

**VISVESVARAYA TECHNOLOGICAL UNIVERSITY  
BELGAUM**



**TRANSPORTATION ENGINEERING**

**(Subject Code: BCV403)**

**LECTURE NOTES**

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**MODULE 2**

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**A J INSTITUTE OF ENGINEERING & TECHNOLOGY**

**DEPARTMENT OF CIVIL ENGINEERING**

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## MODULE 2

### Topics to be covered

**HIGHWAY MATERIALS AND PAVEMENTS:** Desirable properties of aggregates, soil subgrade & Bitumen, Application of bituminous emulsion, Desirable properties of Bituminous Mixes

**Pavement Design:** Factors Controlling design of highway pavements, Pavement types, component parts of pavements and their functions; types of joints used in rigid pavement. Critical stresses in flexible and rigid pavement.

**Highway Drainage:** Significance and requirements, Surface drainage system and design-Examples, sub surface drainage system, Types of cross drainage structures their choice and location.

*Problems on design of Longitudinal drain.*

### **Subgrade Soil**

Subgrade soil is an integral part of the road pavement structure which directly receives the traffic load from the pavement layers. The subgrade soil and its properties are important in the design of pavement structure. The main function of the subgrade is to give adequate support to the pavement and for this the subgrade should possess sufficient stability under adverse climate and loading conditions. .

### **Desirable Properties The desirable properties of soil as a highway material are**

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

The soil should possess adequate stability or resistance to permanent deformation under loads, and should possess resistance to weathering, thus retaining the desired subgrade support. Minimum variation in volume will ensure minimum variation in differential strength values of the subgrade. Good drainage is essential to avoid excessive moisture retention and to reduce the potential frost action. Ease of compaction ensures higher dry density and strength under particular type and amount of compaction.

### **Aggregates**

Aggregates form the major portion of pavement structure and they form the prime materials used in pavement construction. Aggregates have to bear stresses occurring due to the wheel loads on the pavement and on the surface course they also have to resist wear due to abrasive action of traffic.

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium (such as water, bitumen, Portland cement, lime, etc.) to form compound materials (such as bituminous concrete and Portland cement concrete).

Aggregate is used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation (quarry). Extracted rock is typically reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a by-product of other manufacturing industries.

### **Desirable Properties of Road Aggregates**

- **Strength:** The aggregates used in top layers are subjected to (i) Stress action due to traffic wheel load, (ii) Wear and tear, (iii) crushing. For a high quality pavement, the aggregates should possess high resistance to crushing and to withstand the stresses due to traffic wheel load.
- **Hardness:** The aggregates used in the surface course are subjected to constant rubbing or abrasion due to moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic. The abrasive action is severe when steel tyred vehicles move over the aggregates exposed at the top surface.
- **Toughness:** Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the effect caused by the jumping of the steel tyred wheels from one particle to another at different levels causes severe impact on the aggregates. Severe impact like hammering is quite common on water bound macadam roads where stones protrude out especially after the monsoons. The magnitude of impact would increase with the roughness of the road surface, speed of vehicle and other vehicular characteristics.
- **Durability:** The stone used in pavement construction should be durable and should resist disintegration due to the action of weather. The property of the stones to withstand the adverse action of weather may be called as soundness. The aggregates are subjected to the physical and chemical action of rain and bottom water, impurities there-in and that of atmosphere, hence it is desirable that the road aggregates used in the construction should be sound enough to withstand the weathering action.
- **Shape of Aggregate:** Aggregates which happen to fall in a particular size range may have rounded, cubical, angular, flaky or elongated particles. It is evident that the flaky and elongated particles will have less strength and durability when compared with cubical, angular or rounded particles of the same aggregate. Hence too flaky and too much elongated aggregates should be avoided as far as

possible.

- **Adhesion with Bitumen:** The aggregates used in bituminous pavements should have less affinity with water when compared with bituminous materials, otherwise the bituminous coating on the aggregate will be stripped off in presence of water.

## **Bitumen**

Crude petroleum obtained from different places is quite different in their composition. The portion of bituminous material present in the petroleum's may widely differ depending on the source. Almost all the crude petroleum's contain considerable amounts of water along with crude oil. Hence the petroleum should be dehydrated first before carrying out the distillation. General types of distillation processes are fractional distillation and destructive distillation. In fractional distillation the various volatile constituents are separated at successively higher temperatures without substantial chemical change and the residue obtained from this is petroleum bitumen.

## **Desirable Properties of Bitumen**

- The viscosity of the bitumen at the time of mixing with aggregates and compaction of the pre-mix should be adequate.
- The bituminous binder should become sufficiently viscous on cooling that the compacted bituminous pavement layer can gain stability and resist deformation under traffic loads.
- In bituminous mix, binder used form ductile thin films around the aggregates to serve as a satisfactory binder in improving the physical interlocking of the aggregates.
- The bituminous binder used should not be highly temperature susceptible. During the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The bitumen binder should have sufficient adhesion with the aggregates in the presence of water.
- There has to be adequate affinity and adhesion between the bitumen and aggregate used in mix.

## **Bituminous Mixes**

Mechanical properties, dense and open textured mixes, flexibility and brittleness, bituminous mix, design methods using Rothfutch's Method and specification using different criteria- voids in mineral aggregates, voids in total mix, density, flow, stability, percentage voids filled with bitumen. Numerical examples

## Requirements of Bituminous Mixes

The aim of mix design is to obtain an economical blend or mix using proper gradation of coarse aggregates, fine aggregates, filler and adequate amount of bituminous binder to fulfil the desirable properties of mix.

### Desirable Properties of Bitumen Mixes

Desirable properties of a good bituminous mix are:

- a. Stability
- b. Durability
- c. Flexibility
- d. Skid resistance
- e. Workability

#### a) Stability

Stability is the resistance of the paving mix to deformation under the load. It is the stress to which specified strain is produced (load at which specified deformation). Depending upon the specification or field condition, it is influenced by density of the mix or percentage voids in the compacted mix or viscosity of bituminous binder. If the voids are less, stability will be more and strength will be more. But there must be minimum voids which would provide space on necessary densification which takes place under the traffic movement and expansion of bitumen at high temperature in the atmosphere. If there are no sufficient voids, the bituminous binder bleeds over the surface and causes skidding.

#### b) Durability

It is the resistance of the mix against weathering and abrasive actions. Due to weathering bituminous mix gets harden which is due to loss of volatiles and oxidation. The tensile strain is induced due to heavy wheel loads and excessive strain may be developed which may cause cracks or plastic failure.

#### c) Flexibility

It is the property of the mix that measures the level bending strength.

#### d) Skid Resistance

It is the resistance of the finished pavement against skidding which depends upon the surface texture and bitumen content of mix. If the bitumen content is more, the surface of the pavement is smoother or slippery. Therefore the bitumen content must be optimum to have better skid resistance.

#### e) Workability

It is the ease with which the mix can be laid and compacted to maximum density. It is the function of gradation of aggregates, their shape and texture, bitumen content and its type.

## Requirements of Bituminous mixes Stability

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

## Bitumen Emulsion

### Characteristics

Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material. An emulsion is a two phase system consisting of two immiscible liquids, the one being dispersed as fine globules in the other. A small proportion of an emulsifier (half to one percent by weight of emulsion) is used to facilitate formation of dispersion and to keep the globules of dispersed in suspension. The function of this emulsifier is to form a protective coating around the globules of binder, resisting the coalescence of the globules. Emulsifiers usually adopted are soaps, surface active agents and colloidal powders. Two common methods followed for the preparation of emulsion are the colloid mill method and the high speed mixer method.

### Types and uses

- ❖ Three types of bituminous emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SC).
- ❖ The main advantage of bitumen emulsion are they can be used without heating for sparing or preparing mixes, they are particularly useful for patch repair works and can be used even the surface is wet.
- ❖ The RC bitumen emulsions are used in spray applications like tack coat, for surface treatments, surface dressing and penetration macadam.
- ❖ The MC bitumen emulsion may be used in cold bituminous mixes in which percentage of coarse aggregates are substantially high, with a desirable gradation of zero percent fines passing 75 microns sieve and they are also used for surface dressing and penetration macadam.
- ❖ The SC bitumen emulsion are used for prime coat, slurry seal treatments, recycling works and on soil stabilization

## **Pavement Design**

### **Requirements of Highway Pavement**

The highway pavements have to fulfill two major requirements, namely

- Functional requirements from the point of view of road users
- Structural requirements from the point of view of highway engineer

#### **Functional requirements of road pavement**

From the point of view of users of road vehicles, the functional requirements of roadway pavement is generally limited to the roadway surface condition. The surface

- Should be firm and non-yielding under the wheel load
- Should have good riding quality
- Should be less slippery

#### **Structural requirements of road pavements**

- The structural design of the pavement is to be carried out considering the various design factors related to the traffic, topography, soil type, drainage, climatic and environmental factors and the desirable design life.
- Each pavement layer is laid evenly and well compacted
- The pavement structure consists of subgrade, sub base, base and surface course

## **Types Of Pavement**

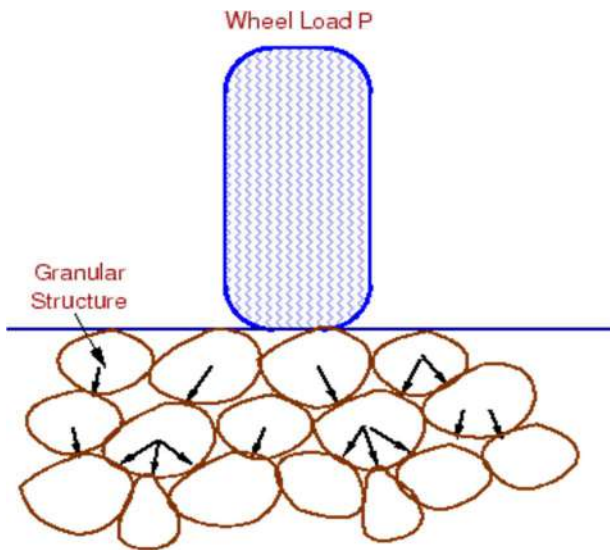
Based on the structural behavior, road pavements are generally classified into two categories

- Flexible pavement
- Rigid pavement

### **Flexible Pavements**

Flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure (Figure). The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear.

The lower layers will experience lesser magnitude of stress and low quality material can be used



Typical cross section of a flexible pavement

- Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways).
- Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.

#### Advantages of flexible pavement

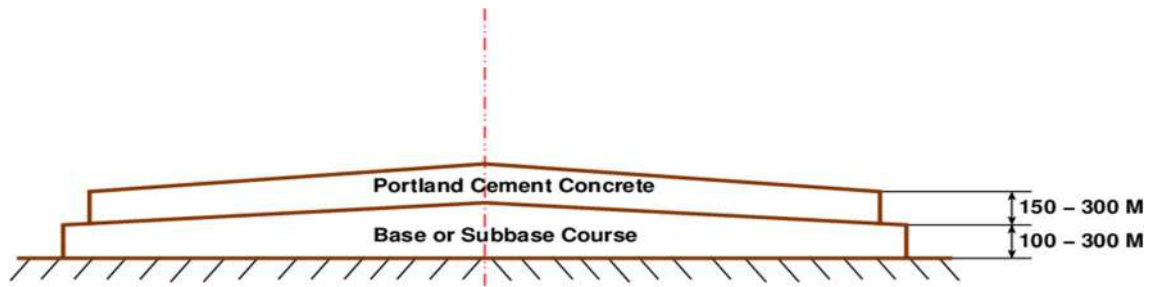
- Adaptability to stage construction
- Availability of low-cost types that can be easily built
- Ability to be easily opened and patched
- Easy to repair frost heave and settlement
- Resistance to the formation of ice glaze

#### Disadvantages of rigid pavement

- Higher maintenance costs
- Shorter life span under heavy use
- Damage by oils and certain chemicals
- Weak edges that may require curbs or edge devices

## **Rigid Pavements**

Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. A typical cross section of the rigid pavement is shown in Figure. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.



**Figure: Typical Cross section of Rigid pavement**

In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

### **Advantages of rigid pavement**

- Low maintenance costs
- Long life with extreme durability
- High value as a base for future resurfacing with asphalt
- Load distribution over a wide area, decreasing base and sub grade requirements
- Ability to be placed directly on poor soils
- No damage from oils and greases.
- Strong edges

### **Disadvantages of rigid pavement**

- High initial costs
- Joints required for contraction and expansion
- Generally rough riding quality
- High repair costs

**Comparison Between Flexible and Rigid Pavement**

<b>Properties</b>	<b>Flexible</b>	<b>Rigid</b>
<b>Design Principle</b>	Empirical method Based on load distribution characteristics of the components	Designed and analyzed by using the elastic theory
<b>Material</b>	Granular material	Made of Cement Concrete either plain, reinforced or prestressed concrete
<b>Flexural Strength</b>	Low or negligible flexible strength	Associated with rigidity or flexural strength or slab action so the load is distributed over a wide area of subgrade soil.
<b>Normal Loading</b>	Elastic deformation	Acts as beam or cantilever
<b>Excessive Loading</b>	Local depression	Causes Cracks
<b>Stress</b>	Transmits vertical and compressive stresses to the lower layers	Tensile Stress and Temperature Increases
<b>Design Practice</b>	Constructed in number of layers.	Laid in slabs with steel reinforcement.
<b>Temperature</b>	No stress is produced	Stress is produced
<b>Force of Friction</b>	Less. Deformation in the sub grade is not transferred to the upper layers.	Friction force is High
<b>Opening to Traffic</b>	Road can be used for traffic within 24 hours	Road cannot be used until 14 days of curing
<b>Surfacing</b>	Rolling of the surfacing is needed	Rolling of the surfacing is not needed.

**Components of Flexible Pavements**

The components of a typical flexible pavement structure consists of

- Prepared soil subgrade
- Granular sub base cum drainage layer
- Granular base course
- Bituminous binder and surface course

### **Functions of soil subgrade**

- The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed.
- It should be compacted to the desirable density, near the optimum moisture content
- To provide an adequate support to the road pavement.
- To provide stability to the road pavement.
- To provide good drainage of rain water percolating through the road pavement
- The minimum thickness of compacted subgrade is 500mm on NH and SH and major arterial roads and 300mm for rural roads which carry low volume of traffic
- The strength test commonly adopted for the evaluation of soil subgrade are CBR, dynamic cone penetrometer test, triaxial compression or direct shear test and plate bearing test

### **Functions of granular sub base (GSB) and drainage layer**

- The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure
- The aggregates of lower strength having good permeability may be used in the GSB layer
- Coarse graded aggregates with low percentage of fines (less than 5% finer than 0.075mm size) will serve as a good drainage layer.
- The GSB cum drainage layer is laid above the subgrade covering the full width of the formation between the longitudinal drains.
- The part of the rain water which may enter into the pavement layers through the shoulders or the pavement surface will get drained out quickly into the longitudinal or road side drains. Thus it is possible to retain the subgrade and other pavement layers in relatively dry condition.

### **Functions of granular base course**

- The granular base course is considered as the most important component of flexible pavement layer which sustains the wheel load stresses and disperses through larger area on to the GSB layer below
- A good base course enhances the load carrying capacity of the flexible pavement structure.
- Good quality coarse aggregates are generally used in the granular base course of flexible pavements.
- As per the specifications laid down by the ministry of road transport and highways, govt. of India (MORTH), the aggregates used in the base course should have low aggregate impact value (less than 30%) and low Los Angeles abrasion value (less than 40%)

**Functions of thin bituminous surface**

- The thin bituminous surface course prevents the entry of surface water into the pavement layers during the rains and thus protects the base course and other pavement layers below
- With a good surfacing and an effective drainage layer, it is possible to keep the soil subgrade in relatively dry condition and retain its stability
- The bituminous surfacing serves as a wearing course for the traffic and provides a dust free pavement surface under dry weather
- Thin bituminous layers such as surface dressing, 20mm thick pre mixed bituminous carpet with seal coat and 20mm thick mixed seal surface are commonly adopted in the wearing course of roads with low traffic volume with less proportion of heavy commercial vehicles.

**Functions of thick bituminous binder and surface courses**

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.
- Marshall Stability test and mix design method has been recommended by the IRC for designing the dense bituminous mixes such as DBM binder course and bituminous concrete surface course in India.

**Components of Rigid Pavements**

The components of a typical rigid pavement or cement concrete (CC) pavement structure consists of

- Compacted soil subgrade at the bottom or lowest layer
- Granular sub base (GSB) course and drainage layer
- Base course
- CC/pavement quality concrete (PQC) pavement slab

**Functions of soil subgrade**

- To provide an adequate support to the road pavement.
- To provide stability to the road pavement.
- To provide good drainage of rain water percolating through the road pavement
- The strength test commonly adopted for the evaluation of soil subgrade in rigid pavement is plate bearing test

**Functions of GSB and drainage layer**

- The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure
- Coarse graded aggregates with low percentage of fines (less than 5% finer than 0.075mm size) will serve as a good drainage layer.
  - An effective drainage layer under the CC pavements has the following benefits
    - ❖ Increase in service life and improved performance of the CC pavements
    - ❖ Prevention of early failures of the rigid pavement due to pumping and blowing
    - ❖ Protection of the subgrade against frost action in frost susceptible areas

**Functions of base course**

- The granular base course is generally provided under the CC pavement slab in low volume roads and also in roads with moderate traffic loads.
- For heavy traffic or load, high quality base course materials such as lean cement concrete or dry lean concrete (DLC) are preferred as base course
- The DLC layer provides a uniform support, high K value and an excellent working platform for laying the PQC slab with a sensor paver
- A separation layer consisting of a suitable type of membrane is laid over the DLC base course before laying the PQC slab in order to prevent bonding between the two.

**Function of PQC pavement slab**

- M40 cement concrete mix with a minimum flexural strength of 45kg/cm<sup>2</sup> is recommended by IRC for use 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 and warping effects in the CC slab due to temperature differences between top and bottom slab caused by daily variation in temperature during the 24 hours cycles.
- The steel reinforcement if any, placed at mid depth of the CC pavement slab is not useful to take up the flexural/tensile stresses caused by the heavy wheel loads or warping in the slabs. Therefore high quality CC mix with heavy wheel strength is used for the construction of the PQC slab of the CC pavements.

**TYPES OF JOINTS USED IN RIGID PAVEMENT**

**I. CONTRACTION JOINTS**

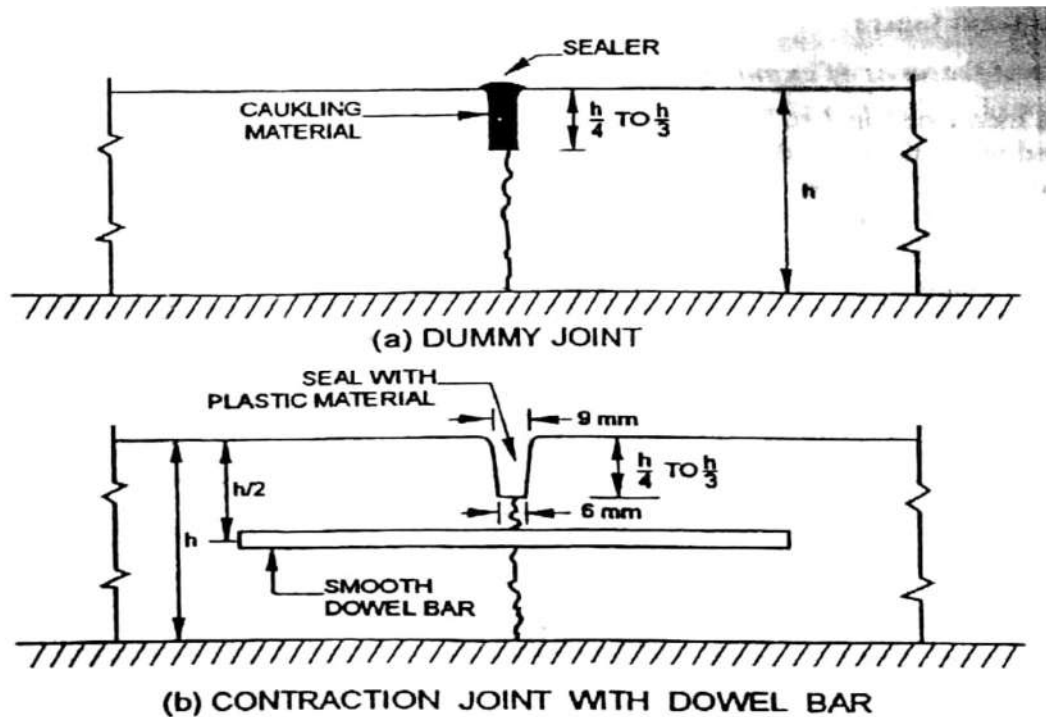
Contraction joints can be constructed either as ‘plain joints’ without dowel bars or with dowel bars.

**1. Construction of contraction joints without dowel bars**

- Markings are made to indicate the exact locations where the grooves of the contraction joints are to be cut.
- Transverse groove cutting work is carried out, soon after each groove is cut, it is cleaned and a temporary seal is inserted to block the ingress of grit and soil.
- After curing for a minimum of 14 days, hessian cloth covers are removed and surface is cleaned. The temporary seal is removed and the grit and dust are thoroughly removed.
- Cold sealant may be used as sealant; alternatively hot sealant may be applied after application of the primer. As shown in fig a

**2. Construction of contraction joints with dowel bars**

- The locations of the contraction joints are marked.
- The dowel bars are cut to the specified length and are placed at appropriate positions of the inserting plate.
- The centre of the dowel bars being placed along the contraction joint and their
- Groove cutting work is carried out and the sealant is applied.



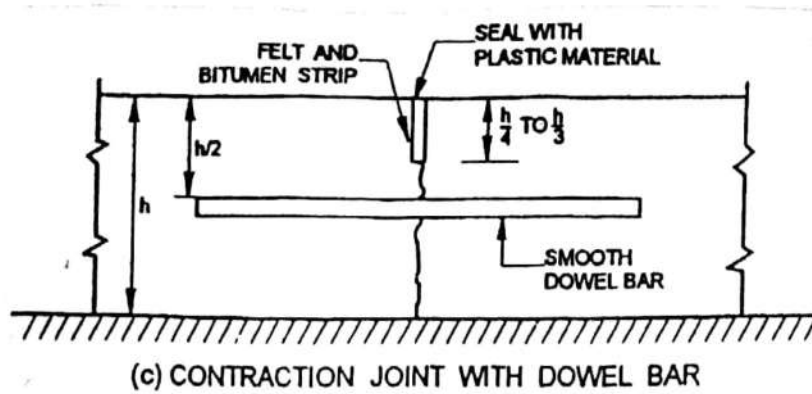


Fig: Some types of contraction joints

## II. EXPANSION JOINTS

Transverse expansion joints are provided in CC pavements at desired intervals or at identified locations during construction of the CC pavements, with a gap of 20 to 25 mm between the slabs.

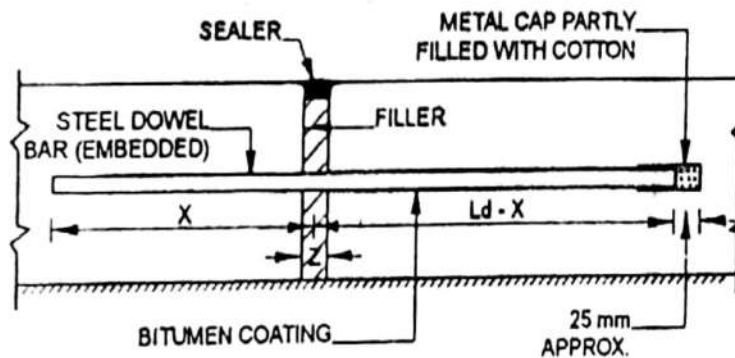


Fig : Expansion joint with dowel bar for load transfer

### Functioning of Expansion Joint with load transfer dowel bars

The special provisions that are made during the construction of expansion joints and their functioning are:

1. Smooth, rounded steel rods of specified dimensions are used as dowel bars at expansion joints.
2. The diameter, length and spacing between the dowel bars are designed based on the design wheel load.
3. About half length of each dowel bar is embedded at mid depth of the slab, such that full bond develops between dowel bars and cement concrete.
4. There is no bonding between this half of the dowel bar and the cement concrete when the adjacent slab is concreted.
5. The free end of each dowel bar is fitted with a cylindrical metal cap of length 100mm, with

compressible sponge like material inside at the closed end, so as to provide space for each dowel bar to move inside gap within the cap during expansion.

6. The gap between the two slabs is filled by inserting a compressible filler board.
7. During hot weather the concrete slab expands and moves towards the gap provided at the expansion joint.
8. During cold weather the slab contracts and the gap increases and the embedded dowel bars also move along with the slab.

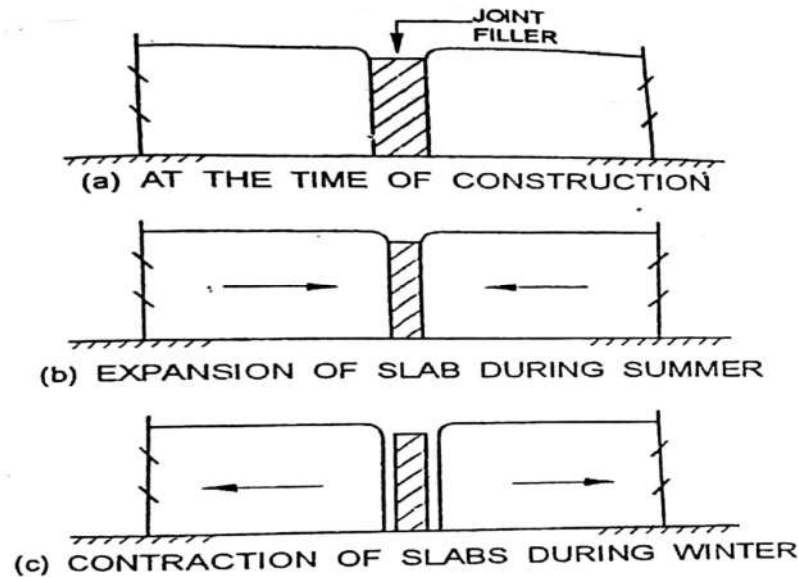


Fig 7: Functioning of joint filler at expansion joint

### Components of expansion joints

- a) Dowel bars
- b) Joint filler
- c) Joint sealer

#### a) Dowel bars

When the wheel load approaches the edge of CC pavement slab near the expansion joint, part of the load is expected to be transferred to the adjoining slab across the expansion joint through the dowel bar system.

#### b) Joint filler

During hot weather when the CC pavement slabs expand, the gap provided at the expansion joints decreases and the joint filler material gets compressed. Therefore, the joint filler material should be compressible.

c) **Joint sealer**

The top portion of the gap at the expansion joint above the joint filler board is sealed using a good sealant material. The sealer prevents entry of coater and grit into the pavement through the expansion joint.

**CRITICAL STRESSES IN FLEXIBLE AND RIGID PAVEMENT.**

**Stresses on a Flexible Pavement**

Stresses are the response of loading on the pavement. Material containing subgrade and environment condition are also responsible for stresses in the pavement. There are various types of stresses yields in flexible and rigid pavements under the applied live load.

The top most paved surface of such type of pavement is flexible, that is extremely dependent on the underlying layers. Due to flexible, pavement is free to move. In such type of pavements following stresses are the most common and are extremely effective.

1. **Vertical stresses**
2. **Shear stress**
3. **Radial stress**

**Vertical stress**

effects the pavement by compressing the pavement material. When pavement compresses, then material in a pavement gets crushed and as a result rutting become visible on the top horizontal pavement.

**Rutting** is the depression in the surface of wheel path. Along the sides of the rutting, pavement may uplift (due to shear). These ruts are very clear in the pavement after rain when ruts filled up with water.

**Shear stress** occurs in the pavement when load is more than the capacity of the pavement. When load approaches the critical point, then as a result movement occurs in the base layer and that movement is responsible for the shear stress in the top pavement.

When tension occurs at the bottom of layers due to seepage, removal of material from particular layer or by any other mean. As a result fatigue cracking occurs in the pavement due to wear and tear of loads. That cracking leads to **radial stresses** in the pavement.

**Stresses on a Rigid Pavement**

**Types of Stresses**

Different types of stresses are developed in CC pavements. The major types of stresses in CC pavements consist of:

- (i) wheel load stresses caused by the heavy wheel loads of vehicles and
- (ii) (warping stresses caused by the temperature differential between the top and bottom of the pavement due to daily variation in temperature.

Other factors which cause additional stresses in CC pavements are

- (a) due to seasonal variation in temperature resulting in overall expansion and contraction of the slab causing frictional stresses, as the friction force resists the slab movement and
- (b) due to volumetric changes of the subgrade or supporting layers, which result in non-uniform support or lack of support to the CC pavement slab at certain locations/stretches.

### Analysis of Stresses

#### Westergaard’s Analysis

H. M. Westergaard is considered the pioneer in providing the rational approach to the analysis of stresses in rigid pavements. His analysis was based on the following assumptions:

- 1) The CC pavement slab is homogeneous, isotropic and has uniform elastic properties.
- 2) The reaction of the subgrade is vertical only and is proportional to the deflection of the slab.
- 3) The reaction of the subgrade at a point is equal to  $K \times \text{Deflection}$  at that point, where  $K$  is the Modulus of Subgrade Reaction. (fig 1)
- 4) The slab is uniform in thickness.
- 5) The load in the interior and the corner is circular in shape and the edge loading is semi-circular. (fig2)

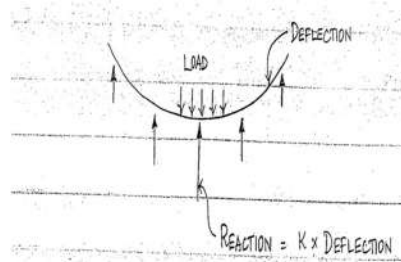


FIG. 1: REACTION OF SUBGRADE UNDER CONCRETE SLAB

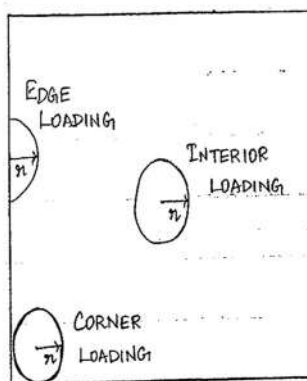


FIG. 2: LOADING POSITIONS FOR RIGID PAVEMENT DESIGN

## **Frictional Stresses**

Frictional stresses are developed due to seasonal variation in temperature.

- During summer season, as the temperature of the slab increase, the concrete pavement expands towards the expansion joints. Due to the frictional resistance at the interface of subgrade and the slab, compressive stress is developed at the bottom of the slab as it tends to expand.
- During winter, the slab contracts causing tensile stresses at the bottom due to the frictional resistance again opposing the movement of the slab.

Stresses developed due to this phenomenon vary with the length of the slab. This is given by,

$$S_f = (W L f) / (2 \times 10^4)$$

where,  $S_f$  = stress developed due to inter-face friction in cement concrete pavement per unit area,  $\text{kg/cm}^2$

$W$  = unit weight of concrete,  $\text{kg/m}^3$  ( $2400 \text{ kg/m}^3$ )

$f$  = coefficient of friction at the interface (maximum value is about 1.5)

$L$  = spacing between the contraction joint = slab length, m

## **Combination of Stresses:**

The cumulative effect of the different stress gives rise to the following three critical cases:

1. During summer, mid-day: The critical combination at interior and edge regions during mid-day occurs when the slab tends to warp downwards. During this period maximum tensile stress will develop at the bottom fibre due to warping and this is cumulative with the tensile stress due to the loading. However, the frictional stress is compressive during expansion. The load stress at edge region is higher than the interior.

**The critical combination of stresses for the edge region is given by,**

$$S_{\text{critical}} = S_e + S_{te} - S_f$$

2. During winter, mid-day: During winter, frictional stress developed will be tensile in nature.

**The critical combination of stresses for the edge region is given by,**

$$S_{\text{critical}} = S_e + S_{te} + S_f$$

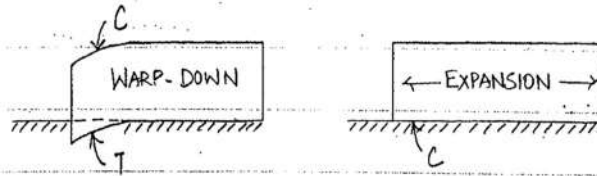
3. During summer mid night: During summer mid night, the critical combination of stress occurs at the corner of the slab on the top when the slab tends to warp upwards and is resisted by the self-weight. There is no frictional stress at the corner region.

The critical stress combination during night at corner region is given by:

$$S_{\text{critical}} = S_c + S_{tc}$$

COMBINATION OF STRESSES

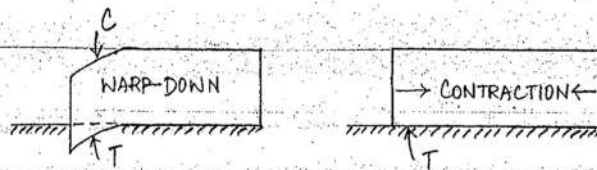
(i) DURING SUMMER - AT EDGE REGION (MID-DAY)



Critical combination of stress

$$= \text{load stress} + \text{warping stress} - \text{frictional stress}$$

(ii) DURING WINTER - AT EDGE REGION (MID-DAY)



Critical combination of stress

$$= \text{load stress} + \text{warping stress} + \text{frictional stress}$$

(iii) AT CORNER REGION - No frictional stress

$$\text{Critical stress combination} = \text{load stress} + \text{warping stress}$$

## HIGHWAY DRAINAGE

### Importance of Highway Drainage

#### Significance of Drainage

An increase in moisture content causes decrease in strength or stability of a soil mass the variation in soil strength with moisture content also depends on the soil type and the mode of stress application. Highway drainage is important because of the following reasons:-

- Excess moisture in soil subgrade causes considerable lowering of its stability the pavement is likely to fail due to subgrade failure as discussed in Article 10.1.
- Increase in moisture cause reduction in strength of many pavement materials like stabilized soil and water bound macadam.
- In some clayey soils variation in moisture content causes considerable variation in flume of subgrade. This sometimes contributes to pavement failure.
- One of the most important causes of pavement failure by the formation of waves and corrugations in flexible pavements is due to poor drainage.
- 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.
- 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.

### REQUIREMENTS OF GOOD HIGHWAY DRAINAGE SYSTEM

Following are the essential requirements of a good highway drainage system:

- (1) **Adjoining land:** The surface water from the adjoining land should be prevented from entering the roadway.
- (2) **Camber:** The road surface should be provided with suitable camber so as to drain off quickly the water that falls on it without allowing the water to percolate.
- (3) **Cross-drainage works:** The design of cross-drainage works should be such that the overflowing of water on the road surface does not occur at the time of the highest flood.
- (4) **Gradient:** The roads passing through zones of heavy rainfall should be provided with minimum gradient even if it is not theoretically required.

**(5) Highest flood level:** The carriageway should be provided least 600 mm higher than the highest flood level (H.F.L.) of the surrounding area.

**(6) Intercepting drains:** Where the topography of the area is such that the water flows towards the roadway itself, it becomes essential to construct intercepting drains parallel to the ad, but outside the road limit, to intercept water before it reaches the road.

**(7) Side drains:** it is necessary to construct sufficiently wide and deep side drains with suitable longitudinal slope to carry away all the water that accumulates to some drainage structure The water level in these drains should remain at all times below the subgrade level

### **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.

### **Collection of Surface Water**

- The water from the pavement surface is removed by providing the camber or cross slope to the pavement. The rate of this cross slope is decided based on type of pavement surface and amount of rainfall.
- where there is restriction of space, Construction of deep open drains may be undesirable. This is particularly true when the road formation is in cutting.
- In such cases covered drains or drainage trenches properly filled with layers of coarse sand and gravel may be used. In urban roads because of the limitation of land width and also due to the presence of foot path, dividing islands and other road facilities, it is necessary to provide underground longitudinal drains.
- Water drained from the pavement surface can be carried forward in the longitudinal direction between the kerb and the pavement for short distances. This water may be collected in catch pits at suitable intervals and lead through underground drainage pipes. Section of a typical catch pit with grating to prevent the entry of rubbish into the drainage system.

Drainage of surface water is all the more important in hill roads. Apart from the drainage of water from the road formation, the efficient diversion and disposal of water flowing down the hill slope across the road and that from numerous cross streams is an important part of hill road construction.

## Surface Drainage System for Roads – Components & Design Aspects

During rains one portion of the rain water flows along the surface as ‘run off water and the remaining portion of water percolates through the soil mass under the action of gravity until it reaches the ground water table. Removal and diversion of surface water from the roadway and adjoining land is termed as surface drainage.

### **Components**

The various components of the surface drainage system are:

#### **1. Cross slope or camber of the pavement and shoulders**

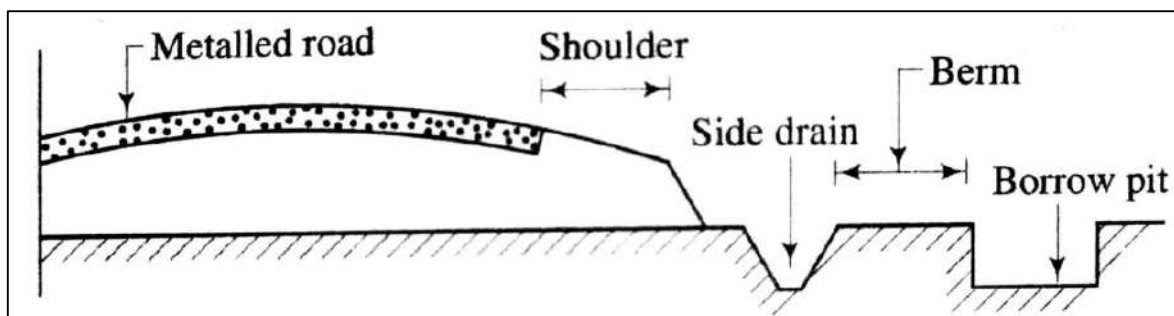
The water from the pavement surface and shoulders is first drained off to the road side drains with the help of camber. The rate of the slope of carriageway is decided based on:

- (a) type of pavement surface (b) amount of rainfall
- For earthen roads: 1 in 25 (4%)
  - Bituminous surface and CC pavements: 1 in 60 (1.7%)
  - Earth shoulders: 4-5%

#### **2. Longitudinal side drains- incase of embankment and cutting**

##### **(1) Side drains for road in embankment:**

For roads in embankment, the side drains are provided on one or both sides of the road beyond the shoulder, as shown in fig. 2. The side drains are constructed at a minimum distance of about 2 m from the edge of embankment so that the water flowing in the drains does not enter the earthwork.



**Fig. Road side drain for embankment filling road**

These drains are also helpful in arresting the rain water falling on the adjacent land parallel to the road and it is thus not allowed to reach the embankment. The water flowing in the side drain can then be suitably disposed off without causing any harm to the roadway.

##### **(2) Side drains for road in cutting:**

For roads in cutting, the side drains are provided on either side of the formation, as shown in fig. 3. These

drains are carefully designed and it is to be seen that they do not overflow under any circumstances and making the roadway submerged in water.

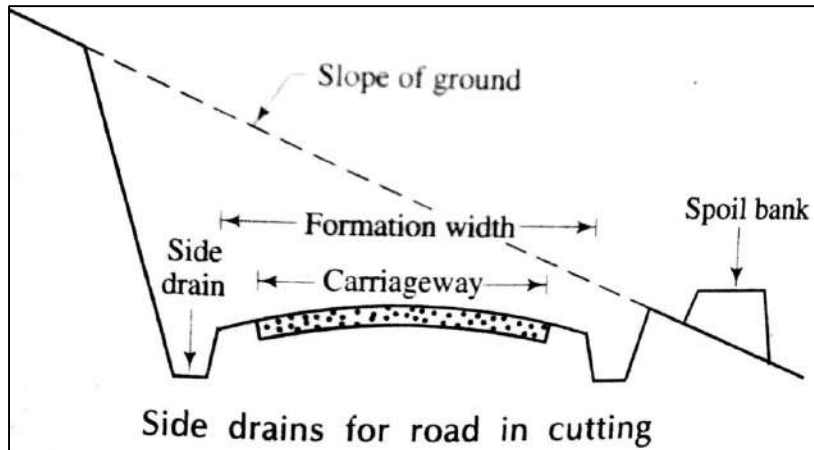


Fig. Road side drain for road in cutting area

The open deep side drains may prove to be dangerous and unsightly especially in cases where there is a restriction of space. In such circumstances, the covered drains or pipe drains or ditches filled properly with suitable materials like coarse sand and gravel may be provide

### Design of side drains / Design of Surface Drainage System

The design of surface drainage system may be divided into two phases:

- (i) Hydrologic analysis
- (ii) Hydraulic analysis

Once the design runoff  $Q$  is determined, the next step is the hydraulic design of drains. The side drains and partially filled culverts are designed based on the principles of flow through open channels.

#### 1. Hydrologic design

**Objective:** To estimate the maximum quantity of water expected to reach the element of drainage system under consideration

**Rational Formula is widely used to estimate the peak run-off** water for highway drainage. The rational formula, in its simplest form is given by the equation

$$Q = C i A_d$$

Where

$Q$  = run-off,  $m^3/sec$

$C$  = run-off coefficient, expressed as a ratio of run off to ratw of rain fall

$A_d$  = drainage area in  $1000m^2$

**Run-off coefficient, C**

The value of run-off coefficient, C depends mainly on the type of surface and its slope. The C-values may taken as,

- a. 0.8 to 0.9 for bituminous and cement concrete pavemnets
- b. 0.35 to 0.7 for gravel and WBM pavement
- c. 0.40 to 0.65 for impervious soil
- d. 0.05 to 0.30 for pervious soil

**Drainage Area A<sub>d</sub>**

When the drainage area, A<sub>d</sub> consists of several types os surfeces with different values of run-off coefficient C<sub>1</sub>,C<sub>2</sub>,C<sub>3</sub>..... and if their respective area A<sub>1</sub>,A<sub>2</sub>,A<sub>3</sub>.....the weightage average value of run off C is determined from the equation

$$C = \frac{A_1C_1 + A_2C_2 + A_3C_3}{A_1 + A_2 + A_3}$$

**2. Hydraulic design**

Once the deisgn runoff Q is determined , the next step is the hydraulic deisgn of the drains. The side drains and partially filled culverts are designed based on the priniciples of flow through open channels

If Q is quantity of surface water (m<sup>3</sup>/sec) to be removed by a side drain and V is the allowable velocity of flow (m/s) on the side drain, the area of cross section A of the chaneel (m<sup>3</sup>) is found from the relation

$$Q = A V$$

The desirable values of velocity of flow are 0.3 to 0.5 m/s for sand and silt , 0.6 to 0.9m/s for loam, 0.9 to 1.5 for clay, 1.2 to 1.5 for gravel and 1.5 to 1.8 m/s for good soil

The velocity of flow of water along drain depends on the longitudinal slopes assuming uniform and steady flow through channel of uniform cross section and slope, Mannings Formula is used for detyermining the velocity of flow or the longitudinal slope which is given by

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Here

V = average velocity of flow m/sec

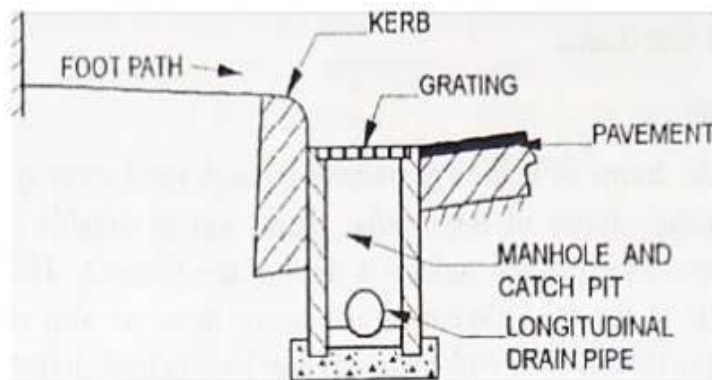
N= Mannings roughness coeffieent

$R$  = Hydraulic radius m (which is equal to cross section area of divided by wetted perimeter

$S$  = Longitudinal slope of channel

### **3. Urban Roads:**

- On urban roads because of the limitation of land width and the presence of foot path and other road facilities, it is necessary to provide underground longitudinal drains.
- under-ground longitudinal drains installed between the kerb and the pavement for short distances.
- The surface water collected in catch pits at suitable intervals and lead through under-ground drainage pipes.



### **3. Cross drains**

- On rural stretches of highways, the water flowing along the road side drains are collected by suitable cross drains through cross drainage structures (CD structures) at locations of natural valleys and streams and disposed off to the natural water course.
- These CD structures may generally be a suitable type of culvert, depending on the quantity of water to be carried across and the span.
- The CD structures should extend up to the full formation width (including the roadway and the shoulders) and the ends may be protected by suitable abutments and parapet walls.

### **SUBSURFACE DRAINAGE**

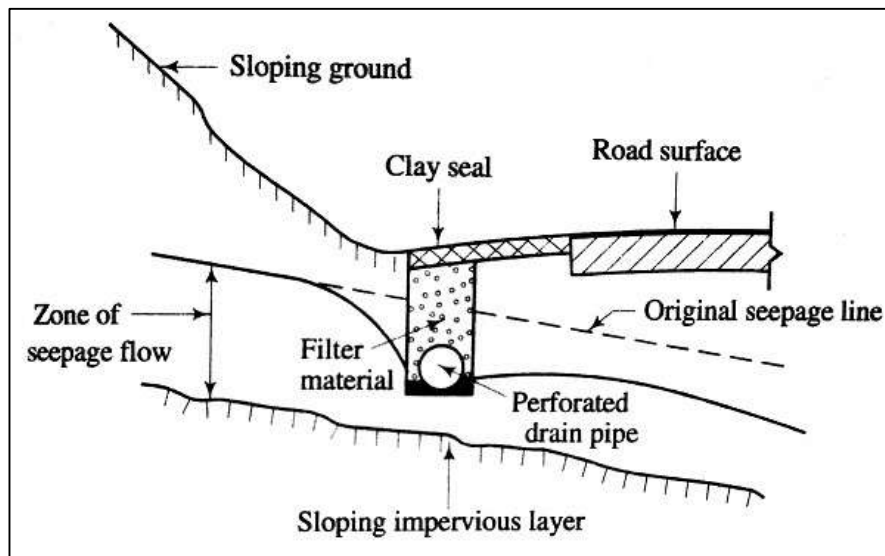
Subsurface drainage is concerned with the interception and removal of water from within the pavement and keep the variation in moisture in subgrade soil to a minimum. Some of the sources of subsurface water include; infiltration through surface cracks, capillary rise from lower layers, seepage from the sides of the pavement. The aim of subsurface drainage is to keep the ground water table (GWT) sufficiently below the level of the subgrade – at least 1.2 m.

When the water table is almost at the natural ground surface, the best option is to raise the formation of the roadway on an embankment, such that it is 1.2 m above the ground. If this is not possible for the reason of unfavorable topography, the only option is to lower the ground water table by means of subsurface drainage arrangements.

A few drainage arrangements for different situations are discussed below:

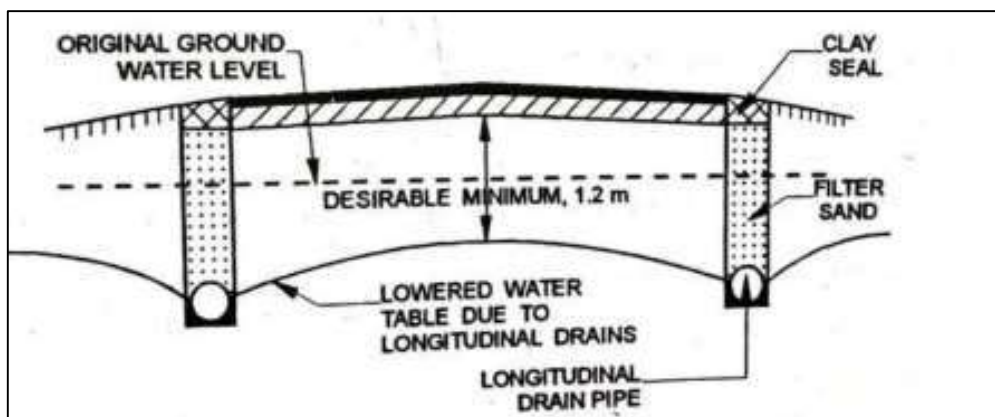
### 1.Subgrade Drain:

One option is to install a drain in the previous layer besides the road to intercept the ground water before it can reach the subgrade, as shown in Fig



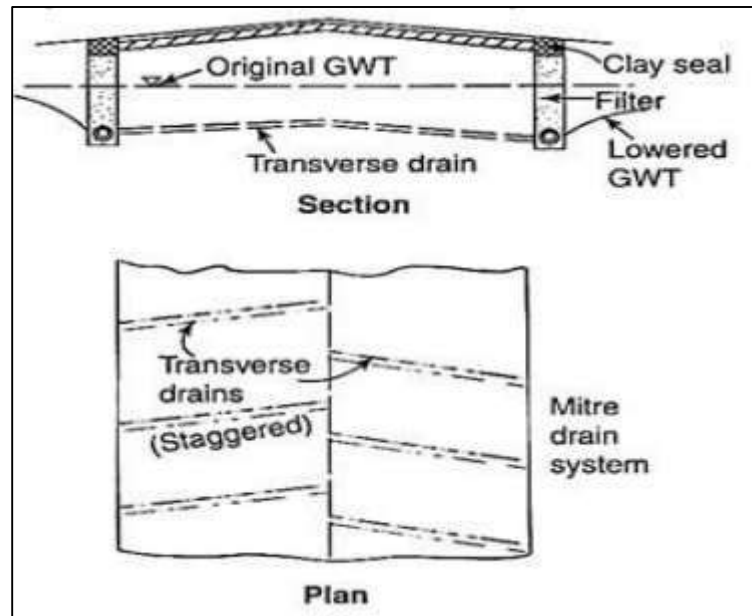
### 2.Longitudinal Drain Trenches and Pipes:

If the soil is relatively pervious, longitudinal drainage trenches with drainpipe, backfilled with filter sand can be used. The depth of the trench depends on the extent of lowering required, soil type, and distance between the trenches. A typical arrangement is shown in Fig.



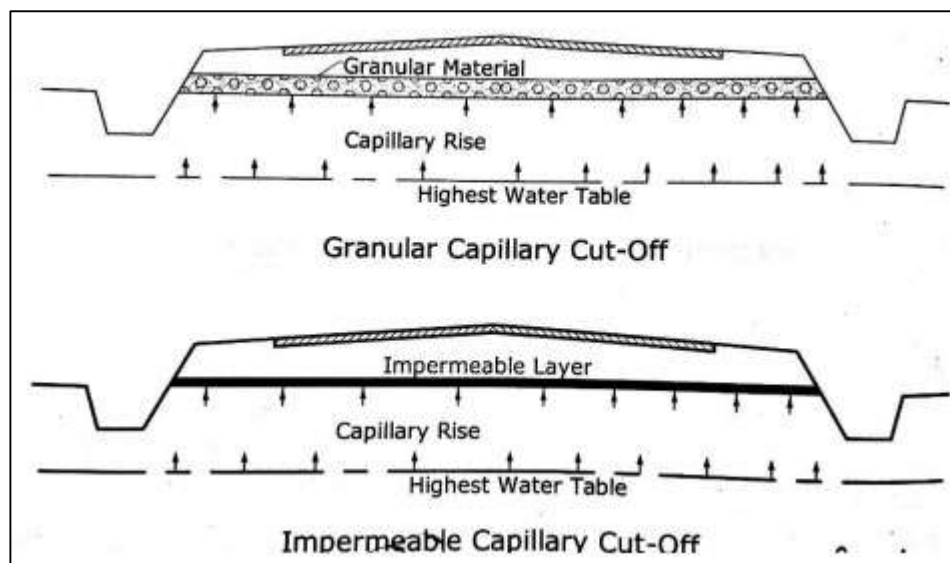
### 3. Longitudinal and Transverse Drains for Lowering GWT:

If the soil is relatively less permeable, longitudinal as well as transverse drains may be needed to lower the ground water table as shown in Fig.



### 4. Capillary Cut-Off for Clayey Subgrade:

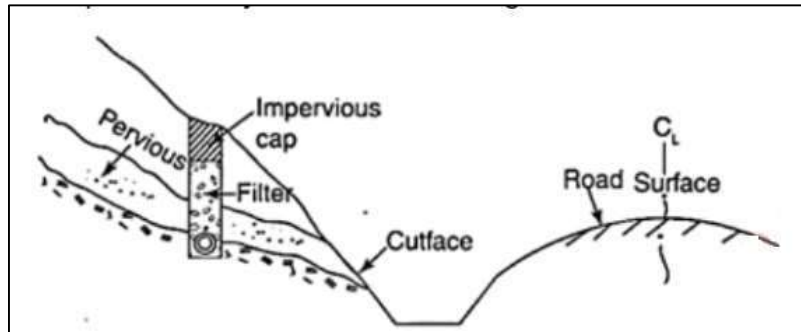
If the subgrade is clayey, the system of sub-surface drains on either side will not be effective, in view of very low permeability of the subgrade. In such a case the subgrade has to be raised with a free-draining material, or a capillary cut-off has to be applied as shown in Fig



The capillary cut-off may even be an impermeable bituminous layer. The location of the cut-off should be above the level of capillary rise expected for the clayey subgrade.

### **5.Sub-Surface Drains to Control Seepage in Cut Slopes:**

Sometimes, seepage water renders cut slopes unstable by reaching the face of the slope. This can be prevented by lowering the seepage line by providing a sub-surface longitudinal drain installed to a depth below the pervious layer as shown in Fig.



If the depth of pervious layer is more, horizontal drains comprising perforated metallic pipes or PVC pipes installed at a suitable slope may be provided to serve the same purpose

### **CROSS DRAINAGE WORKS**

When a stream or river happens to cross the road alignment, facilities for cross drainage has to be provided. When road alignment gets away from the ridge line, the rainwater on the area encircled by ridge and road alignment has to be passed from one side of the road to the other lower side. At the point of crossing, masonry structure known as cross drainage work or drainage structure has to be constructed.

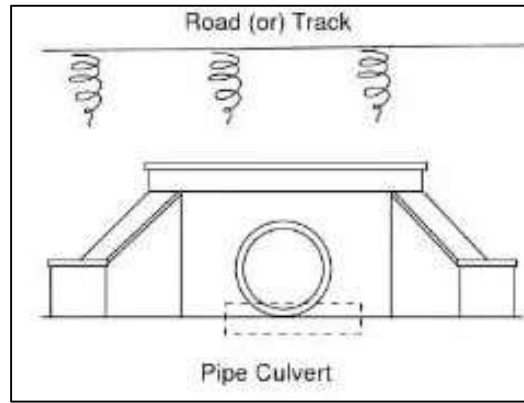
The commonly used cross drainage structure are the culverts and small bridges. When linear water way between the inside faces of abutments of a drainage structure is less than 6m, it is called a culvert. When linear water way exceeds 3m, the cross-drainage work is called a bridge. Thus, culvert is just a small bridge. Across small streams, culverts are constructed but in case of large streams or rivers, bridges are constructed.

***Slab culvert, Boc culvert, Arch culvert and Pipe culvert are the usual types of culverts most commonly used for cross drainage works.***

#### **1.Pipe Culverts**

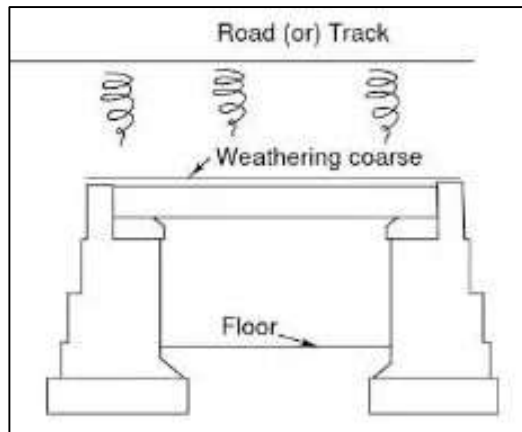
When the stream carries low discharge and is having high embankment, pipe culverts are considered more suitable. Pipe is laid slightly inclined. For ease in inspection minimum diameter of pipe should be 75 cm. There should be at least 90 cm cover of soil so that traffic load transmitted on pipe is of small intensity and also without vibrations.

Pipes may be made of stone ware, concrete, etc. Pipes should be laid on 15 cm cement concrete bedding. A protective rubble apron should be provided in sandy or clay beds.



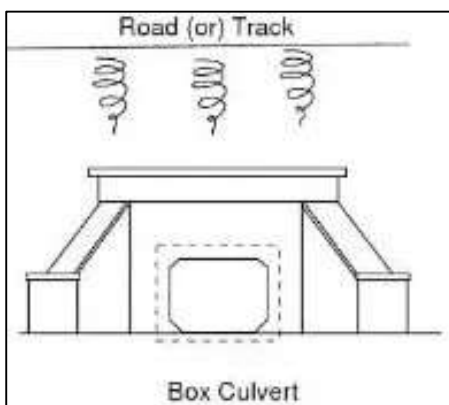
## 2.Slab Culvert

These culverts have masonry abutments with stone slab over them. In localities where stone is easily available, these culverts are mostly used. These culverts are mostly used up to about 2 m span. Where stone patties are not available, Rein-concrete slabs are used. Rein-concrete slabs are designed as simply supported slabs. Span of rein-concrete slab may be about 3 m.



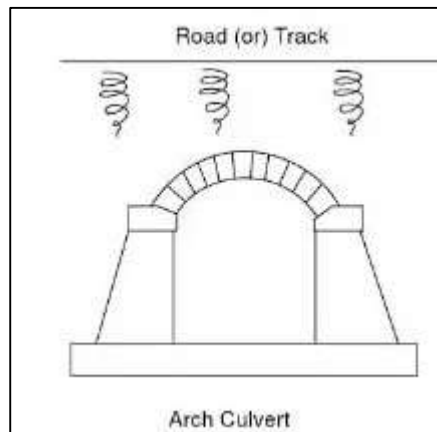
## 3.Box Culvert

These culverts are constructed where the nature of the soil below the foundation is not suitable for individual footing under piers and abutments. It is a monolithic rectangular drainage structure. The size of the rectangular passage should not be less than 60cm X 60 cm for easy cleaning of debris. Short span box culverts can be precast



#### 4. Arch Culvert

This culvert is preferred under the conditions where high fillings are involved and there are heavier loadings on the culvert. Arches may be built from brick, or stone masonry, or plain cement concrete. Span of each arch should be kept less than 3 m.



Selection of culvert to be used is done on the basis of availability of construction materials and economic considerations.