3.3 DESIGN FACTORS

Various factor considered for the design of pavements

a. Pavement design consists of two parts
   - ✓ Mix design of materials
   - ✓ Thickness design of pavement and component layers.

b. Factors for the design of pavement
   - ✓ Design wheel load
   - ✓ Sub grade soil
   - ✓ Climatic factors
   - ✓ Pavement component materials
   - ✓ Environmental factors.

Design wheel load:

The various wheel load factors to be considered in pavement design are:

1. Maximum wheel load
2. Contact pressure
3. Dual or multiple wheel loads
4. Repetition of loads.

Maximum wheel load:

- The wheel load configurations are important to know the way in which the loads of a given vehicle are applied on the pavement surface.
- For highways the maximum legal axle load as specified by Indian road congress is 8170 kg with a maximum equivalent single wheel load of 4085kg.
- The evaluation for vertical stress computations under a uniformly distribute of
- circular load based on Boussineq's theory is given by:

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

σ_z = vertical stress at depth z P= surface pressure

Z=depth at which σ_z computed. A=radius of loaded area.

Contact pressure:

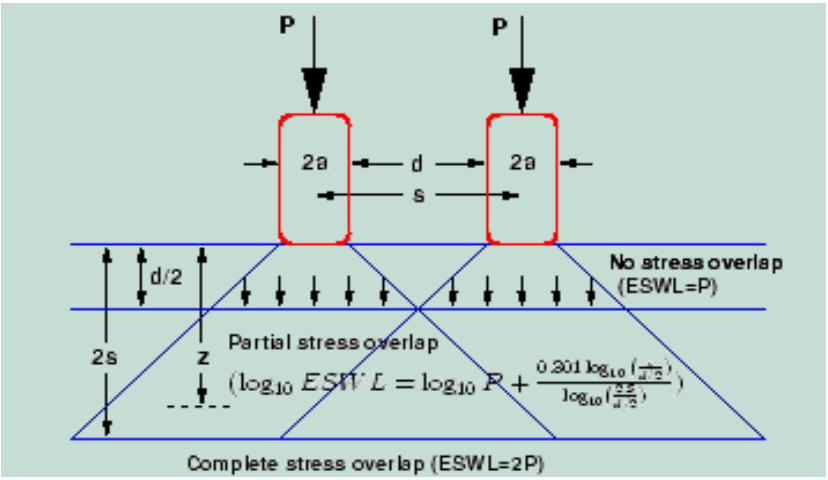
Generally the wheel load is assumed to be distributed over a circular area. But by measurementoftheimprintsoftyerswithdifferentloadandinflationpressures.Three terms in use with reference to tyre pressure are:

1. Tyre pressure
2. Inflation pressure
3. Contact pressure

The ratio of contact pressure to type pressure is defined as **rigidity factor**. Thus value of rigidity factor is 1.0 for an average tyre pressure of 7 Kg/cm2.This value is higher than unity for lower type pressures and less than unity for tyre pressures higher than 7 kg/cm2.

ESWL:

- ESWL is the single wheel load having the same contact pressures, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth. The procedure of finding the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method.
- ESWL may be determined based on either equivalent deflection or equivalent stress criterian. Multiple wheel loads are convert to ESWL and this value is used in pavement design. The ESWL is usually determined by the equivalent stress criterion using a simple graphical method.
- A straight line relationship is assumed between ESWL and depth on log scales.



Repetition of loads

- The deformation of load pavement (or) sub grade due to a single application of wheel load may be small. It required carrying out traffic surveys for accounting the factor of repetitions for wheel loads in the design of pavement.

- Data collected are converted to some constant equivalent wheel loads. Equivalent wheel load is a single load equivalent to the repeated applications of any particular wheel load on a pavement which requires the same thickness and strength of pavements.

- McLeod has given a procedure for evolving equivalent load factors for designing flexible pavements.

3.2DESIGN PRINCIPLES

Flexible pavement:

- A load of magnitude may be dissipated by carrying it deep into ground through layers of granular materials.
- The intensity of load diminishes in geometric proportions as it is transmitted downwards from the surface by virtue of spreading it over an increasing larger area.
- Strength of each layer could be reduced with increased depth.

Rigid pavement:

- Design is based on providing flexural strength in a structural slab to resist destructive action of wheel loads.
- A rigid pavement because of its rigidity and high modulus of elasticity tends to distribute the load over a relatively wider area of soil.

FUNCTIONS OF PAVEMENT COMPONENTS

The functions are:

Soil sub grade and its evaluation:

- The soil sub grade is a layer of natural soil prepared to receive the layers of pavement materials placed over it. It is essential that at no time the soil sub grade is overstressed, it means that the pressure transmitted on the top of the sub grade is within the allowable limit.
- Many tests are known for measuring the Strength properties of the sub grades .Some of the tests have been standardized for the use. The common strength test for the evaluation of soil sub grade is:
  1. California bearing ratio test.
  2. California resistance value test.
  3. Triaxial compression test
  4. Plate bearing test.

California bearing ratio (CBR) test:

It is evolved for the empirical method of flexible pavement design. The CBR test is carried out either in the laboratory on prepared specimens or in the field by taking in situ measurements.

California resistance value:

It is found by using hveem stabliometer. This test is used in an empirical method of flexible pavement design based on soil strength.

Triaxial test:

It is the most important soil strength, but still the test is not very commonly used in structural design of pavements.

Plate bearing test:

It is carried out using a relatively large diameter plate to evaluate the load supporting capacity of supporting power of the pavement layers. The results are plate bearing tests are used in flexible pavement design method like McLeod method on based on layer system analysis by brumister.

Sub base and base courses and their evaluation:

- There layers are made of broken stones, bound or unbound aggreagate, some times in sub base course a layer of stabilized soil.(or) Selected granular soil is also used. however at the sub base course it is desirable to use smaller size graded aggregates. When the sub grade consists of fine grained soil and when the pavement carries heavy wheel loads.
- Sub base course primarily has the similar function as of the base course and is provided with inferior materials than of base course. Base courses are used, under rigid pavement for
  1. Preventing pumping
  2. Protecting the sub grade against frost action.
- Thus the fundamental purpose of abase course and sub base course is to provide a stress transmitting medium to spread the surface wheel loads in such manner.
- The sub base and base course layers may be evaluated by suitable strength or stability test like plate bearing CBR test.

The function of wearing course

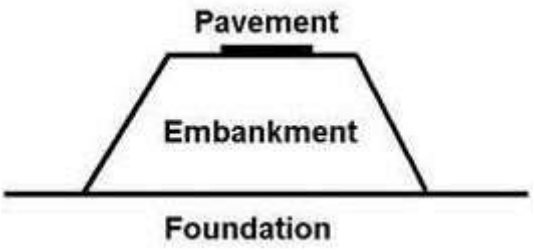
- To provide a smooth riding surface
- To resist pressures exerted by tyres.

- To take up wear andtear
- To prevent infiltration of rainwater into the pavement and subgrade

3.6 EMBANKMENTS

An Embankment is an artificial barrier that typically is used to hold back water or to support a roadway, railway or canal.

- ✓ It is a ridge to prevent water from passing beyond desirable limits.
- ✓ These man-made mounds mainly consist of stones, rocks and earth.
- ✓ Most have sloping slides, much like small hills. Generally, embankments are longer than they are in height.



Design and construction stages

- Evaluate the embankment height
- Embankment materials
- Compaction and its materials
- Construct the embankment with equal slopes
- Check settlement

Design of Embankment

The embankment design elements are as follows,

- Selection of dimensions
- Slopes
- Settlement analysis
- Materials
- Drainage

Selection of dimensions

The dimensions are select due to the roadway width , height and its side slopes.

- ✓ Width - its fixed as per IS recommendations . It may be single, two and multiple lane roads.
- ✓ Height - its based on desired grade line of the highway and the topography
- ✓ Side slope - in this basis generally flat slope is considered , because of the erosion control

Selection of embankment materials

- ✓ The embankment materials should have the strength and stability.
- ✓ Silts and clays are not a constructing soil,
- ✓ On the site locating soil is best to the embankment foundation

3.1 Highway Pavement

A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil sub-grade, whose primary function is to distribute the applied vehicle loads to the sub-grade. The pavement structure should be able to provide a surface of acceptable riding quality, adequate skid resistance, favorable light reflecting characteristics, and low noise pollution.

Need of Highway Pavement

- ✓ Road surface should be stable and un-yielding.
- ✓ Uneven and undulating, vehicle operating cost, road user cost, time cost and accident cost will increase.
- ✓ Earthen roads yield and are unstable under adverse weather condition and wheel loads.

Basic Requirements of Quality Pavement

The 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

Types of Highway Pavement

1.Flexible Pavements - flexible pavements will transmit wheel load stresses to the lower layers by grain-to-grain transfer through the points of contact in the granular structure. The Typical layers of a flexible pavement are,

Seal Coat:

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

Tack Coat:

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

Prime Coat:

- ✓ It is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed.
- ✓ Provides bonding between two layers.

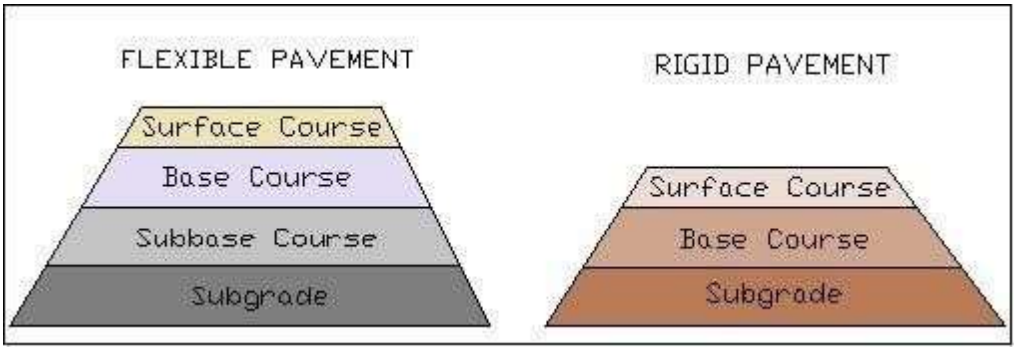
2. Rigid pavements -Rigid pavements have sufficient flexural strength to transmit the wheel load stresses to a wider area.

Types of Rigid Pavement

Rigid pavements can be classified into four types:

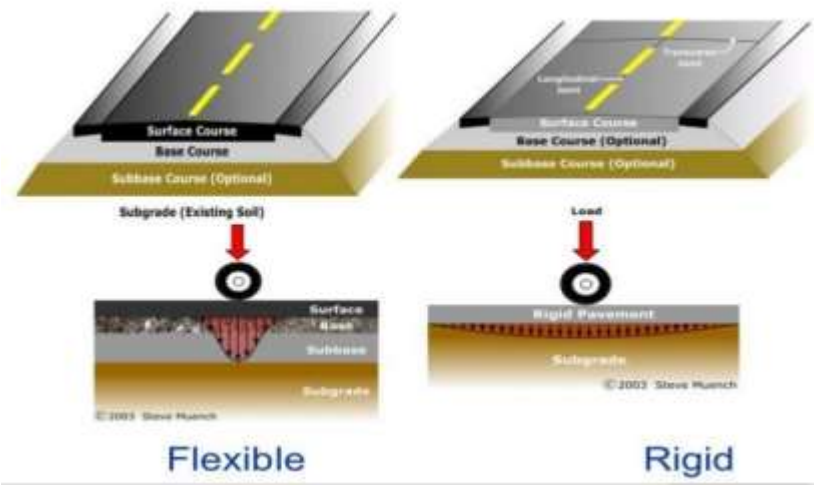
- Jointed plain concrete pavement(JPCP)
- Jointed reinforced concrete pavement(JRCP)
- Continuous reinforced concrete pavement (CRCP)and
- Pre-stressed concrete pavement(PCP)

FLEXIBLE PAVEMENT RIGID PAVEMENT



Critical Load Positions

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 are *interior, edge* and *corner*. These locations are termed as critical load position



Factors Affecting Pavement Design

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 tire pressure is an important factor, as it determines 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.

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

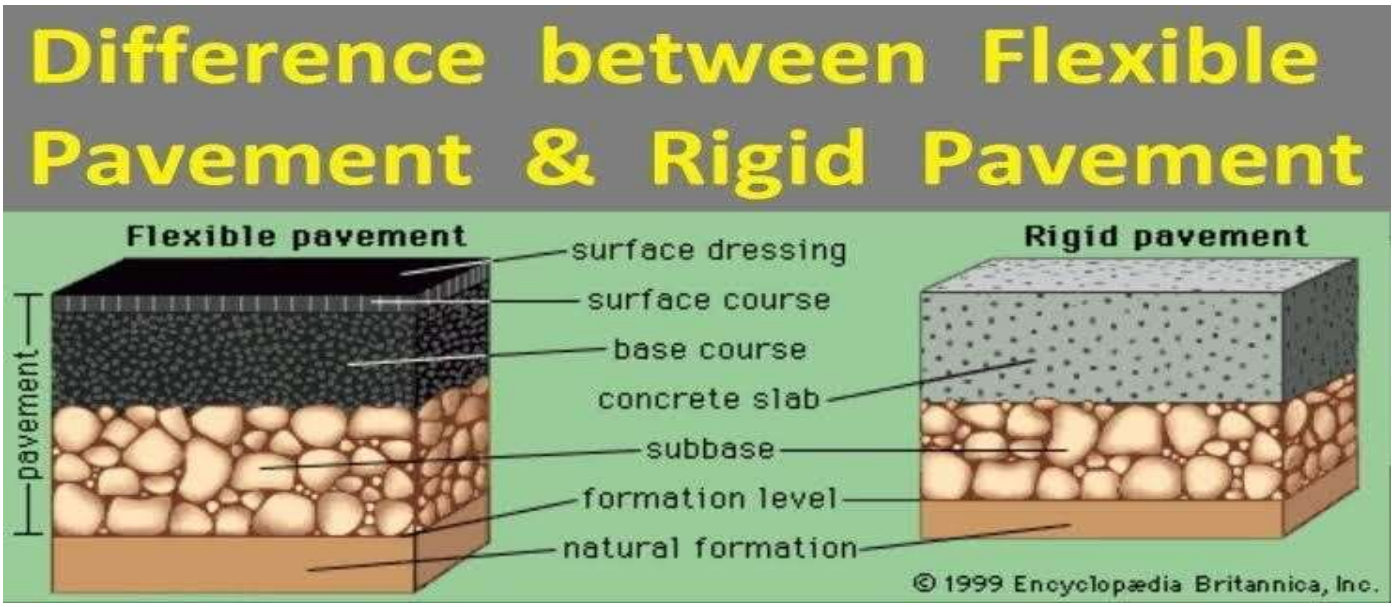
The influence of traffic on pavement not only depends on the magnitude of the wheel load, but also on the frequency of the load applications. Each load application causes some deformation and the total deformation is the summation of all these.

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.

Difference Between Flexible Pavement and Rigid Pavement

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



3.5 Design of Flexible Pavement- C.B.R METHOD (IRC:37-2001)

- The flexible pavement is built with number of layers. In the design process it is to be ensured that under the application of load none of the layers is overstressed.
- The maximum intensity of stresses occurs in the top layer of the pavement .The magnitude of load stresses reduces at lower layers.
- In the design of flexible pavements, it has yet not been possible to have a rational design method wherein design process and service behavior of the pavement can be expressed by mathematical laws.
- Flexible pavement design methods are accordingly either empirical or semi empirical. In these methods, the knowledge and experience gained on the behavior of the pavements in the past are use fully utilized.

Flexible Pavement Design Method:

California bearing ratio method:

✓ California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.Porter.

✓ One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including sub grade, sub base and base course.

✓ Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.

✓ A higher load needs a thicker pavement layer to protect the sub grade. Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.

It is possible to extend the CBR design curves for various loading conditions,using the expression:

$$t = \sqrt{p}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{\frac{1}{2}}$$

$$t = \left[\frac{1.75p}{CBR} - \frac{A}{\pi}\right]^{\frac{1}{2}}$$

Hence,

T= pavement thickness, cm

P= Wheel load,kg

CBR= California bearing ratio,percent

P=tyrepressure,kg/cm^2

A=areaofcontact.cm^2

IRC Recommendations:

- ✓ The CBR tests should be performed on remoulded soils in the laboratory. The specimens should be prepared by static compaction wherever possible and otherwise by dynamic compaction.
- ✓ For the design of new roads, the sub grade soil sample should be compacted at OMC to proctor density whenever suitable compaction equipment.
- ✓ The CBR test samples may be soaked in water for four days period before testing .the annual rainfall is less than 50 cm and the water table is too deep to affect the sub grade and imperable surfacing is provided to carrying out CBRtest.
- ✓ If the maximum variations in CBR value of the three specimens exceed the specified limits, the design CBR should be average of at least six samples.
- ✓ The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.
- ✓ An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.
- ✓ The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G.The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500kg.
- ✓ When sub base course materials contain substantial proportion of aggregates of

size above 20mm, the CBR value of these materials would not be valid for the design of subsequent layers above them.

The CBR method of pavement design gives the total thickness requirement of the pavement above a sub grade and thickness value would remain the same quality of materials used in component layers.

Recommended method of design (IRC 37-2001):

1. Context
2. Design Approach and Criteria
3. Estimation of design traffic
4. Data requirements
    - No. of vehicle commercial per day
    - Traffic growth rate during design life
    - Design life in number of years
    - Vehicle damage factors: VDF is the number of standard axles per truck. So determination of VDF can be made through the determination of the load equivalency factor (LEF) for each axle of the truck and then taking the sum total of the equivalent standard axles for all the axles in the truck.
    - Distribution of commercial traffic over a carriage way
5. Computations of design traffic
6. Sub grade
    - Compaction requirements for different class of roads
    - Dry density and moisture content

PAVEMENT DESIGN:

1.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.

(i) Two lane carriageway

Initial traffic in the year of completion of construction = 300 CVPD (sum of both directions)

Traffic growth rate = 7.5%

Design life = 15years

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).

Bituminous surfacing = 20 mm PC + 50 mmBM

Road-base = 250 mm Granular base

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.

Advantages of using modified bitumen are:

- ✓ 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.Design the pavement for construction of a new bypass with the following data: Twolanecarriageway,Initialtrafficintheyearofcompletionofconstruction=400CVPD(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).

1. Bituminous surfacing = 25 mm SDBC + 70 mmDBM
2. Road-base = 250 mm WBM
3. sub-base = 315 mm granular material of CBR not less than 30%

Design procedure for rigid pavements.

Design procedure

Step 1: Find the length of the dowel bar embedded in slab by equating Eq.

Step 2: Find the load transfer capacities ,and of single dowel bar with the

Step 3: Assume load capacity of dowel bar is 40 percent wheel load, find the load capacity factor f as

Step 4: Spacing of the dowel bars.

- ✓ Effective distance upto which effective load transfer take place is given by , where is the radius of relative stiffness.
- ✓ Assume a linear variation of capacity factor of 1.0 under load to 0 at.
- ✓ Assume 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.

3.4 Design Procedure of Rigid Pavements as Per IRC 58

Salient features ofIRC-58-2002

- Computation of flexural stress due to the placement of single and tandem axle loads along the edge.
- Introduction of the cumulative fatigue damage approach in the design.
- Revision of criteria for design of dowel base.
- Design of tie bars.

Factors:

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.
- In flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes differential settlements and pavement roughness.

Precipitation

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

Traffic and Loading

- 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

- The thickness is governed by the number of repetitions of a standard axle load.
- The axle load is not a standard one, and 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 determines the contact area and the contact pressure between the wheel and the pavement surface.
- The shape of the contact area is elliptical, for sake of simplicity in analysis, a circular area is often considered.

Wheel load:

- To determines the depth of the pavement required to ensure that the sub grade 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.