CMR
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Solutions

Sub: Pavement Design **Code:** 10CV833

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1. Briefly explain the various design factors affecting the design of a pavement.
   There are many factors that affect pavement design which can be classified into four categories as traffic and loading, structural models, material characterization, environment.

   Traffic and loading

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

   Contact pressure:

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

   Wheel load:

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

   Axle configuration:

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

   Moving loads:

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

   Repetition of Loads:

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

   Structural models

   The structural models are various analysis approaches to determine the pavement responses (stresses, strains, and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are layered elastic model and visco-elastic models.

   Layered elastic model:

A layered elastic model can compute stresses, strains, and deflections at any point in a pavement structure 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, the material properties are same at every point in a given layer and the layer will rebound to its original form once the load is removed. The layered elastic approach works with relatively simple mathematical models that relates stress, strain, and deformation with wheel loading and material properties like modulus of elasticity and poissons ratio.

Material characterization

The following material properties are important for both flexible and rigid pavements.

- When pavements are considered as linear elastic, the elastic moduli and poisson ratio of subgrade and each component layer must be specified.
- If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided.

However, many of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which require the modulus of elasticity and poisson ratio only.

Environmental factors

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

Temperature

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

Precipitation

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

2. (a) Bring out the differences between Highway and Airfield pavement.

S. No.	**Highway pavement**	**Airfield pavement**
1.	Width of pavement depends upon no. Of lanes and no of lanes depend upon the traffic intensity. Width of 2 lane highway is 7.0m	Width of pavement depend upon the class of airport, type of area in operations and standard clearance values width of pavement ranges from 13 to 60m.
2.	Weight of truck is less than that of an aero plane. Around 20 tonnes for dual tandem wheels.	Gross weight of aero plane ranges between 80 to 250 tonnes.
3.	Design wheel load is about 5.1 tonnes.	Design wheel load is around 50 tonnes.
4.	Tyre proof pressure is about 4 to 7 kg/cm^2.	Tyre proof pressure is about 25 to 30 kg/cm^2.

5.	Normally highway pavement is not subjected to impact effect.	Airport pavements are subjected to different types of impacts during landing and take –off.
6.	Traffic loading on highway pavement is concentrated at edges of pavements.	Traffic load is concentrated at the centre of the pavement.
7.	Distress is developed at the edges.	More distress is developed at the centre of pavement.
8.	No of repetitions of wheel loads are more.	No of repetitions of wheel loads are less.

(b) Mention the various measures adopted to reduce the effects of frost action..

Mitigating of frost action and its detrimental effects generally involves structural design considerations as well as other techniques applied to the base and subgrade to limit the effects of frost action. The basic methods used can be broadly categorized into the following techniques:

- **Limit the depth of frost into the subgrade soils**. This is typically accomplished by specifying the depth of pavement to be some minimum percentage of the frost depth. By extending the pavement section well into the frost depth, the depth of frost-susceptible subgrade under the pavement (between the bottom of the pavement structure and frost depth) is reduced. The assumption is that a reduced depth of soil under frost action will cause correspondingly less damage.
- **Removing and replacing frost-susceptible subgrade.** Ideally the subgrade will be removed at least down to the typical frost depth. Removing frost-susceptible soils removes frost action.
- **Design the pavement structure based on reduced subgrade support**. This method simply increases the pavement thickness to account for the damage and loss of support caused by frost action.
- **Providing a capillary break**. By breaking the capillary flow path, frost action will be less severe because, frost heaving requires substantially more water than is naturally available in the soil pores.

3. **Explain the process of Frost Action and how it affects the pavements.**

Frost Action

Frost action can be detrimental to pavements and refers to two separate but related processes:

1. Frost heave. An upward movement of the subgrade resulting from the expansion of accumulated soil moisture as it freezes.
2. Thaw weakening. A weakened subgrade condition resulting from soil saturation as ice within the soil melts.

Frost Heave

Frost heaving of soil is caused by crystallization of ice within the larger soil voids and usually a subsequent extension to form continuous ice lenses, layers, veins, or other ice masses. An ice lens grows through capillary rise and thickens in the direction of heat transfer until the water supply is depleted or until freezing conditions at the freezing interface no longer support further crystallization. As the ice lens grows, the overlying soil and pavement will “heave” up potentially resulting in a cracked, rough pavement (see Figure 1). This problem occurs primarily in soils containing fine particles (often termed “frost susceptible” soils), while clean sands and gravels (small amounts of fine particles) are non-frost susceptible (NFS). Thus, the degree of frost susceptibility is mainly a function of the percentage of fine particles within the soil.

The three elements necessary for ice lenses and thus frost heave are:

1. Frost susceptible soil (significant amount of fines).
2. Subfreezing temperatures (freezing temperatures must penetrate the soil and, in general, the thickness of an ice lens will be thicker with *slower* rates of freezing).
3. Water (must be available from the groundwater table, infiltration, an aquifer, or held within the voids of fine-grained soil).

By removing any of the three conditions above, frost effects will be eliminated or at least minimized. If the three conditions occur uniformly, heaving will be uniform; otherwise, differential heaving will occur resulting in pavement cracking and roughness.

Differential heave is more likely to occur at locations such as:

- Where subgrades change from clean not frost susceptible (NFS) sands to silty frost susceptible materials.
- Abrupt transitions from cut to fill with groundwater close to the surface.
- Where excavation exposes water-bearing strata.
- Drains, culverts, etc., frequently result in abrupt differential heaving due to different backfill material or compaction and the fact that open buried pipes change the thermal conditions (i.e., remove heat resulting in more frozen soil).

Additional factors which will affect the degree of frost susceptibility (or ability of a soil to heave):

- Rate of heat removal.
- Temperature gradient
- Mobility of water (e.g., permeability of soil)
- Depth of water table
- Soil type and condition (e.g., density, texture, structure, etc.)

Thaw Weakening

Thawing is essentially the melting of ice contained within the subgrade. As the ice melts and turns to liquid it cannot drain out of the soil fast enough and thus the subgrade becomes substantially weaker (less stiff) and tends to lose bearing capacity. Therefore, loading that would not normally damage a given pavement may be quite detrimental during thaw periods (e.g., spring thaw)

Thawing can proceed from the top downward, or from the bottom upward, or both. How this occurs depends mainly on the pavement surface temperature. During a sudden spring thaw, melting will proceed almost entirely from the surface downward. This type of thawing leads to extremely poor drainage conditions. The frozen soil beneath the thawed layer can trap the water released by the melting ice lenses so that lateral and surface drainage are the only paths the water can take.

Sources of Water

The two basic forms of frost action (frost heave and thawing) both require water. Water sources can be separated into two broad categories:

1. **Surface water**. Enters the pavement primarily by infiltration through surface cracks and joints, and through adjacent unpaved surfaces, during periods of rain and melting snow and ice. Many crack-free pavements are not entirely impermeable to moisture.
2. **Subsurface water**. Can come from three primary sources:
    - Groundwater table (or perched water table).
    - Moisture held in soil voids or drawn upward from a water table by capillary forces.

- Moisture that moves laterally beneath a pavement from an external source (e.g., pervious water bearing strata, etc.).

4. **(a) Give a comparison between flexible and rigid pavement.**

S. No	**Flexible pavement**	**Rigid pavement**
1.	Stress transformation to the lower layers take place by grain to grain contact through the contact surfaces of the granular structure.	Stress transformation takes place by the bending action of the slab.
2.	Max critical stress is the maximum compressive stress due to the wheel load and no of repetitions.	Critical stress is the maximum flexural stress due to wheel load and temperature effect. Also tensile stresses are developed.
3.	Pavement possess negligible flexural strength.	Possess maximum rigidity and high young's modulus.
4.	Design depends on the wheel load and also on the no. of repetitions of wheel load.	Design depends on wheel load and flexural strength of concrete.
5.	Life of pavement is 5-15 years.	Life ranges from 30-60 years.
6.	Always call for maintenance works.	No maintenance required except at joints.
7.	Not economical in the long run.	Economical in the long run.
8.	Initial cost is low.	Initial cost is high.
9.	Joint not required.	Joints essentially required.
10.	Moderate skill and less supervision is required.	High skill and more supervision is needed.
11.	Repair work is easy.	Repair work is difficult.
12.	It is easy to lay, locate or repair underground pipes below the pavement.	It is difficult to lay, locate or repair underground pipes below the pavement.
13.	Can be opened soon after construction.	Minimum one month for curing after construction which delay the opening of traffic.
14.	Less durable	More durable
15.	Stresses are not developed due to temperature changes.	Stresses are developed due to temperature changes.
16.	More resistant to traffic loads	Less resistant to traffic loads
17.	They develop more corrugations	They do not develop corrugations
18.	Suitable for all types of traffic.	They become noisy under heavy wheeled traffic.
19.	They adjust according to any deformations of sub grade without rupture.	They do not adjust according to any deformations of sub grade without rupture
20.	They offer more tractive resistance.	They offer less tractive resistance.
21.	Provide poor visibility at night	They possess good visibility at night.
22.	They do not cause glassy effect due to reflected sunlight.	They offer glassy effect under reflected sunlight.
23.	Stage development is feasible.	Stage development is not feasible
24.	Maintenance cost is high.	Maintenance cost is less.

25.	Thickness is more.	Thickness is less.

(b) Briefly explain the desirable characteristics of 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.

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

(b) Write short notes on types of rigid pavements.

Types of Rigid Pavements
Rigid pavements can be classified into four types:
• Jointed plain concrete pavement (JPCP),
• Jointed reinforced concrete pavement (JRCP),
• Continuous reinforced concrete pavement (CRCP), and
• Pre-stressed concrete pavement (PCP).

Jointed Plain Concrete Pavement: 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.

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.

Continuous Reinforced Concrete Pavement: Complete elimination of joints are achieved by reinforcement.

6. **Draw a neat sketch of flexible pavement section and show the component parts. Briefly explain each component.**

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade as shown in the Figure.

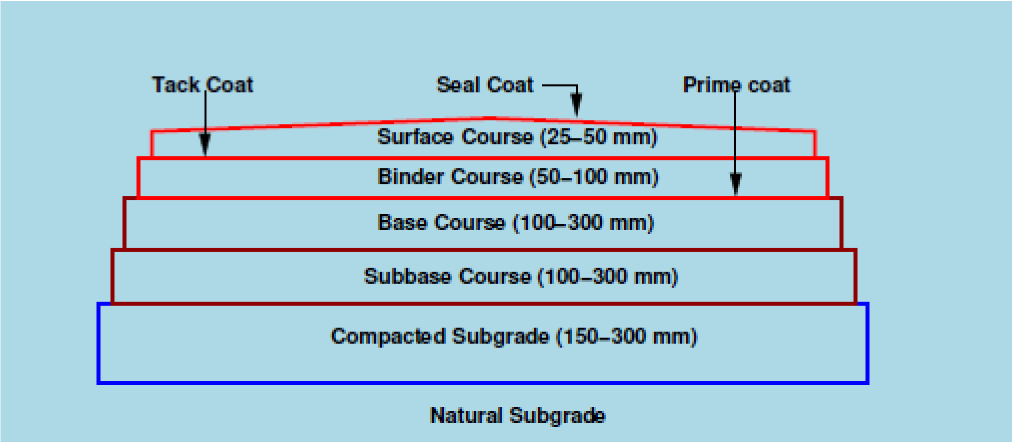

Figure: Typical cross section of a flexible pavement

Seal Coat: Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.
Tack Coat: Tack coat is a very light application of asphalt, usually asphalt emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.
Prime Coat: Prime coat 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

Surface course 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. 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.

Binder course

This layer provides the bulk of the asphalt concrete structure. It's 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

The base course 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

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 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 sub-base course is not always needed or used. 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.