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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – I - PRINCIPLES OF PAVEMENT DESIGN – SCI1610

UNIT – 1 - PRINCIPLES OF PAVEMENT DESIGN

Components of a road - Functions - Factors affecting pavement stability - Equivalent single wheel load - Load Calculation Vehicle and traffic vectors - Moisture factors - Climatic factors - Soil stability - Stress distribution in different condition - remedies.

INTRODUCTION

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

REQUIREMENTS OF A PAVEMENT

An ideal pavement should meet the following requirements:

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

COMPONENTS OF A ROAD

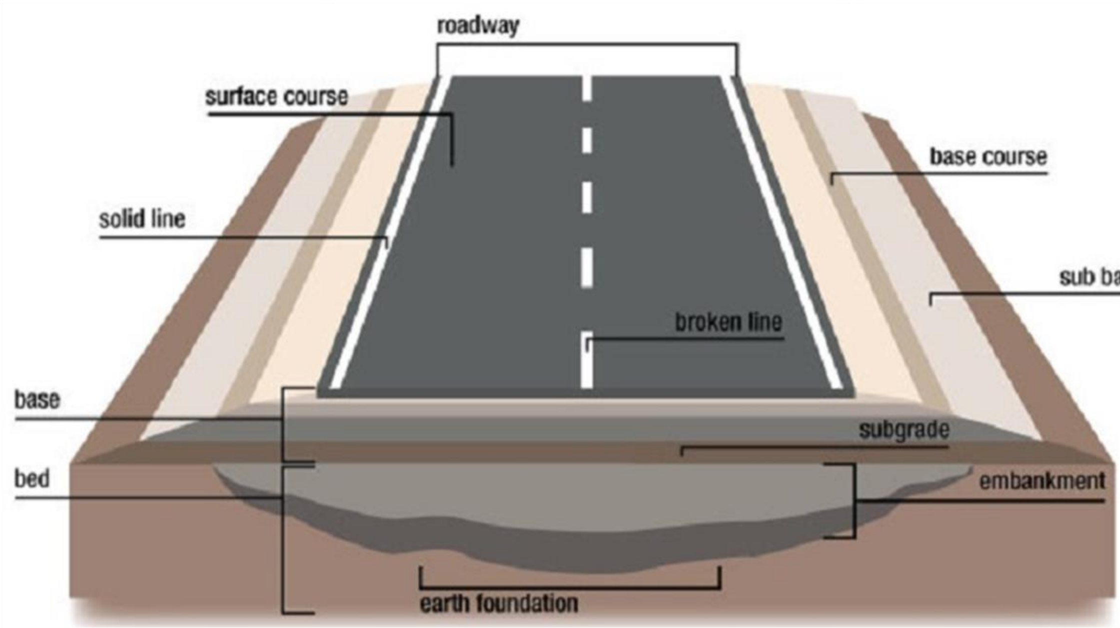


Figure No. 1 Components of road

COMPOSITION OF FLEXIBLE PAVEMENTS

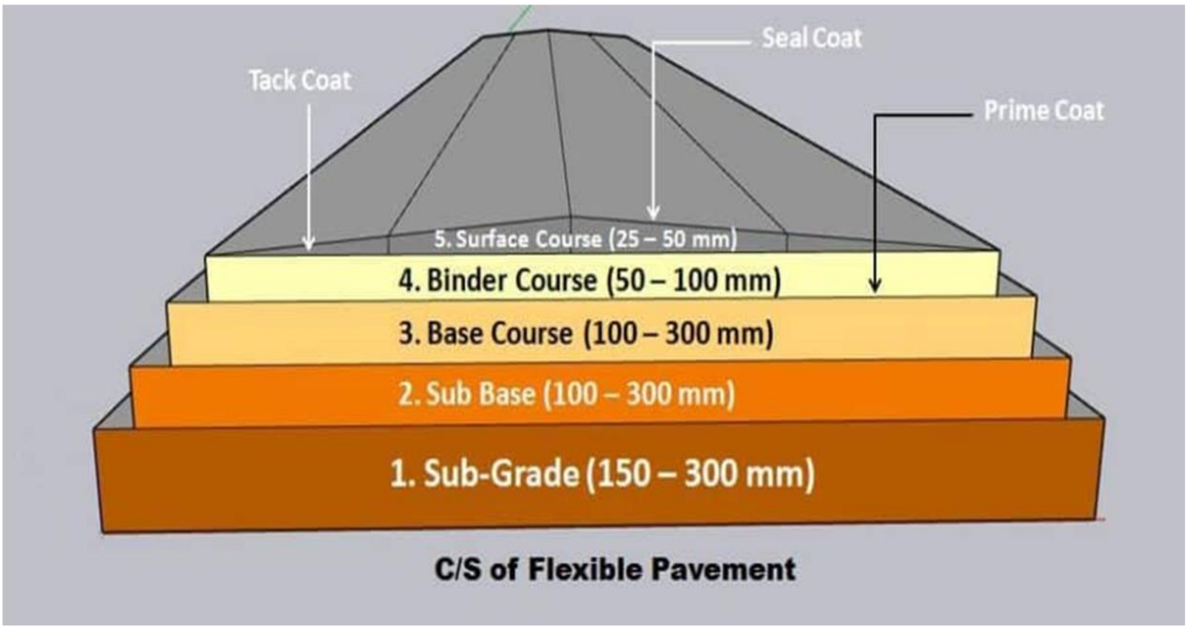
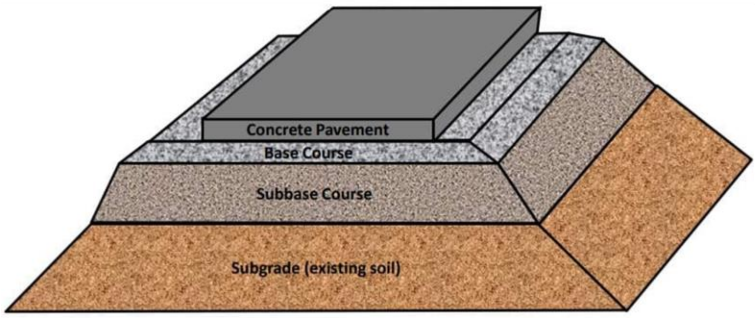


Figure No.2 Components of flexible pavement

COMPOSITION OF RIGID PAVEMENTS



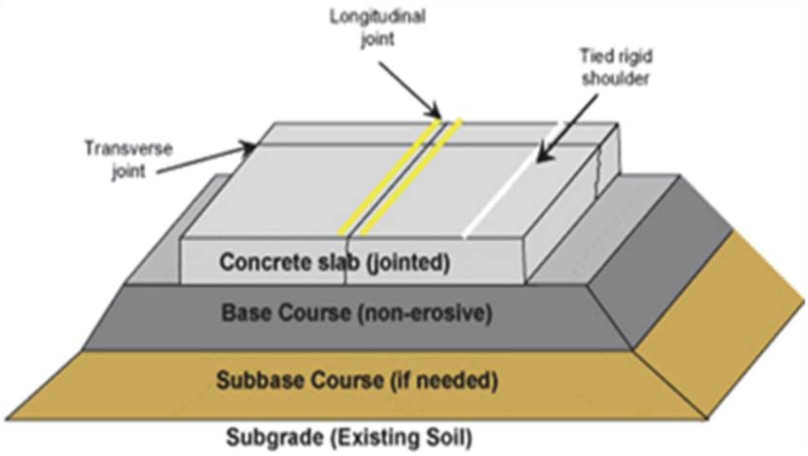


Figure No.3 Components of Rigid pavements

FUNCTIONS OF A PAVEMEMT LAYERS

Seal Coat

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

Tack Coat

- It is a very light application of asphalt, usually asphalt emulsion diluted with water.
- It provides proper bonding between two layers of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat

- It is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed.

- It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

SURFACE COURSE

It is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC).

The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc.
- It will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade
- It must be tough to resist the distortion under traffic and provide a smooth and skid- resistant riding surface.
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water

BINDER COURSE

- This layer provides the bulk of the asphalt concrete structure.
- Its chief purpose is to distribute load to the base course.
- The binder course generally consists of aggregates having less asphalt and
- doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design

BASE COURSE

- It is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage.
- It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials

SUB - BASE COURSE

- It is **the layer of material beneath the base course** and the primary **functions are to provide structural support, improve drainage and reduce the intrusion** of fines from the sub-grade in the pavement structure

- If the **base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course**

- A **<u>sub-base course is not always needed or used</u>**.

- For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided

SUB – GRADE

- The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above.

- It is essential that at no time soil sub-grade is overstressed

- It should be compacted to the desirable density, near the optimum moisture content


Providing Sub grade Course


Providing Sub base Course


Providing Base Course


Providing Binder Course

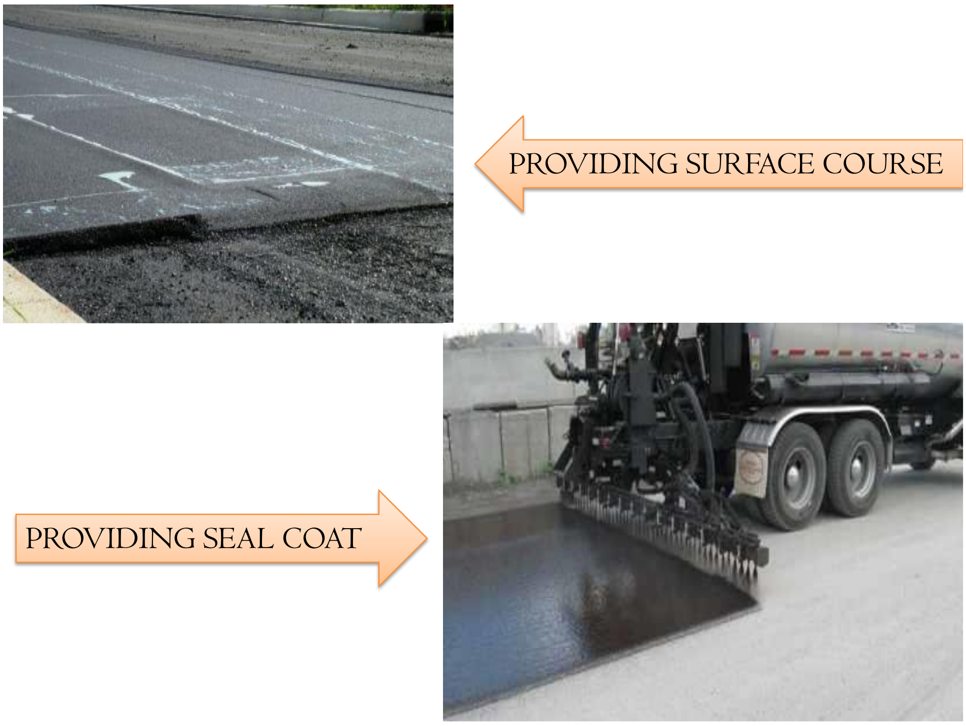


Figure No.4 Layers of flexible pavement

CONCRETE SLAB / SURFACE COURSE

- The concrete slab is the top most layer of rigid pavement which is in direct contact with the vehicular loads.
- This is also called as surface course.
- It is water resistant and prevents the water infiltration into the base course.
- It offers friction to the vehicles to provide skid resistance.
- The thickness of concrete slab is kept between 150 mm to 300 mm.

GRANULAR SUB BASE OR STABILIZED SUB BASE COURSE

- It is the third layer from the top and is in contact with the subgrade soil and base course.
- It is constructed by using low quality aggregates than the base course but they should be better quality than subgrade.

- Generally **sub base course is not required when the traffic loading** is light but when the loading exceeds 100000 pounds / 45000 Kgs it should be constructed.
- Its primary function is to provide support for the top layers and it also serves as frost action controller and prevents the intrusion of fines from subgrade to top layers.
- The drainage facility will also improve when there is a sub base course.

FROST PROTECTION LAYER

- In low temperature regions there is a problem of frost action on the pavements.
- If the soil contains high ground water table, during low temperatures the water will freeze and frost heave will formed under the subgrade which will cause the pavement to rise because of non-uniform formation of ice crystals.
- Similarly, when the ice melts the pavement will penetrate into the subgrade when load comes on it.
- To overcome this frost protection layer should be provided.
- Generally a good base course and sub base course themselves acts as frost protection layers.

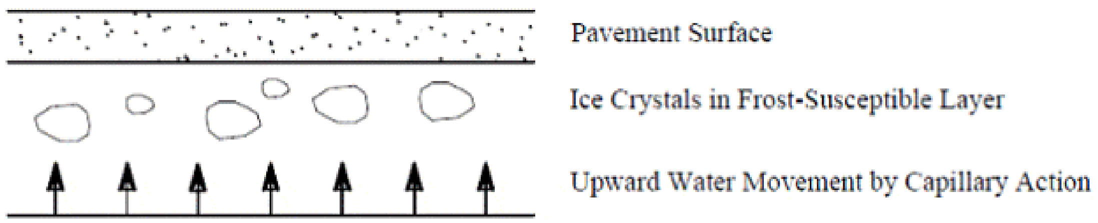


Figure No.5 ***Frost Protection Layer***

Figure No.6 Layers of rigid pavement

FACTORS AFFECTING PAVEMENT STABILITY

There are so many factors which influencing the pavement design.

The factors may be of loading, environment, materials used etc. Which are as follows,

1. **Wheel load**
2. **Axle configuration**
3. **Contact pressure**
4. **Vehicle speed**
5. **Repetition of loads**
6. **Subgrade type**
7. **Temperature**
8. **Precipitation**

Wheel load

Wheel load on pavement is an important factor **to determine the pavement thickness to be adopted.** By providing adequate thickness, **the load coming from wheels doesn't affect the subgrade soil.** The wheel load is acts at particular point on pavement and cause deformations.

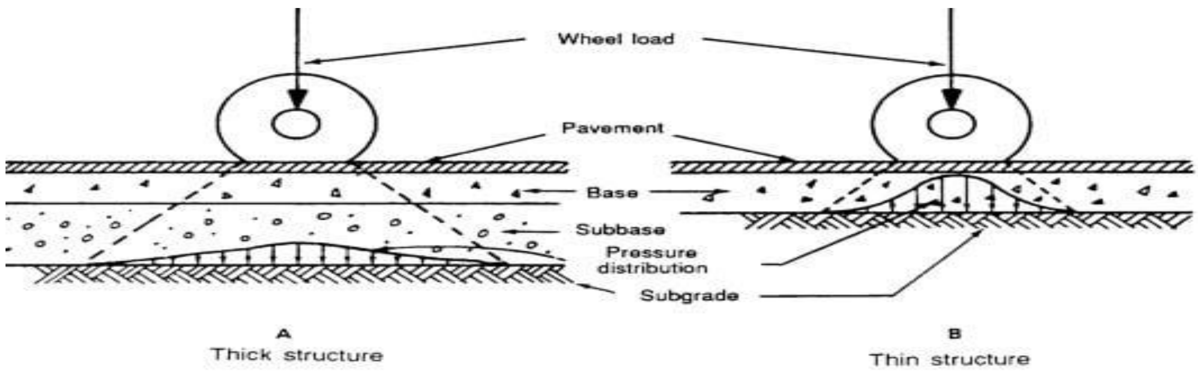


Fig. 7 Wheel load

AXLE CONFIGURATION

- Axles are the important part of the vehicles **which enables the wheels to rotate while moving**.
- By providing multiple axles, vehicle can carry more load.
- So, the **axle load also influences the design of pavement**.

TIRE CONTACT PRESSURE ON PAVEMENT

- When the vehicle is moving on pavement, a pressure developed between the tire and pavement.
- If the tire is low pressure tire, then contact pressure will be greater than tire pressure.
- If it is high pressure tire, then contact pressure will be less than tire pressure. The original Shape of contact area is generally elliptical. But to ease the calculations circular shape is considered.

VEHICLE SPEED

- If the vehicle is moving at creep speed then also damage occurs to the pavement.
- If vehicle speed is gradually increased then it will cause smaller strains in the pavement

REPETITION OF LOADS

- Constructed pavement is used by several vehicles in its design life.

- The wheel loads are repeated all the time due to this some deformation occurs on the pavement.
- Total deformation is the sum of all wheel loads acting on it.
- So, in the design of pavement frequency of load is also considered.
- For the design of pavement, single axle with dual wheels carrying 80 Kn load is considered as standard axle.

SUBGRADE TYPE

- To construct pavement sub grade soil need to be tested. Various test like CBR, Tri axial etc. will helps to determine the quality of subgrade.
- From this we can adopt the required thickness to the pavement.
- If subgrade soil is poor then the pavement should damage easily.

TEMPERATURE

- Temperature is the important environmental factor to be considered in the design of pavement.
- In case of asphalt roads, temperature affects the resilient modulus of surface course.
- In very hot condition asphalt layers lose their stiffness.
- At low temperature, asphalt layers become brittle and cracks are formed.
- In case of rigid pavement, temperature stresses are developed.
- Curling of concrete is also possible due to variation of temperature in top and bottom layers of pavement.

PRECIPITATION

- Moisture variations or precipitation from rain affects the depth of groundwater table.
- Good drainage facilities should be provided for good strength and support.
- The ground water table should be at least below 1m from the pavement surface.

EQUIVALENT SINGLE WHEEL LOAD

- In heavy vehicles, rear axle generally has two wheels at one side instead of single wheel.

- Here **pressure at certain depth below**, **cannot be obtained by numerically adding the pressure caused by each wheel load**.
- So equivalent single wheel load is used.

LAYERED ELASTIC MODEL

- A layered elastic model can **compute stresses, strains and deflections at any point in a pavement structur**e resulting from the application of a surface load.
- **Layered elastic models assume that each pavement structural layer is homogeneous, isotropic, and linearly elastic**.
- In other words, it is the **same everywhere and will rebound to its original form once the load is removed**.

ASSUMPTIONS IN LAYERED ELASTIC MODEL

The layered elastic approach works with relatively simple mathematical models and thus requires following assumptions

- **Pavement layer extends infinitely in the horizontal direction**
- **The bottom layer (usually the subgrade) extends infinitely downwards**
- **Materials are not stressed beyond their elastic ranges**

WHY EQUIVALENT SINGLE WHEEL LOAD?

- Vehicles can have many axles which will distribute the load into different axles, and in turn to the pavement through the wheels.
- **A standard truck has two axles, front axle with two wheels and rear axle with four wheels**.
- But **to carry large loads multiple axles** are provided.
- Since the **design of flexible pavements is by layered theory**, **only the wheels on one side needed to be considered**.
- On the other hand, the **design of rigid pavement is by plate theory** and hence **the wheel loads on both sides of axle need to be considered**.

WHAT IS EQUIVALENT SINGLE WHEEL LOAD?

- Equivalent single wheel load (ESWL) is **the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth as two individual wheel produces.**

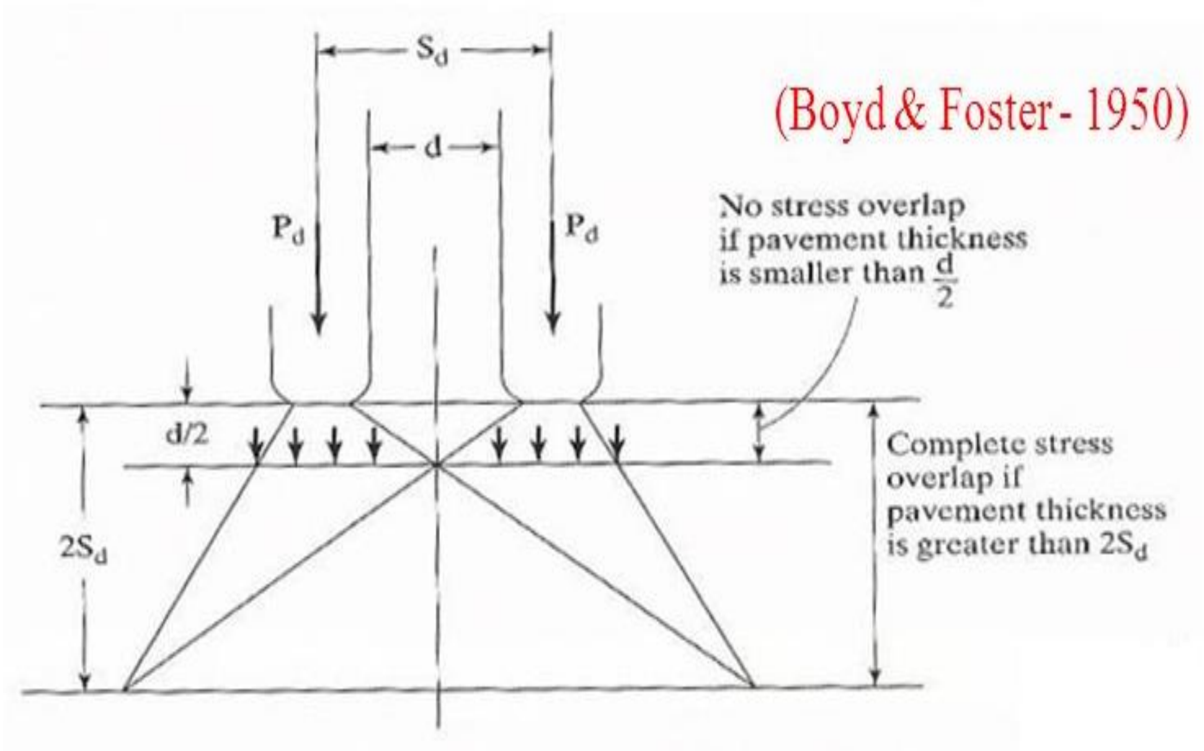


Fig. 8 Wheel load/stress distribution

ASSUMPTIONS FOR ESWL CALCULATION

1. Contact Area is Circular
2. Influence Angle is 45 Degree
3. Soil is Isotropic
4. Soil is Homogeneous
5. Soil is Elastic
6. Overlapping of stress is effective in between d/2 to 2S
7. Up to Depth d/2, Overall Stress = Stress Due To Tire(1) + Stress Due To Tire (2)
8. After Depth 2S, Overall Stress = Stress Due To Tire (1) + Stress Due To Tire (2)

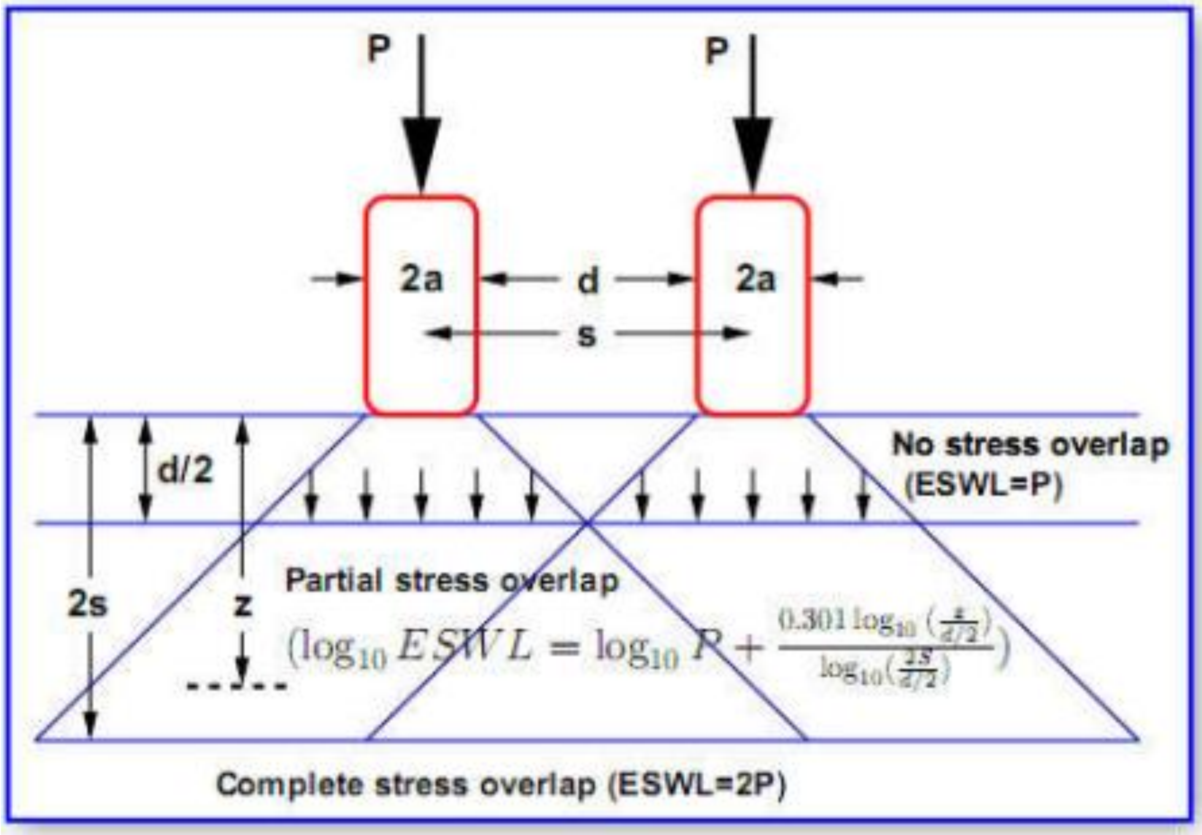


Fig. 9 Stress distribution

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

where ,

P $\longrightarrow$ wheel load,

s $\longrightarrow$ center to center distance between the two wheels,

d $\longrightarrow$ clear distance between two wheels, and

z $\longrightarrow$ desired depth.

Example 1

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

<u>Given data:</u>

s	=	20 cm
d	=	10 cm
P	=	2044 kg
Depth, z	=	5, 20 and 40 cm

For desired depths

z	=	5cm (which is half the distance between the walls of the tire)
ESWL	=	P
	=	2044kN.

z	=	40cm (which is twice the tire spacing)
ESWL	=	2P
	=	2 * 2044
	=	4088 kN

For desired depth where partial stress overlap

$$z = 20\text{cm}$$

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

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

=3.511

Therefore,

ESWL = antilog(3.511)

= **3244.49 kN**

EQUIVALENT WHEEL LOAD FACTOR

WHEEL LOAD (Kg)	REPETITIONS TO FAILUR (in No.)	EQUIVALENT TO 2268 Kg	EQUIVALENT LOAD FACTOR
2268	**105000**	**1.0**	**1**
2722	**50000**	**2.0**	**2**
3175	**22500**	**4.7**	**4**
3629	**13000**	**8.2**	**8**
4082	**6500**	**16.3**	**16**
4536	**3300**	**32.0**	**32**
4990	**1700**	**62.0**	**64**
5443	**1000**	**105.0**	**128**

Calculate design repetitions for 20 years period for various wheel loads equivalent to 2268 Kg wheel load using the following survey on a four lane road.

WHEEL LOAD (Kg)	AVERAGE DAILY TRAFFIC (BOTH DIRECTIONS)	% OF TOTAL TRAFFIC VOLUME
2268	Total Volume (considering traffic growth rate) is 215	13.17
2722		15.30
3175		11.76
3629		14.11
4082		6.21
4536		5.84

Design repetitions for a period of 20 years calculated is given. The equivalent load factor must be taken from the standard Table values given.

WHEEL LOAD (Kg)	AVERAGE DAILY TRAFFIC (BOTH DIRECTIONS)	% for each load	Days per year	No. of years	ELF	Design Repetitions equivalent of 2268 Kg load
2268	**215**	**0.137**	**365**	**20**	**1**	**206703**
2722	**215**	**0.135**	**365**	**20**	**2**	**480267**
3175	**215**	**0.1176**	**365**	**20**	**4**	**739293**
3629	**215**	**0.1411**	**365**	**20**	**8**	**1771652**
4082	**215**	**0.0621**	**365**	**20**	**16**	**1599455**
4536	**215**	**0.0584**	**365**	**20**	**32**	**2933082**

Total estimated repetitions = 7729452

Design repetitions equivalents of 2268 Kg wheel load per lane = 7729452 / 4

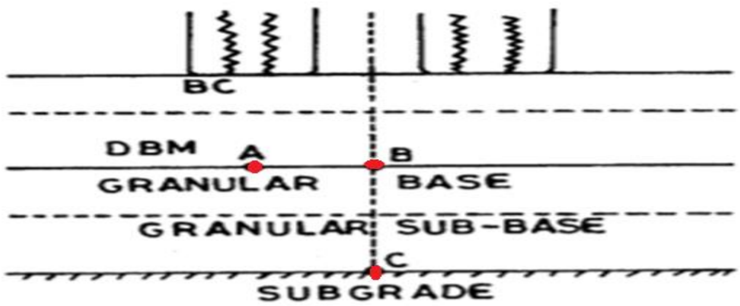
= 1932363

Stress and Strain in flexible pavement as per IRC:37-2001

Annexure-I

CRITICAL LOCATIONS, RELATIONSHIP BETWEEN NUMBER OF CUMULATIVE STANDARD AXLES, STRAIN VALUES AND ELASTIC MODULUS OF MATERIALS

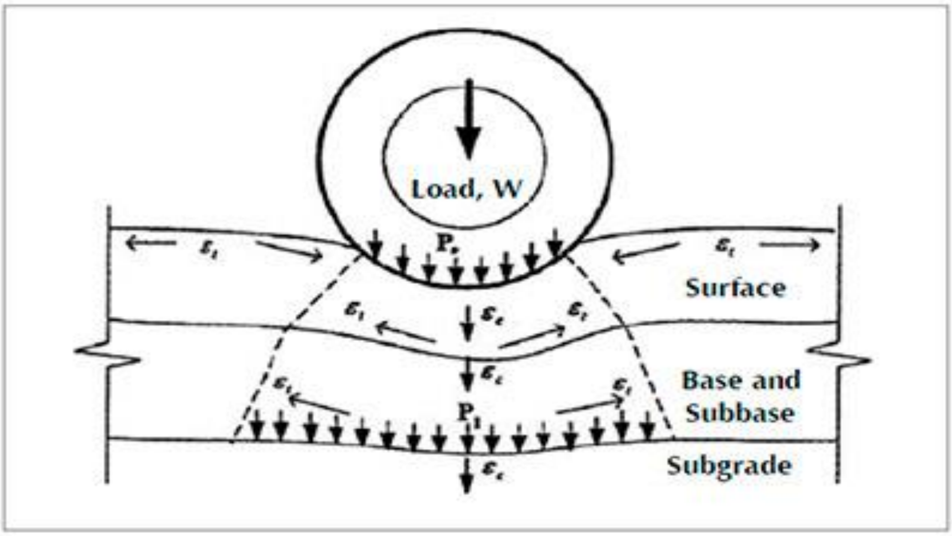
Critical Locations in Pavement

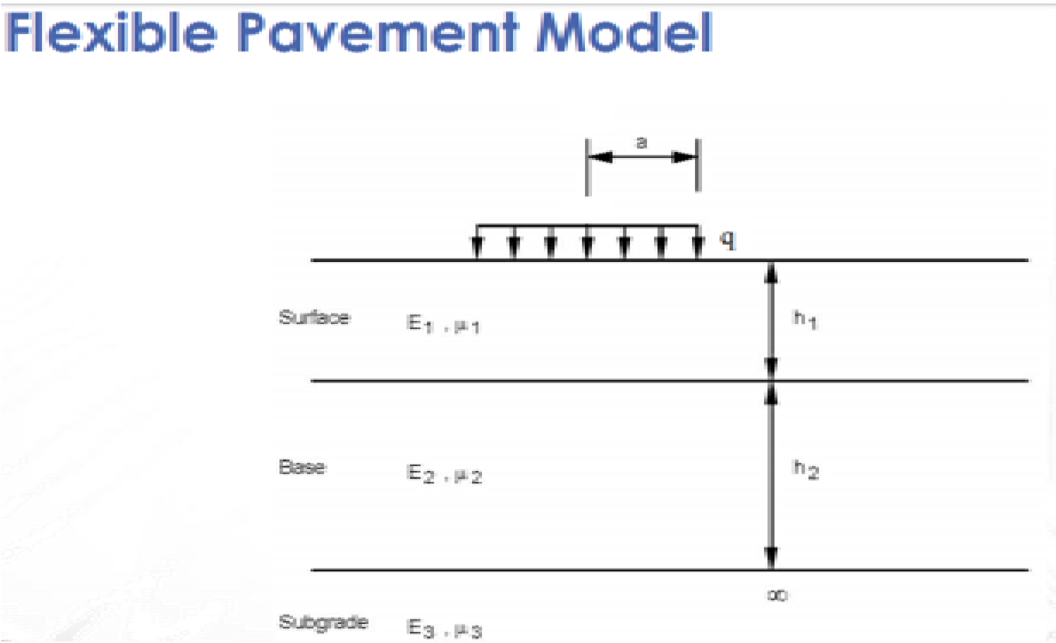


A and B are the critical locations for tensile strains (ε_t). Maximum value of the strain is adopted for design.

C is the critical location for the vertical subgrade strain (ε_z) since the maximum value of the ε_z occurs mostly at C.

STRESS DISTRIBUTION IN DIFFERENT CONDITION

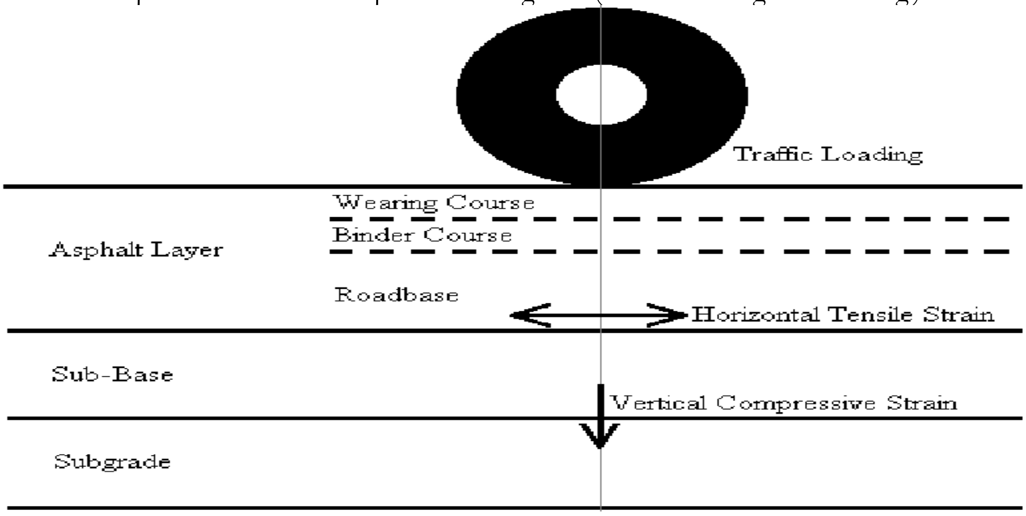




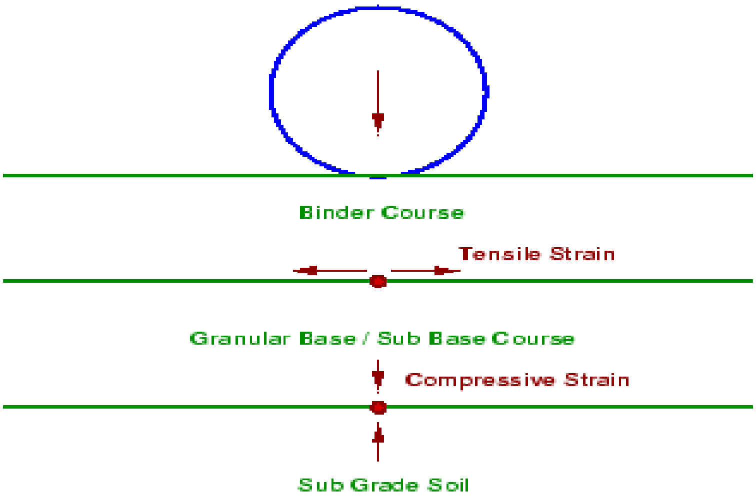
PAVEMENT RESPONSES IN FLEXIBLE PAVEMENT

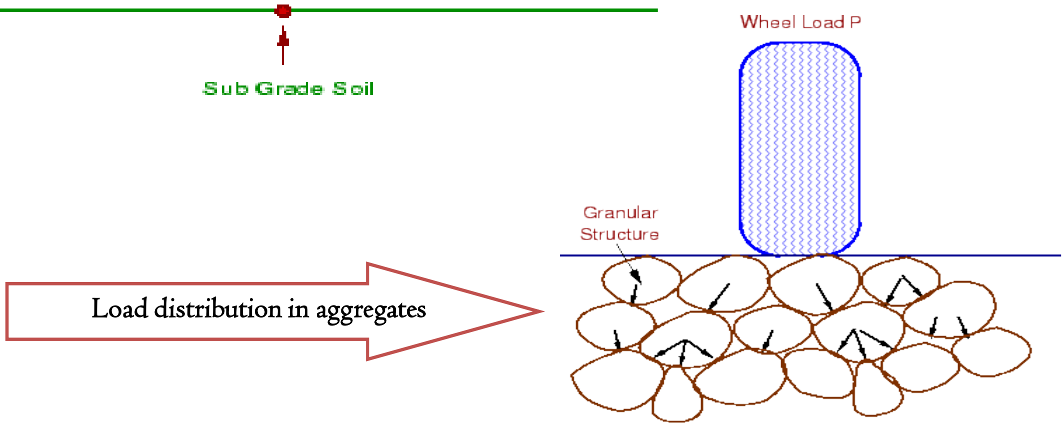
Pavement responses generally of interest:

- Surface deflection (represents surface rutting)
- Horizontal tensile strain at bottom of AC layer (controls bottom up fatigue cracking)
- Vertical compressive strain on top of intermediate layer (base or sub-base rutting)
- Vertical compressive strain on top of the subgrade (controls subgrade rutting)



Stress distribution in different condition





STRESS IN RIGID PAVEMENT

- **Temperature Stresses**

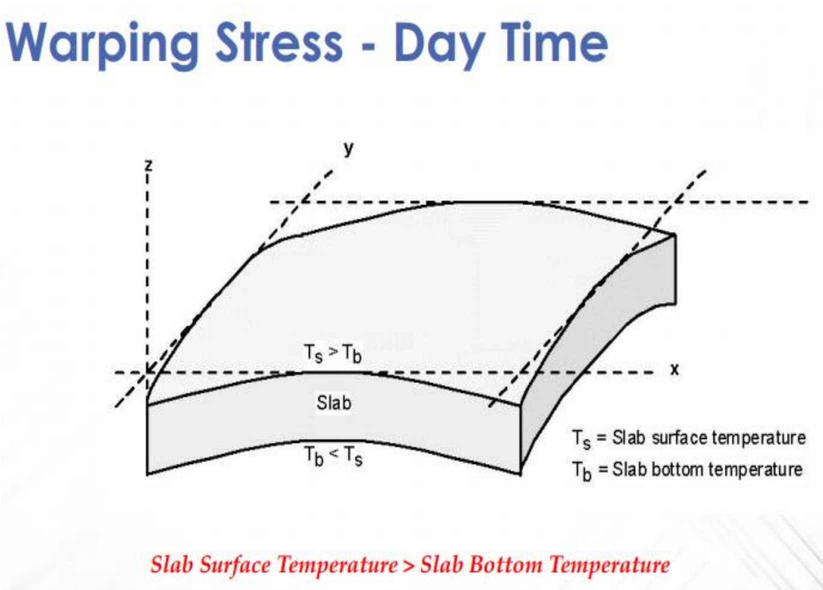
  Due to the temperature differential between the top and bottom of the slab, **curling stresses (similar to bending stresses)** are induced at the bottom or top of the slab

- **Frictional stresses**

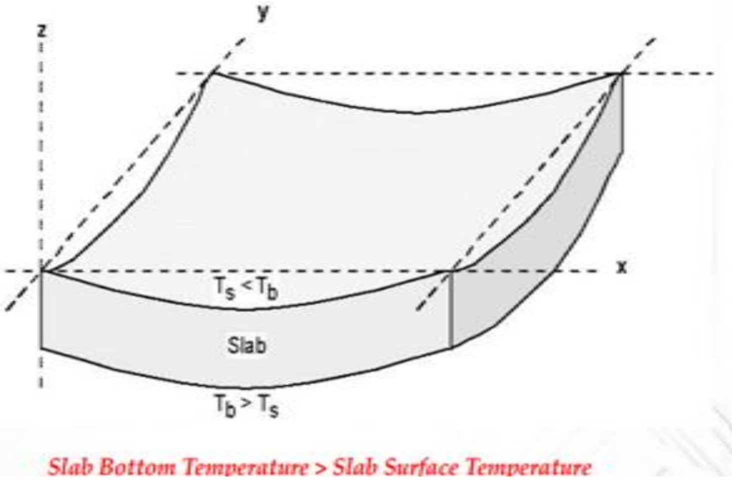
  Due to the contraction of slab due to shrinkage or due to drop in temperature **tensile stresses** are induced at the middle portion of the slab

- **Wheel Load Stresses**

  CC slab is subjected to **flexural stresses** due to the wheel loads



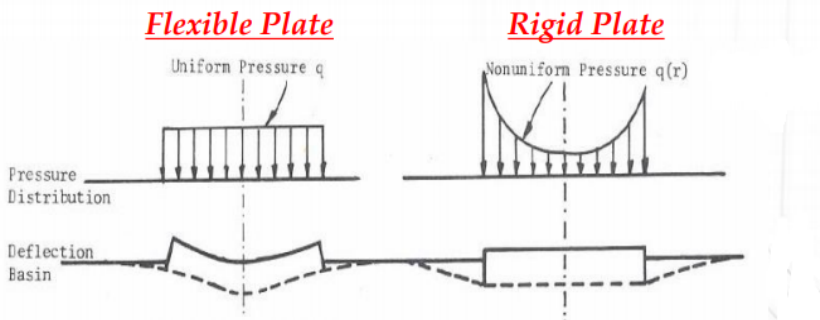
Warping Stress - Night Time



Nature of Responses under Flexible and Rigid Plates

Flexible plate:
- ✓ Uniform Contact Pressure
- ✓ Variable Deflection Profile

Rigid Plate plate:
- ✓ Non-Uniform Contact Pressure
- ✓ Equal Deflection



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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – II - FLEXIBLE PAVEMENT DESIGN – SCI1610

UNIT – 2 - FLEXIBLE PAVEMENT DESIGN

Bitumen characteristics - Test in bitumen - Aggregate gradation - principles of bituminous mix design – IRC - Asphalt Institute method - AASTHO - Burmister method - Super - pave mix design - construction of Flexible pavement, defects and maintenance - Demonstration of Pavement Design Software.

INTRODUCTION

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

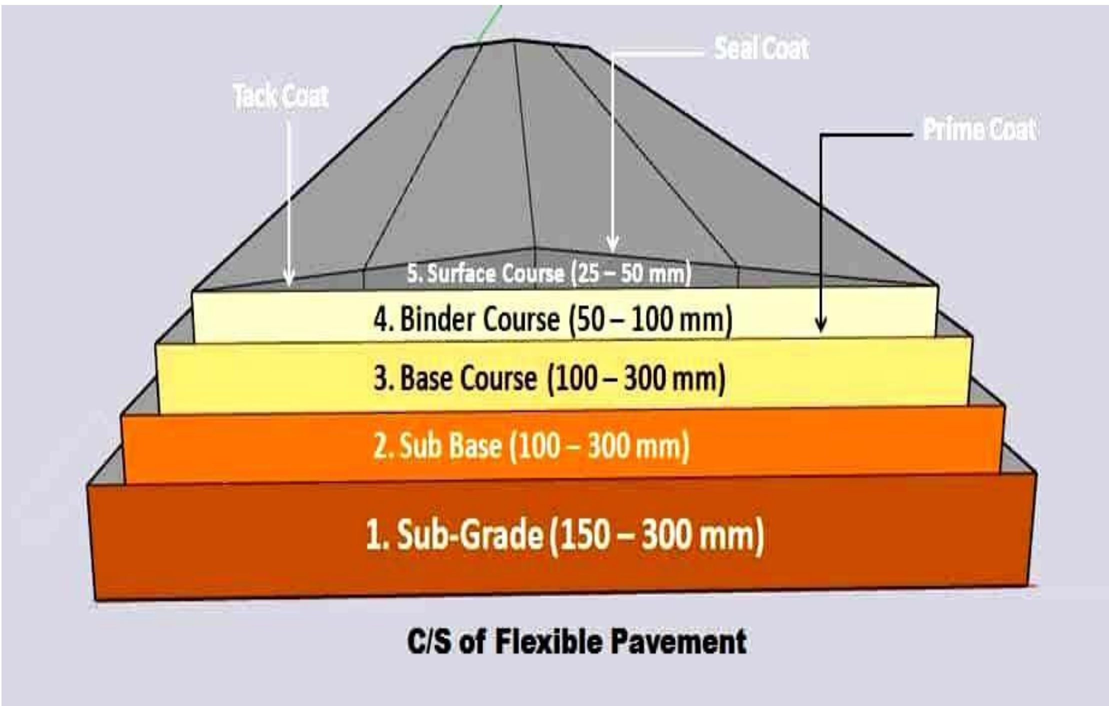


Fig No. 1 Flexible pavements composition

DESIRABLE PROPERTIES OF MATERIALS

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

BITUMINOUS MATERIALS

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

Production of Bitumen

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

DIFFERENT FORMS OF BITUMEN

CUTBACK BITUMEN

- Normal practice is to heat bitumen to reduce its viscosity.
- In some situations preference is given to use liquid binders such as cutback bitumen.
- In cutback bitumen suitable solvent is used to lower the viscosity of the bitumen.

- The distillates used for preparation of cutback bitumen are naphtha, kerosene, diesel oil, and furnace oil.
- From the environmental point of view also cutback bitumen is preferred.
- There are different types of cutback bitumen like
    - Rapid curing (RC),
    - Medium curing (MC), and
    - Slow curing (SC)

BITUMEN EMULSION

- Bitumen emulsion is a liquid product in which bitumen is suspended in a finely divided condition in an aqueous medium and stabilized by suitable material.
- Three types of bituminous emulsions are available, which are
    - Rapid setting (RS),
    - Medium setting (MS), and
    - Slow setting (SC).
- Bitumen emulsions are ideal binders for hill road construction.

BITUMINOUS PRIMERS

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

MODIFIED BITUMEN

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

The advantages of using modified bitumen are as follows

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

REQUIREMENTS OF BITUMEN

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

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.

- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.

- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

TESTS ON BITUMEN

There are a number of tests to assess the properties of bituminous materials.

The following tests are usually conducted to evaluate different properties of bituminous materials.

- Penetration test
- Ductility test
- Softening point test
- Specific gravity test
- Viscosity test
- Flash and Fire point test
- Float test
- Water content test

- Loss on heating test

PENETRATION TEST

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

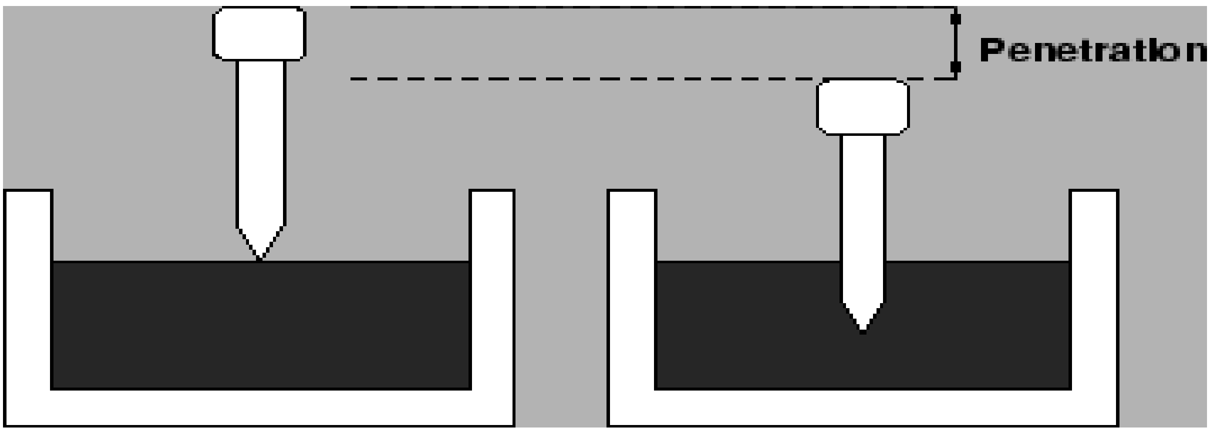


Fig. 2 Penetration test

DUCTILITY TEST

- Ductility is **the property of bitumen that permits it to undergo great deformation or elongation.**
- Ductility is defined as the distance in cm, to which a standard sample or briquette of the material will be elongated without breaking.
- Dimension of the briquette thus formed is exactly 1 cm square.
- The bitumen sample is heated and poured in the mould assembly placed on a plate.

- These samples with moulds are cooled in the air and then in water bath at 27 C temperature.
- The excess bitumen is cut and the surface is levelled using a hot knife.
- Then the mould with assembly containing sample is kept in water bath of the ductility machine for about 90 minutes.
- The sides of the moulds are removed, the clips are hooked on the machine and the machine is operated.
- The distance up to the point of breaking of thread is the ductility value which is reported in cm.
- The ductility value gets affected by factors such as pouring temperature, test temperature, rate of pulling etc.
- A minimum ductility value of 75 cm has been specified by the BIS.
- **In flexible pavement design, it is necessary that binder should form a thin ductile film around aggregates so that physical interlocking of the aggregates is improved**

Figure below shows ductility moulds to be filled with bitumen

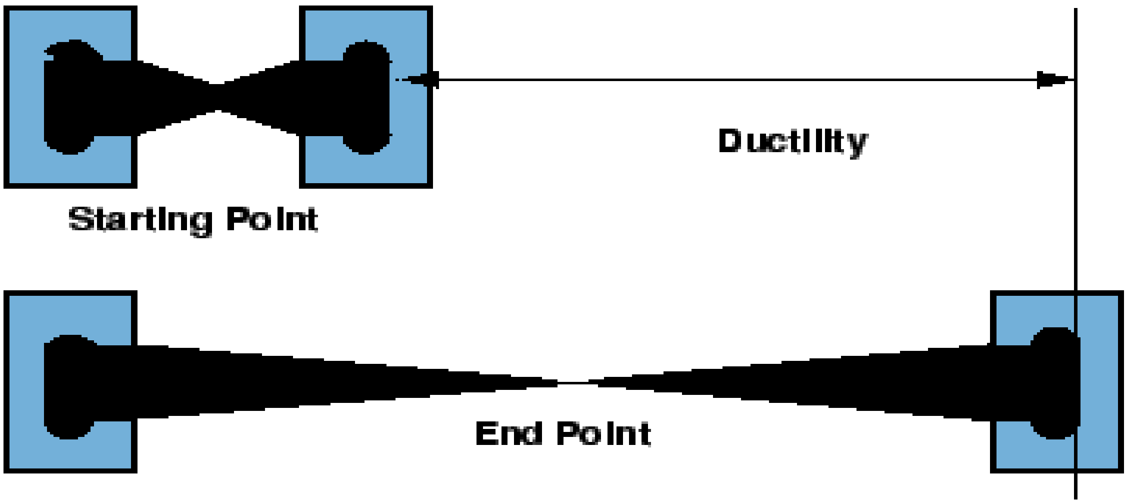


Fig. 3 Ductility test

SOFTENING POINT TEST

- Softening point **denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test**.
- The test is conducted by using Ring and Ball apparatus.
- A brass ring containing test sample of bitumen is suspended in liquid like water or glycerine at a given temperature.

- A steel ball is placed upon the bitumen sample and the liquid medium is heated at a rate of 5 C per minute.
- Temperature is noted when the softened bitumen touches the metal plate which is at a specified distance below.
- Generally, **higher softening point indicates lower temperature susceptibility and is preferred in hot climates.**
- The Figure shows Softening Point test setup.

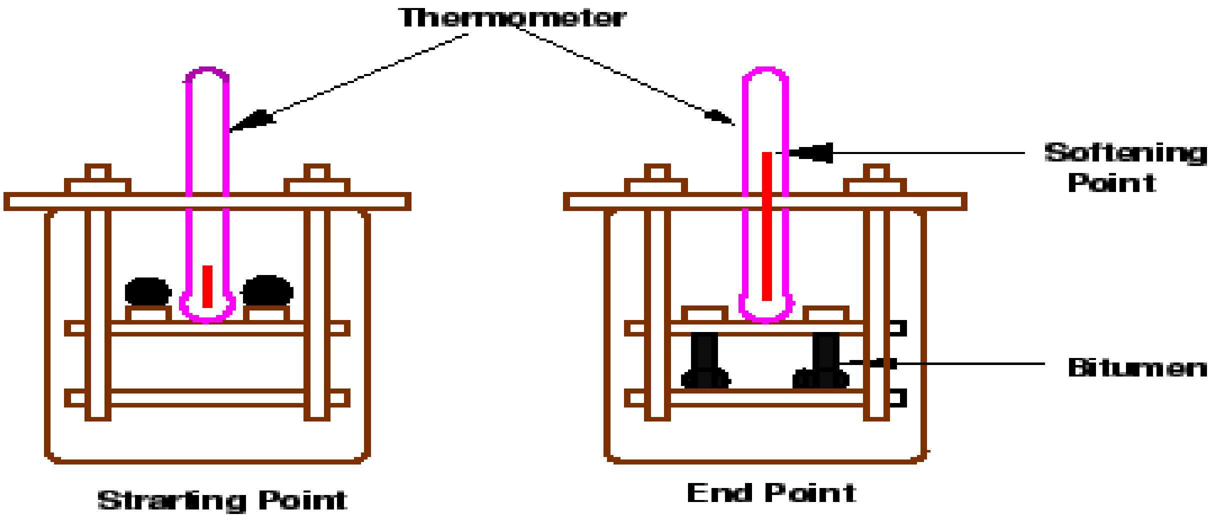


Fig. 4 Softening point test

SPECIFIC GRAVITY TEST

- In paving jobs, to classify a binder, density property is of great use.
- **In most cases bitumen is weighed, but when used with aggregates, the bitumen is converted to volume using density values.**
- The **density of bitumen is greatly influenced by its chemical composition**. Increase in aromatic type mineral impurities cause an increase in specific gravity.
- The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27 C.
- The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi solid or solid state.
- The specific gravity of bitumen varies from 0.97 to 1.02.

VISCOSITY TEST

- Viscosity denotes the fluid property of bituminous material and it is a measure of resistance to flow.
- At the application temperature, this characteristic greatly influences the strength of resulting paving mixes.

- Low or high viscosity during compaction or mixing has been observed to result in lower stability values.
- At high viscosity, it resists the compactive effort and thereby resulting mix is heterogeneous, hence low stability values.
- And at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles.
- Orifice type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions.
- The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature.
- Viscosity of a cutback can be measured with either 4.0 mm orifice at 25 C or 10 mm orifice at 25°or 40 °C.

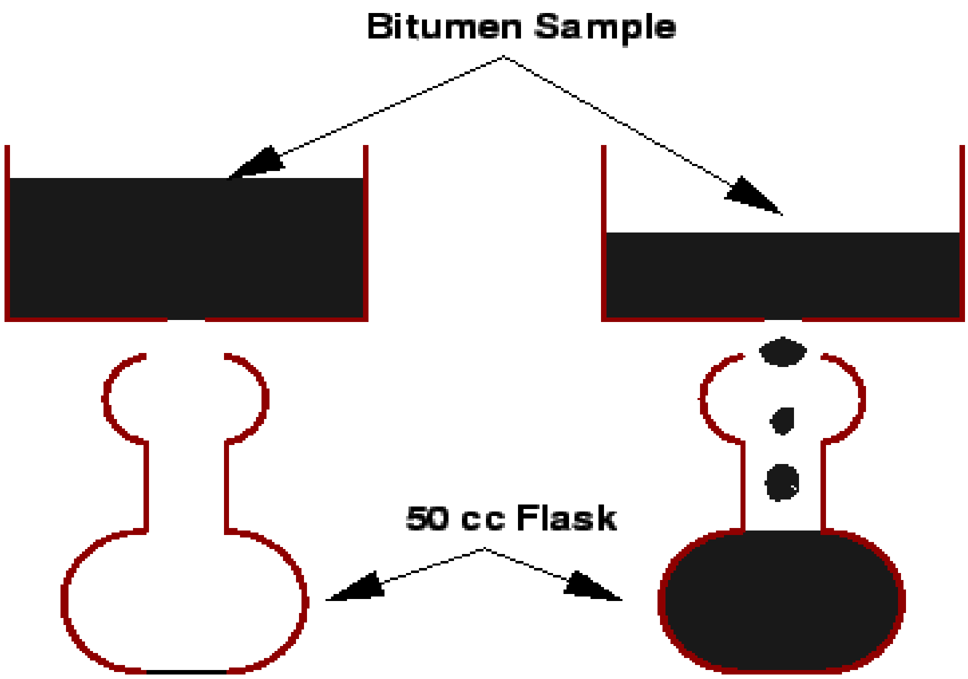


Fig. 6 Viscosity test

FLASH AND FIRE POINT TEST

- At high temperatures depending upon the grades of bitumen materials leave out volatiles(sudden change leading to violent behaviour of material).
- And these volatiles catches fire which is very hazardous and therefore it is essential to qualify this temperature for each bitumen grade.
- BIS defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions.

- The fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns.
- The flash point tells the critical temperature at and above which suitable precautions are required to be taken to eliminate the danger of fire during heating

FLOAT TEST

- Normally the consistency of bituminous material can be measured either by penetration test or viscosity test.
- But for certain range of consistencies, these tests are not applicable and Float test is used.
- The apparatus consists of an aluminum float and a brass collar filled with bitumen to be tested.
- The specimen in the mould is cooled to a temperature of 5° C and screwed in to float.
- The total test assembly is floated in the water bath at 50 ° C and the time required for water to pass its way through the specimen plug is noted in seconds and is expressed as the float value.

WATER CONTENT TEST

- It is desirable that the bitumen contains minimum water content to prevent foaming of the bitumen when it is heated above the boiling point of water.
- The water in bitumen is determined by mixing known weight of specimen in a pure petroleum distillate free from water, heating and distilling of the water.
- The weight of the water condensed and collected is expressed as percentage by weight of the original sample.
- The allowable maximum water content should not be more than 0.2% by weight.

LOSS ON HEATING TEST

- When the bitumen is heated it loses the volatility and gets hardened. About 50gm of the sample is weighed and heated to a temperature of 163 °C for 5hours in a specified oven designed for this test.
- The sample specimen is weighed again after the heating period and loss in weight is expressed as percentage by weight of the original sample.
- Bitumen used in pavement mixes should not indicate more than 1% loss in weight, but for bitumen having penetration values 150-200 up to 2% loss in weight is allowed.

AGGREGATE GRADATION

- The particle size distribution of an aggregate as determined by sieve analysis is termed as gradation of aggregates.
- If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids whereas aggregate comprising particles of various sizes will give a mass with lesser voids.
- The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles.
- The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement waste, therefore, it is essential that coarse and fine aggregates be well graded to produce quality concrete.
- Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate used as well as cement and water requirements, workability and durability of concrete.
- In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength.

TYPES OF GRADING OF AGGREGATES

- **Dense-or well-graded aggregate** – Has gradation close to the maximum density grading curve.
- **Gap-graded aggregate** – Has only a small percentage of particles in the mid-size range.
- **Uniformly graded aggregate** – Composed mostly of particles of the same size.
- **Open-graded aggregate** – Contains only a small percentage of small-size particles.

DENSE GRADED AGGREGATE

- A dense gradation refers to a sample that is **approximately of equal amounts of various sizes of aggregate.**
- By having a dense gradation, most of the **air voids between the materials are filled with particles.**
- A dense gradation will result in an even curve on the gradation graph.

a) Wide range of sizes.

b) Grain-to-grain contact.

c) Low void content.

d) Low permeability.

e) High stability.

f) Difficult to compact.

GAP GRADED AGGREGATE

- Gap-graded aggregate contains **only a small percentage of aggregate particles in the mid-size range.**
- The curve is flat in the mid-size range.
- Some **PCC mix designs use gap graded aggregate to provide a more economical mix since less sand can be used for a given workability.**
- When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum.
- Gap-graded aggregate are **used to obtain uniform textures** in exposed aggregate concrete.

GAP GRADED AGGREGATE

Close control of mix proportions is necessary to avoid segregation.

a) Missing middle sizes.

b) No grain-to-grain contact.

c) Moderate void content.

d) Moderate permeability.

e) Low stability.

f) Easy to compact.

OPEN GRADED AGGREGATE

- In this type of gradation of aggregates, **only a small percentage of aggregate particles are in the small range**.
- This **results in more air voids because there are not enough small particles to fill in the voids between the larger particles**.
- The curve is near vertical in the mid-size range, and flat and near-zero in the small-size range.

UNIFORM GRADED AGGREGATE

- It refers to a gradation that contains most of the particles in a very narrow size range.
- In essence, all the particles are the same size.
- The curve is steep and only occupies the narrow size range specified.

a) Narrow range of sizes.

b) Grain-to-grain contact.

c) High void content.

d) High permeability.

e) Low stability.

f) Difficult to compact.

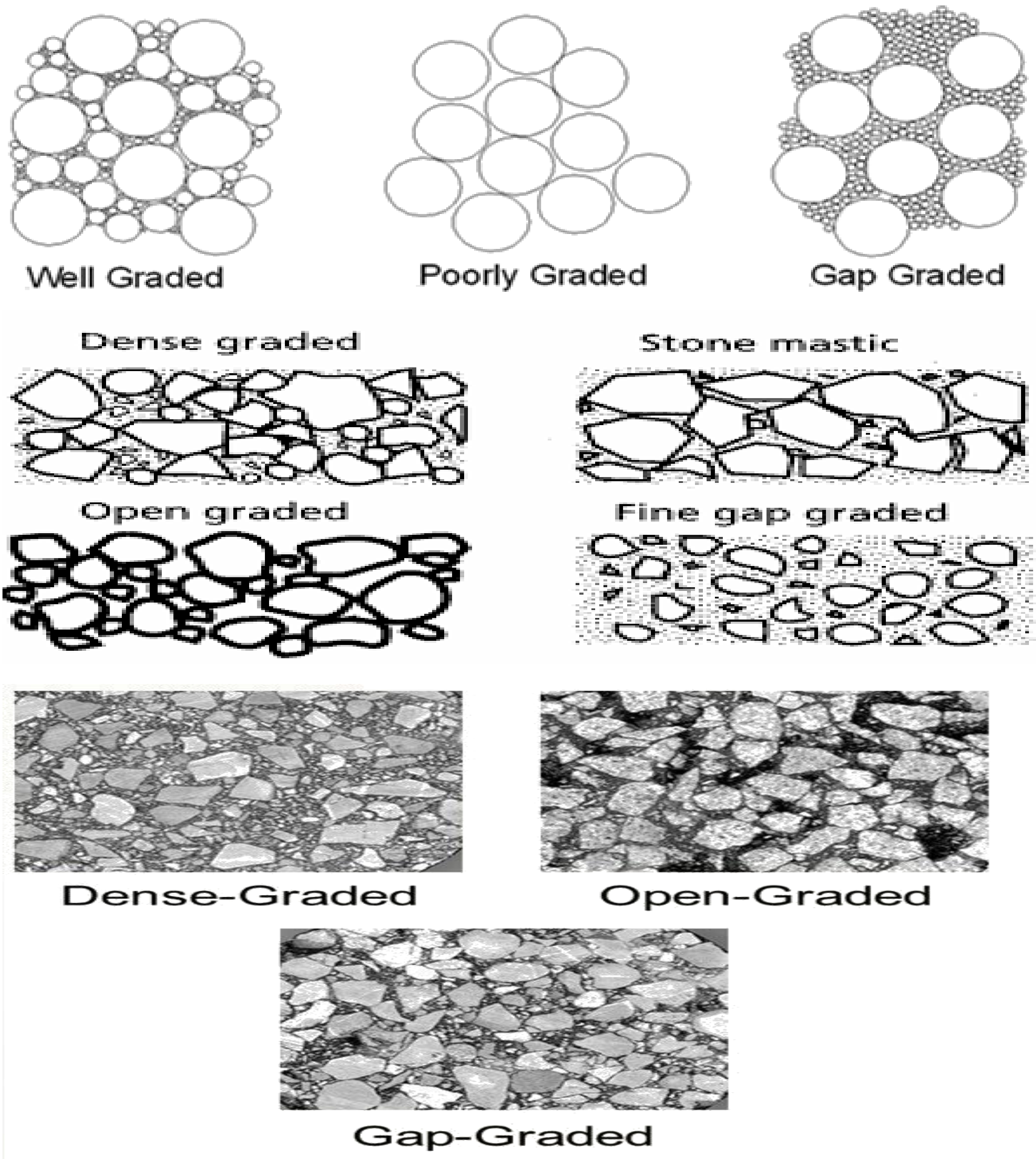


Fig. 7 Examples for Gradation of aggregate

PRINCIPLES OF BITUMINOUS MIX DESIGN

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

Constituents of a mix

- **Coarse aggregates:** Offer compressive and shear strength and shows good interlocking properties. E.g. *Granite*
- **Fine aggregates:** Fills the voids in the coarse aggregate and stiffens the binder. E.g. *Sand, Rock dust*
- **Filler:** Fills the voids, stiffens the binder and offers permeability. E.g. *Rock dust, cement, lime*
- **Binder:** Fills the voids, cause particle adhesion and gluing and offers impermeability. E.g. *Bitumen, Asphalt, Tar*

OBJECTIVES OF MIX DESIGN

The objective of the mix design is to produce a bituminous mix by proportioning various components so as to have:

- Sufficient bitumen to ensure a durable pavement,
- Sufficient strength to resist shear deformation under traffic at higher temperature,
- Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic,
- Sufficient workability to permit easy placement without segregation,
- Sufficient flexibility to avoid premature cracking due to repeated bending by traffic and
- Sufficient flexibility at low temperature to prevent shrinkage cracks.

PROPERTIES OF MIX DESIGN

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

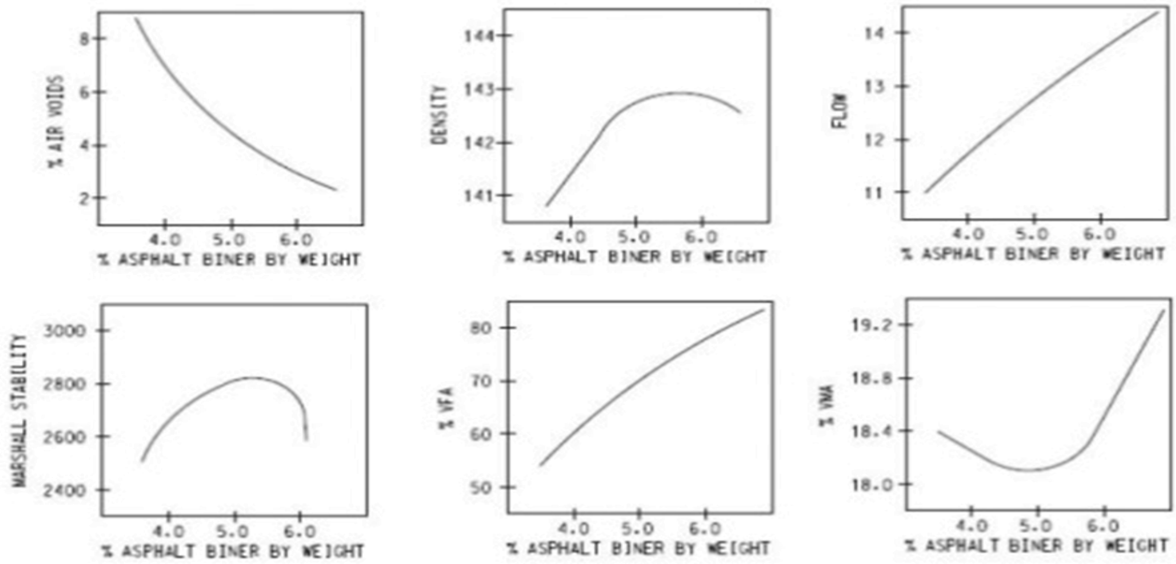
- Stability to meet traffic demand
- Bitumen content to ensure proper binding and water proofing
- Voids to accommodate compaction due to traffic
- Flexibility to meet traffic loads, esp. in cold season
- Sufficient workability for construction
- Economical mix

The Marshall mix design method consists of 6 basic steps:

- Aggregate selection
- Asphalt binder selection
- Sample preparation (including compaction)
- Stability determination using the Hveem Stabilometer
- Density and voids calculations
- Optimum asphalt binder content selection

The Marshall Mix Design method consists mainly of the following steps:

1. Determination of physical properties, size and gradation of aggregates.
2. Selection of types of asphalt binder.
3. Prepare initial samples, each with different asphalt binder content.
4. For example, three samples are made each at 4.5, 5.0, 5.5, 6.0 and 6.5 percent asphalt by dry weight for a total of 15 samples.
5. There should be at least two samples above and two below the estimated optimum asphalt content.
6. Plot the following graphs:
    1. Asphalt binder content vs. density
    2. Asphalt binder content vs. Marshall stability
    3. Asphalt binder content vs. flow
    4. Asphalt binder content vs. air voids
    5. Asphalt binder content vs. voids in mineral aggregates
    6. Asphalt binder content vs voids filled with asphalt
7. Determine the asphalt binder content which corresponds to the air void content of 4 percent
8. Determine properties at this optimum asphalt binder content by reference with the graphs.
9. Compare each of these values against design requirements and if all comply with design requirements, then the selected optimum asphalt binder content is acceptable. Otherwise, the mixture should be redesigned.



Design graphs for Marshall Mix Design

Fig 8 Marshal charts

ASPHALT INSTITUTE METHOD

1. Empirical Mechanistic Method
2. Distress Models
   - Fatigue cracking
   - Rutting
3. Traffic Analysis
   - Determination of ESAL
4. Material Properties
   - Resilient modulus for subgrade and granular layers
   - Dynamic modulus for Asphalt layers
5. Environmental Effects
   - Monthly temperature changes, freezing and thawing For any given material and environmental conditions, two thicknesses were obtained, one by each criteria and the larger of the two was used to prepare the design charts

The basic equation of AASHTO flexible pavement design given in 1993 design guide for the structural number is as,

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

where:	W_{18}	predicted number of 80 kN (18,000 lb.) ESALs
	Z_R	standard normal deviate
	S_o	combined standard error of the traffic prediction and performance prediction
	SN	Structural Number (an index that is indicative of the total pavement thickness required)
		$a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots a_i$ = ith layer coefficient D_i = i^{th} layer thickness (inches)m_i = i^{th} layer drainage coefficient
	ΔPSI	difference between the initial design serviceability index, po, and the design terminal serviceability index, pt
	M_R	subgrade resilient modulus (in psi)

SUPER - PAVE MIX DESIGN

- One of the principal results from the **Strategic Highway Research Program** (SHRP) was the Superpave mix design method.
- The Superpave mix design method was designed **to replace the Hveem and Marshall methods.**
- The **volumetric analysis common to the Hveem and Marshall methods provides the basis for the Superpave mix design method**.
- The **Superpave system ties asphalt binder and aggregate selection into the mix design process**, and considers **traffic and climate as well**.
- The compaction devices from the Hveem and Marshall procedures have been replaced by **a gyratory compactor** and the compaction effort in mix design is tied to expected traffic.

Superpave Procedure

The Superpave mix design method consists of 7 basic steps:

1. Aggregate selection.
2. Asphalt binder selection.
3. Sample preparation (including compaction).
4. Performance Tests.

5. Density and voids calculations.
6. Optimum asphalt binder content selection.
7. Moisture susceptibility evaluation.

CONSTRUCTION OF FLEXIBLE PAVEMENT

Highway Construction Project consists of 2 phases:

1. Earthwork and Preparation of Subgrade
   - Excavation and Embankment
   - Site Clearance, Grading and Compaction
2. Construction of Pavement Structure

Earthwork excavation

Fig 9 Construction phase of flexible pavement

PROCEDURE OF BITUMINOUS CONSTRUCTION

- Preparation of existing surface
- Application of binder
- Application of stone chipping
- Rolling of 1st coat
- Application of binder and stone chipping for 2nd coat
- Rolling of 2nd coat
- Finishing and opening to traffic

PROCEDURE OF PENETRATION MACADAM

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

PROCEDURE OF BUILT-UP SPRAY GROUT

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

PROCEDURE OF BITUMINOUS MACADAM

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

- Placement
- Rolling and finishing

PROCEDURE OF PRE-MIXED BITUMINOUS CARPET

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

PROCEDURE OF BITUMINOUS CONCRETE

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

Fig 10 Construction procedure of flexible pavement

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – III - RIGID PAVEMENT DESIGN – SCI1610

UNIT – 3 - RIGID PAVEMENT DESIGN

Stress in Concrete Pavements - IRC Method - Design of Steel Reinforced - Design of Different Joints in Concrete Pavements and their Function - Construction of Concrete Pavements and their Maintenance.

INTRODUCTION

- Rigid pavements are constructed of Portland cement concrete slabs resting on a prepared sub-base of granular material or directly on a granular subgrade.
- The loads will distribute to natural soil layer through different layers of rigid pavement.
- The composition and structure of rigid pavement tells us about the function of each layer of rigid pavement

COMPOSITION OF RIGID PAVEMENT

- In general, Portland cement concrete is used as primary structural element for rigid pavement.
- The reinforcement is provided in the slab depending upon the soil strength and loading conditions.
- Pre-stressed concrete slabs can also be used as surface course.
- The concrete slab usually lies on a compacted granular or treated subbase, which is supported, in turn, by a compacted subgrade.
- Better results of pavement are obtained when the support layers under the pavement are uniform.
- Rigid pavement mostly depends upon the concrete slab so, it should be laid strongly while the bottom layers are constructed using low cost materials to make it economical.

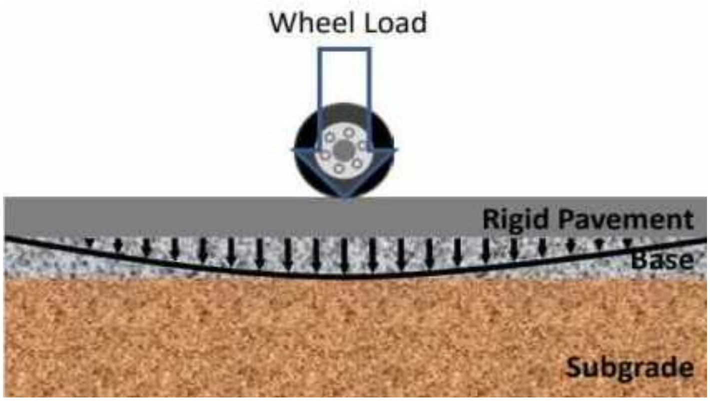


Fig. 1 Transfer of Wheel Load to Subgrade in Rigid Pavement

STRUCTURE OF RIGID PAVEMENT

The structure of a rigid pavement consists following layers.

1) Concrete slab or surface course
2) Granular base or stabilized base course
3) Granular subbase or stabilized subbase course
4) Frost protection layer
5) Subgrade soil

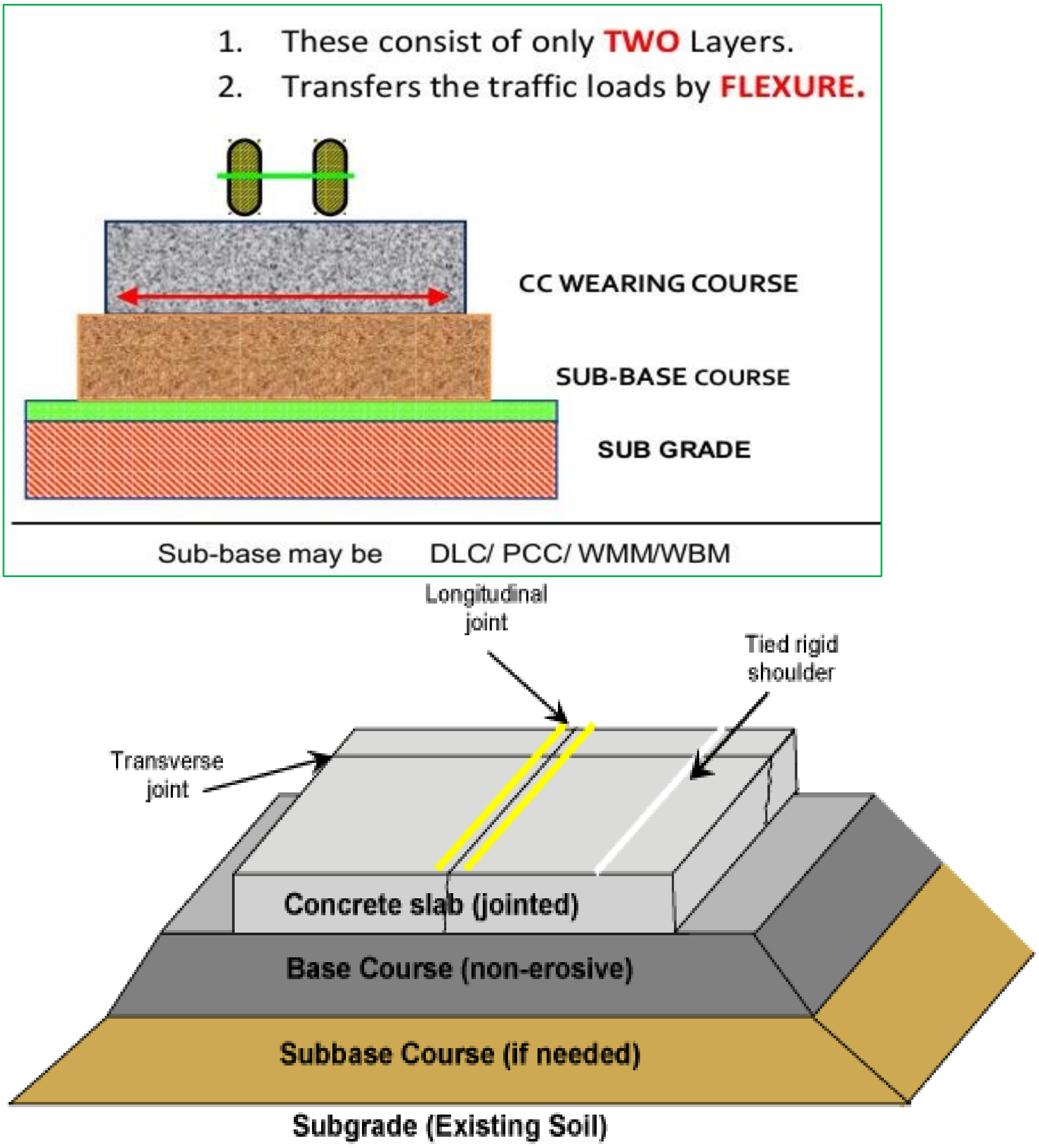


Fig. 2 Typical Rigid Pavement Structure

CONCRETE SLAB

- The concrete slab is the top most layer of rigid pavement which is in direct contact with the vehicular loads.
- This is also called as surface course.
- It is water resistant and prevents the water infiltration into the base course.
- It offers friction to the vehicles to provide skid resistance.
- The thickness of concrete slab is kept between 150 mm to 300 mm

Fig. 3 Concrete Slab Laying

GRANULAR BASE OR STABILIZED BASE COURSE

- The base course or granular base or stabilized base is **the second layer from the top and is constructed using crushed aggregates**.
- This course **helps the surface course to take additional loads.**
- It provides stable platform to construct rigid pavement.
- It is also useful to provide sub surface drainage system.
- In frost areas, the frost action can be controlled by the stabilized base course.
- It helps to control swelling of subgrade soil.
- **The base course thickness should be minimum 100mm**.

Fig. 4 Providing Base Course

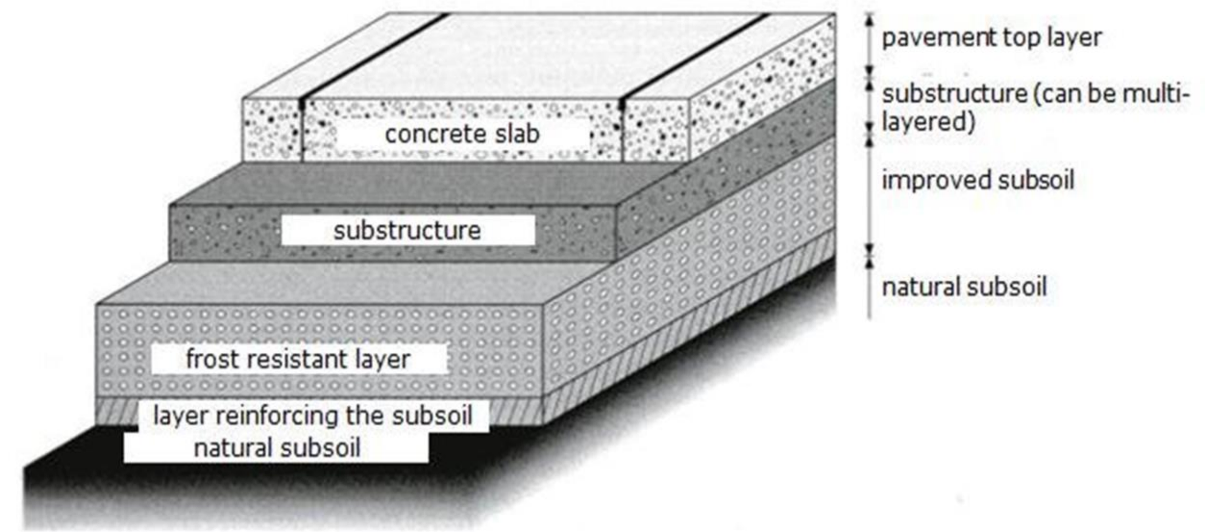
GRANULAR SUBBASE OR STABILIZED SUBBASE COURSE

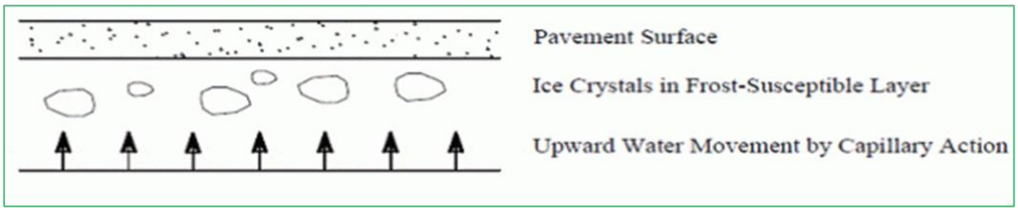
- It is the **third layer from the top** and is **in contact with the subgrade soil and base course.**
- It is **constructed by using low quality aggregates than the base course** but they **should be better quality than subgrade**.
- Generally subbase course is not required when the traffic loading is light. When the loading exceeds 100000 pounds it should be constructed.
- Its primary **function is to provide support for the top layers and it also serves as frost action controller and prevents the intrusion of fines from subgrade to top layers**.
- The drainage facility will also improve when there is a subbase course

Fig. 5 Laying of Subbase Course

FROST PROTECTION LAYER

- In low temperature regions there is a problem of frost action on the pavements.
- If the soil contains high ground water table, during low temperatures the water will freeze and frost heave will formed under the subgrade which will cause the pavement to rise because of non-uniform formation of ice crystals.
- Similarly, when the ice melts the pavement will penetrate into the subgrade when load comes on it.
- To overcome this frost protection layer should be provided.
- Generally a good base course and subbase course themselves acts as frost protection layers





Formation of Ice Crystals in Frost-Susceptible Soil

SUBGRADE SOIL

- The subgrade is nothing but **the existing soil layer which is compacted using equipment to provide stable platform for rigid pavement**.
- The **subgrade soils are subjected to lower stresses than the top layers since the stresses will reduce with depth**.
- Subgrade soils may vary considerably. The stresses coming from the top layers is received by different soils in different manners. Some soils may resist them and some may not.

- It is ***depends upon the interrelationship of texture, density, moisture content and strength of subgrade***.
- So, proper examination should be done on subgrade before construction.
- At the same time the pavement layers above the subgrade should be capable of reducing stresses imposed on the subgrade soil to prevent the displacement of subgrade soil layers.

TYPES OF RIGID PAVEMENT

Rigid pavements can be classified into four types:

1. **Jointed plain concrete pavement (JPCP),**
2. **Jointed reinforced concrete pavement (JRCP),**
3. **Continuous reinforced concrete pavement (CRCP), and**
4. **Pre-stressed concrete pavement (PCP).**

Jointed Plain Concrete Pavement

- These are plain cement concrete pavements constructed with closely spaced contraction joints.
- Dowel bars or aggregate interlocks are normally used for load transfer across joints.
- They normally has a joint spacing of 5 to 10m.
- No temperature steel

Jointed Reinforced Concrete Pavement

- Although reinforcements do not improve the structural capacity significantly, they can drastically increase the joint spacing to 10 to 30m.
- Dowel bars are required for load transfer.
- Reinforcements help to keep the slab together even after cracks.
- Temperature steel placed at mid height and discontinued at the joints

Continuous Reinforced Concrete Pavement:

- Complete elimination of joints are achieved by reinforcement.
- Not popular in India – very costly

Pre-stressed concrete pavement (PCP):

- Not popular

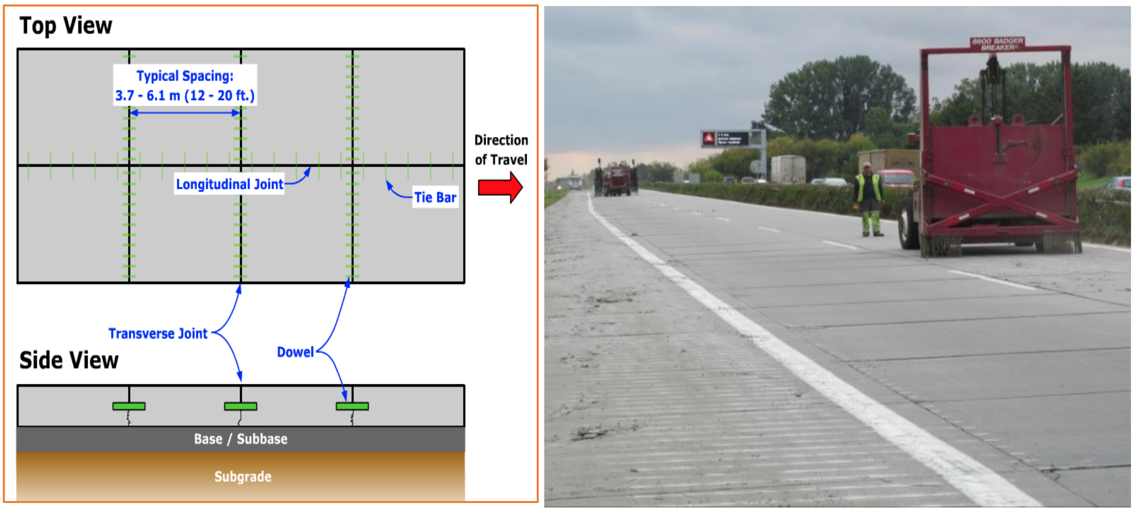


Fig 7 Jointed Plain Concrete Pavements (JPCP)

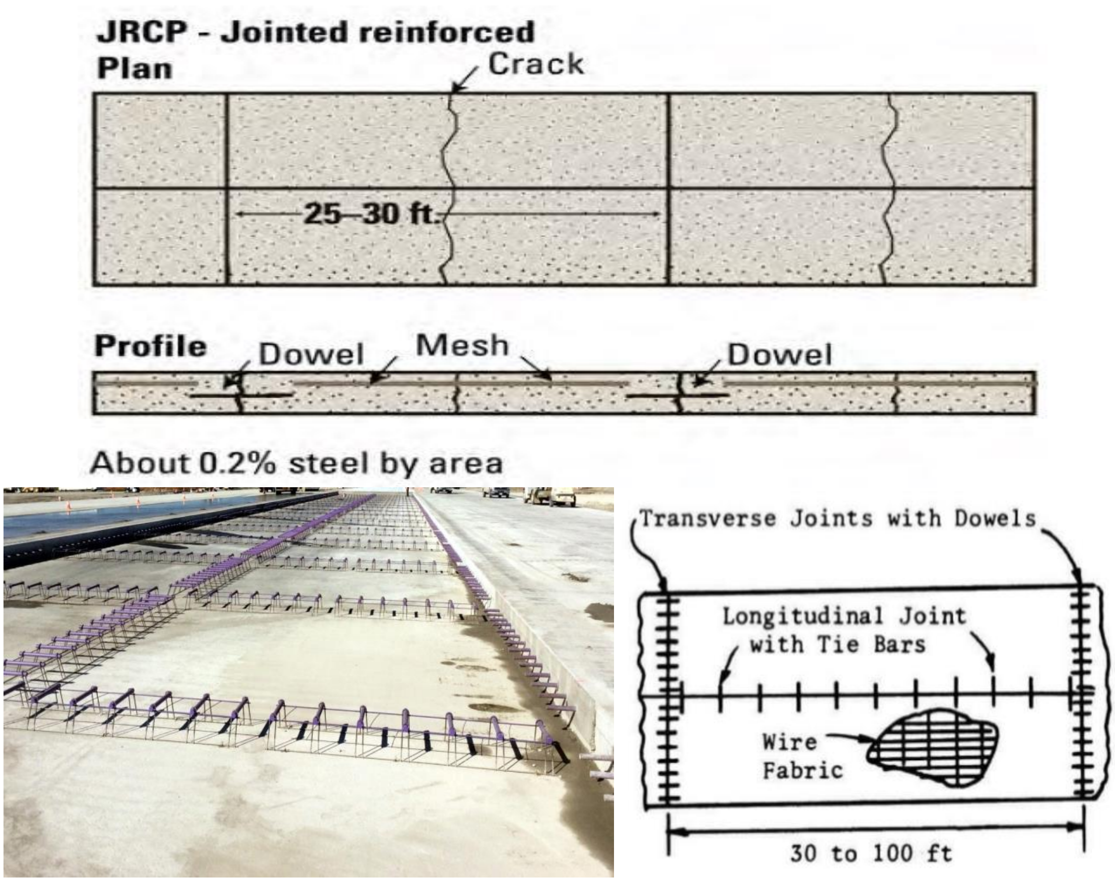
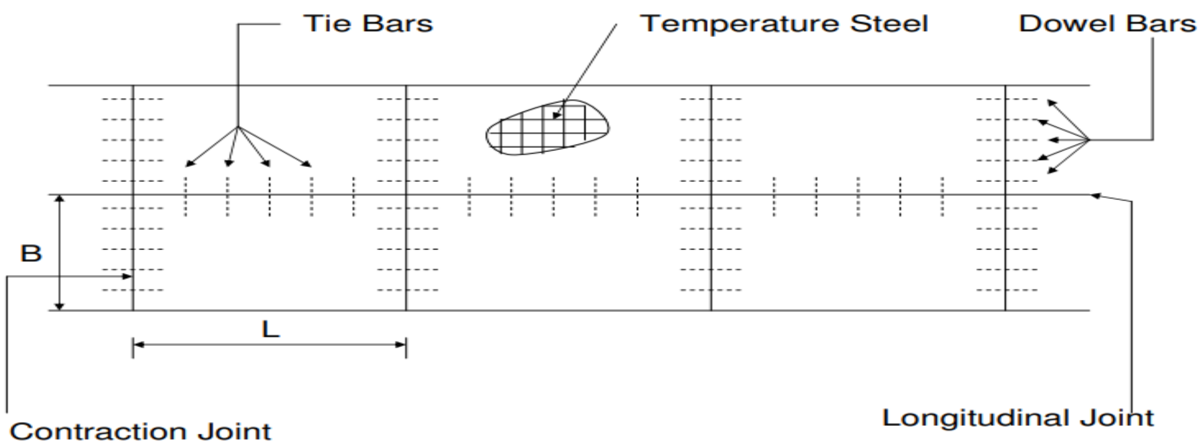
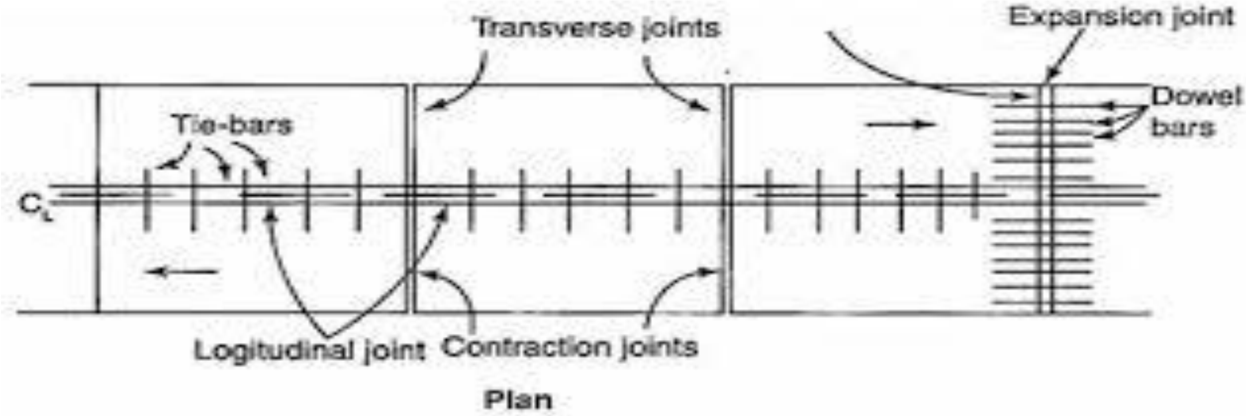


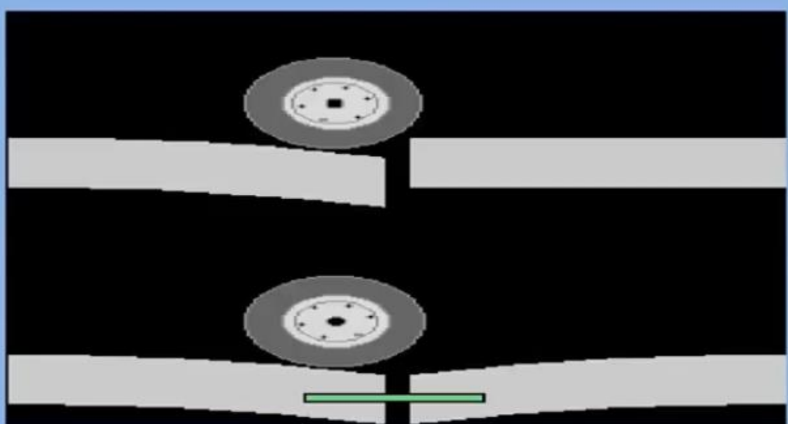
Fig 8 Jointed Reinforced Concrete Pavements (JRCP)

Jointed CC Pavement





Necessity of providing dowel bars



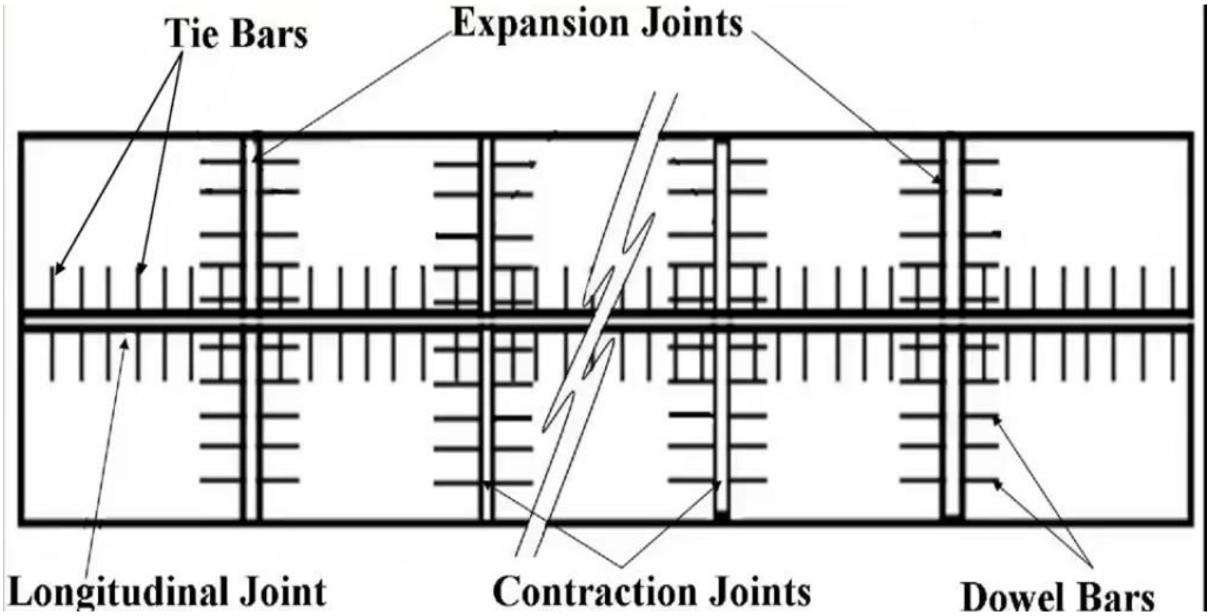


Fig. 9 Joints in CC roads

STRESSES IN RIGID PAVEMENT

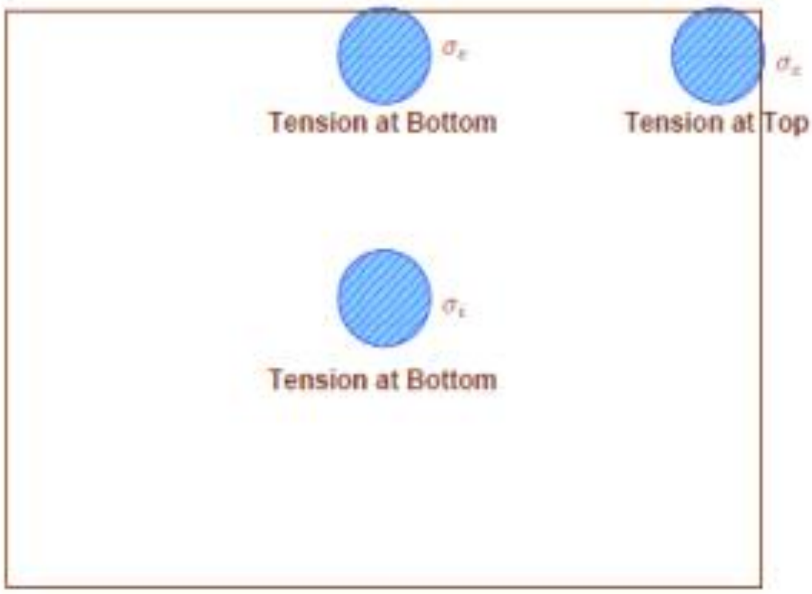
1) **Wheel load stresses**
2) **Temperature stresses**
3) **Combination of stresses**

CRITICAL LOAD STRESSES

- This is very important to know the various combinations of stresses that will be induced in the slab.
- There are two kinds of loading:
    - ✓ Traffic Loading
    - ✓ Temperature variation.
- Traffic loading will induce the compressive or tensile stresses in the pavement
- Temperature variation results in to kinds of stresses.
- One is known as warping stress and another is frictional stress.

  That makes total of <u>three kinds of stresses</u> that will be induced in the pavement slab.

  Now, we have to find out the <u>critical combination of these three</u>.



Critical stress locations

In Summer Season:

- In summer season the average temperature is higher and it results in the overall expansion of the slab.
- This induces the frictional stresses which will be compressive so as to restrict the expansion.
- Remember friction will always act in the opposite direction of the movement of the bottom of the slab.
- That means when it tries to expand, friction will try to contract it or restrict the expansion.
- That makes it to induce the compressive stress.
- In the after mid-noon hours in summer season, the temperature at the top layer will be higher as compare to the bottom layer.
- That will make the slab to tend to warp in downward direction.
- Under the self weight of the slab warping will be restricted and therefore will result in the tensile stress in the bottom layer.

- Downward warping results in contraction of the bottom layer which is restricted through the induction of the tensile warping stress.
- So, warping stress of tensile nature is induced.
- Now, at the edge region the traffic load stress of tensile nature is also induced and that is where the critical load combination is formed.

Critical stress combination (At the edge) = Traffic stress + Warping stress – frictional stress.

In Winter Season:

- In the after mid-noon hours in winter season again, traffic load stress and the warping stresses will be tensile in the bottom layer.
- Also, the frictional stresses will be tensile because, there is overall contraction of the pavement due to lower average temperature and therefore friction will act along the tensile direction.
- So, the **Critical stress combination** is given as below:

Critical stress combination (At the edge) = *Traffic stress + Warping stress + frictional stress.*

- ***At the corners*** the critical load combination is that of the traffic load and the warping stress at the top layer at the mid-night hours.
- See, in the night the temperature at the bottom layers will be higher as compare to the temperature at the top layers so, there will be upward warping.
- That will induce tensile warping stress at the top layer.
- So, **Critical stress combination(At the corner) is given as**

  Critical stress combination (At the corner) = *Traffic stress + Warping stress*

WHEEL LOAD STRESSES

- The cement concrete slab **is assumed to be homogeneous** and to have **uniform elastic properties** with vertical sub-grade reaction being proportional to the deflection.
- Westergaard developed relationships for the stress at interior, edge and corner regions, denoted as σ_i, σ_e, σ_c in kg/cm^2 respectively and given by the equation

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

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

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

Where

h - slab thickness in cm, P is the wheel load in kg,

a - the radius of the wheel load distribution in cm,

l - the radius of the relative stiffness in cm and

b - the radius of the resisting section in cm

TEMPERATURE STRESSES

- Temperature stresses are developed in cement concrete pavement due to variation in slab temperature.
- This is caused by

(i) daily variation resulting in a temperature gradient across the thickness of the slab and

(ii) Seasonal variation resulting in overall change in the slab temperature.

- The former results in warping stresses and the later in frictional stresses.

WARPING STRESS

- The warping stress at the interior, edge and corner regions, denoted as σti σte σtc in kg/cm^2 respectively and given by the equation

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

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

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

Where,

E is the modulus of elasticity of concrete in kg/cm^2 (3X10^5),

ϵ is the thermal coefficient of concrete per °C (1X10^7)

t is the temperature difference between the top and bottom of the slab,

Cx and Cy are the coefficient based on Lx/l in the desired direction and Ly/l right angle to the desired direction,

μ is the Poisson's ration (0.15), a is the radius of the contact area and

l is the radius of the relative stiffness.

Frictional stresses

The frictional stress σ_f in kg/cm^2 is given by the equation

$$\sigma_f = \frac{WLf}{2 \times 10^4}$$

Where

W is the unit weight of concrete in kg/cm^2 (2400),

f is the coefficient of sub grade friction (1.5) and

L is the length of the slab in meters.

Combination of stresses

The cumulative effect of the different stress give rise to the following thee critical cases

Summer, mid-day: The critical stress is for edge region given by $\sigma_{critical} = \sigma_e + \sigma_{te} - \sigma_f$

Winter, mid-day: The critical combination of stress is for the edge region given by $\sigma_{critical} = \sigma_e + \sigma_{te} + \sigma_f$

Mid-nights: The critical combination of stress is for the corner region given by $\sigma_{critical} = \sigma_c + \sigma_{tc}$

RIGID PAVEMENT DESIGN

- Joints are designed to take care of the environmental stresses
- Thickness of the CC pavement slab is decided based on the following two points:
  - The maximum bending tensile stress resulting out of maximum wheel load stress and critical environmental stress should be less than the flexural strength of concrete
  - The CC pavement should withstand the expected number of repetitions of axle loads during its design life

SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – IV - PAVEMENT EVALUATION AND STRENGTHENING – SCI1610

UNIT – 4 - PAVEMENT EVALUATION AND STRENGTHENING

Structural Evaluation of Flexible & Rigid Pavement - Distresses in flexible & rigid pavements – Serviceability index - Evaluation by deflection measurements - Strengthening of pavements - Flexible overlays - Rigid overlays Demonstration of Evaluation Procedures

INTRODUCTION

The overall purpose of highway maintenance is to fix defects and preserve the pavement's structure and serviceability. Defects must be defined, understood, and recorded in order to select an appropriate maintenance plan. The Defects varies between flexible and rigid pavements.

There are four main objectives of highway maintenance:

- Repair of functional pavement defects
- Extend the functional and structural service life of the pavement
- Maintain road safety and signage
- Keep road reserve in acceptable condition

The maintenance activities include:

- Identification of defects and their possible causes
- Determine appropriate remedial measures
- Implementations of remedial measures in the field
- Monitoring of results

CAUSES OF FAILURES IN FLEXIBLE PAVEMENTS

This may be due to settlement of any one of the components of the pavement.

Causes of Failure in subgrade soil:

- Excessive settlement of the subgrade of soil in the form of excessive undulations or waves or corrugations on the pavement surface.

- Inadequate stability is due to excessive moisture, improper compaction and inherent weakness of the soil
- Excessive stress application causes the deformation of the subgrade to be plastic and unrecoverable resulting in subsidence of the subgrade

Causes of Failure of sub-base or base course:

- Settlement of layers due to internal readjustment of aggregates and movement of wheel loads which results in loosening of compacted layer.
- Lack of stability due to inadequate thickness or poor mix of base or sub-base course.
- Loss of base course materials

Causes of Failure of wearing course:

- Inferior or improper mix design
- Inadequate binder cement and Inferior quality of binder

TYPES OF FLEXIBLE PAVEMENT FAILURES

Alligator cracking or Map cracking (Fatigue)

This is a common type of failure of flexible pavements. This is also known as fatigue failure. Followings are the primary causes of this type of failure.

- Relative movement of pavement layer material
- Repeated application of heavy wheel loads
- Swelling or shrinkage of subgrade or other layers due to moisture variation

Shear failure cracking

Shear failure causes upheaval of pavement material by forming a fracture or cracking.

Followings are the primary causes of shear failure cracking.

- Excessive wheel loading
- Low shearing resistance of pavement mixture

Longitudinal cracking

This types of cracks extents to the full thickness of pavement. The following are the primary causes of longitudinal cracking.

- Differential volume changes in subgrade soil
- Settlement of fill materials
- Sliding of side slopes

Frost heaving

Frost heaving causes upheaval of localized portion of a pavement. The extent of frost heaving depends upon the ground water table and climatic condition.

Lack of binding to the lower course

When there is lack of binding between surface course and underlying layer, some portion of surface course looses up materials creating patches and potholes. Slippage cracking is one form of this type of failure.

Lack of prime coat or tack coat in between two layers is the primary reason behind this type of failure.

Reflection cracking

This type of failure occurs, when bituminous surface course is laid over the existing cement concrete pavement with some cracks. This crack is reflected in the same pattern on bituminous surface.

Formation of waves and corrugation

Transverse undulations appear at regular intervals due to the unstable surface course caused by stop- and-go traffic.

Bleeding

Excess bituminous binder occurring on the pavement surface causes bleeding. Bleeding causes a shiny, glass-like, reflective surface that may be tacky to the touch. Usually found in the wheel paths.

Pumping

Seeping or ejection of water and fines from beneath the pavement through cracks is called pumping.

CAUSES OF FAILURES OF RIGID PAVEMENTS

1. Deficiencies in Pavement materials
2. Structural Inadequacy
3. Improper Construction and Maintenance

Deficiencies in Pavement materials

Causes are;

- Soft aggregates
- Dirty aggregates with silt and clay
- Low quality joint filler
- Poor sealer material
- Poor quality steel
- Improper use of cement for the specific region

Structural Inadequacy

Causes are;

- Poor subgrade soil and improper assessment of its strength
- Improper mix design approach
- Inadequate pavement thickness
- Incorrect spacing of joints
- Incorrect design of load transfer devices
- Absence of longitudinal hinge joints
- Long length of slab
- Non-existence of temperature steel
- Deep foundation movements

Improper Construction and Maintenance

Causes:

- Poor workmanship in pavement and joint construction
- Poor surface finish
- Improper and insufficient curing
- Use of concrete mixes which are wet

TYPICAL RIGID PAVEMENT FAILURES

1. Scaling of Cement Concrete
2. Shrinkage Cracks
3. Warping Cracks
4. Spalling of Joints

Scaling of cement concrete

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. This may be due to the following reasons

1. Improper mix design
2. Excessive vibration during compaction of concrete
3. Performing finishing operation while bleed water is on surface

Shrinkage cracks

Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks. Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.

Joint spalling

Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- Faulty alignment of incompressible material below concrete slab
- Insufficient strength of concrete slab near joints
- Freeze-thaw cycle
- Excessive stress at joint due to wheel load

Warping cracks

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause formation of warping cracks of the concrete slab near the joint edge. This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.

Pumping

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping.

The common reasons for this defect are

- Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.
- When there is void space between slab and the underlying base of sub-grade layer
- Poor joint sealer allowing infiltration of water
- Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support. When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks.

This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.

PAVEMENT EVALUATION

It is the study of various factors pertaining to pavement, such as subgrade support, pavement composition and its thickness, traffic loading and environmental condition.

The main aim:

- To assess as to whether and to what extent the pavement fulfills the design requirements.
- To investigate the structural inadequacy of pavements and also the requirements for providing safe and comfortable traffic operations.

Methods of Evaluation of Pavements:

1. Structural Evaluation
2. Evaluation of Pavement Surface Condition

STRUCTURAL EVALUATION

- Plate bearing test can be conducted for both flexible and rigid pavements to assess the structural capacity.
- The assessment may be made by
  - The load carried at a specified deflection at a place or
  - The amount of deflection at a specified load on the plate
- The performance of a flexible pavement is closely related to the elastic deformation under loads or its rebound deformation.

EVALUATION OF PAVEMENT SURFACE CONDITION

- Surface conditions of flexible pavements may be determined by their unevenness, patches, ruts and cracks. These surface conditions affect the riding quality of the pavements.
- Unevenness of the pavements may be measured using unevenness indicator, profilograph, profilometer or roughometer.

Unevenness Index:

It is the index by adding the unevenness of the surface on a cumulative scale represented as cm/km length of road.

UNEVENNESS INDEX, cm/km	RIDING QUALITY
In old pavements Below 95 95 to 119 120 to 144 145 to 240	Excellent Good Fair Poor
Above 240	Very poor (Resurfacing required)
In new pavements	
Below 120	Good
120 to 145	Fair
Above 145	Poor

STRENGTHENING OF EXISTING PAVEMENTS

- ✓ A highway is expected to have adequate stability to withstand the design traffic under prevailing climate and subgrade conditions.
- ✓ Only solution to manage the increased traffic is either to direct the traffic on some adjacent roads or to strengthen the existing pavements.
- ✓ Strengthening may be done by providing additional thickness of pavement provided the subgrade is strong enough.

Overlay:

Construction of one or more layers over the existing pavement

Types of overlay:

1. Flexible overlays are bituminous surfaces constructed over existing flexible pavements or existing concrete pavements.
2. Rigid overlays consist of plain, simply reinforced or continuously reinforced concrete pavements.

Combination of Overlays:

Existing pavement	Overlay
Cement concrete	Cement concrete
Cement concrete	bituminous
Bituminous or flexible	Cement concrete
Bituminous or flexible	Bituminous or flexible

The choice of overlay depends on various factors,

- ✓ Total thickness of overlay required
- ✓ Wheel load
- ✓ Subgrade strength, etc.

BENKELMANN BEAM DEFLECTION METHOD FOR STRUCTURAL EVALUATION OF PAVEMENT

Benkelman Beam is a device used to measure the rebound deflection of a pavement.

Principle:

A well designed and constructed flexible pavement which has been well conditioned also deforms elastically under the design wheel load i.e. there is an elastic recovery or rebound of the deformed pavement surface. This is the basic principle of deflection method of pavement which is used to design the overlay thickness.

Equipment:

Benkelman beam consists of a slender beam 3.66 m long pivoted at a distance of 2.44 m from the tip. The tip is a probe end. The datum frame rests on a pair of front leveling legs and a rear leg with adjustable height.

By suitably placing the probe between the dual wheels of loaded trucks, it is possible to measure the rebound and the residual deflection of the pavement structure. Rebound deflection is used for overlay design and the residual deflection may be used attributed to non-recoverable deflection of the pavement.

Procedure

- The road to be evaluated is first surveyed to assess the general conditions of the
- pavement. The pavement stretches of length not less than 500 m are classified and grouped on to different classes of length, viz., good, fair and poor for the purpose of studies.
- Loading points for deflection measurements are located along the wheel paths.
- A minimum of 10 deflection observation points may be selected and its may be staggered if necessary.
- The truck is stopped in such a way that the left side rear dual wheel is centrally placed over the first point for deflection measurement.
- The probe end of the benkelmann beam is inserted between the gap and positioned exactly over the deflection observation point.
- The initial dial gauge reading, D_o is noted.

- The truck is moved forward through a distance of 207 m from the point and stopped.
- The intermediate dial gauge reading D_i is noted.
- The truck is then moved further forward 9.0 m. The final dial reading, D_f is recorded.
- These three deflection dial readings, D_o, D_i and D_f form one set of readings at one deflection point.
- Temperature at intervals of one hour is taken on the pavement surface.

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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF CIVIL ENGINEERING

UNIT – V - HIGHWAY MAINTENANCE – SCI1610

UNIT – 5 - HIGHWAY MAINTENANCE

Strengthening of Shoulders and Drainage System in flexible and rigid pavements - Maintenance of Bridges and Road Structures - Pavement Management System

HIGHWAY DRAINAGE

Highway drainage may be defined as the process of interception and removal of water from over, under and the vicinity of the road surface. Road drainage is very important for safe and efficient design of the road way.

Function of Highway Drainage:

- Remove water from the road surface
- Prevent ingress of water into the pavement
- Pass water across the road, either under or over
- Prevent scour and/ or washout of the pavement, shoulder, batter slopes, water courses and drainage structures

EFFECTS OF IMPROPER DRAINAGE

One of the major causes of road failure is its improper drainage. Improper drainage of the road causes destruction in the following ways:

- ✓ Road surface if made of soil, gravel or water bound macadam, it will becomes soft and losses strength.
- ✓ The road sub-grade may be softened and its bearing capacity reduced.
- ✓ Variation in moisture content in expensive soils, causes variation in the volume of sub-grade and thus causes failure of roads.
- ✓ Failure of formation slopes is also attributed to poor drainage.
- ✓ If rain water is not properly drained and allowed to flow along the road

side for long distances, slip and landslides may occur causing road failures.

- ✓ Erosion of side slopes, side drains, formation of gullies may result if proper drainage conditions are not maintained.
- ✓ Flexible pavement's failure by formation of waves and corrugations is due to poor drainage.
- ✓ Continuous contact of water, with bituminous pavements causes failures due to stripping of bitumen from aggregates like loosening or detachment of some of the bituminous pavement layers and formation of pot holes.
- ✓ Rigid pavement's prime cause of failure in by mud pumping which occurs due to water in fine sub-grade soil.
- ✓ Excess moisture causes increase in weight and thus increase in stress and simultaneous reduction in strength of the soil mass. This main reason of failure of earth slopes and embankment foundation.
- ✓ Erosion of soil from the top of un-surfaced roads and embankment slopes in also due to surface water

TYPES OF DRAINAGE SYSTEM

- ❖ A part of rainwater falling on road surface and adjoining area is lost by evaporation and percolation. The remaining water known as surface water, either remains on the surface of the road and adjoining area, or flows away from it, depending upon the topography and general slope of the area. Removal and diversion of this surface water from highway and adjoining land is known as **surface drainage.**
- ❖ Due to percolation, if water table does not rise near of the road sub-grade, it does not create any problem as it does not affect the road sub-grade. If water table rises to the vicinity of road sub-grade, it requires to be lowered as it will definitely affect road sub-grade. Measures adopted to lower the subsoil water table are called **sub surface drainage.**

SURFACE DRAINAGE SYSTEM

Kerb and Gullies

- Road gullies generally discharge to longitudinal carrier pipes
- They are safety hazard for high speed vehicles and are generally not suitable on trunk roads
- One advantage of kerb and gullies is that its ability to carry road surface runoff to outfall is not dependent upon the longitudinal gradient of the roads itself

Surface Water Channel

- Normally of triangular or trapezoidal concrete section, usually slip-formed, set at the edge of hard strip or hard shoulder and flush with the road surface.
- They may not be appropriate for roads with long stretches of zero longitudinal gradients.
- Can be constructed quickly
- Comparatively less maintenance
- Potentially less hazardous
- Give Less chance of surface water entering the road foundation and causing premature failure

SUB-SURFACE DRAINAGE SYSTEM

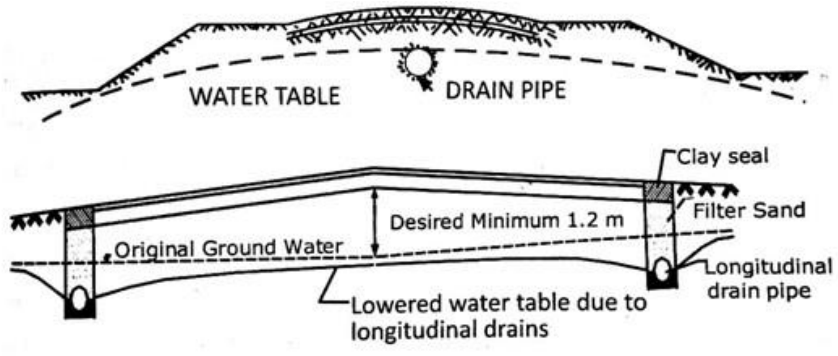
Subgrade may be damaged by sub soil water. Sub soil water as free water, when water table is high or it may come up by capillary action to the subgrade when water table is low. Subgrade should be of self draining material so that it may pass off the percolation water that comes to it to remain dry and stable. But if subgrade is of soft and retentive soil, or there are underground springs bringing free water to the subgrade for that reason subsurface drains should be constructed about 1 ½' to 2' below the formation level to carry away water from the subgrade and thus keep it dry.

Cross-drains may be in the form of trapezoidal trenches filled with selected rubble called rubbled drains or trench drains. Depth is not much and the discharge is small. The pipes are surrounded by filler material and the remaining of the cross trench is filled with graded rubble, the bigger size rubble being nearer to the pipe.

Water of wet subgrade passes through the open joint of pipes and enter the lateral drain which discharge into the longitudinal drain pipe in the two longitudinal side trenches. Longitudinal drain carry water to the nearby stream. Cross-drains, staggered in herring bone fashion. Spacing of lateral drains is less in impermeable soil and more in permeable soil.

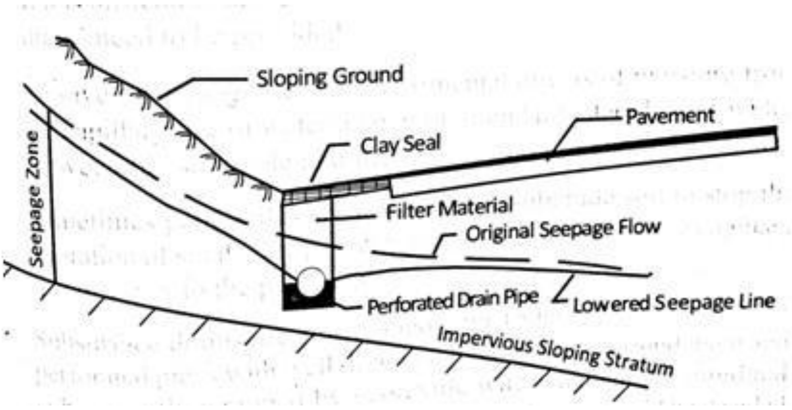
DRAINAGE OF SUB-SURFACE WATER

1. **Lowering of Water Table**



The highest level of water table should be fairly below the level of sub grade, in order that the sub grade and pavements layers are not subjected to excessive moisture. From practical considerations it is suggested that the water table should be kept at least 1.0 to 1.2 meter below the sub grade. In place where water table is high (almost at ground level at times) the best remedy is to take the road formation on embankment of height not less than 1.0 to 1.2 meter. When the formation is to be at or below the general ground level, it would be necessary to lower the water table. If the soil is relatively permeable, it may be possible to lower the high water table merely construction of longitudinal drainage trenches with drain pipe and filter sand. If the soil is relatively less permeable, the lowering of ground water level may not be adequate at the center of the pavement or in between the two longitudinal drainage trenches. Hence in addition, transverse drainage may have to provide in order to effectively drain off the water and thus lower the water table up to the level of transverse drains.

Control of Seepage Flow



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

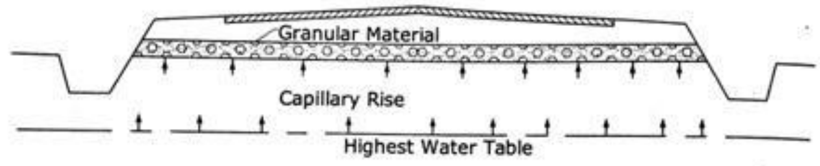
Control of Capillary Rise

If the water reaches the sub grade due to capillary rise is likely to be detrimental, it is possible to solve the problem by arresting the capillary rise instead of lowering the water table.

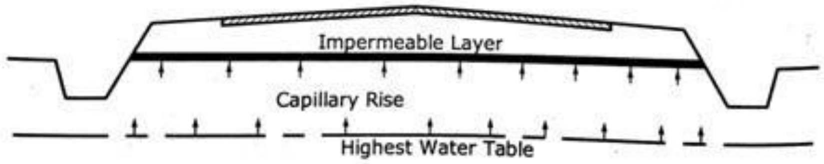
The capillary rise may be checked either by capillary cut-off of any one of the following two types:-

a) A layer of granular material of suitable thickness is provided during the construction of embankment, between the sub grade and the highest level of sub surface water table. The thickness of the granular capillary cut-off layer should be sufficiently higher than the anticipated capillary rise with in the granular layer so that the capillary water cannot rise above the cutoff layer.

b) Another method of providing capillary cut-off is by inserting an impermeable or Bituminous layer in the place of granular blanket.



Granular Capillary Cut-Off

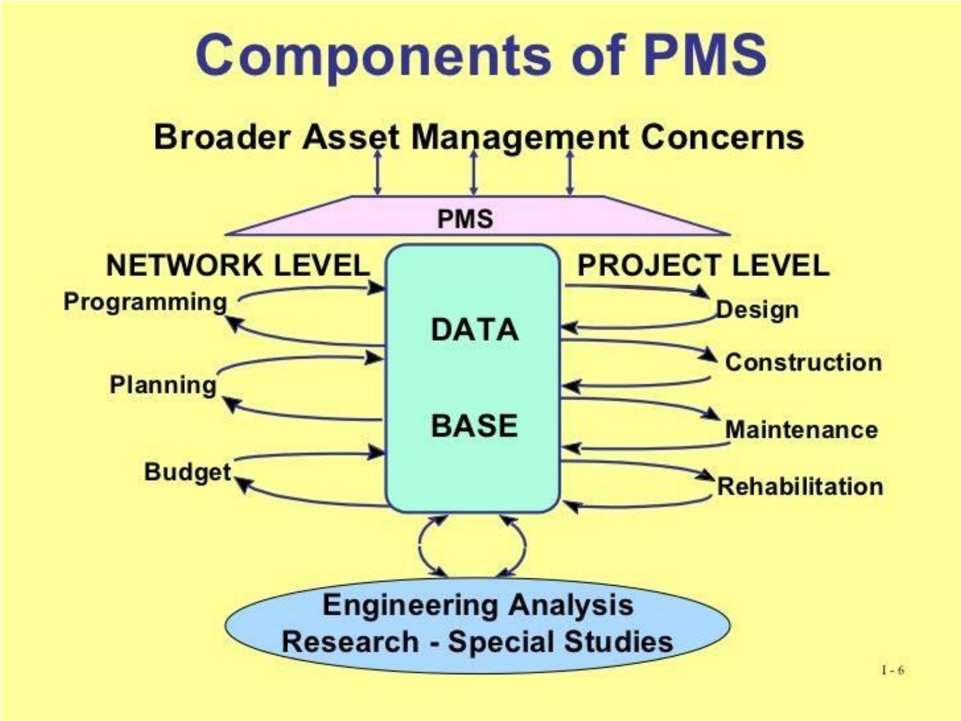


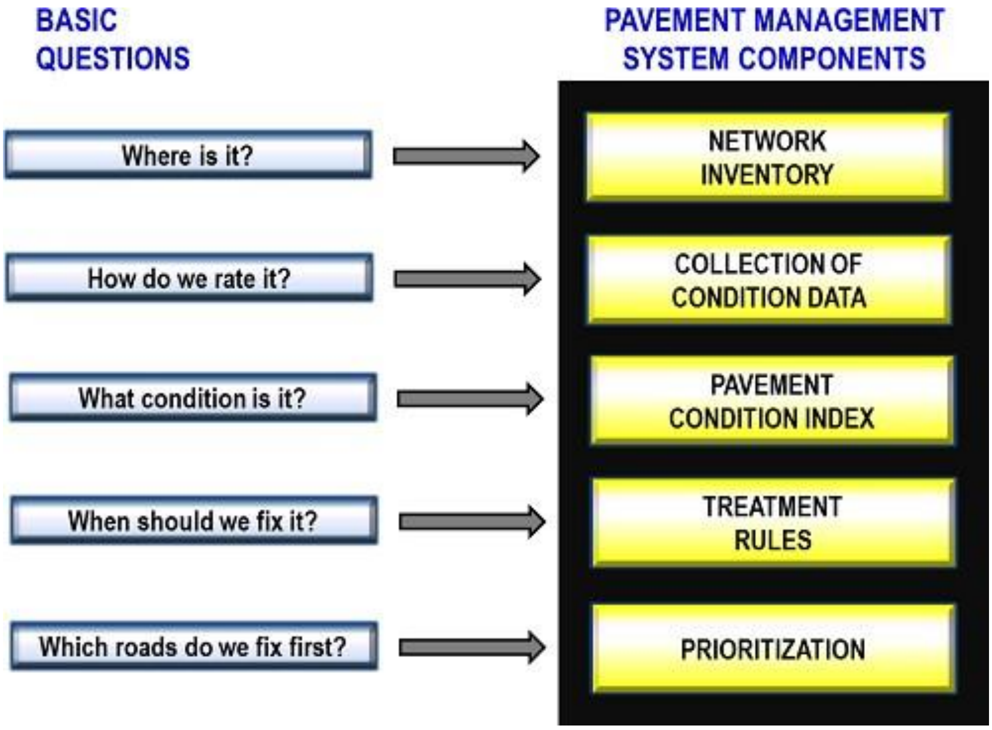
Impermeable Capillary Cut-Off

PAVEMENT MANAGEMENT SYSTEM

Pavement management is the process of planning the maintenance and repair of a network of roadways or other paved facilities in order to optimize pavement conditions over the entire network.

A pavement management system (PMS) is a planning tool used to aid pavement management decisions. PMS software programs model future pavement deterioration due to traffic and weather, and recommend maintenance and repairs to the road's pavement based on the type and age of the pavement and various measures of existing pavement quality. Measurements can be made by persons on the ground, visually from a moving vehicle, or using automated sensors mounted to a vehicle. PMS software often helps the user create composite pavement quality rankings based on pavement quality measures on roads or road sections. Recommendations are usually biased towards predictive maintenance, rather than allowing a road to deteriorate until it needs more extensive reconstruction.


Components of PMS
Broader Asset Management Concerns
PMS
NETWORK LEVEL
PROJECT LEVEL
Programming
Planning
Budget
DATA
BASE
Design
Construction
Maintenance
Rehabilitation
Engineering Analysis
Research - Special Studies
I - 6


BASIC QUESTIONS
PAVEMENT MANAGEMENT SYSTEM COMPONENTS
Where is it?
NETWORK INVENTORY
How do we rate it?
COLLECTION OF CONDITION DATA
What condition is it?
PAVEMENT CONDITION INDEX
When should we fix it?
TREATMENT RULES
Which roads do we fix first?
PRIORITIZATION

Typical tasks performed by pavement management systems include:

1. Inventory pavement conditions, identifying good, fair and poor pavements.
2. Assign importance ratings for road segments, based on traffic volumes, road functional class, and community demand.
3. Schedule maintenance of good roads to keep them in good condition
4. Schedule repairs of poor and fair pavements as remaining available funding allows.