UNIT 5 PAVEMENT DESIGN

PART-A

SHORT QUESTIONS WITH SOLUTIONS

Q1. Draw a sketch of flexible pavement cross section and show the component parts.

Model Paper-I, Q1(i)

Answer :

Flexible Pavement

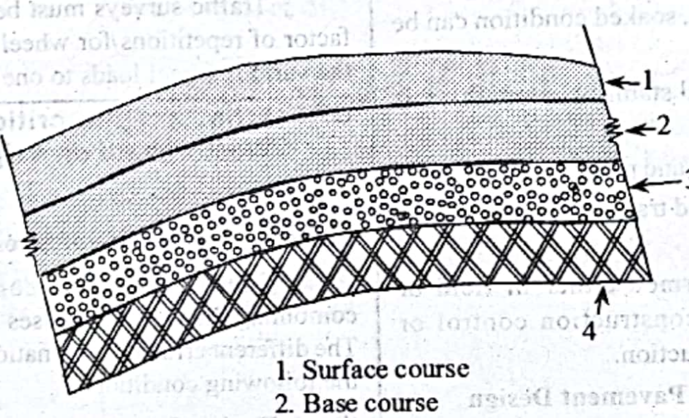


Figure: Components of Flexible Pavements

Q2. Explain how the sub-base thickness varies in the design of flexible pavements?

Model Paper-II, Q1(i)

Answer :

The sub-base course is generally applied in flexible pavement for improving the load supporting capacity, which is carried out by the distribution of load through a finite thickness. The desired thickness of sub-base layer in the flexible pavement usually varies. This variation depends on certain factors, which are as follows,

(a) Materials used

(b) Magnitude and number of repetitions of traffic load

(c) Environmental conditions

(d) Expected service life of the pavement.

These factors are usually considered during the design process to ensure that the pavement would last for the expected designed life without excessive distresses. The requirements and the specified distribution of grain size of the sub-base material are to be applied effectively in order to satisfy the stability and drainage requirements of the granular sub-base layer. Therefore, from the drainage considerations, the granular sub-base is to be extended above the complete formation width, which generally leads to the variation in the sub-base thickness.

Generally, when the design traffic is less than 10 msa, the thickness of sub-base should be equal to 150 mm.

When the design traffic is equal to 10 msa, then the sub-base thickness should be equal to 200 mm.

Q3. How the CBR method of pavement design is useful to determine the thickness of component of layers.

Answer :

Thickness Determination of the Component of Layers

For designing a pavement by CBR method, the value of soaked CBR of the soil subgrade is estimated initially. Then by considering a suitable design load, appropriate design curve is selected. In certain cases, anticipated traffic is also considered. Thus, from the curve, the total thickness of flexible pavement required to cover the subgrade of the specified value of CBR is estimated. The sub-base course thickness is equal to the total thickness minus the thickness over the sub-base.

Q4. Discuss the advantages and disadvantages of CBR method of pavement design.

Answer : Model Paper-III, Q1(i)

Advantages of CBR Method of Pavement Design

1. Large number of pavement design and analysis procedures are based on CBR values.
2. With the help of this method, soaked condition can be estimated easily.
3. As it is a measure of material stability (strength), this method is widely accepted.
4. Soil can be tested with simple and portable equipments.
5. It requires less experience and training (highly skilled labors are not required).
6. This method can be performed either in field or in laboratory for design, construction control or estimation of existing construction.

Disadvantages of CBR Method of Pavement Design

1. This method is laborious, slow and expensive when compared to other methods of pavement design.
2. The differentiation of layers is not possible with this method.
3. Maximum aggregate size (passing through 20 mm sieve size) is limited.
4. The value of CBR is not a fundamental soil property.
5. The consideration of completely saturated sub-grade condition results in low factor of safety.

Q5. Explain ESWL and the concept in the determination of the equivalent wheel load.

Answer :

The maximum wheel load within the specified limit is maintained by providing dual wheel assembly to the rear axles of road vehicles. The pressure below the surface of pavement at a particular depth may not be achieved by adding the pressure numerically caused by one wheel load. The effect is in between the single load and the load carried two times by any of the wheel. The assumed load dispersion is at 45° angle. In the dual wheel load assembly, let the spacing between the wheels centers be S, the clear gap between two wheels be d, and the radius of circular contact area of each wheel be a. Then $S = (d + 2a)$.

Each and every wheel load P acts independently up to the depth of $d/2$ and after this point, the overlapping of the stresses induced because of each load begins. At the depth above $2S$, the induced stresses are because of the effect of both wheels as there is considerable area of overlap. So, at any depth, the total stresses because of dual wheels more than $2S$ is known to be equal to a single wheel load of $2P$ magnitude.

The determination of equivalent single wheel load depends on either equivalent stress criterion or equivalent deflection. Multiple wheel loads are converted to ESWL and in the design of pavement, these values are used.

Q6. What is meant by Repetition of loads?

Answer : Model Paper-I, Q1(j)

Repetition of Loads

The pavement deformation due to single application of wheel load may be minimum. But if the load is applied repeatedly then the magnitude of plastic and elastic deformations would be increased.

Traffic surveys must be carried out for accounting the factor of repetitions for wheel loads. It is required to convert the various wheel loads to one single standard wheel load.

Q7. What are the critical load stresses as per Westergaard on a rigid pavement?

Answer : Model Paper-II, Q1(j)

Critical Combination of Stresses

The most critical combinations are obtained by combining the various stresses in current concrete pavements. The different critical combinations are provided by considering the following conditions,

(i) During Summer

When the slab tends to warp downwards at the interior and edge regions during the mid day, then the critical combinations are attained. During expansion, the frictional stresses are compressive. The load stresses at the edge region is higher when compared to the load stresses at the interior region.

∴ Critical combination of stresses = (Load stress + Warping stress + Frictional stress) at the edge region.

(ii) During Winter

In the above regions, the critical combination of stresses occur at the bottom fibre. This is when the slabs contracts and warps downwards during the mid day.

∴ Critical stress combination,

= (Load stress + Warping stress + Frictional stress) at edge region.

(iii) The frictional stresses are absent at the corner regions as the critical combination occurs at the top fibre of the slab and when the slab warps upwards during the mid rights.

∴ Critical stress combination,

= (Load stress + Warping stress) at corner regions.

Q8. What are the factors to be considered for slab thickness in rigid pavements?

Answer :

The various factors to be considered while fixing thickness of the slab are as follows,

1. Wheel load
2. Variation in temperature
3. Allowable flexural stress in concrete
4. Coefficient of sub-grade resistance, friction between slab and sub-grade.
5. Coefficient of sub-grade reaction or the sub-grade support.
6. Distance between joints.

Q9. Discuss the objectives of flexible pavement design.

Answer : Model Paper-III, Q1(j)

The objectives of flexible pavement design are,

(i) To permit heavy vehicles of road traffic with minimum rolling resistance.

(ii) To allow the fast vehicles to move comfortably and safely at the speed specifically designed.

(iii) To maintain an even and stable surface for the vehicles, the structure of pavement is particularly designed and constructed.

(iv) To allow the pavement to act as a carriageway which is constructed on a prepared soil subgrade.

(v) To maintain the elastic deformation within the permissible limits, so that the pavement can bear heavy loads.

(vi) To spread the stress of wheel load through a larger area by a layer of pavement.

(vii) To maintain the subgrade dry even during the period of monsoons, the pavement is constructed above the highest level of ground water.

Q10. Write short notes on contact pressure.

Answer :

In vertical stress distribution the effect of tyre pressure predominates in the upper layers. The effect of tyre pressure at a greater depth diminishes and the total load has an effect on vertical stress magnitudes. Thus the higher magnitude tyre pressure demand good quality of materials in upper layers. Any how the entire depth is not effected by the tyre pressure.

The contact pressure is more than tyre pressure when the tyre pressure is not more than 7 kg/cm2. Contact pressure can be calculated by using the relationship,

$$\text{Contact pressure} = \frac{\text{Load on wheel}}{\text{Contact area}}$$

Q11. Draw the sketch of rigid pavement cross-section and show its component parts.

Answer :

Rigid Pavement

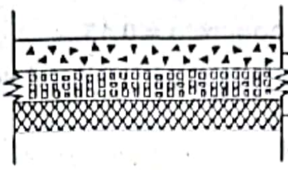


Figure: Components of Rigid Pavement

Cement Concrete Slab

The flexural strength of the cement concrete slab that bridges over soft spots resists the developed stresses. It is generally placed directly over the sub-grade provided that the sub grade possess minimum desirable strength, drainage and on site conditions. In order to satisfy this condition, there exists a provision for sub-base layer. In rigid pavement, slab plays a critical role in resisting the load of vehicles. The material with weak spots or small defects below the slab is controlled by slab.

Q12. Write the formula to determine the cumulative standard axles for design of a flexible pavement, and explain the terms in the formula.

Answer :

The cumulative equivalent standard axle load of 80 kN during the design period at traffic growth rate as,

$$N_{80} = 365 \times \text{TGF} \times A \times \text{VDF} \times \text{LDF}$$

Where,

TGF – Cumulative traffic growth factor based on geometric growth.

$$\text{TGF} - \left(\frac{(l+r)^{nd} - 1}{r}\right)$$

nd – Design period.

LDF – Lane distribution factor = 1.0 for single lane (or) 0.75 for dual lane.

VDF – Vehicle damage factor. (Whose value changes for different types of vehicles).

Q13. Discuss about maximum wheel load.

Answer :

Maximum Wheel Load

The configuration of wheel load is important to know the way in which the application of loads of a given vehicle is carried out on the pavement surface. The maximum legal axle load for highways recommended by Indian road congress is 8170 kg with maximum single wheel load of 4085 kg. Total load effects the requirements of pavement thickness. The quality of surface course is effected by tyre pressure. The magnitude of vertical pressure at any depth of soil subgrade mass is based on the total load and surface pressure.

Q14. Compute the radius of relative stiffness of 15 cm thick cement concrete slab from the following data:

Modulus of elasticity of cement concrete = 2,10,000 kg/cm²

Poisson's ratio for concrete = 0.15

Modulus of sub-grade reaction, K (i) 3.0 kg/cm³ (ii) 7.5 kg/cm³

Answer :

(i) For modulus of sub-grade reaction,

$K = 3$ kg/cm³

Westergaard's equation for radius of relative stiffness is given as,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$E = 2.1 \times 10^5$ kg/cm²

$h = 15$ cm

$\mu = 0.15$

$$l = \left[\frac{2.1\times10^5\times15^3}{12\times3(1-0.15^2)}\right]^{\frac{1}{4}} = 66.99 \text{ cm}$$

$(\therefore l = 66.99$ cm)

(ii) For modulus of sub-grade reaction, $K = 7.5$

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$l = \left[\frac{2.1\times10^5\times15^3}{12\times7.5[1-(0.15^2)]}\right]^{\frac{1}{4}}$$

$\therefore\ l = 53.276$ cm

Q15. Compute the equivalent radius of resisting section of 22 cm slab, given that the radius of contact area wheel load is 16 cm.

Answer :

Given that,

Slab thickness, $h = 22$ cm

Radius of wheel load distribution, $a = 16$ cm

The equivalent radius of resisting section is given as per Westergaard's analysis is,

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

$$b = \sqrt{1.6\times16^2 + 22^2} - 0.675\times22$$

$= 29.89 - 14.85$

$b = 15.04$ cm

$\therefore$ Equivalent radius of resisting section, $b = 15$ cm

Q16. Calculate the spacing of expansion joint from the following data: maximum width of joint = 3 cms, temperature of laying concrete = 19°C, maximum slab temperature expected = 56°C and coefficient of thermal expansion = 10 × 10⁻⁶ per °C.

Answer :

Given that,

Maximum width of joint, $\delta = 3$ cms

Temperature of laying concrete, $T_1 = 19$°C

Expected concrete slab temperature, $T_2 = 56$°C

Coefficient of thermal expansion $= 10 \times 10^{-6}$ per °C

Maximum expansion in slab joints,

$$\delta' = \frac{\delta}{2} = \frac{3}{2} = 1.5 \text{ cm}$$

Spacing of expansion joint is given as,

$$L_e = \frac{\delta'}{100\times C\times(T_2 - T_1)}$$

$$= \frac{1.5}{100\times10\times10^{-6}\times(56-19)} = \frac{1.5}{1\times10^{-3}\times37}$$

$= 40.54$ m

$\therefore$ Spacing of expansion joint, $L_e = 40.54$ m

PART-B

ESSAY QUESTIONS WITH SOLUTIONS

5.1 DESIGN OF PAVEMENTS – DESIGN OF FLEXIBLE PAVEMENT BY CBR METHOD AS PER IRC 37-2012 AND THEORY OF EMPIRICAL MECHANISTIC METHOD

Q17. Enumerate the desirable characteristics of a pavement.

Model Paper-I, Q10(a)

Answer :

Following are the desirable characteristics of a pavement,

(i) The pavement should be free from dust to ensure safety of traffic from pollution.

(ii) The pavement surface should have sufficient roughness and texture to control the vehicles from skidding.

(iii) The pavement should be strong enough to bear the loads applied on it.

(iv) The surface of the pavement should be impermeable to prevent the water from entering the subgrade and lower layers and cause disintegration.

(v) The thickness of the pavement should be sufficient so that the stresses and loads are distributed to a safe value on the subgrade soil.

(vi) The pavement surface should not generate high levels of sound from moving vehicles.

(vii) The surface of the pavement should be hard so as to prevent the damage from abrading action of wheels. (i.e., Pneumatic and iron-tyred).

(viii) The pavement surface should not produce high friction with the tyres of vehicles for low energy consumption of the vehicles.

(ix) The life span of the pavement surface should be more and the maintenance should be low.

(x) The riding quality of pavement should be good and smooth to provide comfort to the vehicle users even at high speed.

Q18. Classify and explain the different types of pavements.

Model Paper-II, Q10(a)

Answer :

From the structural point of view, pavements can be classified as,

(i) Flexible pavement

(ii) Rigid pavement

(iii) Semi-rigid pavement

(iv) Composite pavement.

(i) **Flexible Pavement**

It is a layered system with low flexural strength. In flexible pavement, the external loads are subjected to the subgrade soil by the lateral distribution. The pavement deflects for an instant due to low flexural strength but regains its original level on removing the load. The pavement is designed in such a way that the subgrade soil resist the stresses and prevented from extreme damage. The role of subgrade in flexible pavement is crucial as it carries the loads of vehicles. The smoothness and strength of pavement depends on the subgrade damage and its resistance to damage. The strong pavement with poor and loose subgrade is a fail structure.

(ii) **Rigid Pavement**

It shows the capacity to resist the loads from the beam strength or flexural strength, allowing the slab to bridge over small-scale unevenness in the subgrade base. In rigid pavement slab plays an important role in resisting the load of vehicles. The material with weak spots or small defects below the slab is controlled by slab. A uniform and stable support of subgrade soil is required for a rigid pavement. Rigid pavement highly depends upon the slab strength when compared to subgrade support.

(iii) Semi-rigid Pavement

Semi-rigid pavement shows an intermediate state between flexible pavement and rigid pavement. Even though the flexural strength of semi-rigid pavement is less, the lateral distribution of load is resisted through the depth of pavement. Examples of semi-rigid pavements are : Lime-Pozzalona concrete and soil-cement construction and lean-concrete base.

(iv) Composite Pavement

It consists of several structurally important layers of various composition. It may also contain heterogeneous composition. An example of composite pavement is brick-sandwiched concrete pavement. The top and bottom layers of brick-sandwiched concrete pavement consists of cement concrete and in the middle a layer of brick is available. The design of composite pavements is far away from the design of flexible or rigid pavement.

Q19. What are the functions of the various layers of a flexible pavement?

Answer :

Model Paper-III, Q10(a)

The various components of a pavement are:

(i) Wearing course

(ii) Sub-base

(iii) Base

(iv) Subgrade

(v) Road bed

(vi) Embankment.

(i) Wearing Course

Wearing course is a top most layer and is very thin. It gives a smooth surface for vehicles and resists the abrasion, wheel load impact and the pressure of tyres. Wearing course also provides a water-resistant layer and resists the effect of weather conditions. In flexible pavement, bituminous surface acts as a wearing course and in rigid pavement cement, concrete acts as a wearing course.

(ii) Sub-base

It is a layer made of specified material (such as broken stones, bound or unbound aggregate) of designed thickness. It is placed on top of the subgrade soil to act as a supporting agent to a base course.

A layer of selected granular soil or stabilized soil may also be used in sub-base course. It is recommended to use soil aggregate mixes or small size graded aggregates.

(iii) Base

It is a layer made up of specified material of designed thickness. It is placed on top of the sub-base course or subgrade soil for supporting a surface course. The purpose of designing the base course is to distribute the wheel loads on the road-bed.

(iv) Subgrade

The top surface of a road-bed on which shoulders with kerbs and the pavement structure are constructed is known as subgrade.

This layer is prepared with natural soil on which the layers of pavement materials are placed. The loads are supplied to the subgrade level by which it is overstressed. It is required to compact the subgrade soil of top 50 cm under the condition of maximum dry density and optimum moisture content.

(v) Road Bed

A part of the highway which is graded in between top slope and side slope is known as road bed. The road bed is made as a foundation for shoulder and pavement structure.

(vi) Embankment

The structure of soil, broken rock or soil aggregate within the subgrade and foundation is known as embankment.

Q20. Discuss the factors responsible for flexible pavement design.

Answer :

The various factors responsible for the design of flexible pavement are:

1. Subgrade soil
2. Design wheel load
3. Environmental factors
4. Climatic factors
5. Pavement component materials
6. Special factors.

1. Subgrade Soil

It is important in determining the thickness needed for pavements. Thicker pavement is required for a subgrade having lower stability in order to protect it from traffic loads. The change in volume and stability of subgrade soil with variation in moisture are to be investigated, because they rely on properties of soil. The performance of pavement highly depends on the properties of subgrade soil and the drainage.

2. Design Wheel Load

The design for thickness of pavement basically depends upon the design wheel load. If design wheel load is considered then multiple wheel load assembly, the total static load effects on each wheel, contact pressure, dynamic effects of transient loads and load repetition are taken into consideration. If there is an increase in speed then the rate of application of the stress increases by which the pavement deformation minimises. Whereas the impact increases with speed on irregular pavements.

3. Environmental Factors

The factors which affect the functioning of pavement are depth of sub-surface water table, depth of cutting, height of embankment and its details of foundation etc. The functioning of the bituminous pavements and selection of the bituminous binder rely on the temperature change in pavement. In rigid pavements, the warping stresses depend on:

(a) The maximum temperature difference between top and bottom of pavement slab and

(b) The daily temperature variations.

4. Climatic Factors

The conditions of moisture in the pavement layers and the subgrade are affected by rainfall. The everyday and seasonal temperature change has importance in the design and functioning of bituminous and rigid pavements. Due to common freezing temperatures during winter, frost action is possible in the subgrade.

5. Pavement Component Materials

The properties of stress distribution of the pavement component layers depend on the qualities of the materials used. The durability of these materials and their exhaust behaviour under unfavourable conditions of weather should also be considered.

6. Special Factors

In the design of semi-rigid pavements, the propagation mode, the exhaust behaviour under unfavourable conditions of hair cracks, creation of shrinkage cracks are to be calculated.

Q21. Enumerate the various methods of flexible pavement design. Briefly indicate the basis of design in each case?

Model Paper-I, Q11(a)

Answer :

The various design methods of flexible pavement are as follows:

(i) Triaxial test method

(ii) Burmister method

(iii) Group index method

(iv) Mcleod method

(v) California bearing ratio method

(vi) California resistance value method

(vii) Mechanistic method.

Group Index Method (G.I Method)

It is a practical method of pavement design which depends upon the physical properties of the subgrade soil. The strength properties of the subgrade soil are not considered in this method.

The G.I value is an arbitrary index alloted to the soil types in numerical equations based on plasticity index, liquid limit and percent fines.

$$G.I = 0.2a + 0.01bd + 0.005ac$$

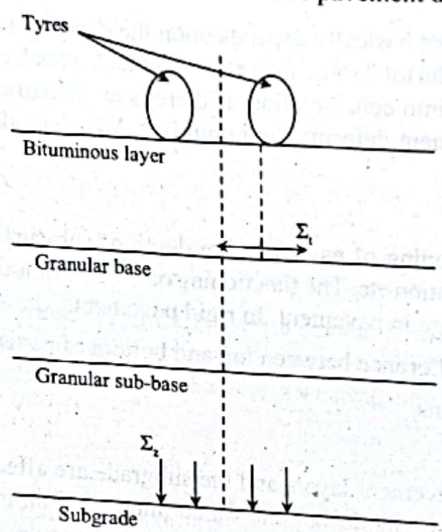
The G.I values of soil differ from 0 to 20. If the G.I value is higher then the soil subgrade is weaker. The required thickness of the pavement is more for uniform value of traffic volume.

In G.I method, the traffic volume for light vehicles is less than 50, for medium, vehicles is in between 50 to 300 and for heavy, vehicles is more than 300.

For designing the thickness of pavement by G.I method, primarily the G.I value of soil is calculated. The expected traffic is determined and is classified as light, medium or heavy volume of traffic.

Mechanistic Method

This method is considered as strong pavement design technique. Two failure criteria are suggested for bituminous pavements design. These failure criteria is considered as foundation of mechanistic pavement design.



The above figure indicates the critical strains in a bituminous pavement structure. The vertical compressive strain ε_z on the subgrade and the horizontal tensile strain ε_t below the bituminous layer are the critical parameters for rutting and fatigue failures respectively.

Q22. Describe the IRC method of flexible pavement design.

Answer :

Model Paper-II, Q11(a)

Procedure for Design

A catalogue of pavement designs and simple design charts are included in the code on the basis of design performance and using analytical approach.

1. Design traffic in terms of cumulative number of standard axles.
2. CBR value of subgrade.

1. Design Traffic

The following information is required for this process,

(a) Vehicle damage factor

(b) Traffic growth rate during the design life

(c) Initial traffic in terms of commercial vehicles per day

(d) Distribution of commercial traffic over the carriage way

(e) Design life in number of years.

(a) **Vehicle Damage Factor**

It is a multiplier which converts the vehicles of various axle configurations and axle loads to the number of standard axle-load repetitions. It is described as equal number of standard axles per commercial vehicle. The vertical damage factor differ with terrain, axle loading, axle configuration, type of road and from area to area. The various axle load repetitions are converted into equivalent standard axle load repetitions by using axle load equivalency factors.

As per IRC 37-2012, clause 4.4 values of vehicle damage factor are mentioned below.

Initial Traffic Capacity in Terms of CVPD	Rolling/Plain Terrain	Hilly Terrain
> 1500	4.5	2.5
150 – 1500	3.5	1.5
0–150	1.5	0.5

(b) **Traffic Growth Rate during the Design Life**

The calculation of traffic growth rates are done by researching the past techniques of traffic growth and by setting up econometric models. In case of unavailable data, or if annual traffic growth rate is less than 5% it is suggested to adopt the average growth rate of 5 percent.

(c) **Initial Traffic in terms of Commercial Vehicles Per Day**

Commercial vehicles with heavy weight of more than three tonnes are considered for the structural pavement design. The initial daily average traffic flow should be calculated on the basis of 7-day 24-hour classified traffic counts.

(d) **Distribution of Commercial Traffic Over the Carriage Way**

It is required to calculate the commercial traffic distribution by lane and by direction because it influences the application of total equivalent standard axle load used in design. If valid data is not available, consider the following distribution:

(i) **Single Lane Roads**

Traffic on signal roads is more channelized when compared to two lane roads. To enable the same flow of wheel load repetitions, the design should be on the basis of vehicles in both directions.

(ii) **Two-lane Single Carriageway Roads**

Based on 50% of the commercial vehicles in both directions, the design of two-lane single carriageway roads is done. However, the traffic corresponding to higher VDF (including VDF in one direction) is considered for design purpose.

(iii) **Four-lane Single Carriageway Roads**

Based on 40% of the commercial vehicles in both directions, the design of four-lane single carriageway roads is done.

(iv) **Dual Carriageway Roads**

Based on 75% of the vehicles in both directions, the design of dual carriageway roads is done.

(e) **Design Life**

The design life recommended for different types of roads are mentioned below.

(i) National and state highways – 15 years

(ii) Urban roads and express ways – ≥ 20 years

(iii) Other types of roads – 10-15 years

Effective CBR

If the obtained value of subgrade does not match with the embankment, then effective CBR is considered for design purpose.

Effective CBR of subgrade is determined from figure 5.1 pg 11 of IRC : 37-2012 by interpolating curve lines of CBR value for soil below 500 mm of subgrade with CBR of 500 mm of subgrade. It is used in the determination of resilient modulus (M_R).

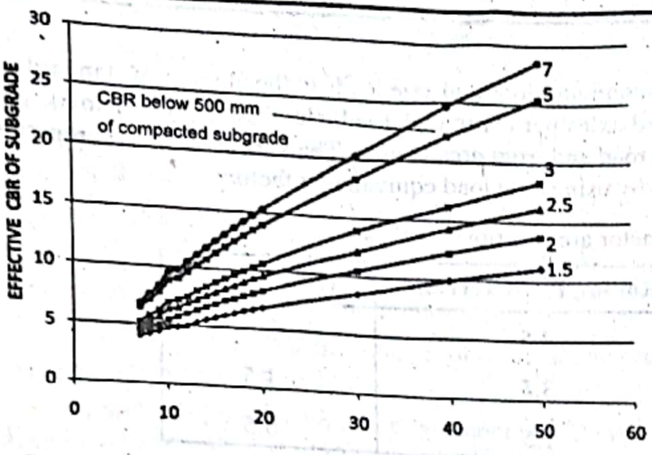


Figure: CBR of Compacted Borrow Material 500 mm Thick

Resilient Modulus (MR)

Resilient modulus of subgrade soil is evaluated in MPa as follows :

$$M_R = 17.6 \times (CBR_{eff})^{0.64} \text{ (f CBR} > 5)$$

$$M_R = 10 \times CBR \text{ if CBR } 5$$

Cumulative number of standard axles (N) is computed by using the following equation.

$$N = \frac{365[(1+r)^n - 1]}{r} \times A \times D \times F$$

Where,

A – Initial traffic in each direction

F – Vehicle damage factor

D – Lane distribution factor

n – Design life

r – Traffic growth rate

To design a flexible pavement, five combinations has been developed by IRC 37-2012 in which the composition of different layers of pavement is explained in clauses 10.1, 10.2, 10.3, 10.4, 10.5 as follows.

(i) Granular Base adn Granular Subbase

Depending upon the CBR values, design charts i.e., plate-1 - plate-8 are given in code to determine thickness of pavement layers.

Based on the cumulative standard axles (N) and effective CBR value, the thickness of granular layers i.e., thickness of Granular sub base, Granular base (wet mix maccadam) is computed. If traffic exceeds 30 msa (million standard axles) VG40 grade bitumen must be used.

(ii) Cementitious Base and Cementitious Subbase Aggregate Interlayer for Crack Relief

In order to prevent rutting of pavements, having traffic volume greater than 30 msa. VG40 grade bitumen is recommended Minimum thickness of bituminous layer (DBM + BC) = 100 mm if N > 30 msa. The period upto which the cemented base sustains without cracks is considered as design period.

Based on N value, effective CBR value thickness of cemented base, sub-base layer is known design charts i.e., plate-9 plate-12 are used in this case.

(iii) Bituminous Pavement with Cemented Base as Cemented Sub-base with Layer of SAM I Over Cemented Base

In this case design charts of CBR 3%, 5% 10%, 15% i.e., plate 13, 14, 15, 16 are used.

VG40 grade bitumen is used for N > 30 msa.

Minimum thickness recommended by AASH T093 is 100 mm for bituminous layer on major highways. Based on N value, effective CBR value the following are determined.

(a) Thickness of cemented base

(b) Thickness of cemented sub-base

(iv) Foamed Bitumen/bitumen Emulsion Treated RAP or Fresh Aggregates Over 250 mm Sub-base

For determining thickness of pavement layers design charts of CBR 3%, 5%, 10%, 15% i.e., plate, 17, 18, 19, 20 are used.

Grade of bitumen used is VG40 if N > 30 msa. Based on N-value, effective CBR value the thickness of treated RAP (Reclaimed asphalt pavement) is determined.

(v) Cementitious Base and Granular Sub-base with Layer of Crack Relief above Cementitious Base

Based on 'N' value (traffic), reliability and bitumen grade to be used varies which are represented in tabular form below.

Traffic	Reliability	Grade of Bitumen
> 30 msa	90%	VG40
< 30 msa	80%	VG30

The thickness of pavement layers is determined with the help of design charts i.e., plate 21, 22, 23, 24 corresponding to 3%, 5%, 10%, 15% CBR respectively. Using N-value, effective CBR value thickness of cemented base, granular sub-baseof pavement is determined. To check the safety of pavement composition the following strains are calculated manually with the help of equations and then they are compared with the strains calculated using "IITPAVE" software.

Strains to be Checked for Safety

1. Vertical compressive strain on subgrade
2. Horizontal tensile strain in bituminous layer
3. Tensile strain in cementitious layer

In case of first combination (granular base and granular subbase) tensile strain in cementitious layer is not evaluated.

Q23. Discuss the IRC recommendations made in CBR method of pavement design.

Answer :

(i) If the constructions are new, then the samples of CBR test can be immersed in water for a period of four days before it is tested. It is not required to immerse the soil specimen in arid climatic areas and when the thick and watertight bituminous surfacing is provided.

(ii) The CBR tests are recommended to perform in the laboratory on remoulded soils and is not suitable for in-situ. The production of specimens should be of static compaction or by dynamic compaction.

(iii) If the size of the substantial amount of aggregates in sub-base course materials is above 20 mm, then the CBR value of sub-base course materials is not applicable for the design of following layers above them.

(iv) The road pavements should be designed by considering the prevailing traffic and growth rate of traffic. The design for the pavements of major roads should have minimum life of 10 years.

The design of traffic is computed by the following formula, $A = P\,[1 + r]^{(n+10)}$

Where,

P – Number of heavy vehicles/day at least count.

A – Number of heavy vehicles/day for design.

n – Number of years between the last count and year of end of construction.

r – Rate of increase of heavy vehicles/year.

(v) The compaction of subgrade soil sample should be at OMC to proctor density for the design of new roads. For existing roads, the sample must be compacted to field density of subgrade soil.

(vi) The traffic is assumed in units of heavy vehicles per day in both directions for the purpose of design. The design thickness assumed for tandem axle loads is suitable upto 14,500 kg and for single axle load is upto 8,200 kg.

(vii) The compaction of top 50 cm of subgrade should be atleast 95 to 100 percent of proctor density.

(viii) On each soil type, minimum three samples should be tested at same moisture content and density. If the maximum change in CBR values of the three specimens is greater than the specified limits, then there should be an average of minimum six samples for CBR design.

Q24. State assumptions made in Burmister method of pavement design. Explain the method in detail.

Answer :

Assumptions of Burmister's Method

1. The surface layer is finite in vertical direction and infinite in horizontal direction; In two layered method, the underlying layer is assumed to be infinite in both directions. (i.e., horizontal and vertical)

2. There is a regular contact of layers, the top layer does not have any normal stresses and shearing outside the loaded area.

3. The materials present in the pavement are elastic, isotropic and homogeneous. A harder reinforcing layer is formed by the pavement with modulus of elasticity greater than that of underlying layer in two layered system.

Burmister's Method

The sections of flexible pavement consists of layers and the top layer has maximum elastic modulus. The entire mass of subgrade and pavement does not obtain a constant value E.

Let us assume a pavement comprising a single layer with elastic modulus E_p lying on the subgrade having elastic modulus E_s.

In vertical stress distribution, there is decrease in vertical stress on the subgrade from 70 to 30 percent by inserting a pavement layer of elastic modulus 10 times greater than the elastic modulus of subgrade soil and having thickness $h = a$. Hence, this method make use of the reinforcing action of the pavement layer.

In two layered system, the deflection factor F_2 is added which is subjected to h/a and E_s/E_p. Therefore, the equations of displacement given by Burmister are,

For rigid plate $\delta = 1.18\,\dfrac{P_a}{E_p}\,.\,F_2$

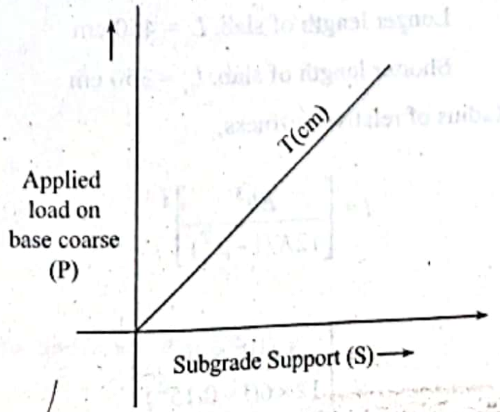
For flexible plate, $\delta = 1.5\,\dfrac{P_a}{E_s}\,.\,F_2$.

Q25. Explain briefly Mc Load method.

Answer : Model Paper-III, Q11(a)

Mcload Method

This test is an extensive plate bearing test and is conducted on airfields, highway pavements etc. It involves conduction of test on plates of different sizes and diameter. A graph is then plotted between the applied load on base course and subgrade support as shown below,



The empirical design equation used is,

$$\therefore T = K \log \frac{P}{S}$$

Where,

T – Thickness of gravel materials (cm)

K – Base coarse constant

P – Gross wheel load (kg)

S – Subgrade support (kg).

Q26. Estimate the thickness of cement concrete using the method suggested by Indian road congress.

Modulus of elasticity of concrete = 3.0 × 10⁵ kg/cm²

Modulus of rupture of concrete = 40 kg/cm²

Poisson's ratio of concrete = 0.15

Modulus of subgrade reaction = 6 kg/cm²

Wheel load = 5100 kg

Radius of contact pressure = 15 cm

Answer :

Given that,

Modulus of elasticity of concrete,

$E = 3.0 \times 10^5$ kg/cm²

Modulus of rupture of concrete, $f_r = 40$ kg/cm²

Poisson's ratio of concrete, $\mu = 0.15$

Modulus of subgrade reaction, $K = 6$ kg/cm²

Wheel load, $P = 5100$ kg

Radius of contact pressure, $a = 15$ cm

Assume,

Trial thickness of slab, $h = 20$ cm

Thermal coefficient of concrete,

$e = 10 \times 10^{-6}$ per °C

Longer length of slab, $L_x = 450$ cm

Shorter length of slab, $L_y = 350$ cm

Radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$= \left[\frac{3\times10^5\times20^3}{12\times6(1-0.15^2)}\right]^{\frac{1}{4}}$$

$$\therefore l = 76.42 \text{ cm}$$

$$\frac{L_x}{l} = \frac{450}{76.42} = 5.89$$

$$\frac{L_y}{l} = \frac{350}{76.42} = 4.58$$

From figure of warping stress coefficient,

C_x at $\frac{L_x}{l}$ of 5.89 = 0.87

C_y at $\frac{L_y}{l}$ of 4.58 = 0.68

$\therefore C_y < C_x$

Assume for zone 5, coastal area bounded by hills, temperature differential for 20 cm thick slab, $t = 15.8$°C

Warping stress at edge,

$$S_{te} = \frac{C_x.E.e.t}{2}$$

$$= \frac{0.87\times3\times10^5\times10\times10^{-6}\times15.8}{2}$$

$$S_{te} = 20.62 \text{ kg/cm}^2$$

Residual strength in concrete slab at edge region = $f_r - S_{te}$

= 40 – 20.62

= 19.38 kg/cm²

Using IRC stress chart, corresponding to $h = 10$, $K = 6$

Load stress in edge regions, Se

= 28 kg/cm²

$$\text{Factor of safety available} = \frac{\text{Residual strength}}{\text{Edge load stress}}$$

$$= \frac{19.38}{28}$$

$$= 0.69$$

As the factor of safety is less than 1.0, it is unsafe. Therefore, assume a higher slab thickness say $h = 24$ cm

Again radius of relative stiffness,

$$l = \left[\frac{3\times10^5\times24^3}{12\times6(1-0.15^2)}\right]^{\frac{1}{4}}$$

$$l = 87.61 \text{ cm}$$

$$\frac{L_x}{l} = \frac{450}{87.61} = 5.14$$

$$\frac{L_y}{l} = \frac{350}{87.61} = 3.99$$

From figure of warping stress coefficient,

C_x at $\frac{L_x}{l}$ of 5.14 = 0.76

C_y at $\frac{L_y}{l}$ of 3.99 = 0.5

$\therefore \quad C_y < C_x$

Temperature differential for 24 cm thick slab (by interpolation) = 16.12 °C

$$S_{te} = \frac{0.76 \times 3 \times 10^5 \times 10 \times 10^{-6} \times 16.12}{2}$$

S_{te} = 18.38 kg/cm²

Residual strength at the edge

$= F_r - S_{te}$

= 40 – 18.38

= 21.62 kg/cm²

Using IRC stress chart, corresponding to $h = 24$, $K = 6$

Load stress in edge region, S_e = 20 kg/cm²

$$\text{Factor of safety available} = \frac{\text{Residual strength}}{\text{Edge load stress}}$$

$$= \frac{21.62}{20}$$

= 1.08 (which is safe and acceptable value).

∴ Provide a tentative design thickness of 24 cm.

Check for corner load stress, using IRC stress chart

For h = 24, K = 6

S_c = 22.5 kg/cm²

$$\text{Corner warping stress, } S_{te} = \frac{E.e.t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

$$= \frac{3 \times 10^5 \times 10 \times 10^{-6} \times 16.12}{3(1-0.15)}\sqrt{\frac{15}{87.61}}$$

$$= 18.964 \times \sqrt{\frac{15}{87.61}}$$

= 18.964 × 0.413

= 7.832 kg/cm²

The worst combination of stresses at corner is,

= 22.5 + 7.832

= 30.33 kg/cm²

Which is also less than the allowable flexural strength of 40 kg/cm² and hence the design is safe.

∴ The thickness of cement concrete = 24 cm

Q27. A subgrade soil sample was tested using standard CBR apparatus and the observations are given below.

Load (kg)	Penetration (mm)
60.5	2.5
80.5	5.0

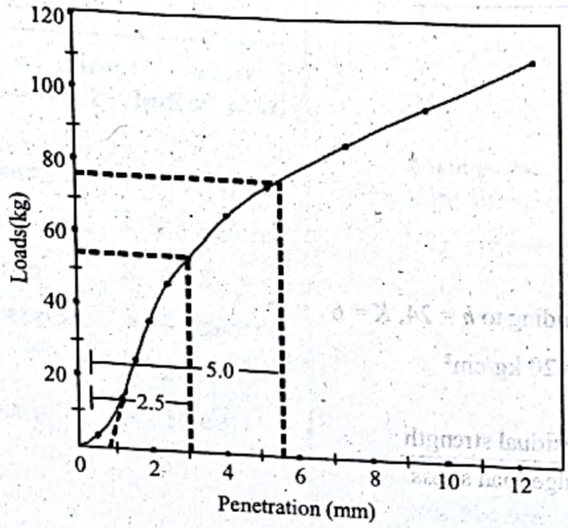
Assuming that the load-penetration curve is convex throughout, what is the CBR value of the sample.

Answer :

Given that,

Load at 2.5 mm penetration = 60.5 kg.

Load at 5.0 mm penetration = 80.5 kg.



Area of plunger $= \frac{\pi D^2}{4} = \frac{\pi}{4} \times 5^2 = 19.6 \text{ cm}^2$

Pressure at penetration of 2.5 mm,

$$= \frac{\text{Load}}{\text{Area}} = \frac{60.5}{19.6} \text{ kg/cm}^2 = 3.087 \text{ kg/cm}^2$$

Pressure at penetration of 5.0 mm,

$$= \frac{80.5}{19.6} \text{ kg/cm}^2 = 4.107 \text{ kg/cm}^2$$

C.B.R of soil at 2.5 mm penetration

$$= \frac{\text{Pressure on plunger at 2.5 mm}}{\text{Pressure as above for standard crushed stones}} \times 100$$

$$= 3.087 \times \frac{100}{70}$$

[∵ The standard load values obtained from tests at 2.5 and 5.0 mm penetration is 70 and 105 kg/cm²]

$$= \frac{308.7}{70}$$

$= 4.41$ percent

C.B.R of soil at 5 mm penetration $= 4.107 \times \frac{100}{105}$

$$= \frac{410.7}{105}$$

$= 3.912$ percent

$\simeq 4$ percent

Q28. Design a flexible pavement for the following data :

1. **Four lane divided carriage way**
2. **Initial traffic at the end of construction = commercial vehicles/day period in both directions**
3. **Percentage of single, Tandem and Tridem axles = 45%, 45% and 10%.**
4. **Growth of traffic per year = 8%**
5. **Design life = 15 years**
6. **Vehicle damage factor = 6**
7. **CBR of soil below 500 mm of subgrade = 7%**
8. **CBR of 500 mm of subgrade from borrow pits = 20%.**

Model Paper-I, Q10(b)

Answer :

Assuming 50% initial traffic on each = $\frac{4500}{2}$

Direction, initial traffic (A) = 2250 commercial vehicles/day

Cumulative number of standard axles is given by,

$$N = \frac{365[(1+r)^n - 1]}{r} \times A \times D \times F$$

Where,

A – Initial traffic in each direction

D – Lane distribution factor

F – Vehicle damage factor

n – Design life

r – Growth rate

For 4-lane divided carriage way, as per clause 4.5.1 of IRC: 37-2012, the lane distribution factor is 0.75.

$$\therefore \quad N = \frac{365 \times [(1+0.08)^{15} - 1]}{0.08} \times 2250 \times 0.75 \times 6$$

$= 100.34$

$\simeq 100$ msa [Million standard axles]

Effective CBR Value

For CBR below 500 mm of subgrade = 7% and CBR of 500 mm of subgrade = 20%, by interpolation from figure 5.1 of IRC:37-2012, we get,

Resilient Modulus (MR)

As per clause 5.3 of IRC : 37-2012,

Resilient modulus, M_R = 10 × CBR (For CBR 5)

= 17.6 × (CBR)0.64 (For CBR > 5)

$\therefore \quad M_R = 17.6 \times (15)^{0.64}$

$= 99.59$

$\simeq 100$ N/mm²

Design of flexible pavement as per IRC:37-2012 involves five combinations. They are,

1. Granular base and granular sub-base
2. Cementitous base and cementitious subbase of aggregate inter layer for crack relief.
3. Cementitious base base and subbase with stress absorbing membrane interlayer (SAMI) at the base and bituminous layer interface.
4. Framed Bitumen/Bitumen emulsion treated reclaimed asphalt pavement (RAP) or fresh aggregates over 250 mm cementitious sub base.
5. Cementitious base and granular subbase with layer of crack relief above cementitious base.

I Granular Base and Granular Sub-base

As per clause 10.2 of IRC:37-2012, for traffic greater than 30 msa, recommended bitumen is VG40 (Viscosity grade). For Bituminous concrete (BC) and dense bituminous macadam (DBM)

Effective CBR value = 15%

Traffic = 100 msa

From pg.no.28 and plate 8 (i.e., CBR = 15%) of IRC : 37 - 2012, pavement thickness for granular layers are,

Wet mix macadam, WMM = 250 mm [Granular base]

Granular subbase, GSB = 200 mm

For granular layer, resilient modulus is equal to,

$$(M_R)_{\text{Granular layer}} = 0.2 \times (\text{WMM} + \text{GSB})^{0.45} \times M_R$$

$$= 0.2\,(250 + 200)^{0.45} \times 100$$

$$= 312.59\ \text{N/mm}^2$$

Cementitious Base and Cementitious Subbase of Aggregate Interlayer for Crack Relief

As per clause 10.2 of IRC:37-2012, for traffic greater than 30 msa, VG 40 (VG-Viscosity grade, bitumen must be used to prevent rutting. After rolling, dense bituminous macadam (DBM) will have air void of 3%. For traffic of 100 msa).

Layer of bitumen with viscosity grade 40 (DBM + BC) = 100 mm [From clause 10.2 of code].

Aggregate interlayer = 100 mm [From clause 10.2 of code]

Cemented base = 90 mm [From pg.31, plate 12 (i.e., CBR 15%) of IRC : 37-2012]

Cemented sub-base = 250 mm [From pg.no.31, plate 12 (i.e., CBR 15%) of IRC : 37-2012

Also clause 10.2 of IRC : 37-2012 says that, upper 100 mm of the cemented sub-base must be graded following gradation 4 of Table V-1 (Annexure - V) Permeability of this layer must be high so that it can absorb more amount of water (say 300 mm/day).

(III) Bituminous Pavement with Cemented Base and Cemented Sub-base with Layer of SAMI over Cemented Base

As per clause 10.3 of IRC:37-2012, for traffic greater than 30 msa, viscosity grade 40 bitumen must be used.

Thickness of bitumen layer = 100 mm

For traffic 100 msa, from pg no.34 and plate 16 (i.e., CBR 15%) the thickness of cemented base and cemented sub base are as follows.

Cemented base (CT base) = 140 mm

Cemented sub-base (CT sub-base) = 250 mm

Also, clause 10.3 says that upper 100 mm of cemented sub-base must be graded so that high value of permeability of about 300 mm/ day can be obtained.

(IV) Foamed Bitumen/Bitumen Emulsion Treated RAP or Fresh Aggregates over 250 mm Sub-base

As per clause 10.4 of IRC:37-2012, for traffic greater than 30 msa, viscosity grade 40 bitumen must be used. To make flexible pavements strong, fresh aggregates treated with Bitumen emulsion/foamed bitumen are used. For traffic 100 msa, from pg.no.36 and plate 20 (i.e., CBR 15% of IRC:37-2012, thickness of treated reclaimed asphalt pavement is,

RAP = 110 mm

Thickness of sub-base = 250 mm [From code]

Thickness of bituminous layer = 100 mm [From code]

(V) **Cementitious Base and Granular Sub-base with Layer of Crack Relief abvoe Cementitious Base**

As per clause 10.5 of IRC:37-2012, for traffic greater than 30 msa, viscosity grade 40 bitumen must be used and thickness of (BC + DBM), wet mix macadam is equal to 100 mm.

∴ Thickness of Bituminous concrete = 50 mm

Thickness of dense Bituminous macadam = 50 mm

Thickness of WMM = 100 mm

From pg.no.40 and plate 24 (i.e., CBR 15%) of IRC : 37-201 2, the thickness of cemented base and granular subbase for traffic equal to 100 msa is,

Thickness of cemented base (CT base) = 160 mm

Thickness of granular sub-base (GSB) = 250 mm

Upper 100 mm of granular sub-base and cemented sub-base must be open graded so that high permeability of 300 mm/day can be obtained which results in more water absorbing capacity.

5.2 STRESSES IN RIGID PAVEMENT BY WESTERGARDS AND IRC METHODS – DESIGN OF OVERLAY BY BENKELMAN BEAM METHOD

Q29. Discuss the following considerations in designing the rigid pavements:

(a) Modulus of sub-grade reaction

(b) Relative stiffness of slab

(c) Critical load position

(d) Radius of resisting section.

Answer : **Model Paper-II, Q10(b)**

(a) Modulus of Sub-grade Reaction

Westergaard provided the formula to calculate the modulus of sub-grade reaction ('K') in kg/cm³. The modulus of sub-grade reaction (K) is proportional to the deflection and is given by,

$$K = \frac{P}{\Delta}$$

Where,

P – Pressure sustained by the rigid plate of 75 cm diameter.

Δ – Displacement level which is taken as 0.125 cm.

(b) Relative Stiffness of Slab

Depending upon the properties of sub-grade such as stiffness or pressure deformation, the rigid pavement of the slab is resisted by the sub-grade. The deflection is also induced in the sub-grade due to the deformation of rigid pavement, which gives the magnitudes of sub-grade pressure. Thus, the property of deflection of pressure of the rigid pavement with respect to sub-grade is termed as relative stiffness.

The Westergaard's formula for the radius of relative stiffness is given by,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

Where,

E – Modulus of elasticity of cement concrete in kg/cm²

μ – Poisson's ratio for concrete = 0.15

h – Thickness of slab in cm

K – Modulus of sub-grade reaction in kg/cm³.

(c) Critical Load Position

The intensity of the stress produced by the traffic load on the rigid pavement depends on the location of load such as interior, edge and corner regions.

(i) Interior Loading

If the load is applied in the interior region, then it isolates from all the edges. This type of loading is known as interior loading.

(ii) Edge Loading

If the load is applied on the edge, it isolates from a corner, which is termed as edge loading.

(iii) Corner Loading

If the application of central load is on the two edges of the slab which intersect at the corners, then the area of loading at these corners is termed as corner loading.

(d) Radius of Resisting Section

The maximum bending moment exists at the loaded area acting radially in all the directions. The equivalent radius of resisting section is approximated according to westergaard's analysis which is given by,

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

Where,

b – Equivalent radius of resisting section (cm)

a – Radius of wheel load distribution (cm)

h – Slab thickness in cm.

Q30. Describe wheel load stresses. Explain the wheel load stresses for the following:

(a) Westergaard's stress equation

(b) Evaluation of stresses for design.

Answer :

Model Paper-III, Q10(b)

(a) Westergaard's Stress Equation

In this theory, the cement concrete slab is assumed as homogeneous with uniformly thin elastic plate and the sub-grade reaction is considered to be vertical and proportional to the deflection. The relationships for the stresses at interior, edge and corner zone by Westergaard is given by,

(Interior loading)

$$\sigma_i = \frac{0.316P}{h^2}\left[4\log_{10}\left[\frac{l}{b}\right] + 1.069\right] \quad \text{... (1)}$$

(Edge loading)

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

(Corner loading).

$$\sigma_c = \frac{3p}{h^2}\left[1 - \left[\frac{a\sqrt{2}}{1}\right]\right] \quad \text{... (3)}$$

Where,

σ_i, σ_e, σ_c are the stresses at interior, edge and corner zones in kg/cm²

h – Thickness of slab in cm

p – Wheel load in kg

a – Radius of wheel load distribution in cm.

l – Radius of the relative stiffness in cm.

b – Radius of resisting section in cm.

(b) **Evaluation of Stresses for Design**

Depending upon the research work done on cement concrete pavement slabs, the Westergaard's wheel load stress equation for interior, edge and corner have been modified. For the design of rigid pavements, the stresses at the edge and corner zones are critical for highways. The load stresses at these zones as per Indian road congress for the design of rigid pavements is given by the following formulae:

1. The modified form of the Westergaard's edge load stresses formula, which is given by Teller and Sutherland for estimating the load stresses in the critical edge region is given by,

$$S_e = 0.529\,\frac{P}{h^2}\,(1+0.54\mu) \times \left[4\log_{10}\left[\frac{l}{b}\right] + \log_{10} b - 0.4048\right]$$

2. For determining the load stress S_c at the critical corner zone, Kelley modified the Westergaard's corner load stress analysis as

$$S_c = \frac{3P}{h^2}\left[1-\left[\frac{a\sqrt{2}}{l}\right]^{1.2}\right]$$

Where,

S_e, S_c are the load stresses at the edge and corner zones in kg/cm² respectively.

P – Design wheel load in kg

h – Thickness of cc pavement slab in cm.

μ – Poisson's ratio of the cement concrete slab.

Q31. Explain the following stresses induced in the rigid pavements,

(a) Temperature

(b) Warping

(c) Frictional.

Answer : Model Paper-II, Q11(b)

(a) **Temperature**

In cement concrete pavements, the temperature stresses are developed due to the temperature changes in slab. The top zone of the pavement slab gets heated under the sunlight and the zone at the bottom remains relatively colder. The warping stress are developed in the evening and the bottom of the slab gets heated up. This is because of the transfer of heat from the top due to the decrease in temperature.

(b) **Warping Stresses**

The slab tends to warp upwards or downwards, when the top and bottom surfaces of concrete pavement posses different temperatures. It mainly depends upon climatic conditions of the region.

The difference between the top 't_1' and the bottom 't_2' of the slab is,

$t_1 - t_2 = t$ (degree).

The temperature at mid depth of the slab is,

$$t_m = \frac{(t_1 + t_2)}{2}$$

The effect of Poisson's ratio, for the interior region in longitudinal and transverse directions is given by the expression.

$$\sigma_{ti} = \frac{Eet}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

$$\sigma_{te} = \left[\frac{C_x E.e.t}{2}\right] \text{ (or)}$$

$$= \frac{C_y E.e.t}{2} \quad \text{[The value which is higher]}$$

$$\sigma_{tc} = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Where,

σ_{it}, σ_{te}, σ_{tc} are the warping stresses at the interior, edge and corner zones respectively in kg/cm^2

E – Modulus of elasticity of concrete

e – Thermal coefficient in C

t – Temperature difference between the top and the bottom of slab

C_x – Coefficient based on $\frac{lx}{l}$ in desired direction

C_y – Coefficient based on $\frac{ly}{l}$ in right angle to the above direction

μ – Poisson's ratio.

(c) Frictional Stresses

The overall expansion and contraction of the slab is due to uniform temperature rise and fall in concrete slab. The frictional resistance prevents the movements thereby including the frictional stress in the bottom fibre of the cement concrete pavement. Due to this phenomenon, the stresses in the slabs varies with slab length.

$$S_f \times h \times B \times 100 = B \times \frac{L}{2} \times \frac{h}{100} \times w \times f.$$

$$S_f = \frac{wLf}{2\times10^4}$$

Where,

S_f – Unit stress developed in cement concrete pavement.

W – Unit weight of concrete

f – Coefficient of sub-grade restraint

L – Slab length

B – Slab width.

Q32. Write the relation between tyre and contact pressure. Draw the neat sketch.

Answer :

Tyre Pressure and Contact Pressure

Tyre pressure is a pressure in an inflated rubber tube of a tyre. The tyre pressures in the AASHTO road test were used in the range between 0.515 to 0.55 MPa. In Indian conditions, and average tyre pressure for design purpose may be assumed as 0.8 MPa.

Tyre contact pressure may be described as a pressure originated because of wheel load over the tyre imprint area. The stresses induced in the pavement structure is calculated by using tyre contact pressure and therefore may be associated to pavement damages.

The contact area decreases by increase in tyre pressure. But there is also increase in contact area and load on tyre. In some cases, there is also increase in contact pressure by increase in axle load and tyre pressure. Generally, this type of situation is seen in summer due to overloaded trucks, since elevated inflation pressures are seen because of maximum temperatures of pavement and air. Any how, for the purpose of design, tyre contact pressure and tyre pressure may be assumed to be equal.

$$\therefore \text{ Tyre Pressure, } P = \frac{\text{Wheel Load}}{\text{Contact Pressure}}$$

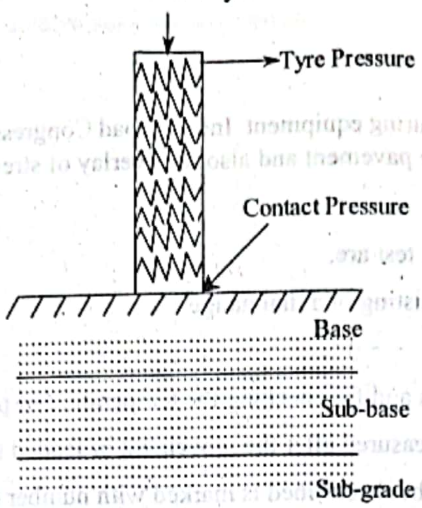


Figure: Contact Pressure and Tyre Pressure

Q33. Explain clearly the differences between rigid and flexible pavements.

Answer :

The differences between rigid and flexible pavements are as follows:

	Flexible Pavement		Rigid Pavement
1.	The upper layers of the sub-grade are subjected to deformation.	1.	The subsequent layer of the sub-grade does not undergo any deformation an act as cantilever beam.
2.	The design of flexible pavement depends on the load distributing characteristics of the component layers.	2.	The design of rigid pavement depends on the parameters like flexural strength or slab action.
3.	The flexural strength is low.	3.	The flexural strength is high.
4.	The life span of flexible pavement is low	4.	When compared to flexible pavement, the life span of rigid pavement is high.
5.	The completion cost is inexpensive but the maintaining costs are expensive.	5.	Maintaining cost is economical but completion cost is high.
6.	Sub-base layer is needed for laying of surface on the sub-grade layer.	6.	Laying of surface can be done directly.
7.	The contraction and expansion properties of the pavement is high, Hence, it does not get exposed to thermal stresses and expansion joints are not required.	7.	The contraction and expansion properties of the pavement is low. Hence, it exposed to various thermal stresses, and expansion joints are required.
8.	Depending on the strength of sub-grade, strength of the road is high.	8.	Depending on the strength of sub-grade, the strength of sub-grade, the strength of the road is less.
9.	Rolling of surface is required.	9.	Rolling of surface is not required.
10.	Traffic can utilize the road within 24 hours.	10.	Before 14 days of curing the road cannot be used.
11.	Frictional force is low.	11.	Frictional force is high.

Q34. Explain the principles and uses of Benkelman Beam test?

Answer : Model Paper-II, Q11(b)

Benkelman Beam Test

Bankelman beam is a deflection measuring equipment. Indian Road Congress gave guidelines for conducting Benkelman beam test for structural evaluation of flexible pavement and also for overlay of strengthening thickness.

Equipment and Working Principle

Equipments used in Benkelman beam test are,

(a) Standard Benkelman beam consisting of a dial gauge

(b) Loaded truck

(c) Tools for collecting soil samples and for checking the temperature of pavement etc.

Rebound deflection of pavement is measured after the movement of loaded truck on the pavement.

1. The road whose deflection is to be determined is marked with number of deflection observation points.
2. Now the loaded truck moves along the pavement.
3. Simultaneously, the rebound values at marked points are noted. Few soil samples are collected to conduct tests like liquid limit, moisture content etc.

Deflection Varies From Point to Point

"Characteristic deflection value" is obtained by statistical analysis of data collected i.e., rebound values.

Uses

Following are the uses of Benkelman Beam test,

1. It is used for calculating deflection of pavement.
2. It is economical
3. Method of study is simple and easy.

Q35. Compute the radius of relative stiffness of 16 cms thick cement concrete slab from the following data: Modulus of elasticity of cement concrete = 2, 15,000 kg/cm², Poisson's ratio for concrete = 0.142 and modulus of sub grade reaction K = (i) 3.2 kg/cm³ and (ii) 7.4 kg/cm³.

Answer : Model Paper-III, Q11(b)

Given that,

Thickness of cement concrete slab, $h = 16$ cm

Modulus of elasticity of cement concrete,

$$E = 2,15,000 \text{ kg/cm}^2$$

$$E = 2.15 \times 10^5 \text{ kg/cm}^2$$

Poisson's ratio for concrete, $\mu = 0.142$

(i) For modulus of sub-grade reaction,

$$K = 3.2 \text{ kg/cm}^3$$

According to Westergaard's theory, the equation for relative stiffness is given as,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$= \left[\frac{2.15\times10^5\times(16)^3}{12\times3.2\times(1-(0.142)^2)}\right]^{\frac{1}{4}}$$

$$\therefore \quad l = 69.55 \text{ cm}$$

(ii) For modulus of sub-grade reaction $K = 7.4$ kg/cm³

Westergaard's equation for radius of relative stiffness is given as,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$= \left[\frac{2.15\times10^5\times(16)^3}{12\times7.4\times(1-(0.142)^2)}\right]^{\frac{1}{4}}$$

$\therefore \quad l = 56.40$ cm

Q36. Calculate the stress at interior, edge and corner regions of a cement concrete pavement using Westergaard's stress equations.

Use the following data.

Wheel load, P = 5100 kg

Modulus of elasticity of cement concrete,

$E = 3.0 \times 10^5$ kg/cm²

Pavement thickness, h = 18 cm

Poisson's ratio of concrete, $\mu = 0.15$

Modulus of sub-grade reaction, K = 6.0 kg/cm³

Radius of contact area, a = 15 cm

Answer :

Equivalent of resisting section, $\frac{a}{h} = \frac{15}{18} = 0.833$

$\therefore \quad \frac{a}{h} < 1.724$

Radius of equivalent distribution of pressure is given as,

$$b = \sqrt{1.6a^2 + h^2} - 0.675\text{ h}$$

$$b = 14\text{cm}$$

Radius of relative stiffness, $l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$

$$l = \left[\frac{3\times10^5\times18^3}{12\times6(1-0.15^2)}\right]^{\frac{1}{4}}$$

$$l = 70.611 \text{ cm}$$

Stress at the interior,

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

$$S_i = \frac{0.316\times5100}{18^2}\left[4\log_{10}\left[\frac{70.611}{14}\right]+1.069\right]$$

$$S_i = 19.299 \text{ kg/cm}^2$$

Stress at the edge,

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

$$S_e = \frac{0.572\times5100}{18^2}\left[4\log_{10}\left[\frac{70.611}{14}\right]+0.359\right]$$

$$S_e = 28.542 \text{ kg/cm}^2$$

Stress at the corner,

$$S_c = \frac{3p}{h^2}\left[2-\left[\frac{a\sqrt{2}}{l}\right]^{0.6}\right]$$

$$S_c = \frac{3\times5100}{18^2}\left[1-\left[\frac{15\sqrt{2}}{70.611}\right]^{0.6}\right]$$

$$S_c = 24.272 \text{ kg/cm}^2$$

Q37. Compute the stresses due to loading at salient locations on a cement concrete slab using Westergaard's equations from the below given data.

Poisson's ratio of concrete = 0.15

Pavement slab thickness = 22 cm

Modulus of elasticity of concrete = 2.77 × 10⁵ kg/cm²

Modulus of subgrade reaction = 4.35 kg/cm³

Radius of contact of tire = 16 cm

Wheel load = 4950 kg.

Answer :

Given that,

Poisson's ratio of concrete, $\mu = 0.15$.

Pavement slab thickness, $h = 22$ cm

Modulus of elasticity of cement concrete is,

$E = 2.77 \times 10^5$ kg/cm²

Modulus of subgrade reaction, $k = 4.35$ kg/cm³

Radius of contact area of tire, $a = 16$ cm

Wheel load, $P = 4950$ kg

Equivalent resisting section,

$$\frac{a}{h} = \frac{16}{22} = 0.727$$

$$\therefore \quad \frac{a}{h} < 1.724$$

∴ Radius of equivalent distribution of pressure is given by,

$$b = \sqrt{1.6a^2+h^2} - 0.675\,h$$

$$= \sqrt{1.6\times(16)^2+(22)^2} - 0.675\times 22$$

$$= 29.9 - 14.85$$

$$b = 15 \text{ cm}$$

Radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$$

$$= \left[\frac{2.77\times10^5\times(22)^3}{12\times4.35\times(1-(0.15)^2)}\right]^{1/4}$$

$$\therefore \quad l = 87.2 \text{ cm}$$

The stresses due to loadings for a cement concrete slab using Westergaards' stress equations are as follows,

(i) Stress at the interior,

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

$$= \frac{0.316\times4950}{(22)^2}\left[4\log_{10}\left(\frac{87.2}{15}\right)+1.069\right]$$

$$= 3.2318 \times 4.1267$$

$$\therefore \quad S_i = 13.33 \text{ kg/cm}^2$$

(ii) Stress at the Edge,

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

$$= \frac{0.316\times4950}{(22)^2}\left[4\log_{10}\left(\frac{87.2}{15}\right)+1.069\right]$$

$$S_e = 5.85 \times 3.4167$$

$$\therefore \quad S_e = 19.98 \text{ kg/cm}^2$$

(iii) Stress at the corner,

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

$$= \frac{0.572\times4950}{(22)^2}\left[4\log_{10}\left(\frac{87.2}{15}\right)+0.359\right]$$

$$= 30.68 \times 0.555$$

$$\therefore \quad S_c = 17.03 \text{ kg/cm}^2$$

Q38. What is the radius of relative stiffness for a 20 cm thick slab with E = 3 × 10⁵ kg/cm² and Poisson's ratio = 0.15, resting on a subgrade having modulus of 5 kg/cm³?

Answer :

Given that,

Thickness of cement concrete slab, $h = 20$ cm

Modulus of elasticity of cement concrete,

$E = 3 \times 10^5$ kg/cm²

Poisson's ratio for concrete, $\mu = 0.15$

For modulus of sub-grade reaction,

$K = 5$ kg/cm³

According to Westergaard's theory, the equation for relative stiffness is given as,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$= \left[\frac{3\times10^5\times(20)^3}{12\times5\times(1-(0.15)^2)}\right]^{\frac{1}{4}}$$

$\therefore \; l = 79.981$ cm

Q39. For a 25 cm thick cement concrete pavement, analysis of stresses gives the following values:

Wheel load stress due to comer loading = 30 kg/cm²

Wheel load stress due to edge loading = 32 kg/cm²

Warping stress at corner region during summer = 9 kg/cm²

Warping stress at corner region during winter = 7 kg/cm²

Warping stress at edge region during summer = 8 kg/cm²

Warping stress at edge region during winter = 6 kg/cm²

Frictional stress during summer = 5 kg/cm²

Frictional stress during winter = 4 kg/cm²

What is the most critical stress value for this pavement?

Answer :

Given that,

At summer:

Wheel load stress due to edge loading = 32 kg/cm²

Wheel load stress due to corner loading = 30 kg/cm²

Warping stress at edge region = 8 kg/cm²

Warping stress at corner region = 9 kg/cm²

Frictional stress = 5 kg/cm²

Critical combination of stresses at redge region = (Wheel load stress – Frictional stress + Warping stress)

= (32 – 5 + 8)

= 35 kg/cm²

Critical combination of stresses at corner region = (Load stress + Warping stress)

= 30 + 9 = 39 kg/cm²

At Winter:

Wheel load stress due to edge loading = 32 kg/cm^2

Wheel load stress due to corner loading = 30 kg/cm^2

Warping stress at edge region = 8 kg/cm^2

Warping stress at corner region = 7 kg/cm^2

Frictional stress = 4 kg/cm^2

Critical combination of stresses at edge region = (Wheel load stress + Frictional stress + Warping stress)

$$= 32 + 4 + 8 = 44 \ kg/cm^2$$

Critical combination of stresses at corner region = (Wheel loads stress + Warping stress)

$$= 30 + 7$$

$$= 37 \ kg/cm^2$$

The most critical stress value for the pavement during summer = 39 kg/cm^2 at corner region

The most critical stress value for the pavement during winter = 44 kg/cm^2 at edge region