1. Differentiate between Prime coat, Seal coat and Tack coat with sketch of the other layers in a typical 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.

2. What are the effects of temperature on rigid pavement?

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.

3. What are the 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)

4. Differentiate tack coat and prime coat.

- **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.
5. Explain rigid pavement?
[M/J-13]
Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area below. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Since there is only one layer of material between the concrete and the sub-grade, this layer can be called as base or sub-base course.

6. What is ESWL?
[M/J-13]
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.

7. What are the factors in pavement design? [M/J-16, M/J-12]
- Wheel load.
- Axle configuration.
- Contact pressure.
- Vehicle speed.
- Repetition of loads.
- Subgrade type.
- Temperature.
- Precipitation.

8. Define Critical load positions. [M/J-16, N/D-14]
Since the pavement slab has finite length and width, either the character or the intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface. There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

9. What are the requirements of an ideal pavement? [N/D-16, N/D-14]
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.

10. Define Equivalent radius of resisting section.

[N/D -16]
When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard’s gives a relation for equivalent radius of the resisting section in cm in the equation

$$b = \begin{cases} \sqrt{1.6a^2 + h^2} - 0.675h & \text{if} \ a < 1.724h \\ a & \text{otherwise} \end{cases}$$

where $a$ is the radius of the wheel load distribution in cm and $h$ is the slab thickness in cm.
1. (i) A two-lane carriage way carries a traffic 150 cv/ day. Rate of traffic growth is 5% pa. Pavement design life is 15 years. VDF = 2.5. Soil CBR is 6%. Calculate cumulative number of standard axles to be catered for, in the pavement design.

(ii) For the above data, determine the total pavement thickness based on the IRC method and the thickness of the different layers forming the total composition.

(iii) What is PMB? How it improves the quality of pavement?

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(i) 1. Two lane carriage way
2. Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)
3. Traffic growth rate = 7.5 %
4. Design life = 15 years
5. Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial

(ii) Distribution factor = 0.75
Total pavement thickness for CBR 6% and traffic 4.4 msa from IRC:37 2001 chart1 = 580 mm
Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
(a) Bituminous surfacing = 20 mm PC + 50 mm BM
(b) Road-base = 250 mm Granular base
(c) sub-base = 280 mm granular material.

(iii) 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.
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
2. (i) List the various factors influencing the design of rigid pavements and describe the design procedure as per IRC 58.

(ii) Design the reinforcement of a cement concrete slab 200 mm thick, assuming the following:

1) Concrete density 2400 kg/ m$^3$
2) Transverse joint spacing 15 m
3) Working stress in steel 140 MPa
4) Friction coefficient 1.5
5) Pavement width 3.75 m

[N/D-15]

(i) 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 in filtrating into the subgrade and the depth of ground water table. Poor drainage may bring lack of shear strength, pumping, loss of support, etc.

Traffic and Loading

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design.

Fixed traffic: Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design.

Fixed vehicle: In the fixed vehicle procedure, the thickness is governed by the number of repetitions of a standard axle load. If the axle load is not a standard one, then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor.
**Variable traffic and vehicle:** In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided into a number of groups and the stresses, strains, and deflections under each load group can be determined separately; and used for design purposes. The traffic and loading factors to be considered include axle loads, load repetitions, and tyre contact area.

**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 affects the stress distribution and deflection within a pavement. 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.
Higher wheel load \( \rightarrow \) TK Pavement.

Various wheel load factors are:

1. Maximum wheel load.
2. Contact Pressure
3. Dial or multiple wheel loads \& ESWL.
4. Repetition of load.

Maximum Wheel Load

\[ \text{Single Axle} \]

For highways, the maximum legal axle load as specified by Indian Road Congress is 2175 kg with a max. equivalent single wheel load of 4088 kg.

Total load influences TK of Pavement.

Tyre pressure influences quality of surface (wearing) course.

The equation for VTH stress computations under a UDL circular load based on Boussinesq's theory is given by

\[
\sigma_z = P \left[ 1 - \frac{x^2}{(a^2 + z^2)^{3/2}} \right]
\]

where,

\( \sigma_z \) = VTH stress at depth \( z \)
\( P \) = Surface Pressure
\( x \) = Depth @ which \( \sigma_z \) is computed
\( a \) = Radius of loaded area.
This value is higher than unity for lower tyre pressure.

is less than unity for tyre pressure higher than 7 kg/\text{m}^2.

R.F. depends on the degree of tension developed in the walls of tyres.

Equivalent Single Wheel Load

To maintain the maximum wheel load within the specified limit and to carry greater load it is necessary to provide dual wheel assembly to the rear axles of the road vehicles.

In doing so the effect on the pavement through a dual wheel assembly is obviously not equal to \( 2 \times \) times the load on any one wheel. In other words, "The pressure at a certain depth, below the pavement surface cannot be obtained numerically adding the pressure caused by one wheel. The effect is in \( b/m\) the single load \( 2 \times \) times load carried by any one wheel.

In order to simplify the analysis, the load dispersion is assumed to be at an angle of \( 45^\circ\).

Let, \( a \) be clear gap \( b/w \) the two loads,
\( s \) be spacing \( b/w \) centres of wheels
\( a \) be radius of circular contact area of each wheel.

Then, \( S = d + 2a \).
3. Design the pavement for construction of a new bypass with the following data: Two lane carriage way, Initial traffic in the year of completion of construction = 400 CVPD (sum of both directions), Traffic growth rate = 7.5 %. Design life = 15 years, Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial vehicle and Design CBR of subgrade soil = 4%.

Two lane carriage way
Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)
Traffic growth rate = 7.5 %
Design life = 15 years
Vehicle damage factor based on axle load survey = 2.5 standard axle per commercial
Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
(a) Bituminous surfacing = 25 mm SDBC + 70 mm DBM
(b) Road-base = 250 mm WBM
(c) sub-base = 315 mm granular material of CBR not less than 30 %

4. What are the most important factor in the pavement design?

*Refer answer 2

5. Explain the functions of the components of flexible pavements.

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 subgrade.

**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.

6. Explain the factors governing the structural design of pavements. [M/J – 13, N/D-16]

*Refer answer 2

7. Explain the design procedure for rigid pavements. [N/D-16]

**Design procedure**
**Step** Find the length of the dowel bar embedded in slab by equating Eq.

\[ L_d = 5d \sqrt{\frac{F_f (L_d + 1.5\delta)}{F_b (L_d + 8.8\delta)}} \]

**Step** Find the load transfer capacities \( P_s \), \( P_f \), and \( P_b \) of single dowel bar with the

**Step** Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor \( f \) as

\[ \max \left\{ \frac{0.4P}{P_s}, \frac{0.4P}{P_f}, \frac{0.4P}{P_b} \right\} \]

**Step** Spacing of the dowel bars.

- Effective distance upto which effective load transfer take place is given by \( 1.8 \, l \), where \( l \) is the radius of relative stiffness.

- Assume a linear variation of capacity factor of 1.0 under load to 0 at \( 1.8 \, l \).

- Assume a dowel spacing and find the capacity factor of the above spacing.

- Actual capacity factor should be greater than the required capacity factor.

- If not, do one more iteration with new spacing.