collect and pool technical Knowhow from various parts of the country and to act as an advisory body on various aspects of the roads.
4. A research organization should be instituted at National level to carry out research and development work and should be available for consultation.



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## **Implementations:**

Majority of the recommendations were accepted by the government implemented by Jayakar Committee.

Some of the technical bodies were formed such as,

1. Central Road Fund (CRF) in 1929
2. Indian Roads Congress (IRC) in 1934
3. Central Road Research Institute (CRRI) in 1950.



## **Central Research Fund (CRF):**

1. Central Research Fund (CRF) was formed on 1st March 1929
2. The consumers of petrol were charged an extra levy of 2.64 paisa/litre of petrol to build up this road development fund.
3. From the fund collected 20 percent of the annual revenue is to be retained as meeting expenses on the administration of the road fund, road experiments and research on road and bridge projects of special importance.
4. The balance 80 percent of the fund to be allotted by the Central Government to the various states based on actual petrol consumption or revenue collected
5. The accounts of the CRF are maintained by the Accountant General of Central Revenues.
6. The control of the expenditure is exercised by the Roads Wings of Ministry of Transport.



## **Indian Road Congress (IRC):**

1. It is a semi-official technical body formed in 1934.
2. It was formed to recommend standard specifications.
3. It was constituted to provide a forum of regular technical pooling of experience and ideas on all matters affecting the planning, construction and maintenance of roads in India.
4. IRC has played an important role in the formulation of the 20-year road development plans in India.
5. Now, it has become an active body of national importance controlling specifications, guidelines and other special publications on various aspects of Highway Engineering.



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## **Central Road Research Institute (CRRI):**

1. CRRI was formed in the year 1950 at New Delhi
2. It was formed for research in various aspect of highway engineering
3. It is one of the National laboratories of the Council of Scientific and Industrial Research.
4. This institute is mainly engaged in applied research and offers technical advice to state governments and the industries on various problems concerning roads.

# INDIAN HIGHWAYS MILESTONE COLOUR CODES

Yellow &  
White



**NATIONAL  
HIGHWAYS**

Green &  
White



**STATE  
HIGHWAYS**

Blue/Black &  
White



**CITY/  
DISTRICT  
ROADS**

Orange &  
White



**RURAL ROADS**  
(PRADHAN MANTRI  
GRAM SADAK YOJNA ROADS)



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## **Classification of Roads:**

### **Types of roads:**

### **Classification based on weather:**

- All weather roads:
- Fair-weather roads:

### **Classification based on the type of carriage way:**

- Paved roads:
- Unpaved roads:

### **Classification based on type of pavement surface:**

- Surface roads:
- Un-surfaced roads



## **Methods of classification of roads:**

The roads are generally classified as

**Traffic volume:** The roads are classified as Heavy, Medium and Light traffic roads.

**Load transported or tonnage:** The roads are classified as class I, class II or class A or class B etc. And the limits may be expressed as tonnes per day.

**Location and function:**



## **Classification of Roads by Nagpur Road plan:**

The Nagpur Road Plan classified the roads in India based on location and function into five categories.

National Highways (NH)

State Highways (SH)

Major District Roads (MDR)

Other District Roads (ODR)

Village Roads (VR)



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## **Modified classification of Road system by Lucknow plan:**

Primary system consists of two categories:

- Expressways
- National Highways (NH)

Secondary system consists of two categories:

- State Highways (SH)
- Major District Roads (MDR)

Tertiary system consists of two categories:

- Other District Roads (ODR)
- Village Roads (VR)



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## **Classification of Urban Roads:**

The urban roads are

- Arterial roads
- Sub-arterial roads
- Collector streets
- Local streets

Arterial roads and Sub-arterial roads are streets primarily for through traffic on a continuous route, but the sub-arterials have a lower level of traffic mobility than the arterials.

Collector streets provide access to arterial streets and they collect and distribute traffic from and to local streets which provide access to abutting property.



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## Road patterns:

Road patterns:

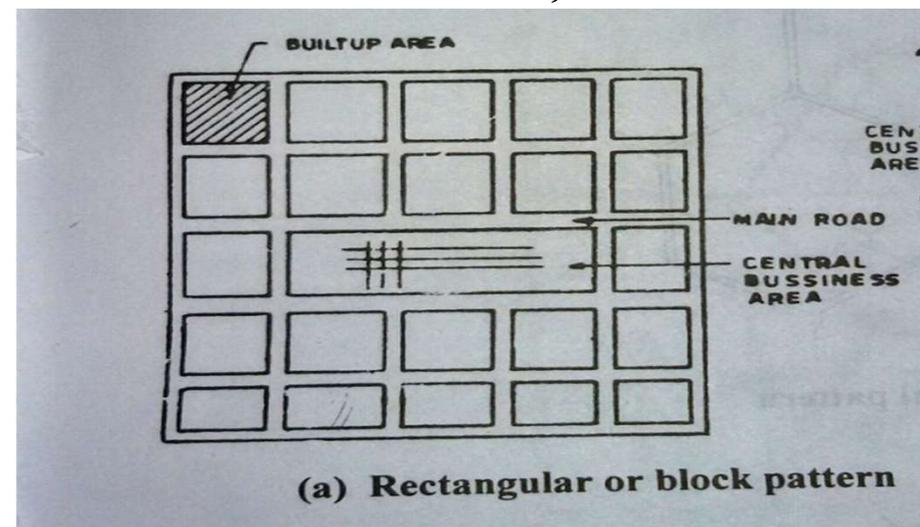
**1. Rectangular or Block pattern:** In this pattern, the whole area is divided into rectangular blocks of plots, with streets intersecting at right angles.

**Advantages:**

The rectangular plots may be further divided into small rectangular blocks for construction of buildings placed back to back, having roads on their front.

**Limitations:**

This pattern is not very much convenient because at the intersections, the vehicles face each other.





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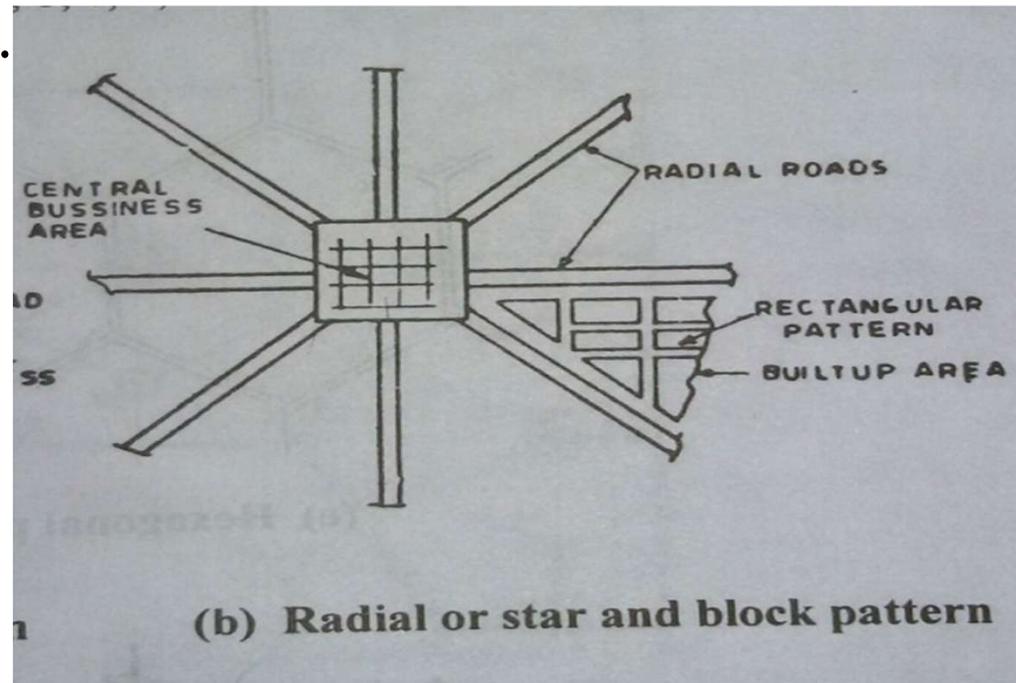
**Radial or Star and block Pattern:** In this pattern, the entire area is divided into a network of roads radiating from the business outwardly.

### **Advantage**

Reduces level of congestion at the primary bottleneck location.

### **Limitations**

Proves particularly effective if two-lane ramp traffic does not have to merge at downstream end of ramp.





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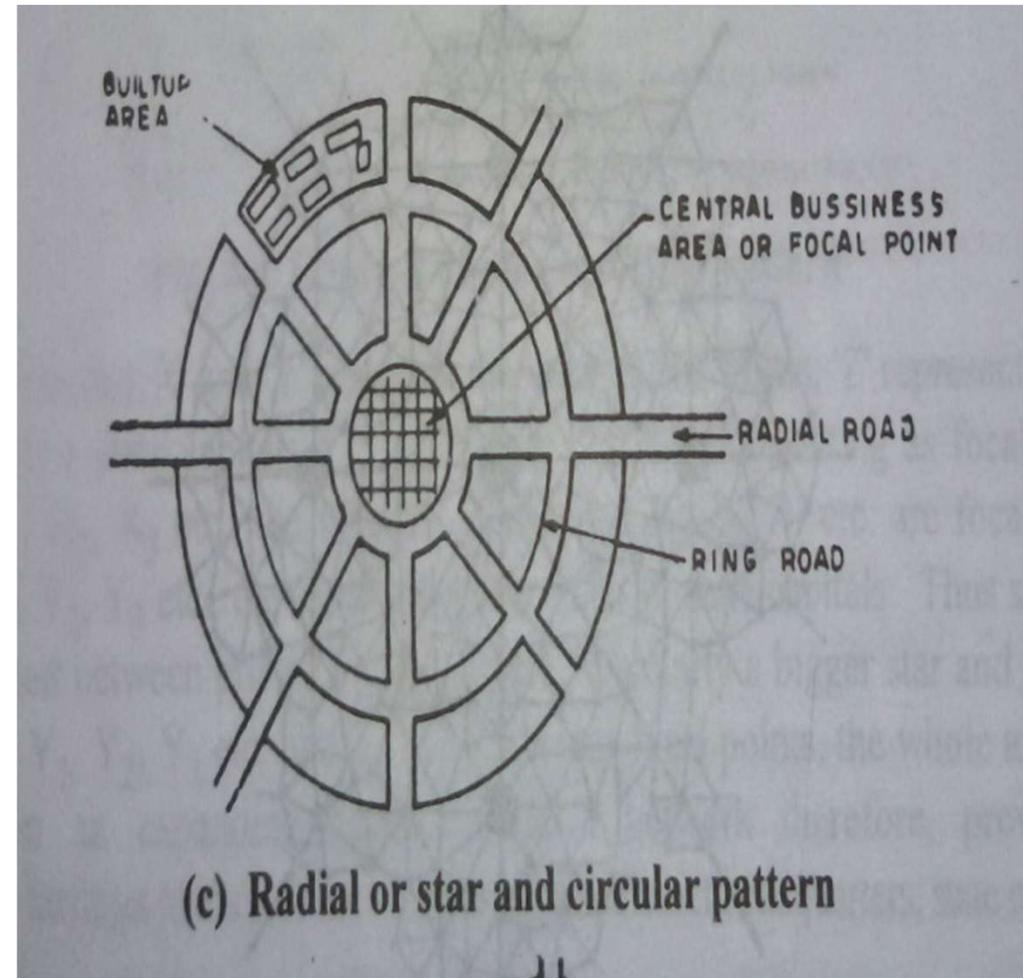
**Radial or Star and Circular Pattern:** In this system, the main radial roads radiating from central business area are connected together with concentric roads.

## Advantages

Installing circular pattern in place of traffic signals can also reduce the likelihood of rear-end crashes.

## Limitations:

Center lines of roads leading to circular pattern should be properly aligned with the central island.





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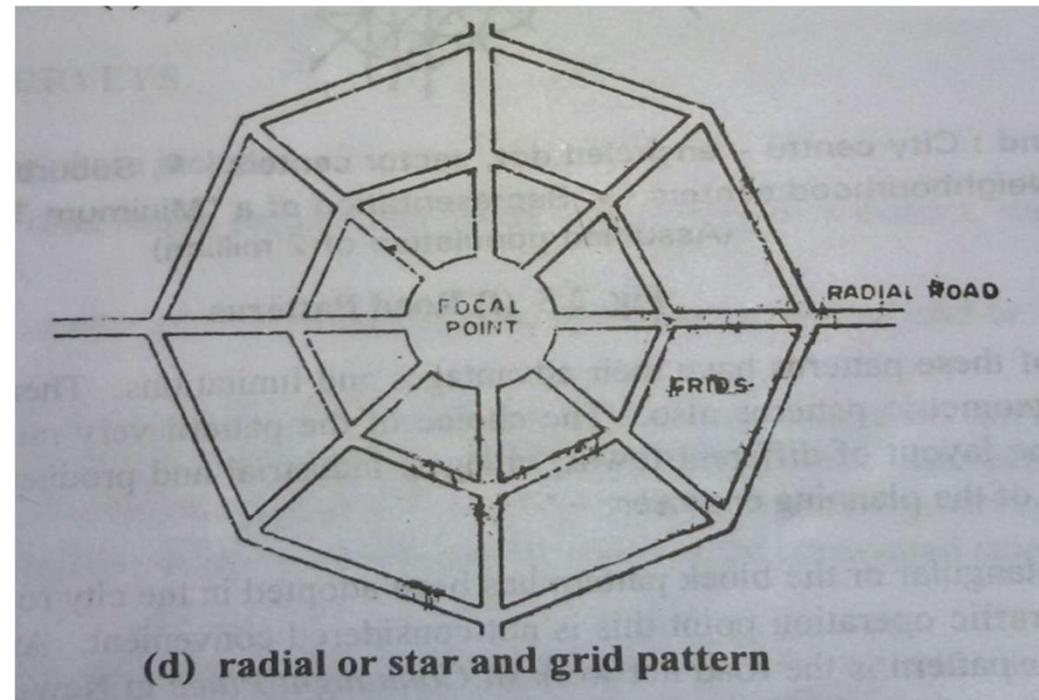
**Radial or Star and Grid Pattern:** Change in direction, and because street patterns are the most enduring physical element of any layout, it could potentially contribute to systematic site planning and, consequently, deserves a closer look.

**Advantages:**

Keep vehicular traffic safe with a high proportion of 3-way intersections.

**Limitations:**

Islands separating the approach and exit lanes, known as splitter islands, should extend far enough.





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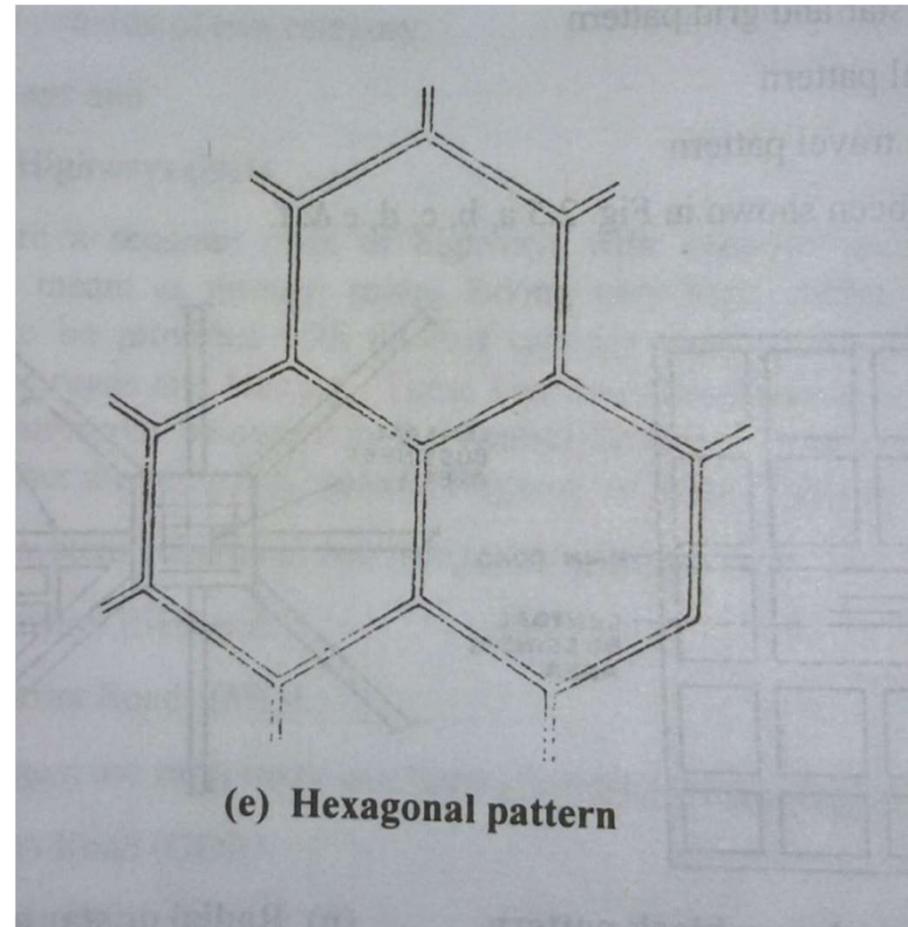
**Hexagonal Pattern:** In this pattern, the entire area is provided with a network of roads formatting hexagonal figures.

**Advantages:**

Three roads meet the built-up area boundary by the sides of the hexagons.

**Limitation:**

Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.





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**Minimum Travel Pattern:** In this road pattern, city is contented by sector center, suburban enter and neighbourhood center by the road which required minimum to connect the city center.

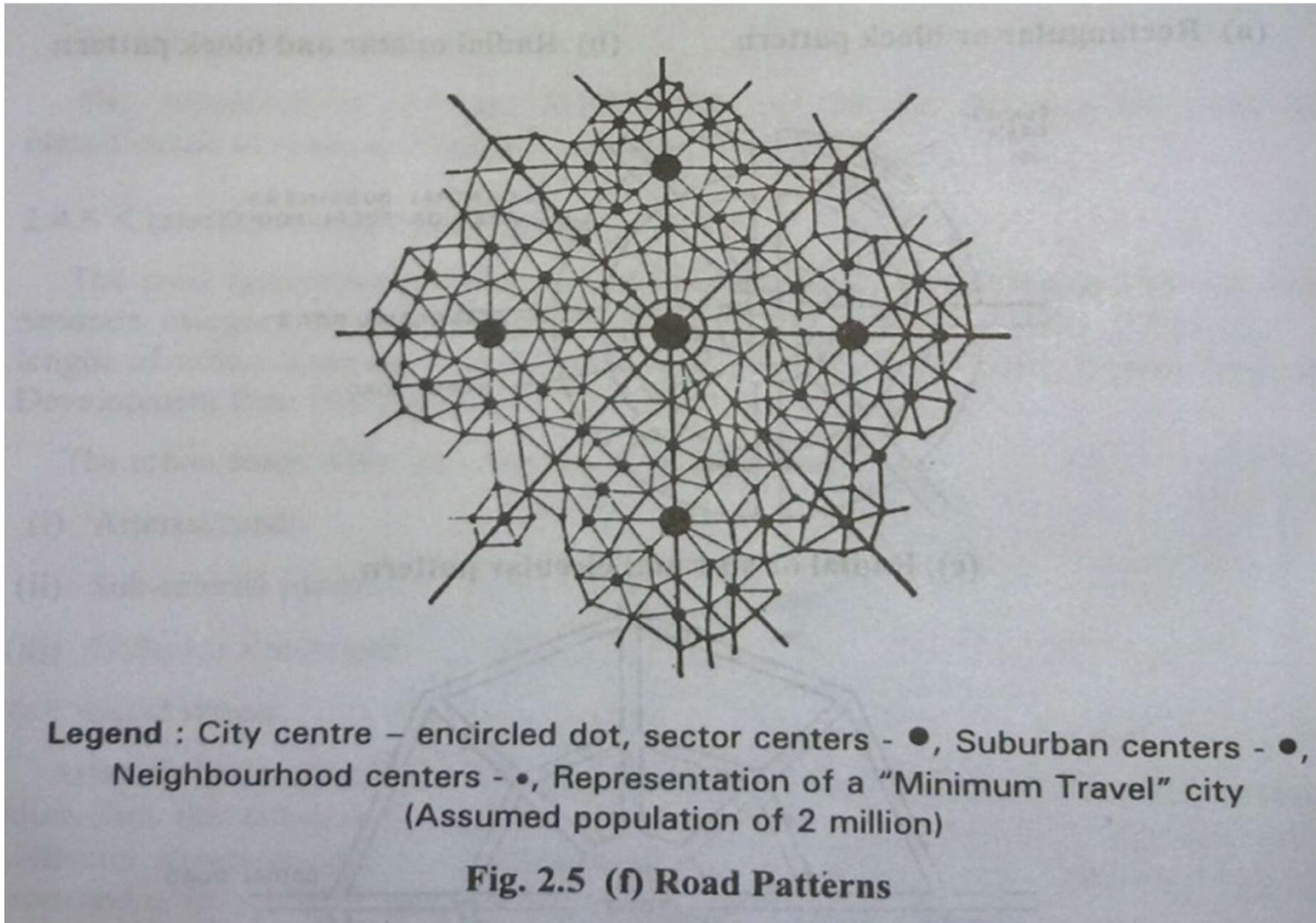
**Advantages:**

These types of potentially serious crashes essentially are eliminated.

**Limitations:**

Traffic signs, pavement markings, and lighting should be adequate so that drivers are aware that they should reduce their travel speed.

## Minimum Travel Pattern:



**Legend :** City centre – encircled dot, sector centers - ●, Suburban centers - ●,  
Neighbourhood centers - •, Representation of a “Minimum Travel” city  
(Assumed population of 2 million)

**Fig. 2.5 (f) Road Patterns**



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## Highway Alignment

### Ideal Alignment

An ideal alignment between two stations should offer maximum utility by serving maximum population and products and also should possess following requirements:

**Short:**

**Easy:**

**Safe:**

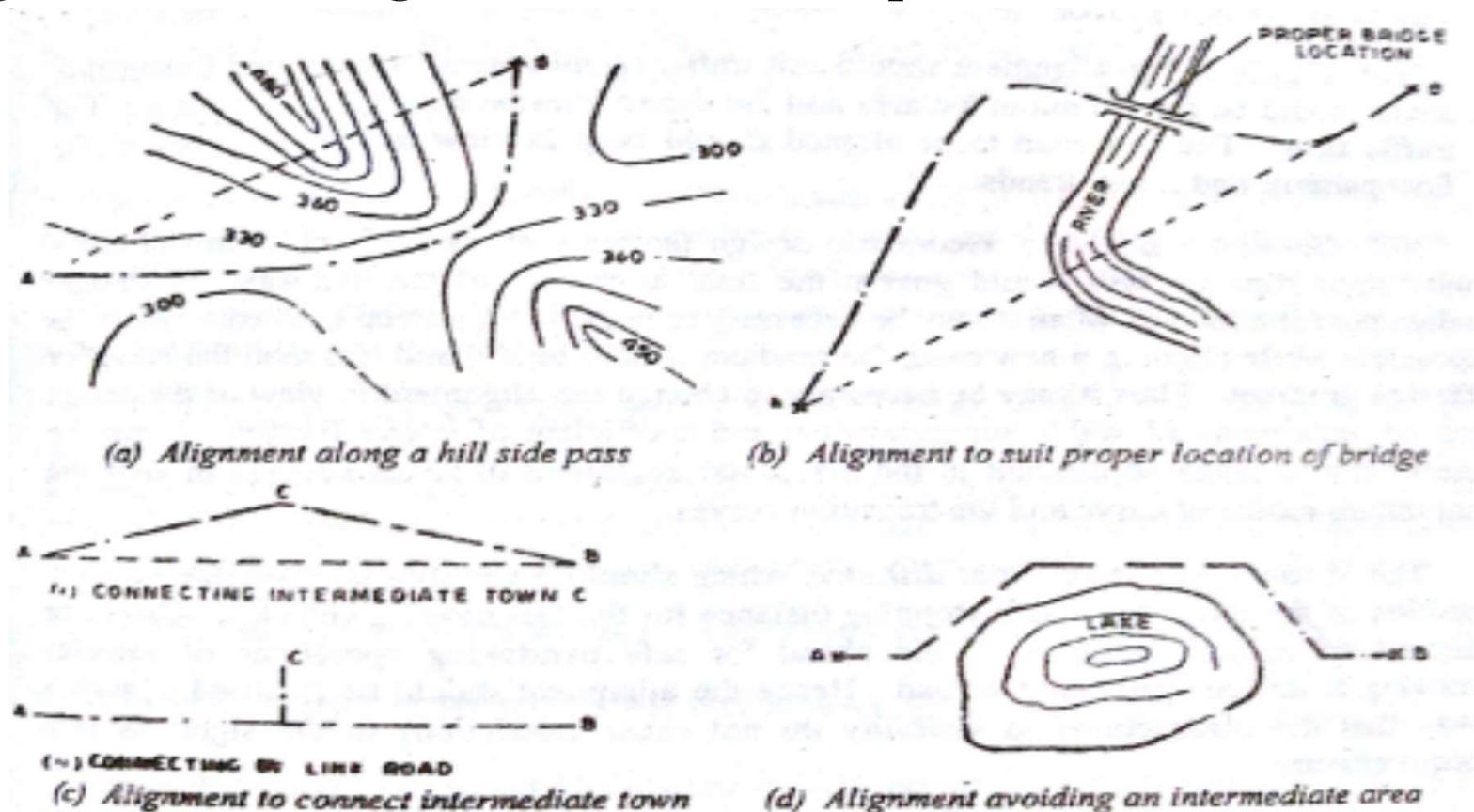
**Economical:**

## Factors affecting alignment

### 1. Obligatory Points:

Points through which the alignment is to pass:

Points through which the alignment should not pass:





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**Traffic:** the alignment should suit traffic requirements. Origin and destination study should be carried out in the area and the desire lines be drawn showing the traffic flow.

**Geometric design:** geometric design factors such as gradient, radius of curve and sight distance, overtaking sight distance, ruling gradient

**Economics:** The safety, saving and returns should be more compared to investment. It is based on the initial cost of construction and maintenance cost of the road, if it a shortest path the cost of construction will be reduced.

**Other consideration:** factors like drainage consideration, hydrological factors, water table, seepage flow, high flood level, political considerations and monotony also affect in deciding the alignment.



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## Engineering surveys

The stages of engineering surveys for Highway locations:

1. Map study
2. Reconnaissance
3. Preliminary surveys
4. Final location and detailed surveys



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## Highway Geometric Design

The position or the layout of the centre line of the highway on the ground is called the alignment. It includes,

Horizontal alignment: - straight path, horizontal deviation and curves.

Vertical alignment: - changes in gradient and vertical curve

The position or the layout of the central line of the highway on the ground is called the alignment. Horizontal alignment includes straight and curved paths. Vertical alignment includes level and gradients. Alignment decision is important because a bad alignment will enhance the construction, maintenance and vehicle operating cost.



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## Factors affecting geometric design of roads

- Design speed: Topography:
- Traffic factors:
- Design Hourly Volume and Capacity:
- Environmental and other factors:



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**Cross-section elements:** It includes cross slope, various widths of road (i.e., width of pavement, formation width and road land width), surface characteristics and features in the road margins.

### **Design Control and Criteria:**

Factors affecting geometric design are as follows

- **Design speed:**
- **Topography:**
- **Traffic factors:**
- **Design Hourly Volume and Capacity:**
- **Environmental and other factors:**



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Highway cross section elements:

Unevenness:



[www.aimil.com](http://www.aimil.com)

## Bump Integrator

AIM 9903



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## Highway cross section elements:

### Friction:

Friction between the wheel and the pavement surface is a crucial factor in the design of horizontal curves and thus the safe operating speed



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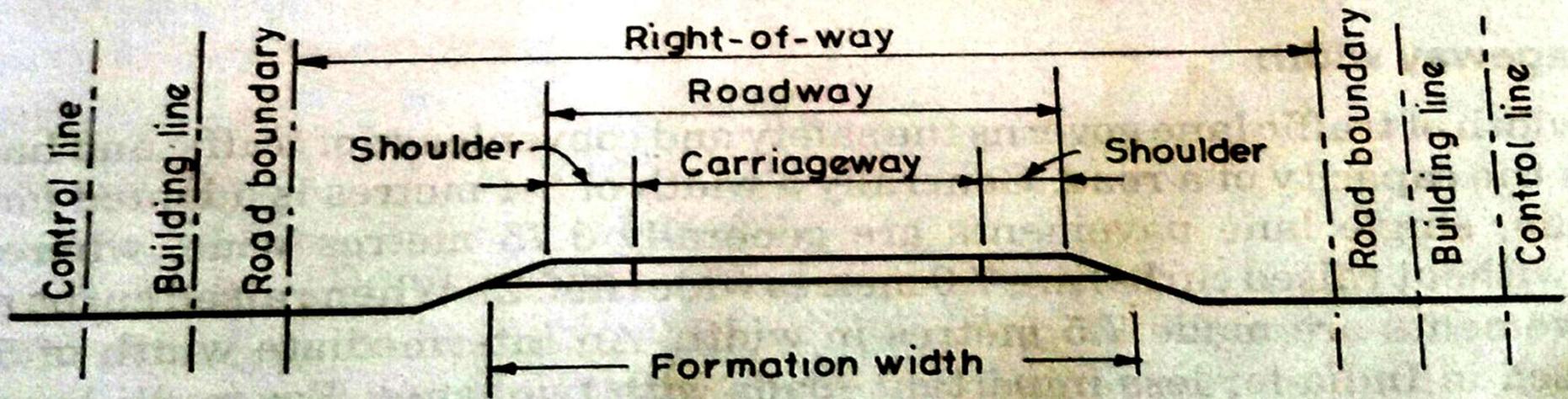
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## Highway cross section elements:

**Right of way:** Right of way (ROW) or land width is the width of land acquired for the road, along its alignment. The width of this acquired land is known as land width and it depends on the importance of the road and possible future development.

- Width of formation:
- Height of embankment or depth of cutting:
- Side slopes of embankment or cutting:
- Drainage system and their size which depends on rainfall, topography etc.



**Fig. 6.18. Right-of-way, building line and control line.**

Sl no.	Road classification	Plain and rolling terrain				Mountainous and steep terrain	
		Open area		Built-up area		Open area	Built-up area
		Normal	Range	Normal	Range	Normal	Normal
1	NH & SH	45	30-60	30	30-60	24	20
2	MDR	25	25-30	20	15-25	18	15
3	ODR	15	15-25	15	15-20	15	12
4	VR	12	12-18	10	10-15	9	9



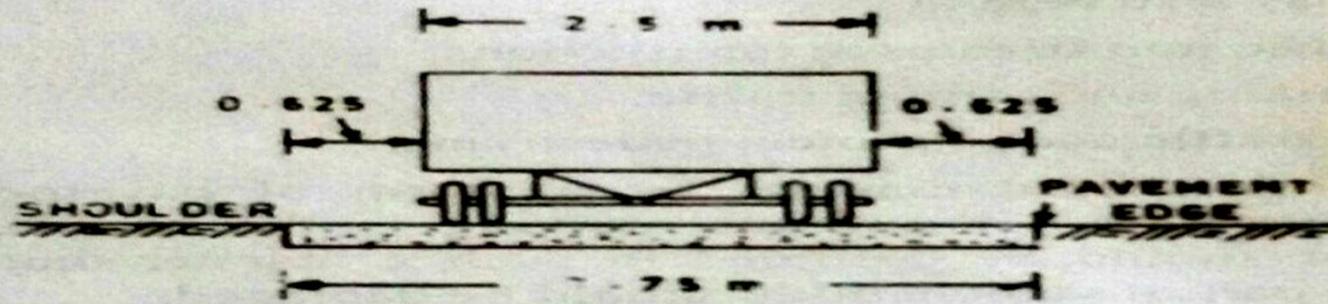
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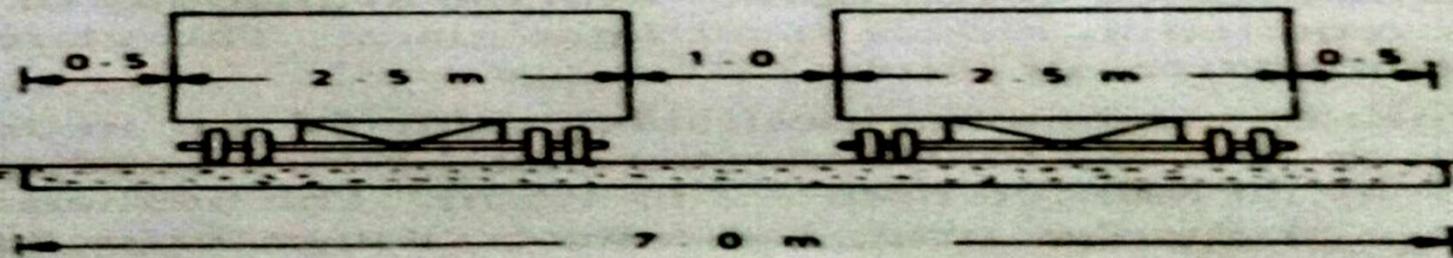
## **Width of carriageway or pavement:**

Carriage way or the width of the pavement depends on the width of the traffic lane and number of lanes. Width of a traffic lane depends on the width of the vehicle and the clearance.

Side clearance improves operating speed and safety. The maximum permissible width of a vehicle is 2.50 and the desirable side clearance or single lane traffic is 0.625 m.



(a) SINGLE LANE PAVEMENT



(b) TWO LANE PAVEMENT

Class of Road		Width of carriageway, m
1	Single lane road	3.75
2	Two lanes without raised kerbs	7.0
3	Two lanes with raised kerbs	7.5
4	Intermediate carriageway	5.5
5	Multi-lane pavements	3.5 per lane



## Camber or cross slope or Cant:

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

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

Sl no	Types of road surface	Range of camber in areas of	
		Heavy rainfall	Low rainfall
1	CC and 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	WBM and 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%



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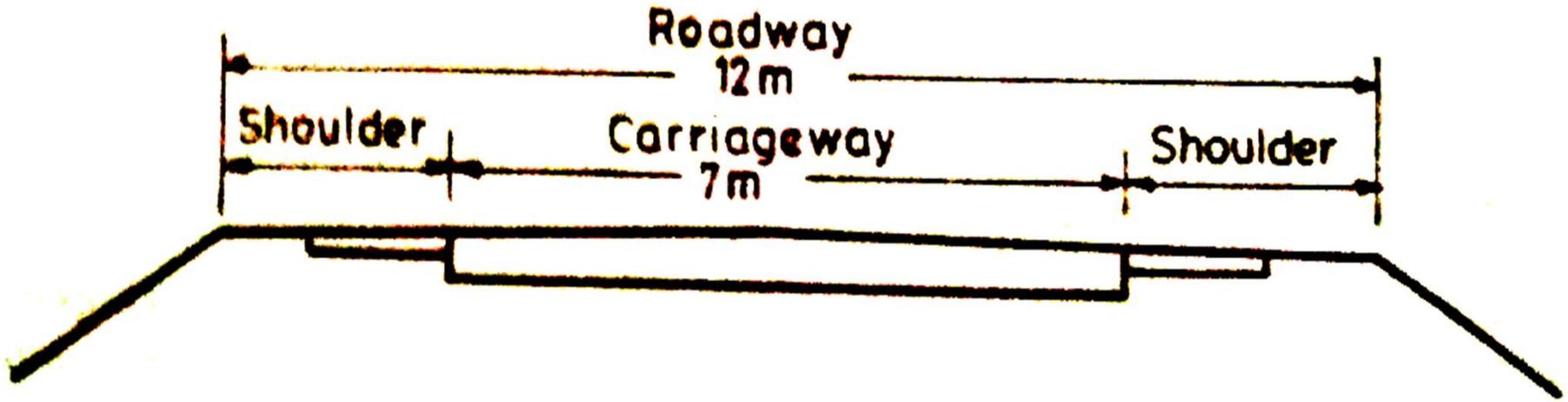
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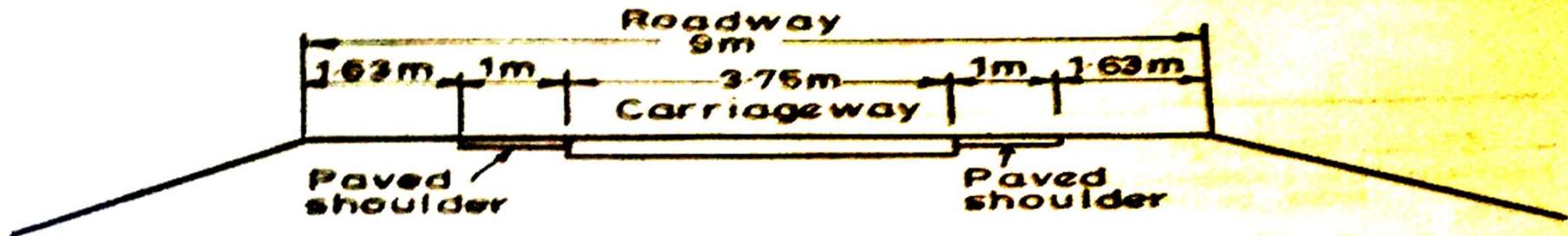
## Width of roadway or formation:

Width of roadway or formation is the sum of widths of pavement or carriageway including separators and the shoulders. Formation or roadway width is the top width of the highway embankment or the bottom width of highway cutting excluding the side drains.

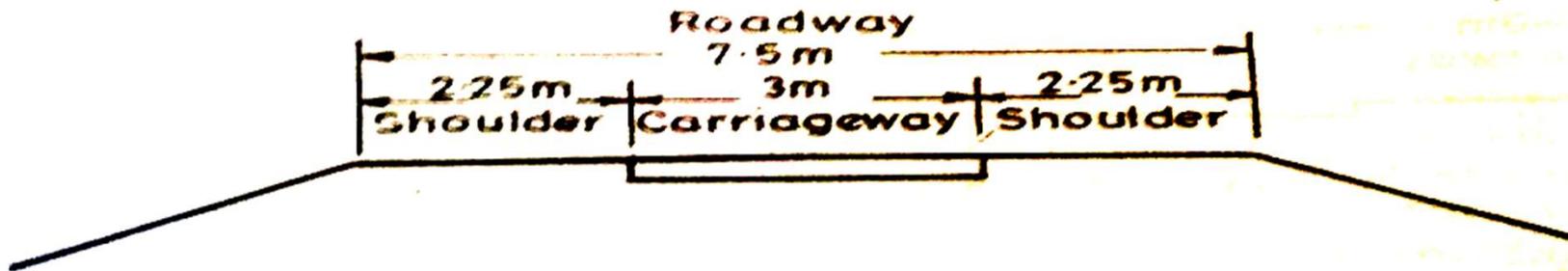
Sl no.	Road classification	Road way width, m	
		Plain & Rolling terrain	Mountainous & steep terrain
1	<b>NH &amp; SH</b>		
	Single lane	12.0	6.25
	Double lane	12.0	8.80
2	<b>MDR</b>		
	Single lane	9.0	4.75
	Double lane	9.0	-
3	<b>ODR</b>		
	Single lane	7.5	4.75
	Double lane	9.0	-
4	<b>Village roads</b>	7.5	4.0



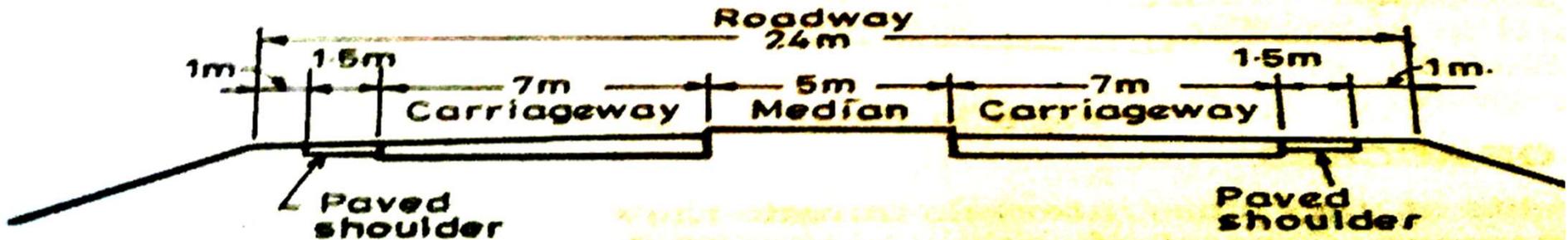
**Fig. 6.22. Typical 2-lane National or State Highway (Rural Section).**



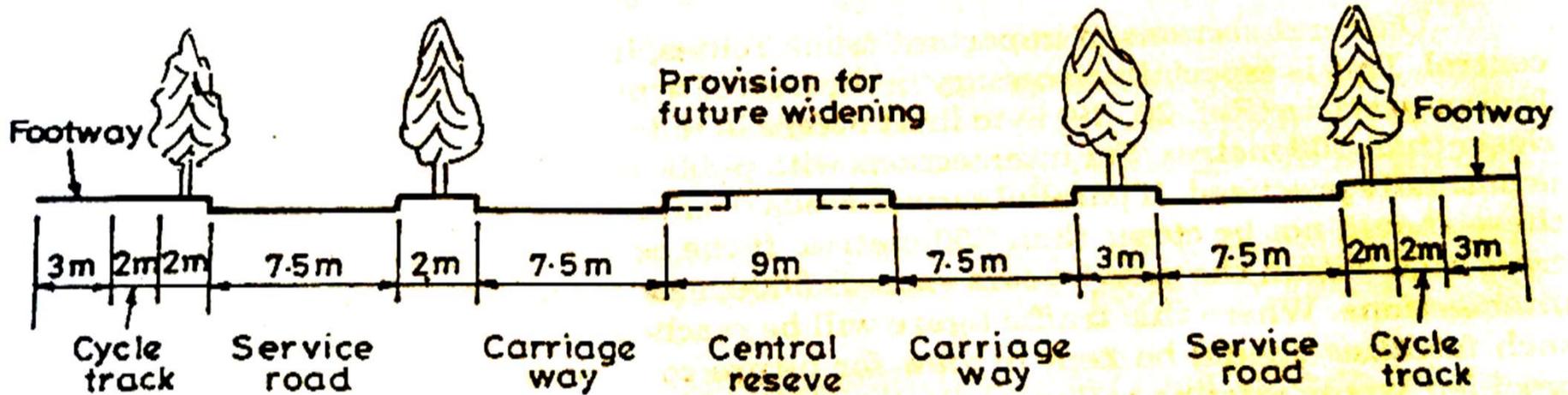
*Fig. 6.23. Typical single lane road with paved shoulders.  
(Major District Road or Other Dist. Road)*



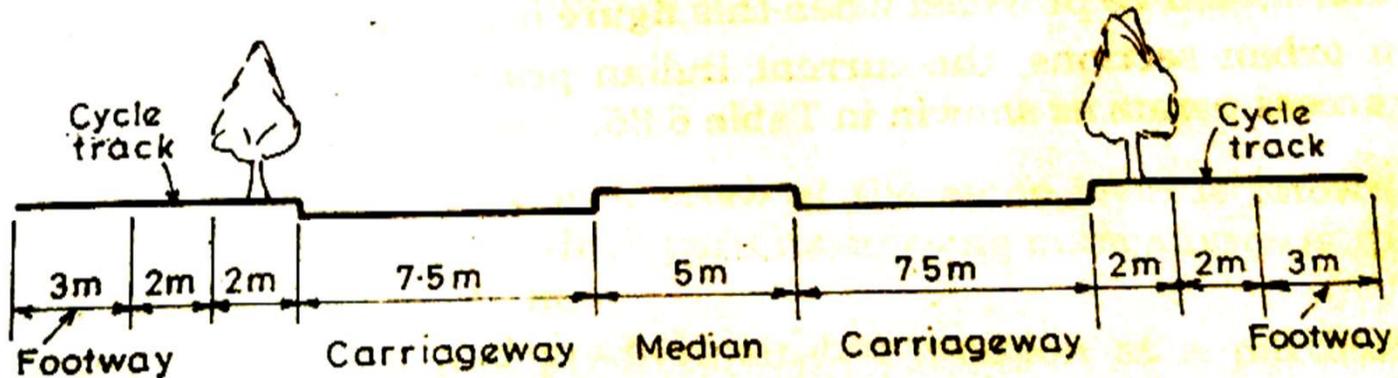
*Fig. 6.24. Typical village road.*



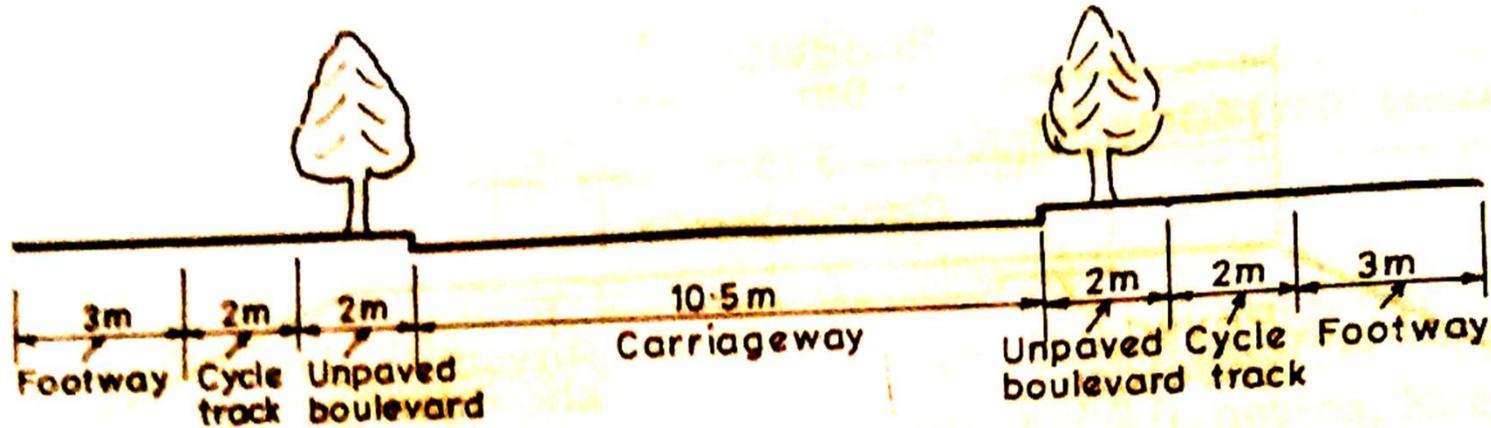
*Fig. 6.25. Typical dual carriageway (2 lane each) in rural areas.*



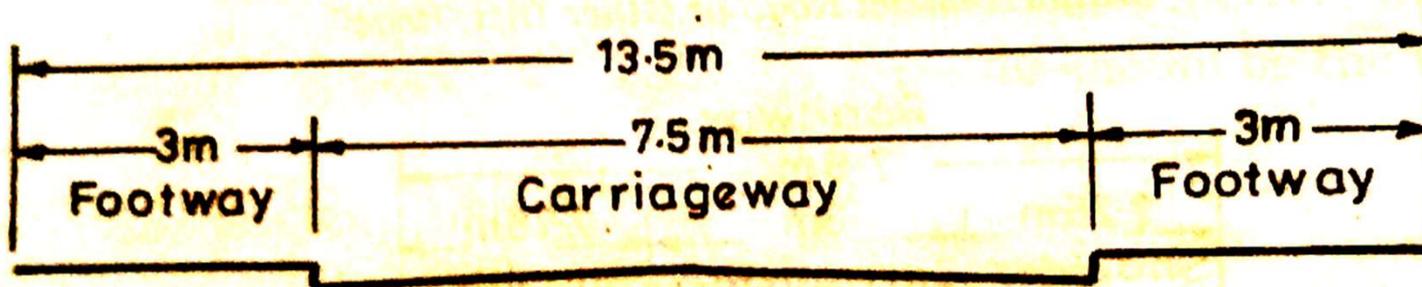
*Fig. 6.26. Urban arterial street.*



*Fig. 6.27. Urban sub-arterial street through open area.*



**Fig. 6.28. Urban collector street through residential area.**



**Fig. 6.29. Urban residential street.**



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

**Low or mountable kerbs:**





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## Semi-barrier type kerbs:





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**Barrier type kerbs:**



**Submerged kerbs:**





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## Sight distances

Visibility is very important for safe vehicle operation on a highway. Restrictions to sight distance may be caused at horizontal curves, by objects obstructing vision at the inner side of the road or at vertical summit curves or at intersections.

Three sight distance situations are considered in the design,

- Stopping or absolute minimum sight distance
- Safe overtaking or passing sight distance
- Safe sight distance for entering into uncontrolled intersections

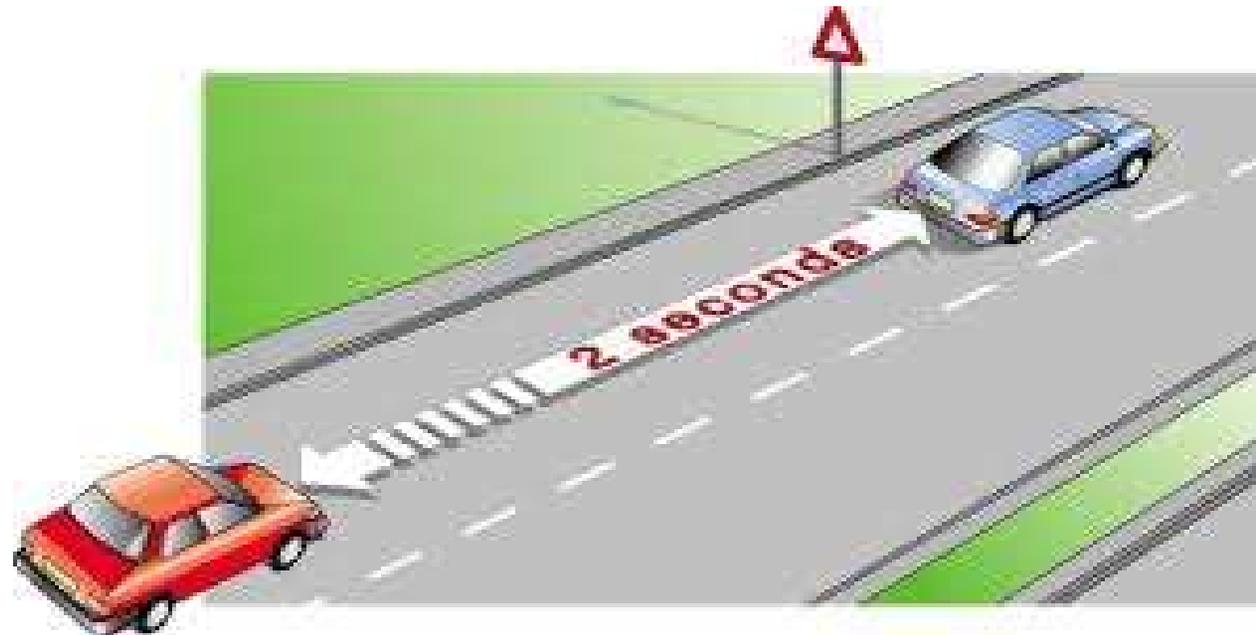


## Stopping sight distance:

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

## Factors affecting sight distance:

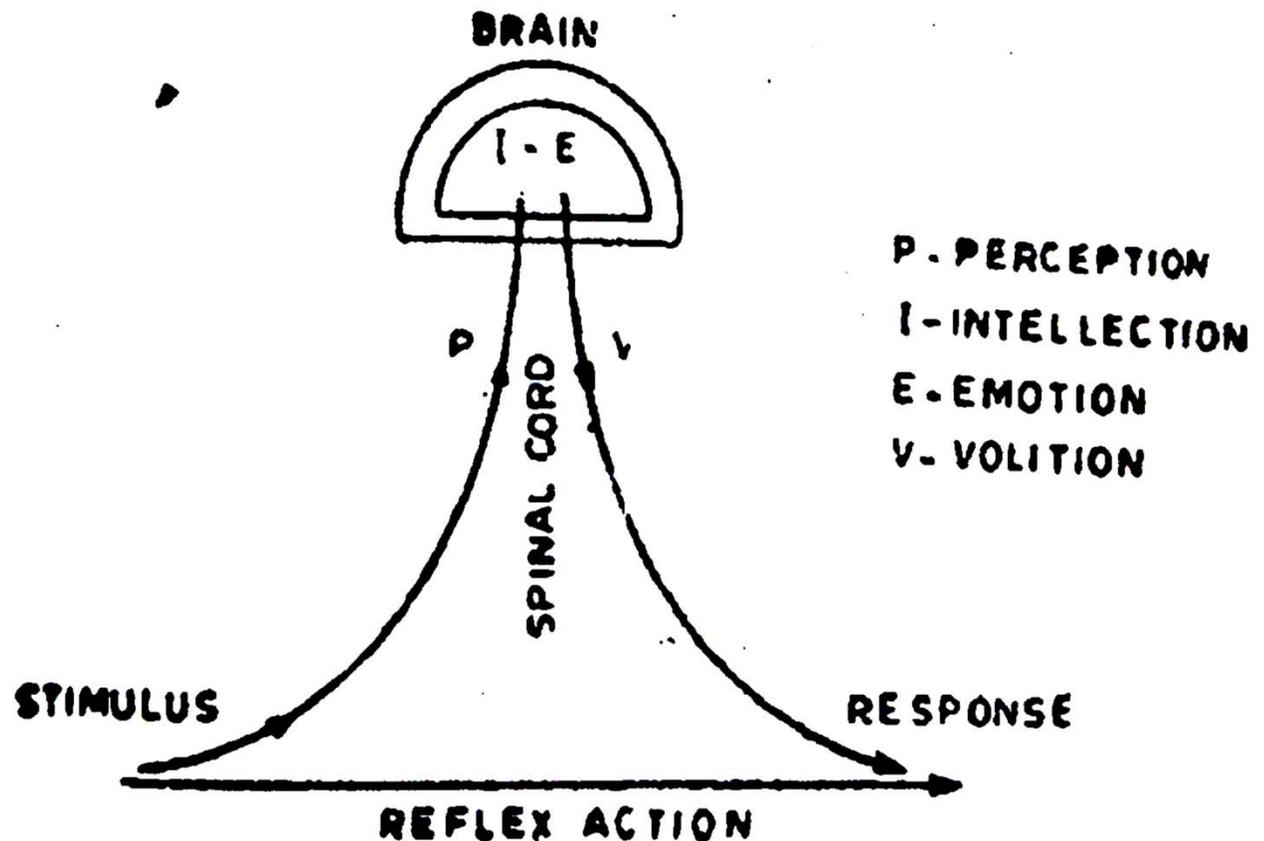
- Frictional resistance between the tire and the road:
- Speed of the vehicle:
- Efficiency of brakes:
- Gradient of the road:



## Reaction time of the driver:

Reaction time of a driver is the time taken from the instant the object is visible to the driver to the instant when the brakes are applied. The total reaction time may be split up into four components based on PIEV theory.

- Perception
- Intellection
- Emotion
- Volition (final action)





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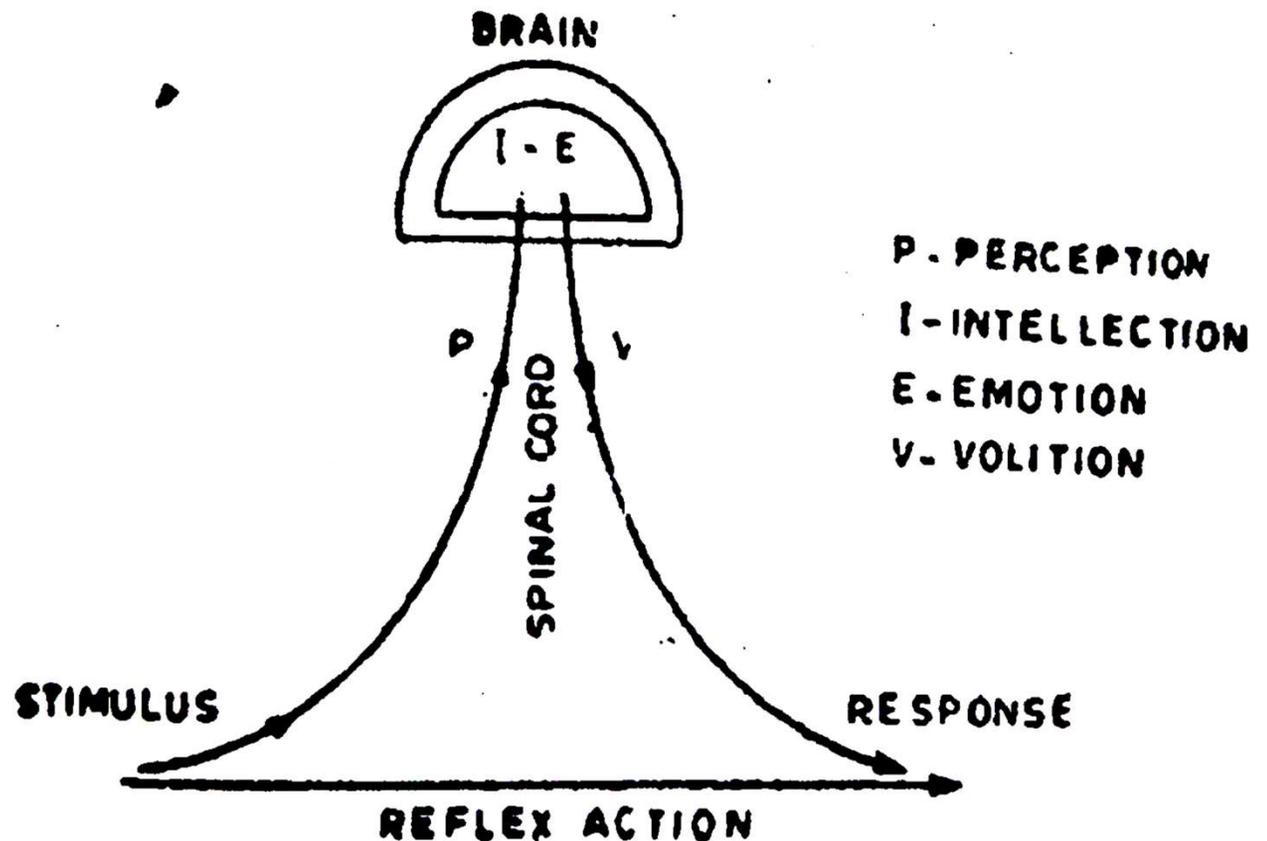


**Perception time** is the time required for the sensations received by eyes or ears

**Intellection time** is the time required for understanding the situation.

**Emotion time** is the time elapsed during emotional sensations

**Volition time** is the time taken for the final action.





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**Sight distance:**

**Braking distance:**

$$l = \frac{v^2}{2gf}$$

**l – Braking distance**

**v – Speed of vehicle, m/sec**

**f – Design co-efficient of friction (0.4 to 0.35)**

**g – Acceleration due to gravity = 9.81 m/sec<sup>2</sup>**



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**Sight distance on level ground:**

**Stopping distance, SD = Lag distance + Braking distance**

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

**If speed is V kmph,**

$$SD, m = 0.278 Vt + (V^2/254f)$$



**Sight distance at slopes:**

$$SD, m = \left[ vt + \frac{v^2}{2g(f \pm 0.01n)} \right]$$

**If speed is V kmph,**

$$SD, m = 0.278 Vt + \frac{V^2}{254(f \pm 0.01n)}$$

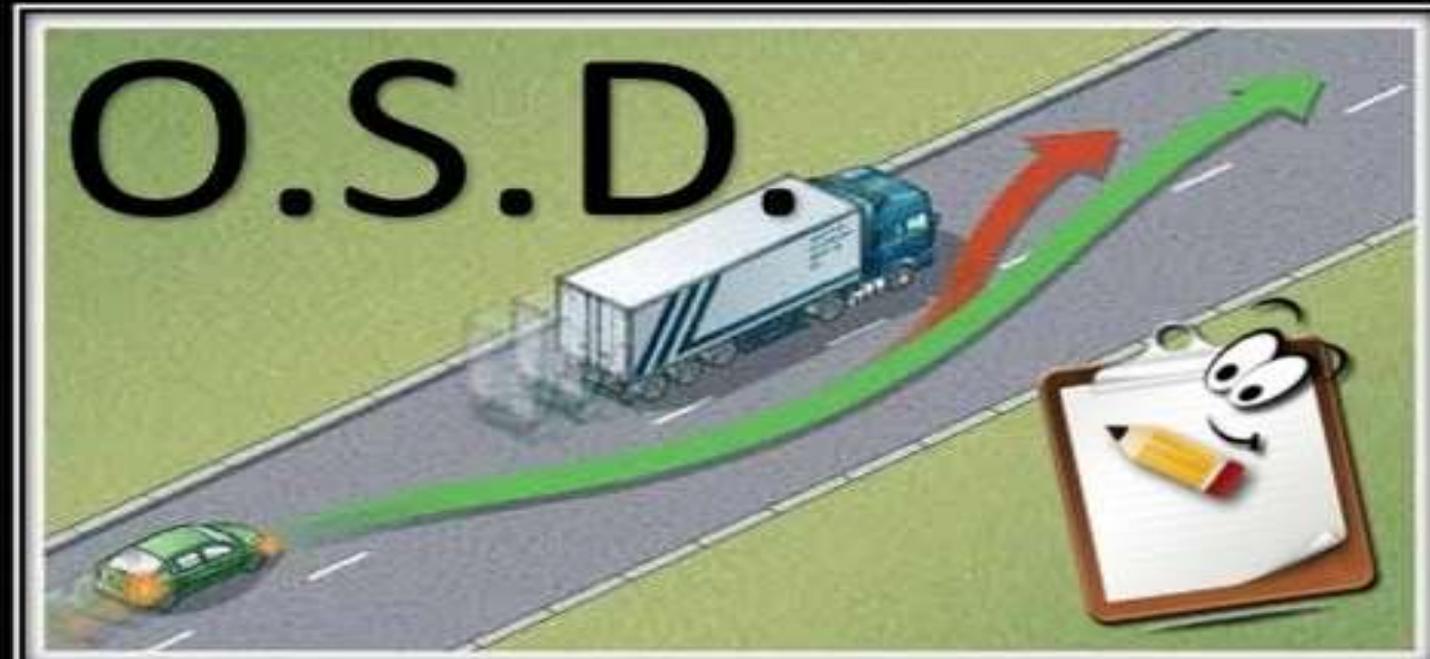


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## Overtaking Sight Distance (OSD):

The minimum distance to open the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction.





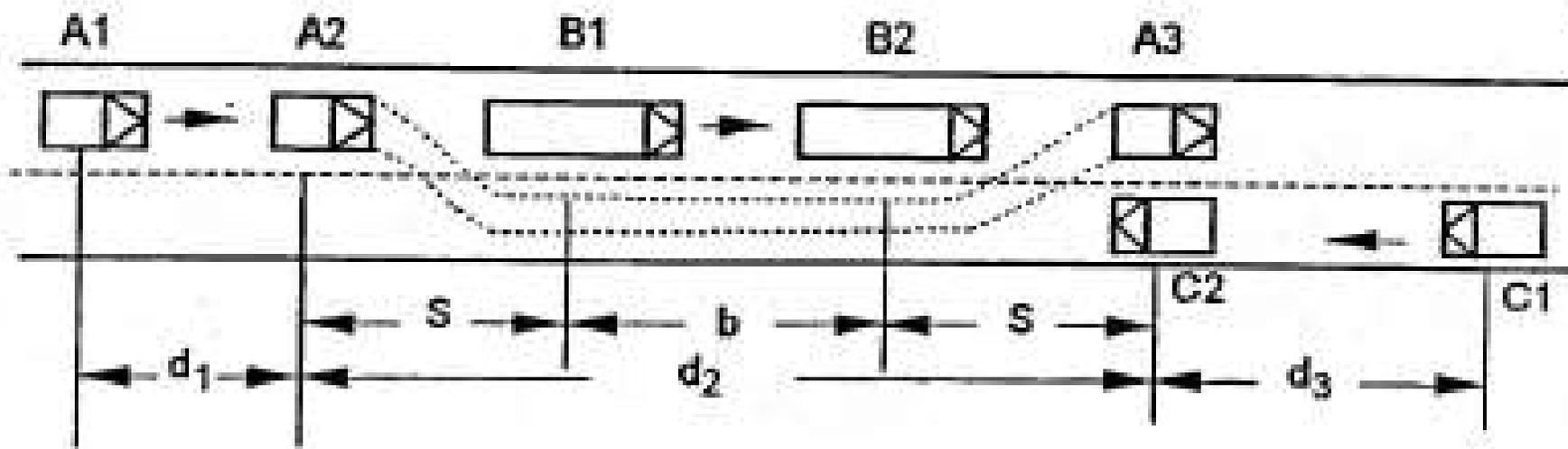
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Factors required for the safe overtaking manoeuvre depends, are

- Speed of (i) overtaking vehicle (ii) overtaken vehicle (iii) the vehicle coming from opposite direction
- Distance between the overtaking and overtaken vehicle: the minimum spacing depends on the speeds
- Skill and reaction time of driver
- Rate of acceleration of overtaking vehicle
- Gradient of the road

## Analysis of OSD on a 2-way road





## Analysis of OSD on a 2-way road

$$d_1 = 2v_b (m)$$

$$s = (0.7 v_b + 6), m$$

$$b = v_b T$$

$$d_2 = (b + 2s), m$$

$$2s = \frac{aT^2}{2}$$

$$T = \sqrt{\frac{4s}{a}} \text{ secs.}$$

$$d_3 = v T (m)$$



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$$\text{OSD} = (d_1 + d_2 + d_3) = (v_b t + v_b T + 2s + vT) \text{ m}$$

$$\text{OSD} = 0.28 V_b t + 0.28 V_b T + 2s + 0.28 V.T$$

$V_b$  = initial speed of overtaking vehicle, kmph

$t$  = reaction time of driver = 2 sec

$V$  = speed of overtaking vehicle or design speed, kmph

$$T = \sqrt{\frac{4 \times 3.6s}{A}} = \sqrt{\frac{14.4s}{A}}$$

$s$  = spacing of vehicles =  $(0.7 v_b + 6) \text{ m} = (0.2 V_b + 6) \text{ m}$

$A$  = average acceleration during overtaking, kmph/sec.



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If  $v_b$  or  $V_b$  is not given, assumed as 4.5 m/sec or 16 kmph

$$v_b = (V - 4.5) \text{ m/s}$$

$$V_b = (V - 16) \text{ kmph}$$

### **Overtaking zone:**

Minimum length of overtaking zone should be = 3 \* OSD

Desirable length of overtaking zone should be = 5 \* OSD

### **Intermediate sight distance:**

$$\text{ISD} = 2 * \text{SSD}$$



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## **Horizontal alignment:**

**Design speed:** The design speed is the main factor on which geometric elements depends. The sight distances, radius of horizontal curve, super elevation, extra widening of pavement, length of horizontal curve are all dependent on speed.

## **Super elevation:**

In order to counteract the effect of centrifugal force and to reduce the tendency of the vehicle to overturn or skid, the outer edge of the pavement is raised with respect to the inner edge, thus providing a transverse slope throughout the length of the horizontal curve. This transverse inclination to the pavement surface is known as super elevation or cant or banking.



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## **Widening of pavement on horizontal curve:**

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

**Mechanical widening:** The widening required to account for the off-tracking due to the rigidity of wheel based is called mechanical widening.

**Psychological widening:** Extra width of pavement is also provided for psychological reasons such as, to provide for greater manoeuvrability of steering at higher speeds, to allow for the extra space requirements for the overhangs of vehicles and to provide greater clearance for crossing and overtaking vehicles on the curves.



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## **Vertical alignment:**

### **Gradient:**

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical to x horizontal units). It is also expressed as a percentage n i.e. n in 100.

Gradients are divided into the following categories:

- Ruling gradient
- Limiting gradient
- Exceptional gradient
- Minimum gradient



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## **Vertical curves:**

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

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

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



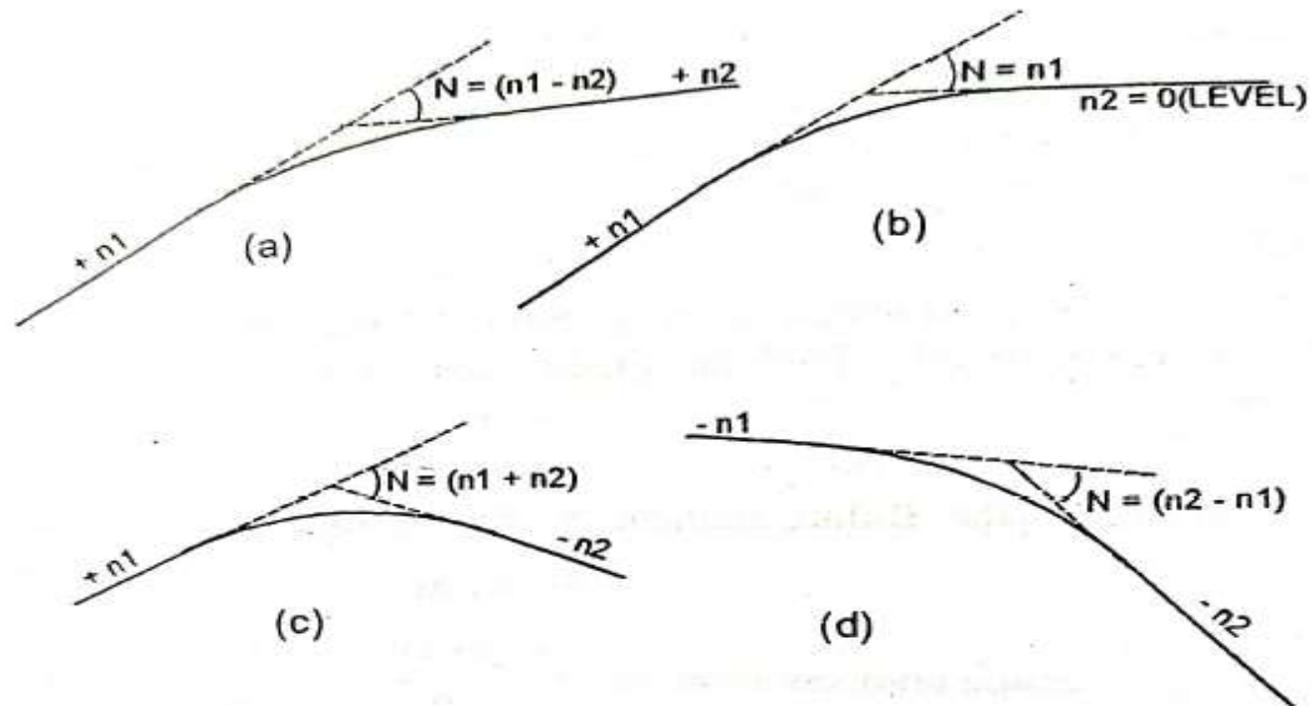
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## Summit curves:

The deviation angle between the two interacting gradients is equal to the algebraic difference between them. Of all the cases, the deviation angle will be maximum when an ascending gradient meets with a descending gradient i.e.  $N = n_1 - (-n_2) = (n_1 + n_2)$



Types of summit curves



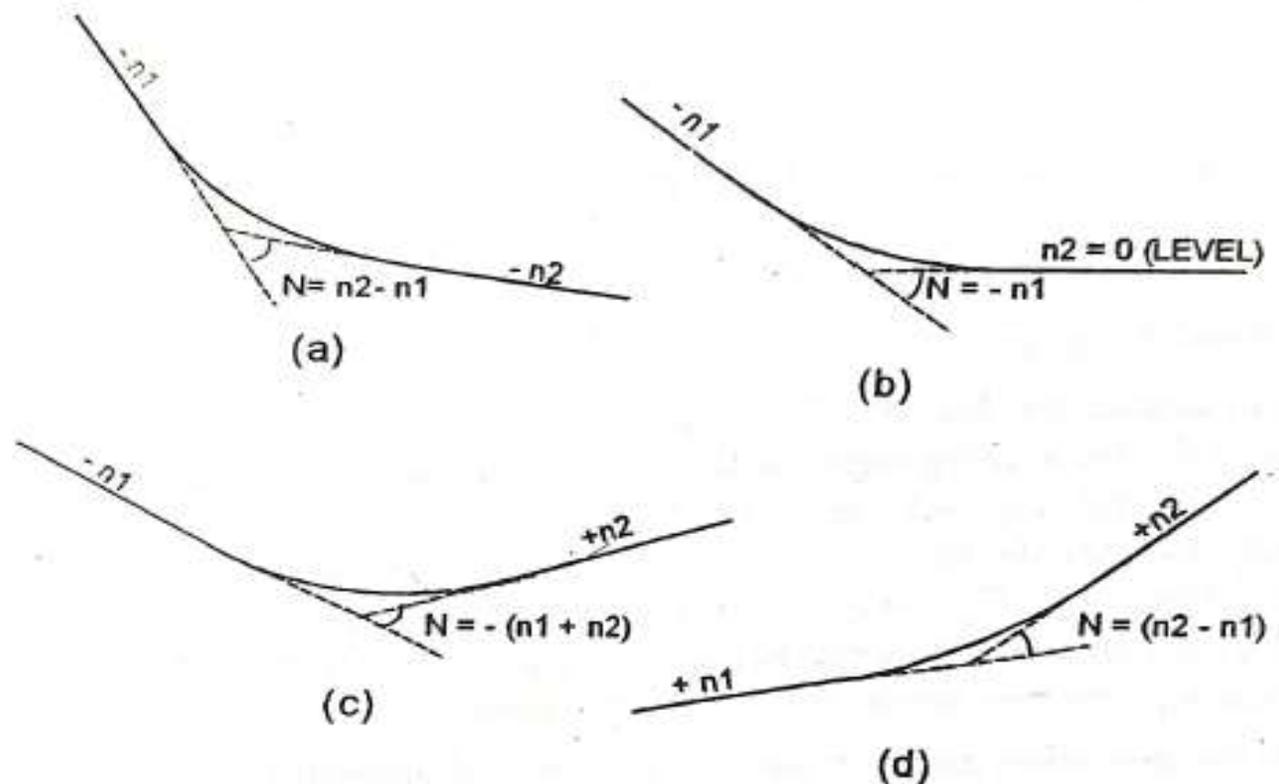
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## Valley curve:

In all the cases the maximum possible deviation angle is obtained when a descending gradient meets with an ascending gradient.



Types of valley curves



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# Module – 2

## Highway Materials and Pavements



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## Subgrade soil

- Subgrade soil is considered as the integral part of the road structure.
- It provides support to the pavement from beneath.
- The properties of subgrade soil are important to the design of pavement structure.
- Its main function is to give adequate support to the pavement.
- It should possess sufficient stability under adverse climate and loading conditions.



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## **Desirable Properties**

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

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



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## **Road Aggregates**

Desirable properties of road aggregates:

- Strength – Crushing
- Hardness - Abrasion
- Toughness – Impact
- Durability - Soundness
- Shape of aggregates – Flaky and elongation
- Adhesion with bitumen



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## **Desirable Properties of Bitumen**

**Viscosity:** The viscosity of the bitumen at the time of mixing and compaction should be adequate. This is achieved by heating the bitumen and aggregate prior to mixing or by use of cutbacks or emulsions of suitable grade.

**Temperature Susceptibility:** The bituminous material should not be highly temperature susceptible. During the hottest weather of the region the bituminous mix should not become too soft or unstable. During cold weather the mix should not become too hard and brittle, causing cracking. The material should be durable.

**Adhesion Property:** In presence of water the bitumen should not strip off from the aggregate. There has to be adequate affinity and adhesion between the bitumen and aggregate used in the mix.



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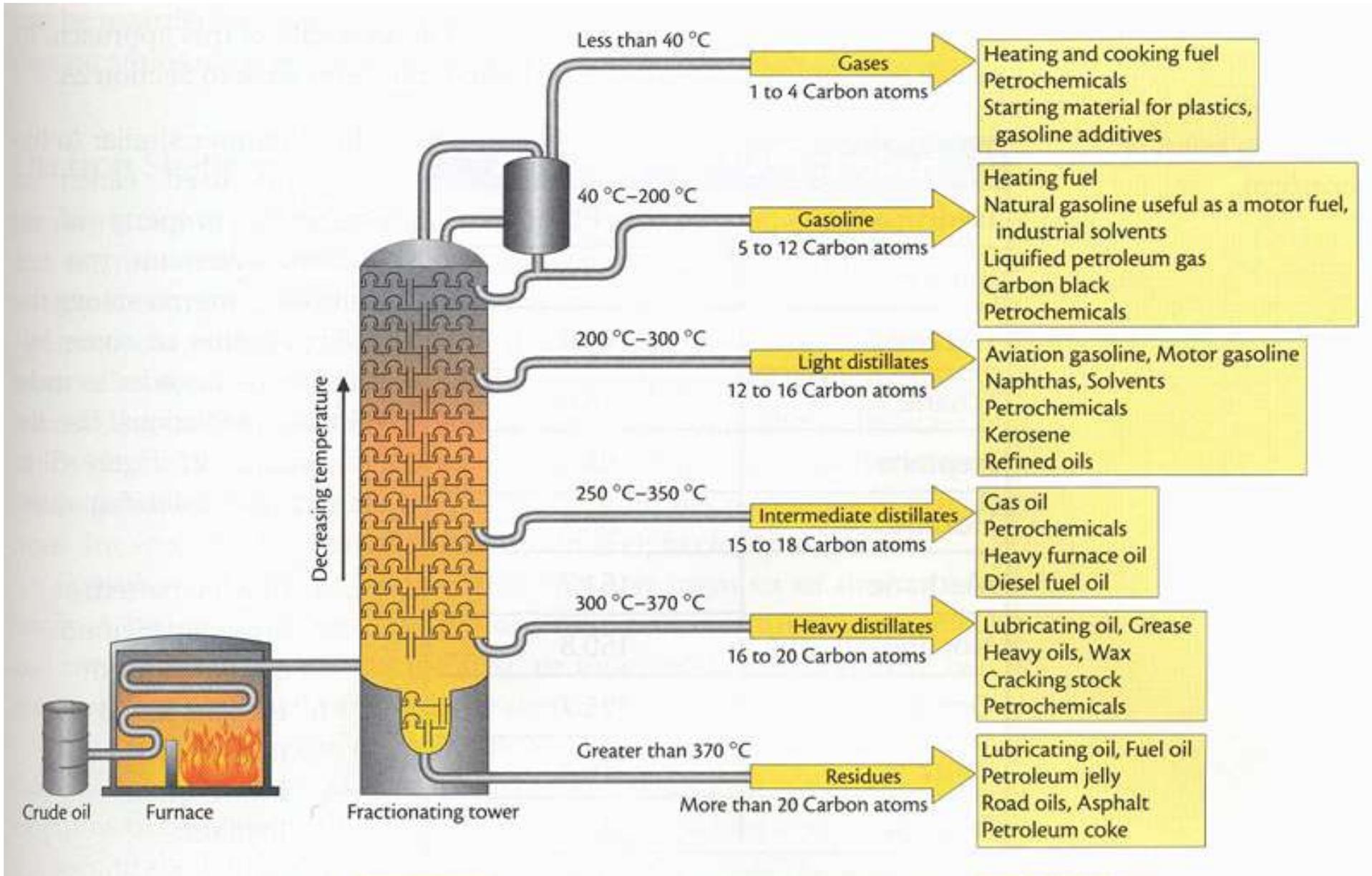


## Bituminous materials

### Overview

- Bitumen - Bitumen is obtained from fractional distillation of crude oil
- Tar - Tar is obtained by destructive distillation of coal or wood

## Production of Bitumen



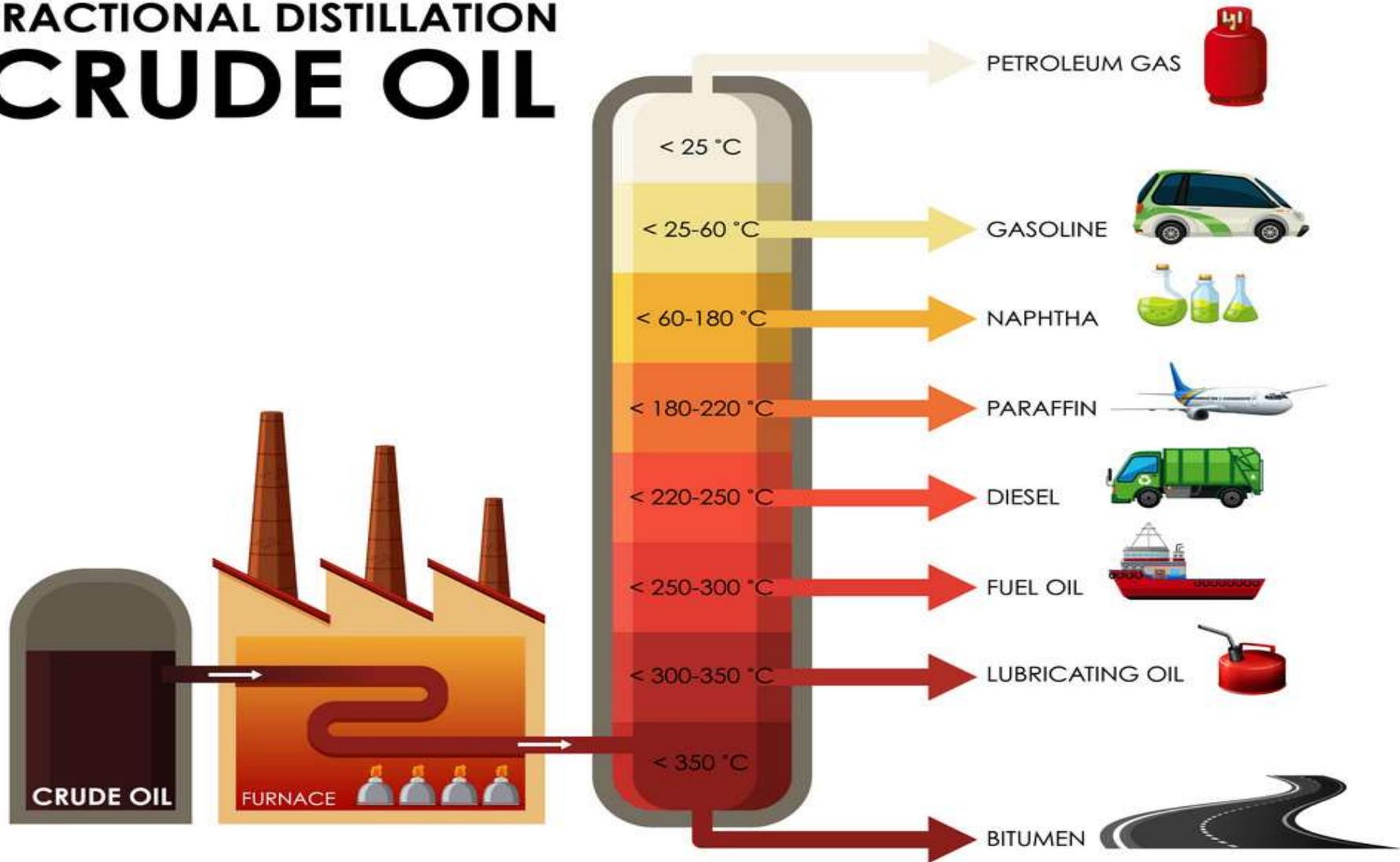


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## FRACTIONAL DISTILLATION CRUDE OIL





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## **Different forms of bitumen**

### **Bitumen Emulsion**

Rapid setting (RS), Medium setting (MS), and Slow setting (SC).

Rapid setting emulsions are used for surface dressing work.

Medium setting emulsions are preferred for premix jobs and patch repairs work.

Slow setting emulsions are preferred in rainy season.



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## **Factors Controlling design of highway pavements**

- Wheel load
- Axle configuration
- Contact pressure
- Vehicle speed
- Repetition of loads
- Subgrade type
- Temperature
- Precipitation



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## **Pavement Design:**

### **Pavement types**

The pavements can be classified based on the structural performance into two,

- Flexible pavements
- Rigid pavements

## Flexible pavements



Typical cross section of a flexible pavement

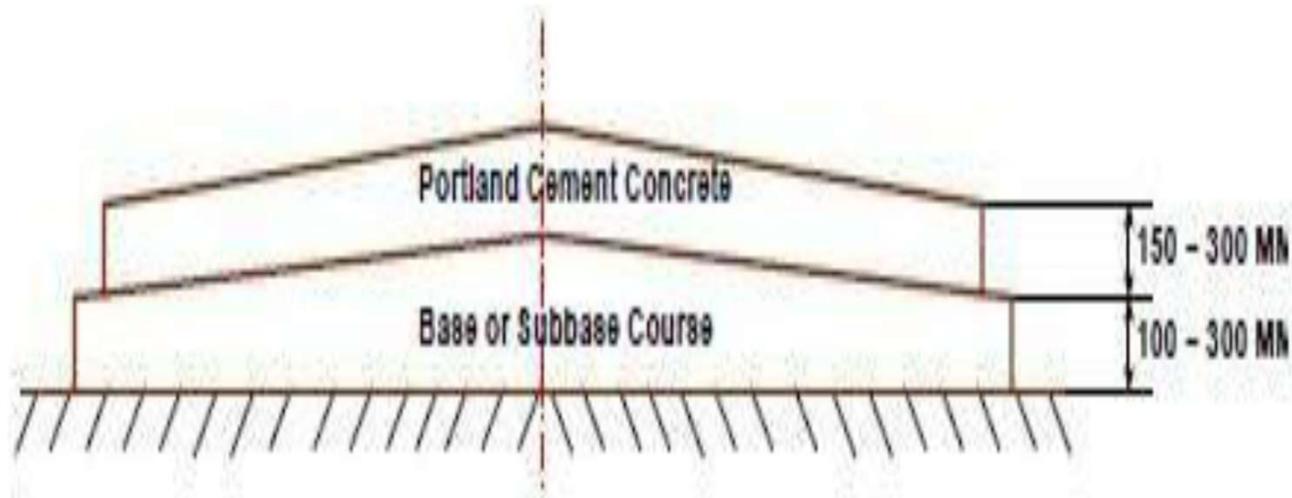


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## Rigid pavements



Typical Cross section of Rigid pavement



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## Factors Controlling design of highway pavements



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## Factors Controlling design of highway pavements



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## Motor grader



## Pneumatic roller





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## Vibratory roller



## Sheepsfoot roller





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## Smooth wheeled or static roller (Double Drum or Tandem)



## Single Drum or Three-wheeled





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## Water sprinkler



## Vibratory plate compactors





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## Harrow



## Rotavator





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## Excavator



## Front and Backhoe loader





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## Bulldozer



## Crawler bulldozer





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## Trenchers



## Front loader





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## Dump truck



## Tipper truck





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## Asphalt paver



## Concrete paver





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## Bitumen sprayer



## Bitumen heater





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## **Introduction:**

Highway drainage is the process of removing and controlling excess surface and sub-soil water with in the right of way.

- Surface drainage.
- Sub-surface drainage.
- Held water.



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## Significance of Drainage

- Excess moisture in soil subgrade causes considerable lowering of its stability
- Increase in moisture cause reduction in strength of many pavement materials
- One of the most important causes of pavement failure by the formation of waves and corrugations
- In clayey soils variations in moisture content cause considerable variation in volume of sub-grade.
- Sustained contact of water with bituminous pavements causes failures due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.



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- In places where freezing temperatures are prevalent in winter, the presence of water in the subgrade and a continuous supply of water from the ground water can cause considerable damage to the pavement due in frost action.
- Excess water on shoulder and pavement edge causes considerable damage.
- Erosion of soil from top of un-surfaced roads and slopes of embankment, cut and hill side is also due to surface water.
- The prime cause of failure in rigid pavements by mud pumping is due to the presence of water in fine sub-grade soil



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## **Requirements of highway drainage system:**

- The surface water from the carriageway and shoulder should effectively be drained off without allowing it to percolate to sub-grade.
- The surface water from the adjoining land should be prevented from entering the roadway.
- The side drains should have sufficient capacity and longitudinal slope to carry away all the surface water collected.
- Flow of surface water across the road and shoulders and along slopes should not cause formation of cross ruts or erosion.



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## **Requirements of highway drainage system:**

- Seepage and other sources of underground water should be drained off by the subsurface drainage system.
- Highest level of ground water table should be kept well below the level of sub-grade, preferably by at least 1.2 m.
- In water logged areas special precautions should be taken, especially if detrimental salts are present or if flooding is likely to occur.



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## **Surface drainage:**

The surface water is to be collected and then disposed off. The water is first collected in longitudinal drains, generally in side drains and then the water is disposed off at the nearest stream, valley or water course.

Cross drainage structures like culverts and small bridges may be necessary for the disposal of surface water from the road side drains.



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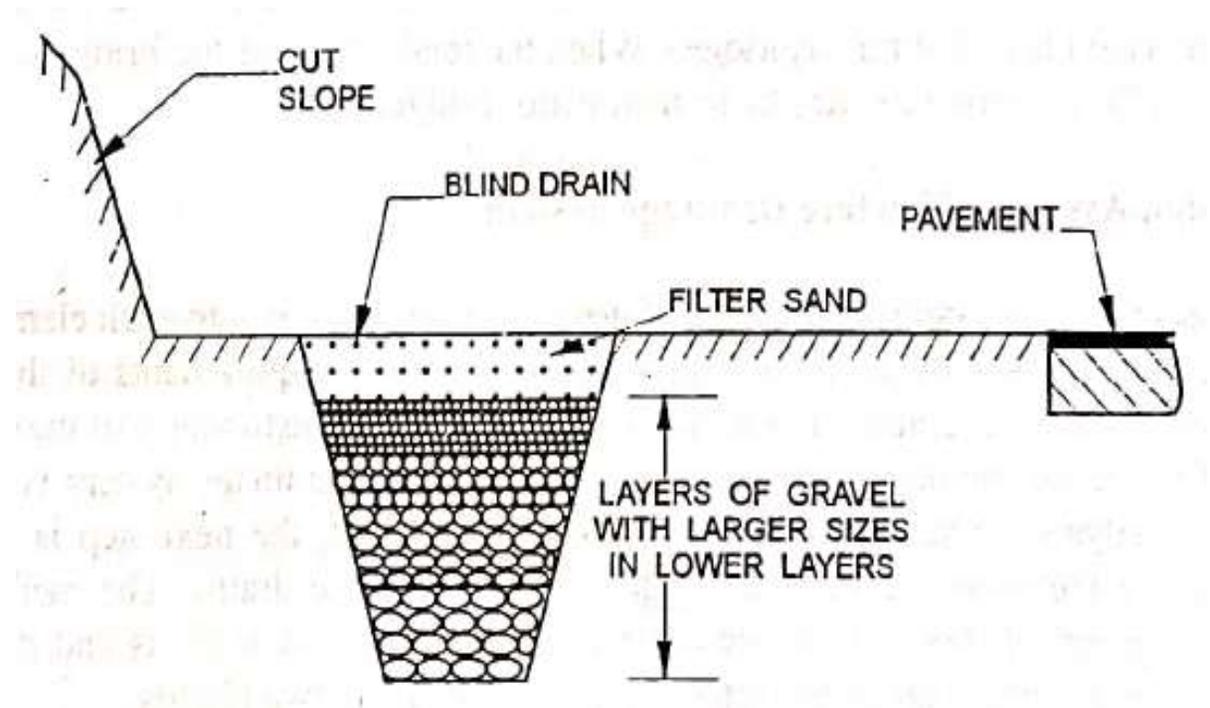
## **Collection of surface water:**

### **Camber or cross slope**

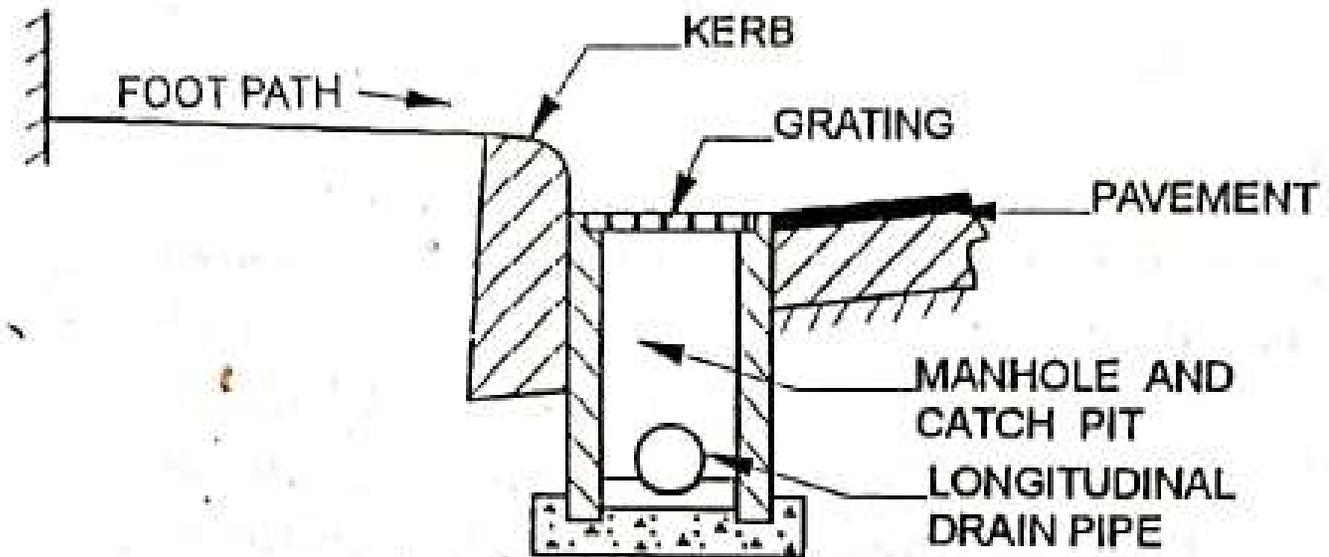
The water from the pavement surface is removed by providing the camber or cross slope to the pavement. Rate of this cross slope is decided based on type of pavement surface and amount of rainfall. The values of camber range from 1 in 25 or 40% for earth road to 1 in 60 or 1.7% for high type bituminous surface and CC pavements.

## Road side drains

Road side drains of highways passing through rural areas are generally open, unlined drains of trapezoidal shape, cut to suitable cross section and longitudinal slopes



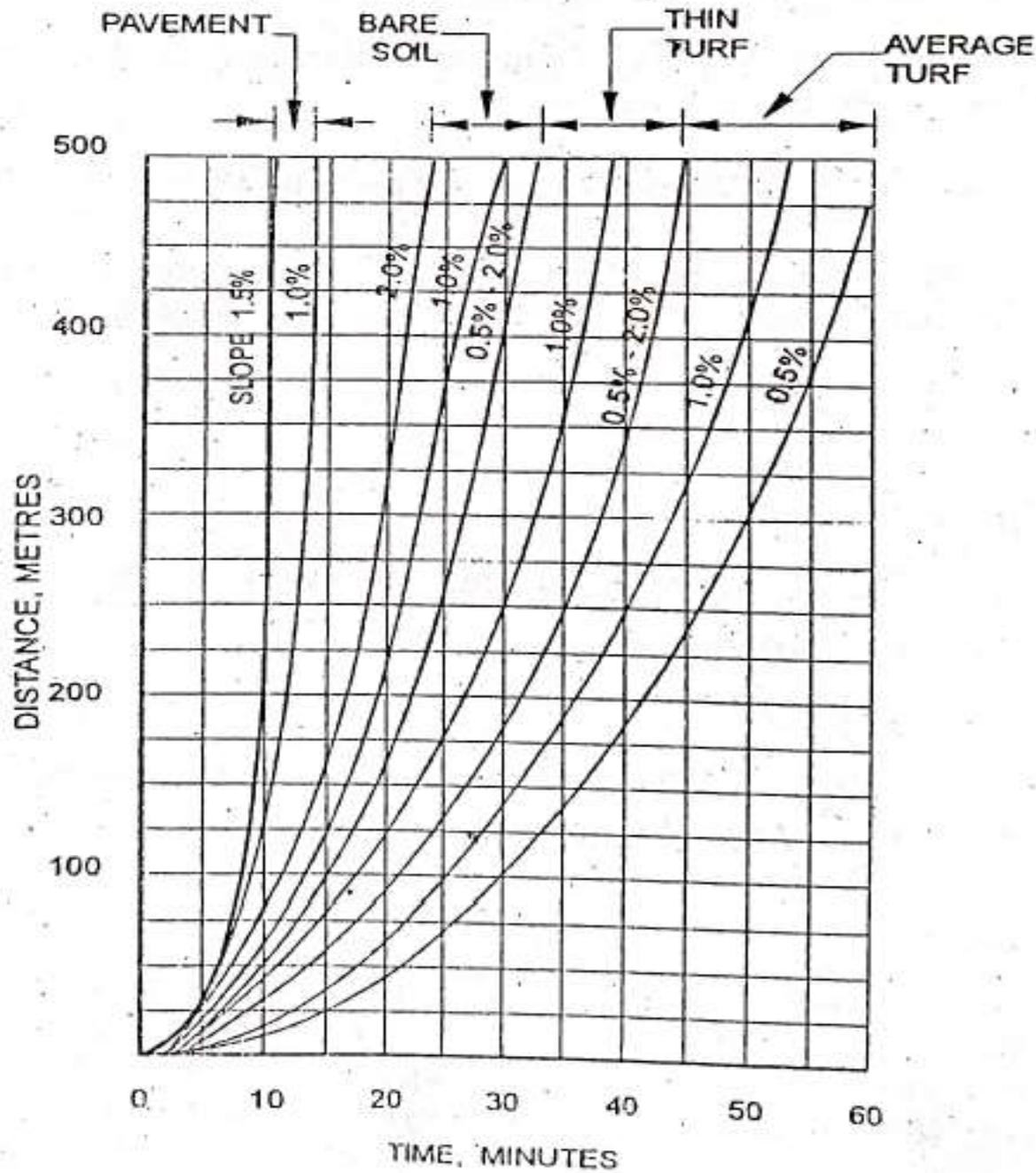
In urban roads because of the limitation of land and also due to the presence of foot path, dividing islands and other road facilities, it is necessary to provide underground longitudinal drains.





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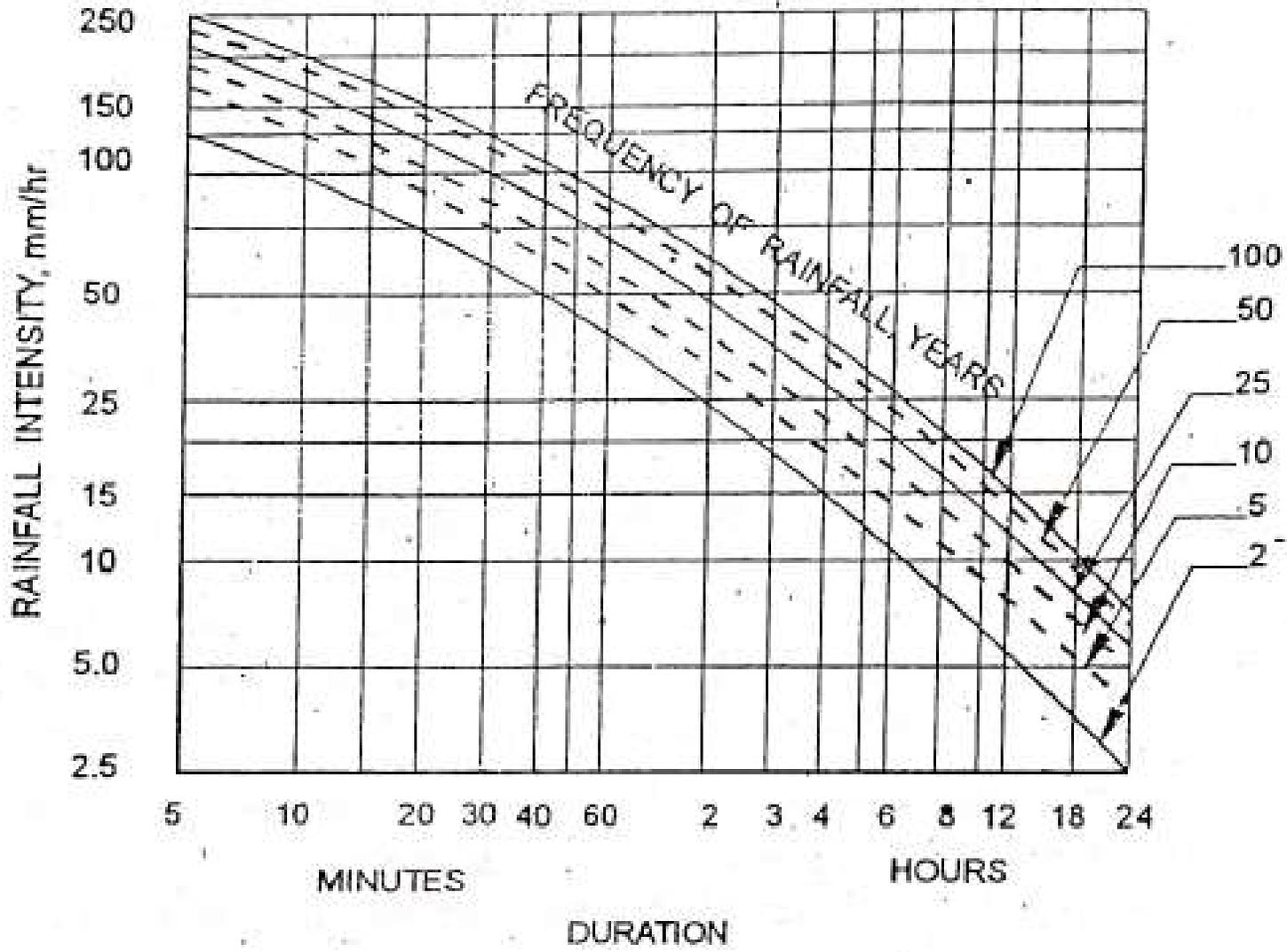
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## **Sub-surface drainage:**

Changes in moisture content of sub-grade are caused by fluctuations in ground water table seepage flow, percolation of rain water and movement of capillary water and even water vapour.



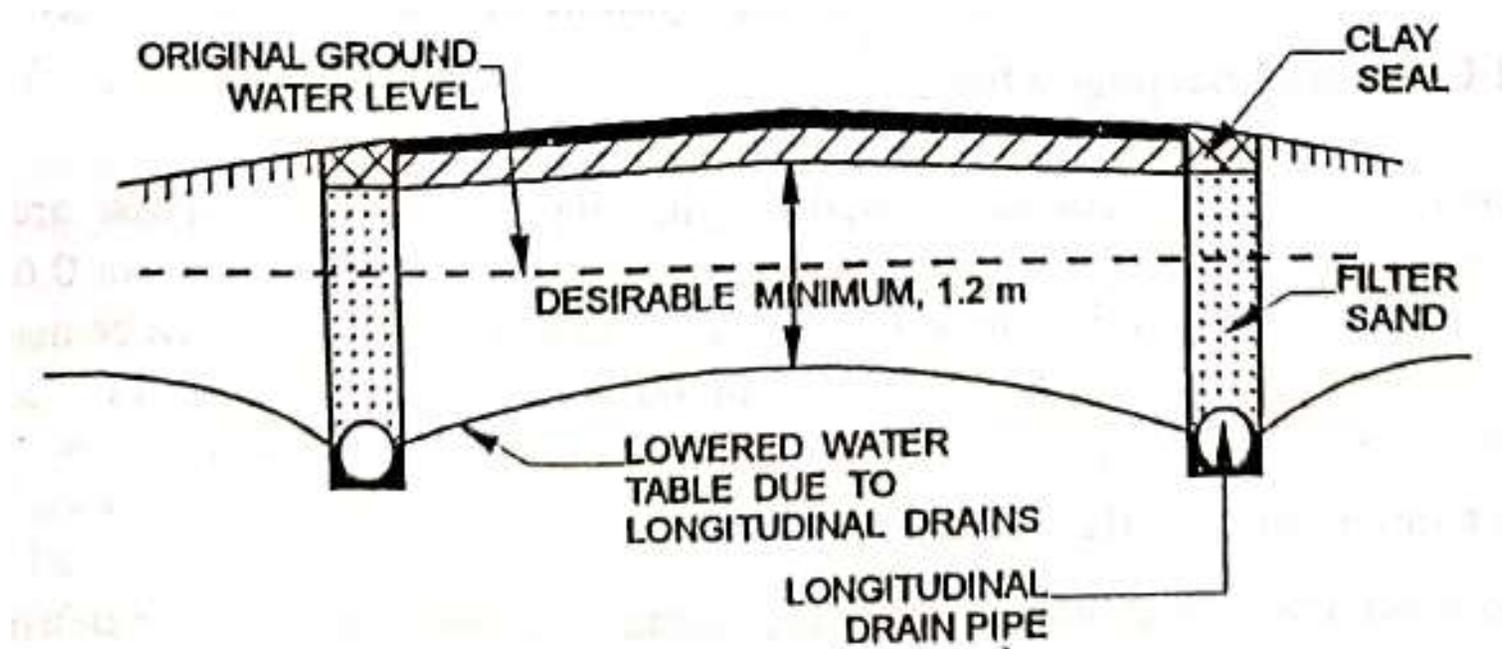
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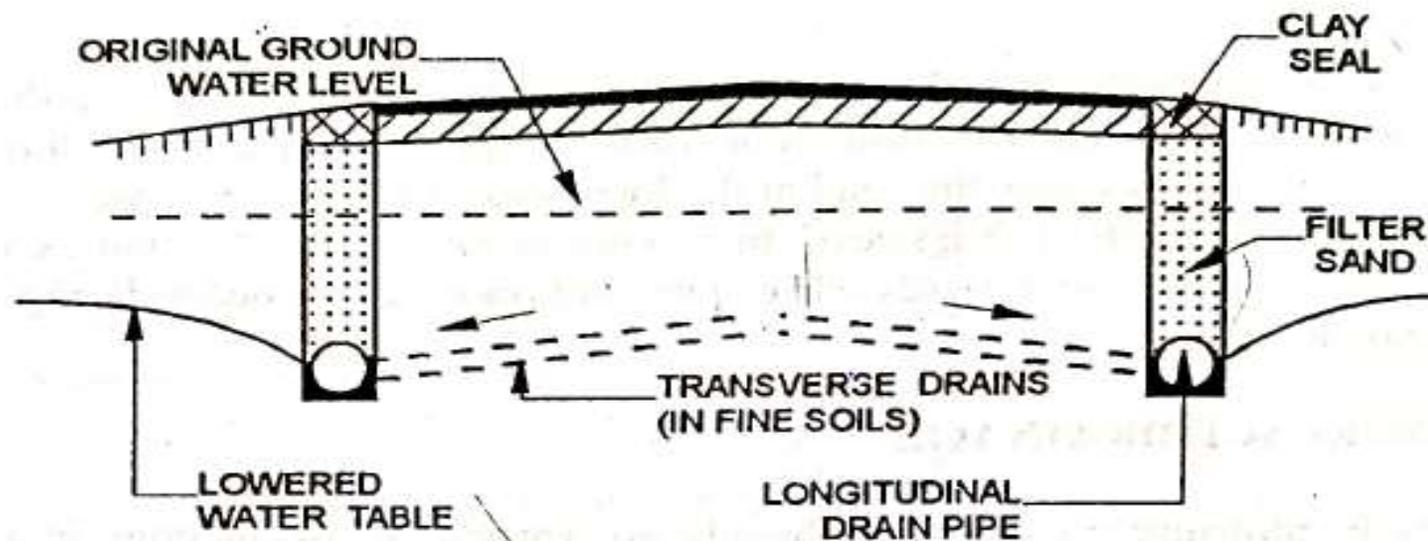
## **Lowering of water table:**

The highest level of water table should be fairly below the level of sub-grade. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 m below the sub-grade. In places where water table is high the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 m.

If the soil is relatively permeable, it may be possible to lower the high water table by merely construction of longitudinal drainage trenches with drain pipe and filter sand.

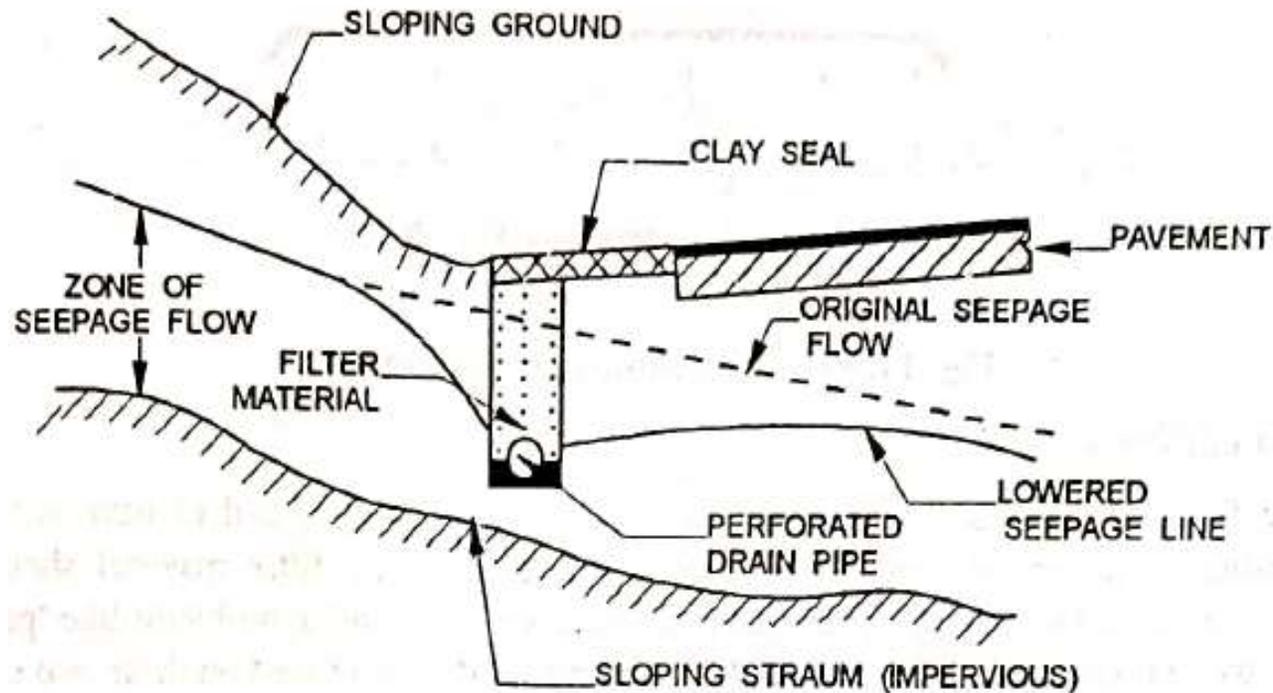


If the soil is relatively less permeable, the lowering of the ground water level may not be adequate at the centre of pavement or in between the two longitudinal drainage trenches. Hence in addition transverse drains may have to be provided in order to effectively drain off the water and thus to lower water table up to the level of transverse drains.



## Control of seepage flow:

When the general ground is having impervious strata below the sloping, seepage flow is likely to exist. If the seepage zone is at depth less than 0.6 t 0.9 m from the sub-grade level, longitudinal pipe drain in trench filled with filter material and clay seal may be constructed to intercept the seepage flow.





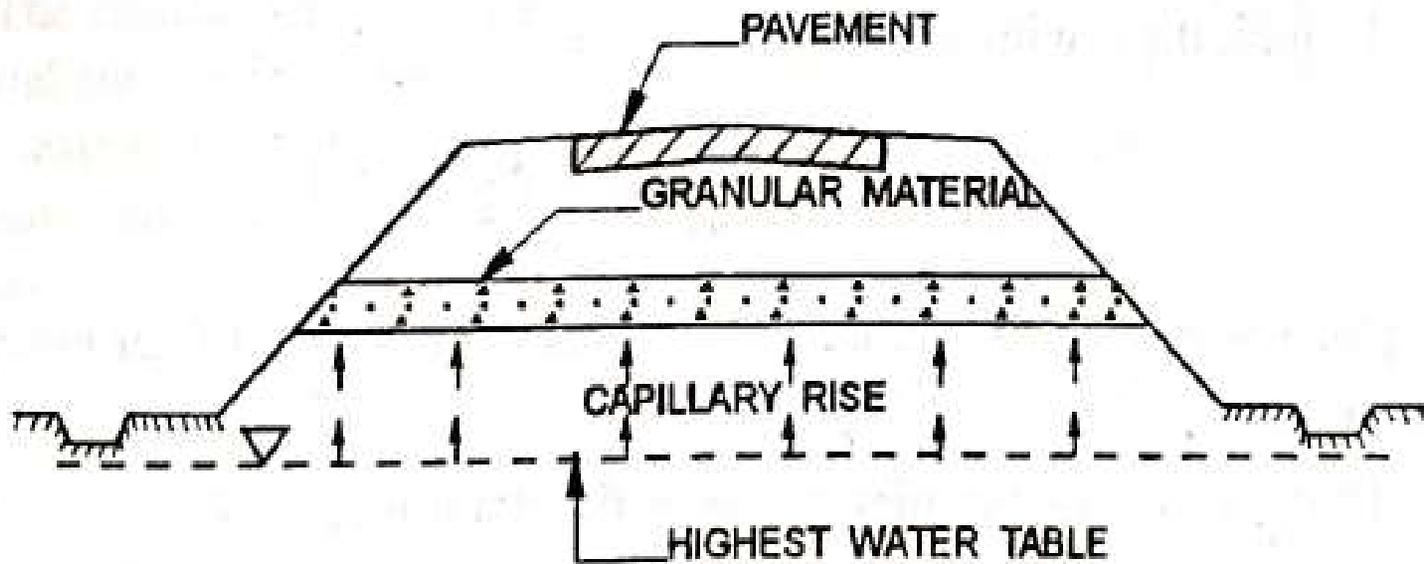
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## **Control of capillary rise:**

If the water reaching the sub-grade due to capillary rise is likely to be detrimental, it is possible to solve the problem by arresting the capillary rise instead of lowering the water table. The capillary rise may be checked either by a capillary cut-off of any of the following two types:

A layer of granular material of suitable thickness is provided during the construction of embankment, between the sub-grade and the highest level of subsurface water table.



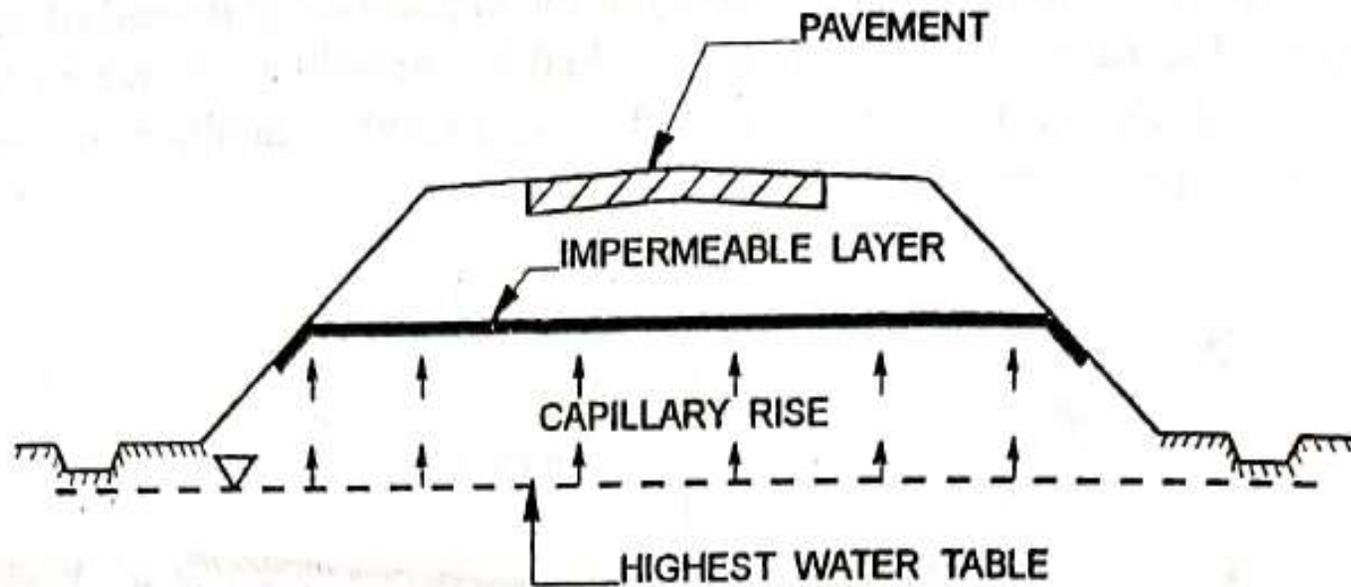


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Another method of providing capillary cut-off is by inserting an impermeable or a bituminous layer in the place of granular blanket





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## **Types of cross drainage structures, their choice and location**

Whenever streams have to cross the roadway, facility for cross drainage is to be provided. The cross drainage structures commonly in use are culverts and small bridges.

When a small stream crosses a road with a linear water way less than about 6m, the cross drainage structure provided is called culvert; for higher values of linear waterway, the structure is called a bridge.



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The common types of culverts in use are: slab culvert, box culvert, arch culvert and pipe culvert.

In slab culvert RCC slab is placed over abutments made of masonry and the span is generally limited to 3m.

Box culverts of square or rectangular shapes are made of RCC.

Arch culvert is generally built using brick or stone masonry or plain cement concrete.

A pipe culverts of minimum diameter 75 cm and made of steel or prefabricated RCC used when the discharge is low.



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Various types of bridges are in use; the choice is based on several considerations including the span. RCC and pre-stressed concrete bridges are commonly constructed these days.

On less important roads in order to reduce the construction cost of cross drainage structures, sometimes submersible bridges or causeways are constructed.

During the floods the water will flow over the road at the locations of the causeways. The total period interruption to traffic has however to be kept as low as possible, not exceeding about 15 days in a year. Such roads interruption to traffic occurs during floods are called fair weather roads.