MODULE-1

Introduction to pavement design

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. The ultimate aim is to ensure that the transmitted stresses due to wheel load are sufficiently reduced, so that they will not exceed bearing capacity of the sub grade. Two types of pavements are generally recognized as serving this purpose, namely flexible pavements and rigid pavements. This chapter gives an overview of pavement types, layers, and their functions, and pavement failures. Improper design of pavements leads to early failure of pavements affecting the ridingquality.

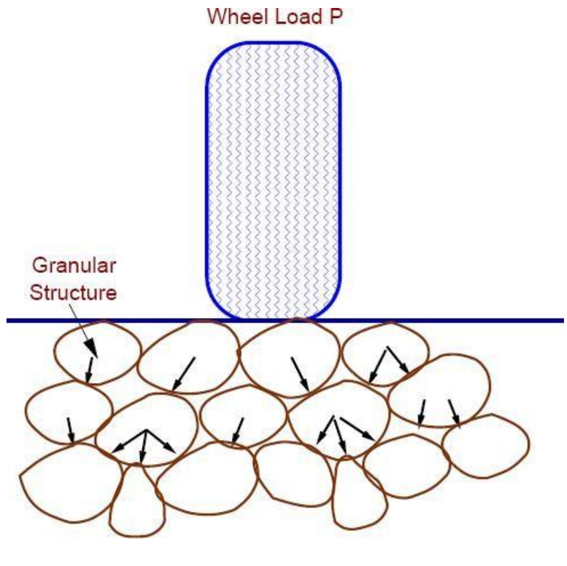
Requirements of a pavement

An ideal pavement should meet the following requirements:

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

cost. **Types of pavements**

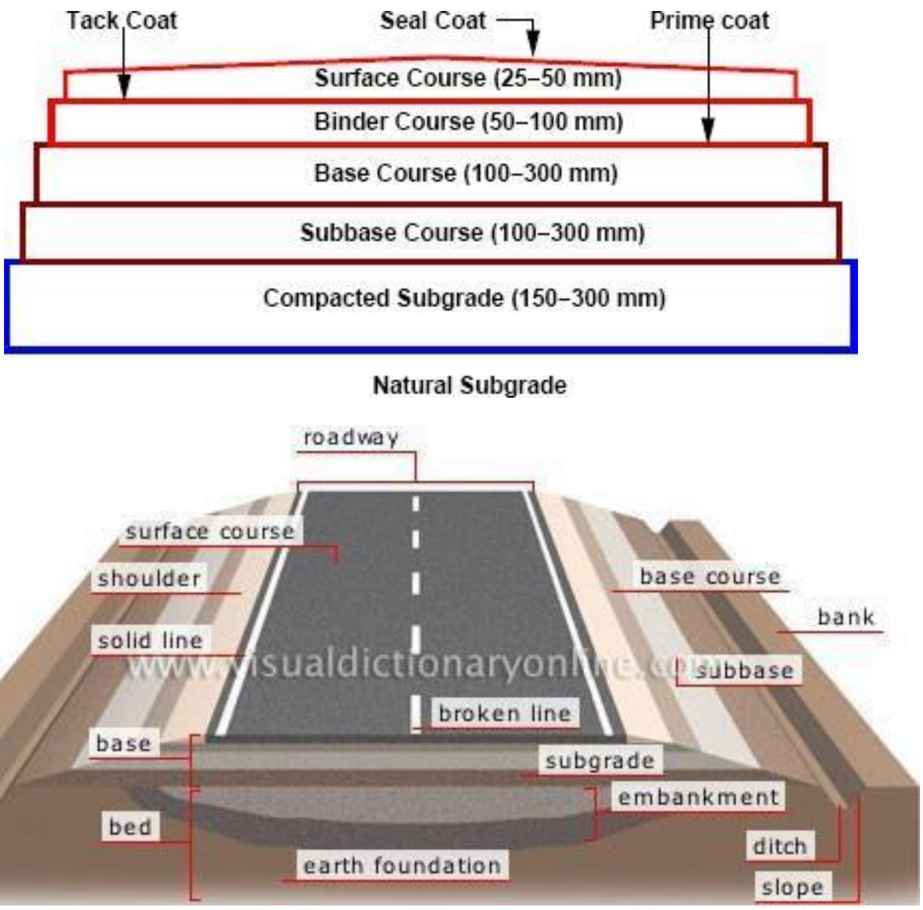
The pavements can be classified based on the structural performance into two, flexible pavements and rigid pavements. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure. The flexible pavement, having less flexural strength, acts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



Load transfer in granular structure

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 (see Figure 19:1). The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of these stress distribution characteristic, flexible pavements normally has many layers. Hence, the design of flexible pavement uses the concept of layered system. Based on this, flexible pavement may be constructed in a number of layers and the top layer has to be of best quality to sustain maximum compressive stress, in addition to wear and tear. The lower layers will experience lesser magnitude of stress and low quality material can be used. Flexible pavements are constructed using bituminous materials. These can be either in the form of surface treatments (such as bituminous surface treatments generally found on low volume roads) or, asphalt concrete surface courses (generally used on high volume roads such as national highways). Flexible pavement layers reflect the deformation of the lower layers on to the surface layer (e.g., if there is any undulation in sub-grade then it will be transferred to the surface layer). In the case of flexible pavement, the design is based on overall performance of flexible pavement, and the stresses produced should be kept well below the allowable stresses of each pavement layer.



Typical cross section of a exible pavement

Types of Flexible Pavements

The following types of construction have been used in flexible pavement:

- ✓ Conventional layered flexible pavement,
- ✓ Full - depth asphalt pavement, and

- ✓ Contained rock asphalt mat (CRAM).

Conventional flexible pavements are layered systems with high quality expensive materials are placed in the top where stresses are high, and low quality cheap materials are placed in lower layers.

Full - depth asphalt pavements are constructed by placing bituminous layers directly on the soil sub grade. This is more suitable when there is high traffic and local materials are not available.

Contained rock asphalt mats are constructed by placing dense/open graded aggregate layers in between two asphalt layers. Modified dense graded asphalt concrete is placed above the sub-grade will significantly reduce the vertical compressive strain on soil sub-grade and protect from surface water.

Typical layers of a flexible pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure 19:2). **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 layers 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

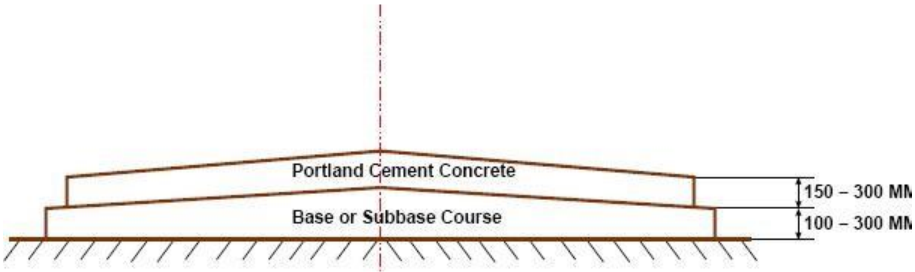
The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines 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, 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

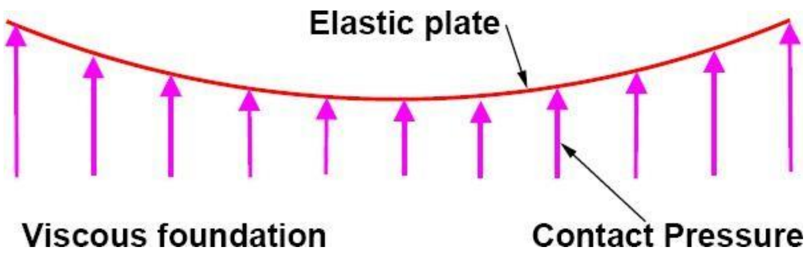
The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

Failure of flexible pavements

The major flexible pavement failures are fatigue cracking, rutting, and thermal cracking. The fatigue cracking of flexible pavement is due to horizontal tensile strain at the bottom of the asphaltic concrete. The failure criterion relates allowable number of load repetitions to tensile strain and this relation can be determined in the laboratory fatigue test on asphaltic concrete specimens. Rutting occurs only on flexible pavements as indicated by permanent deformation or rut depth along wheel load path. Two design methods have been used to control rutting: one to limit the vertical compressive strain on the top of sub grade and other to limit rutting to a tolerable amount (12 mm normally). Thermal cracking includes both low- temperature cracking and thermal fatigue cracking.



Typical Cross section of Rigid pavement



Elastic plate resting on viscous foundation

Rigid pavements:

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

A typical cross section of the rigid pavement is shown in Figure 19:3. 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. In rigid pavement, load is distributed by the slab action, and the pavement behaves like an elastic plate resting on a viscous medium (Figure 19:4). Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory, assuming an elastic plate resting on viscous foundation. Plate theory is a simplified version of layer theory that assumes the concrete slab as a medium thick plate which is plane before loading and to remain plane after loading. Bending of the slab due to wheel load and temperature variation and the resulting tensile and flexural stress.

Types of Rigid Pavements

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

Jointed Plain Concrete Pavement is plain cement concrete pavements constructed with closely spaced Contraction joints. Dowel bars or aggregate interlocks are normally used for load transfer across joints. They Normally have a joint spacing of 5 to 10m.

Jointed Reinforced Concrete Pavement: Although reinforcements do not improve the structural capacity Significantly, they can drastically increase the joint spacing to 10 to 30m. Dowel bars are required for load Transfer. Reinforcement's help to keep the slab together even after cracks.

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

Failure criteria of rigid pavements

Traditionally fatigue cracking has been considered as the major or only criterion for rigid pavement design.

The allowable number of load repetitions to cause fatigue cracking depends on the stress ratio between flexural tensile stress and concrete modulus of rupture. Of late, pumping is identified as an important failure Criterion.

Pumping is the ejection of soil slurry through the joints and cracks of cement concrete pavement, caused during the downward movement of slab under the heavy wheel loads. Other major types of distress in rigid pavements include faulting, spalling, and deterioration.

Difference between Highway pavement and air field pavement

	Highway pavement	Air field pavement
Volume of the trafffic	Highway pavement are typically constructed to support a high volume of auto mobile and truck traffic	The majority of airport pavement see only a few dozen aircraft passesper day
Repetition of loads	The no. Repetition of load is about 1000 to 2000 trucks per day per lane	The no. Of repetition considerably less. i.e., 20000 to 40000
Distresses type	Highway pavement are more prone to lead associated distresses types, such as rutting and fatigue cracking	Airport pavement predominantly exhibit environmental associated distresses types such as weathering, raveling and cracking.
Gross load	It is less around 20tonnes for dual tandem wheels	Gross load on the airport pavement is greater than

		on a highway pavement is about 80 to 250tonnes
Application of loads	The major portion of load is applied just several feet from the edge of the rigid highway pavement	Loads are primarily applied on the centre of the air field slabs.
Tyre pressure	Highway pavement can with stand a tyre pressure up to 4 to 7 kg/cm^2	The tyre pressure of air craft pavement is much greater than highway vehicles upto 25 to 30 kg/cm^2
Design criteria	The design of highway pavement is based on moving load with the loading duration as an input for visco elastic behaviour	The design of air port pavement is basede on moving load in the interior of runway but stationary load at the end of run way. As a result, thicker pavement is used at the runway end than in the interior.
Major failure	Puming can be major problem on highway	Pumping is of less importance for rigid air field pavement
Width of pavement	Width of highway pavement depends upon the no. Lanes and the no. Lanes depends on the traffic intensity. Usual width of the two way pavement is 7m	Width of air port pavement depends upon the class of the air port, type of the area in operation and standard clearance value. The width of air way pavement ranges from 13-60m.
Design wheel load	Design wheel load is about 5.1 tonnes.	Desig wheel load about 50 tonnes.

Difference between Rigid pavement and flexible pavement

FEATURE	**FLEXIBLE PAVEMENT**	**RIGID PAVEMENT**
Flexural strength	Negligible or very low	Very high
Design principle	Layered system concept	Plate theory concept
Stress	Compressive stress	Tensile stress and temperature stress
Transfer of stress	Grain to grain transfer and deformation on the top is reflected on bottom layer	No such transfer and deformation. If any, it is not reflected below
Material	Granular material, load spreading ability depends upon the type of material	Portland cement concrete capable of transmitting load stress through a wider

	and thickness. Distribute the load in the form of a truncated cone	area below
Design life	Flexible pavement are genaerally designed and constructed for a design life of 15 years	Cc pavement of major rads are generallly designed and constructed for 30years period
Curing period	The curing period of bituminous surface course is less and hence the surface can be opened to traffic with in 24 hours	Generally a long curing period of 28days is required befor eopening to traffic
Night visibility	Night visibility of bituminous surface is very poor, particularly under wet weather condition	Good visibility even under wet weather condition
Life cycle cost	For long service life, the life cycle cost of flexible pavement are higher than CC pavement	The life cycle cost of CC pavement are much lower than that of flexible pavement
Total thickness of pavement	Higher than CC pavement particularly for the construction of highway passing through weak subgrade soil and carrying heavy traffic load	Lower than flexible pavement
Durability	Less durable	More durable

DESIGN STATERGIES OF VARIABLES

In order to complete a pavement design, numerous variables must be determined.

✓ **Pavement performance**

The initial and terminal serviceability of the pavement are required inputs. Serviceability is a measure of functional level services at a given point in time of the life of a pavement. In addition to serviceability, the pavement service life, or period of performance, for a pavement must be established.

✓ **Traffic**

Accurate cumulative load estimates are very important to pavement structural design. Load estimates should be based on vehicle counts and classification, truck weight data and anticipated growth in traffic volume and weights.

✓ **Sub grade soil characteristics**

The stiffness and strength of the sub grade soil has significant impact on the structural requirement of a pavement and is one of the most sensitive variables within the flexible pavement design. In areas with soft or expansive soils, consideration of unique design element such as installation of positive flow subsurface drainage , chemical treatment of soil, use of geosynthesis or over excavation should occur.

✓ **Material**

Quality pavement material and construction are essential. All the material should meet the specific requirement.

✓ **Environmental consideration**

The two main environmental factors to be considered are:

Temperature- Temperature affects the stability of bitumen, bitumen oxidation rates, thermal induced cracking, contraction and expansion of PCC pavement.

Rainfall- Rainfall will influence the properties of the sub grade soil, base and surfacing materials.

Factors affecting pavement design:

In the previous chapter we had discussed about the types of pavements and their failure criteria. There are many factors that affect pavement design which can be classified into four categories as traffic and loading, structural models, material characterization, environment. They will be discussed in detail in this chapter.

Traffic and loading

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

Contact pressure: The tyre pressure is an important factor, as it 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 sub grade soil is not failed. Wheel configuration affects the stress distribution and deflection with in 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. Although the pavement deformation due to single axle load is very small, the cumulative effect of number of load repetition is significant. Therefore, modern design is based on total number of standard axle load (usually 80 kN single axle).

Structural models

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

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

Material characterization

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

- ✓ When pavements are considered as linear elastic, the elastic moduli and poisson ratio of sub grade and each component layer must be specified.

- ✓ If the elastic modulus of a material varies with the time of loading, then the resilient modulus, which is elastic modulus under repeated loads, must be selected in accordance with a load duration corresponding to the vehicle speed.
- ✓ When a material is considered non-linear elastic, the constitutive equation relating the resilient modulus to the state of the stress must be provided. However, many of these material properties are used in visco-elastic models which are very complex and in the development stage. This book covers the layered elastic model which requires the modulus of elasticity and poisson ratio only.

Environmental factors:

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

Temperature

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

Precipitation

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

Assumption for boussinesq's

Boussinesq's theory formula is based on following assumptions.

1. The soil mass is semi-infinite, homogeneous and isotropic.
2. The soil has a linear stress-strain relationship,
3. The soil is weightless.
4. The load is a point load acting on the surface.

Boussineq's theory

Ideal Masses = analysis soil reaction under load by using Mathematical Theory of Elasticity Assumption- Soil is in elasticity material , Homogeneouse , Isotropic , Semi-infinite Medium . Soil prosperities following by Hook's law Unit weight of soil is zero ($\gamma = 0$) , consider only load action over the soil surface. No stress born before load acting. Poisson's Ratio(μ) is constant due to load transfer ; normally using μ =0.5, Linear Stress function distribution.

A ssumption for Burmister

Two layer systems were presented by Burmister, the solutions of stresses and deflections under the center of circular load of the two-layer system by using assumption

1. Soil is homogenous, Isotropic and Elastic
2. Definite in depth and Infinite in the lateral direction
3. This theory can be used Boussinesq's Theory apply in each layers.

4. NO shear stress between each contact layers

Two-layer systems

Flexible Plate Δ = 1.5paF2/E2 (flexible pavement)

• Rigid Plate Δ = 1.18paF2/E2 (concrete pavement)

given p = stress pressure on circular area a = radius of circular load E2 = modulus of elasticity of last layer of soil F2 = factor depended on E2/ E1 and z/a.

F2 is the deflection factor, a function of layer modulus ratio, (E2/ E1) and the layer depth in multiple of contact radius, the values of E2/ E1 are curve and E1 represents the modulus of the upper layer where E2 as the modulus of half space.

Three – Layer System

• The solution for vertical stress was given by Pattie. The horizontal stress solution was obtained from John.

• The problem treated is the axi-symetric type so the stress tensors reduce to only 4components; the vertical normal stress, the horizontal radial normal stress, the circumferential normal and the shearing stress

Important assumptions made in the analysis are as follow:

• The materials are weightless

• The surface of top layer is free of shear stress

• The layers are welded contact.

One –Layer Systems- Boussineq's theory

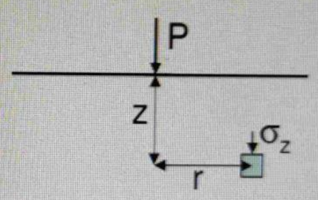
• If, one-layer system is assumed as a homogeneous half space, Boussinesq equations can be applied.

• Half space is an infinite large area with infinite depth with a top plane on which loads are applied.

• Boussinesq's equations are developed for computing stresses in a homogeneous, isotropic and elastic media due to a point load at the surface.

$$\sigma_z = K\frac{P}{z^2}$$

$$K = \frac{3}{2\pi}\frac{1}{\left[1+(r/z)^2\right]^{5/2}}$$



– Stress is independent of the properties of the transmitting medium.

– Maximum stress occurs on the vertical plane passing through the point of load application, on a particular horizontal plane.

– Pressure is maximum at shallow depths, theoretically becoming zero at infinite depth. But, for all practical purposes, σz is taken as zero when z is sufficiently large.

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

• Load is not a point load – it is distributed over an elliptical area. This contact area can be approximated to a circular shape.

- Variation of stress follows the same general pattern
- Vertical stress resulting from uniformly distributed circular load may be obtained by integration of Boussinesq equation.
- Love has obtained the following closed from equation for the vertical stress beneath the centre of the loaded area:
- Newmark has developed charts for foundation work for computing stresses.
- Foster and Alvin (1954) developed charts for computing vertical, tangential and radial stresses. The charts were developed for $\mu = 0.5$.
- This work was subsequently refined by Ahlvin and Ulery (1962) allowing for evaluation of stresses and strains at any point in the homogenous mass for any μ.

- Due to axis symmetry, there are only three normal stresses, σz, σr and σt and one shear stress τ rz .
- One-layer theory can be applied as an approximation for a conventional flexible pavement with granular base/sub base with a thin asphaltic layer on a stiff sub grade comparable to the base/sub base. (i.e., $E1 / E2 \cong 1$)
- The deflection that occurs within the pavement (Δp) is neglected and therefore, the pavement surface deflection (ΔT) is equal to the deflection on the top of sub grade (Δs)

$$\Delta T = \Delta s + \Delta p \quad \Delta p = 0$$

Therefore, $\Delta T = \Delta s$ E1, μ1, h1 E2, μ2, h2 = α ΔT Δp Δs One –Layer Systems Charts for One-layer Solution

Example problems on one-layer Systems

1. A homogeneous half space is subjected to a circular load, 254 mm in diameter. The pressure on the circular area is 345 kPa. The half space has an elastic modulus of 69 MPa and a Poisson's ratio of 0.5. Determine the vertical stress, strain and deflection at point A, which is located 254 mm below and 508 mm away from the centre.

2. A homogeneous half space is subjected to two circular loads, each 254 mm in diameter and spaced at 508 mm on centers. The pressure on the circular area is 345 kPa. The half space has an elastic modulus of 69 MPa and a Poisson's ratio of 0.5. Determine the vertical stress, strain and deflection at point A, which is located 254 mm below the centre of one of the wheels.

Two-layer Systems- burmister’s theory

- ✓ The effect of layers above subgrade is to reduce the stress and deflections in the subgrade.
- ✓ Burmister (1958) obtained solutions for two-layer problem by using strain continuity equations.
- ✓ Vertical stress depends on the modular ratio (i.e., E 1 / E2)
- ✓ Vertical stress decreases considerably with increase in modular ratio.

  For example, for a/h1=1 and E1 / E2 = 1,

  σz at interface = 65% of contact pressure for a/h1=1 and E1 / E2 = 100,

  σz at interface = 8% of contact pressure

Vertical Surface Deflection in a Twolayer System

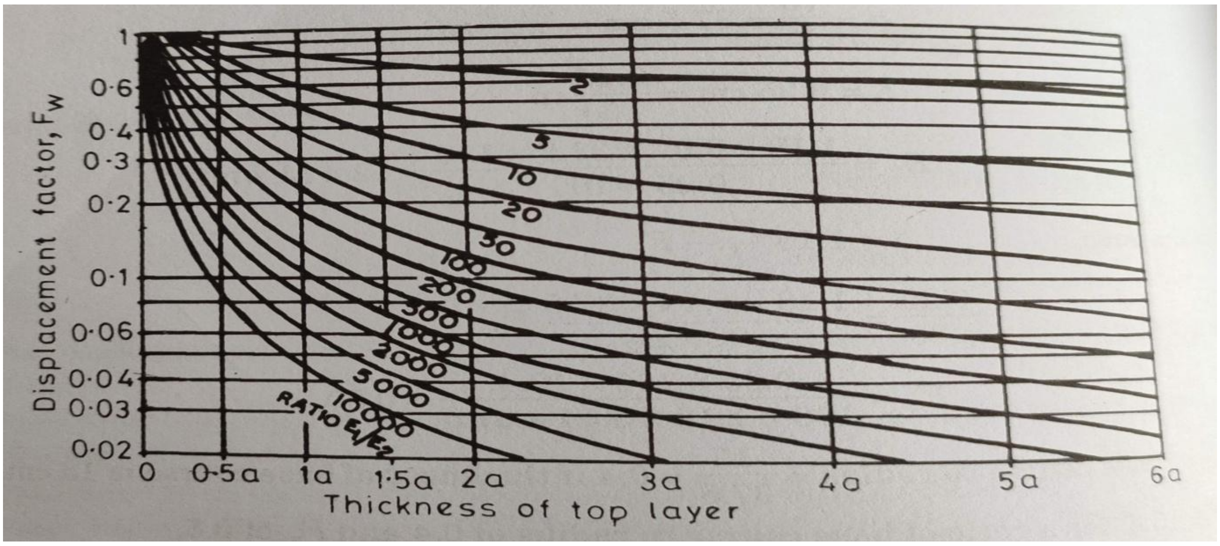
- Burmister (1958) dveloped a chart for computing vertical surface deflection in a two-layer system.
- The deflection factor, F2, is obtained from the chart based on the values of a/ h 1 and E 1 / E2 .

- Then the deflection is computed from the following equations: –

Deflection under a flexible Plate = $\Delta_T = \frac{1.5\,pa}{E_2} F_2$

Deflection under a rigid Plate = $\Delta_T = \frac{1.18\,pa}{E_2} F_2$

Vertical Surface Deflections for Two Layer Systems (Burmister, 1958)



MODULE 2

Factors Influencing Pavement Design

Many factors such as number of vehicles, speed, climatic conditions and other factors affect are to be considered for the design of pavement. In this article we will discuss about the factors influencing pavement design.

Pavements are engineered structures which are used as roads, runways, parking areas, etc. Ground or surface transportation is the most widely used transportation in the world. So, construction of pavements should be done as it is strong and durable for their design life.

Fig 1 : Factors Affecting Pavement Design

Factors Affecting Pavement Design

There are so many factors which influencing the pavement design. The factors may be of loading, environment, materials used etc. Which are as follows.

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

1. Wheel Load Influence on Pavements

Wheel load on pavement is an important factor to determine the pavement thickness to be adopted. By providing adequate thickness, the load coming from wheels doesn't affect the subgrade soil. The wheel load is acts at particular point on pavement and cause deformations. If the vehicle contains dual wheels on one side of axle, then convert it into equivalent single wheel load. Dual wheeled axle vehicles control the contact pressure within the limits

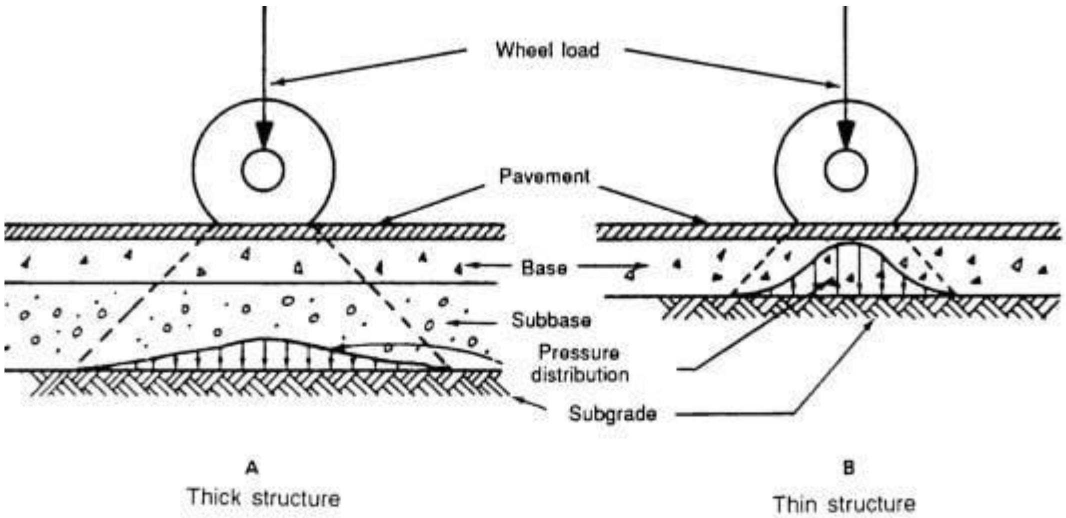


Fig 2 : Wheel Load Influence on Pavement Design

2. Axle Configuration

Axles are the important part of the vehicles which enables the wheels to rotate while moving. By providing multiple axles, vehicle can carry more load. So, the axle load also influences the design of pavement. In the layer theory of flexible pavement design wheels on one side of axles are considered to design the pavement. Similarly in the plate theory of rigid pavement design wheels on both sides are considered

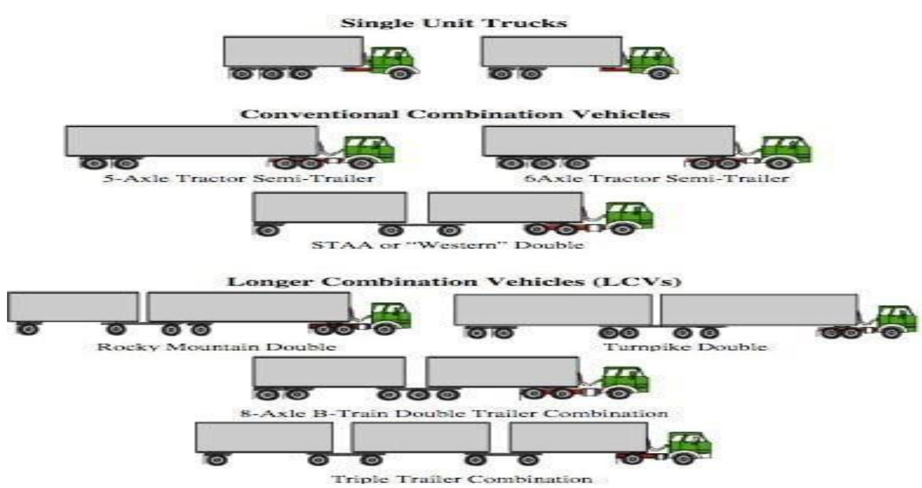


Fig 3: Effect of Axle Configuration on Pavement Design

3. Tire Contact Pressure on Pavement

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

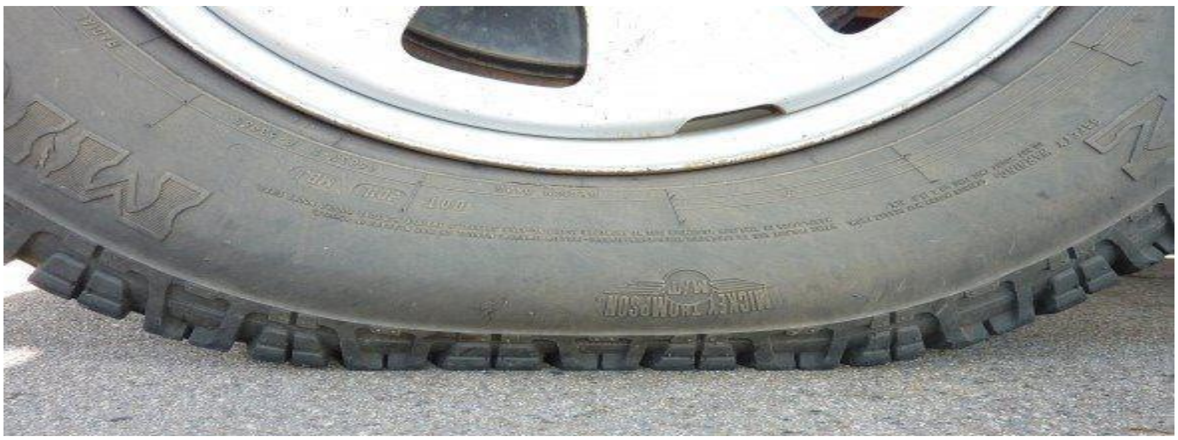


Fig 4: Tire Contact Pressure on Pavement

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

5. Repetition load: Constructed pavement is used by several vehicles in its design life. The wheel loads are repeated all the time due to this some deformation occurs on the pavement. Total deformation is the sum of all wheel loads acting on it. So, in the design of pavement frequency of load is also considered. For the design of pavement, single axle with dual wheels carrying 80 Kn load is considered as standard axle.

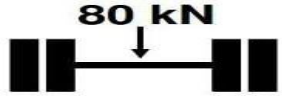


Fig 5: Axle Load on Pavement

6. Subgrade Type

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

Fig 6: Effect of Subgrade Type on Pavement Design

7. Temperature Effects on Pavements Design

Temperature is the important environmental factor to be considered in the design of pavement. In case of asphalt roads, temperature affects the resilient modulus of surface course. In very hot condition asphalt layers lose their stiffness. At low temperature, asphalt layers become brittle and cracks are formed

Fig 7: Temperature Effects on Pavements Design

In case of rigid pavement, temperature stresses are developed. Curling of concrete is also possible due to variation of temperature in top and bottom layers of pavement.

8. Precipitation

Fig 8: Effect of Rain on Pavement Design

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

Design life

The initial and terminal serviceability of the pavement are required inputs. serviceability is a measure of the functional level of service at a given point in time of the life of a pavement. In addition to serviceability, the pavement service life (or) period of performance , for a pavement must be established.

Traffic factors

Accurate cumulative load estimates are very important to pavement structural design. Load estimates should be based on vehicle counts and classification ,truck weight data and anticipated growth in traffic volumes and weights.

Climatic factor

Among the climatic factors, rainfall affects the moisture conditions in the subgrade soil and also the pavement layers. Where freezing conditions are likely to exist during winter the possibility of frost action in the subgrade and the harmful effects should be considered at the design stage itself.

Road geometry

For the design of a pavement, road geometrics such as gradient, radius of curve, sight distance should be given due importance.

Subgrade strength and drainage

The properties of the soil subgrade also play important role in deciding the thickness requirement of the pavement. A weaker subgrade requires thicker pavement to protect it from traffic loads. Change in volume of the subgrade due to change in moisture content is tob be studied as these properties depend largely on the soilcharacteristics. Stress-strain behavior of the subgrade soil under static and repeated loads have also significance.

Water and pavement layers are not good for each other. Maintaining proper drainage within the pavement structure is an important the effects of moisture on the performance of the pavement

Equivalent single wheel load

To carry maximum load with in the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. 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. 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, based on the following assumptions:

- equalancy concept is based on equal stress;
- contact area is circular;
- influence angle is 45 $^\circ$; and
- soil medium is elastic, homogeneous, and isotropic half space.

The ESWL is given by:

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10}\left(\frac{z}{d/2}\right)}{\log_{10}\left(\frac{2S}{d/2}\right)} \qquad (1)$$

where P is the wheel load, S is the center to center distance between the two wheels, d is the clear distance between two wheels, and z is the desired depth.

PROBLEMS

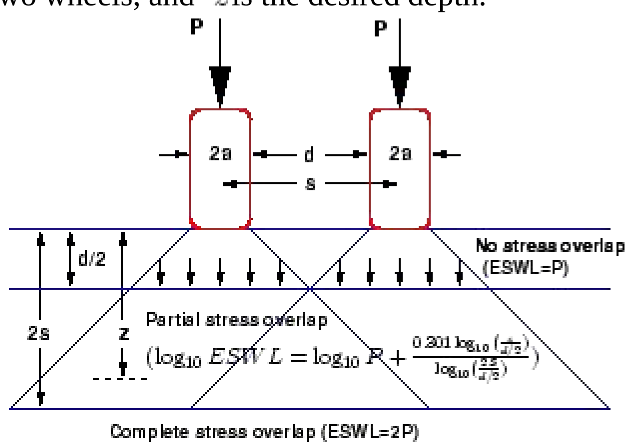


Figure 1: ESWL-Equal stress concept

1) Calculate the ESWL of a dual wheel load assembly carrying 20.44KN load on

pavement thickness of 150mm, 300mm and 450mm. The centre to centre spacing of tyres=300mm and the distance between the walls of the tyresis 110mm.

SOLUTION:

P=20.44KN

S=300mm=30cm

D=110mm=11cm

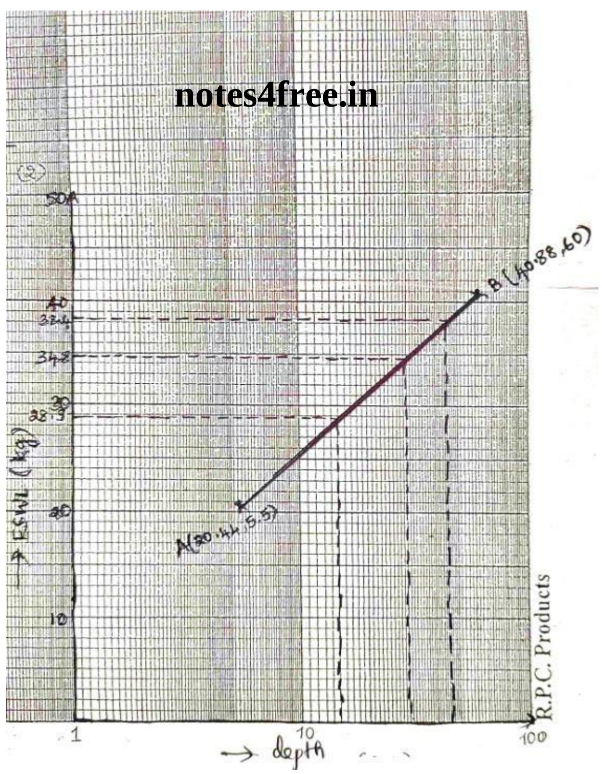
Now, 2P=2x20.44=40.88KN

2S=2x30=60cm

d/2=11/2=5.5cm

The co-ordinates are A= (P, d/2) = (20.44, 5.5)

B= (2P, 2S) = (40.88, 60)



Thickness of pavement,cm	ESWL (KN)

15	28.9
30	34.8
45	38.4

2)A dual wheel load assembly with load on each wheel of 70KN with a contact pressureof $0.75N/mm^2$ has c/c distance of 600mm. determine the ESWL by graphical method for pavement thickness of 600mm and 800mm.

SOLUTION:

P=70KN

S=600mm=60cm

Contact pressure=wheel load/area of imprint

$0.75=70x10^3/(\pi*a^2)$

a=172.36mm

Also, S=d+2a

d=S-2a=600-2x172.36=255.23mm

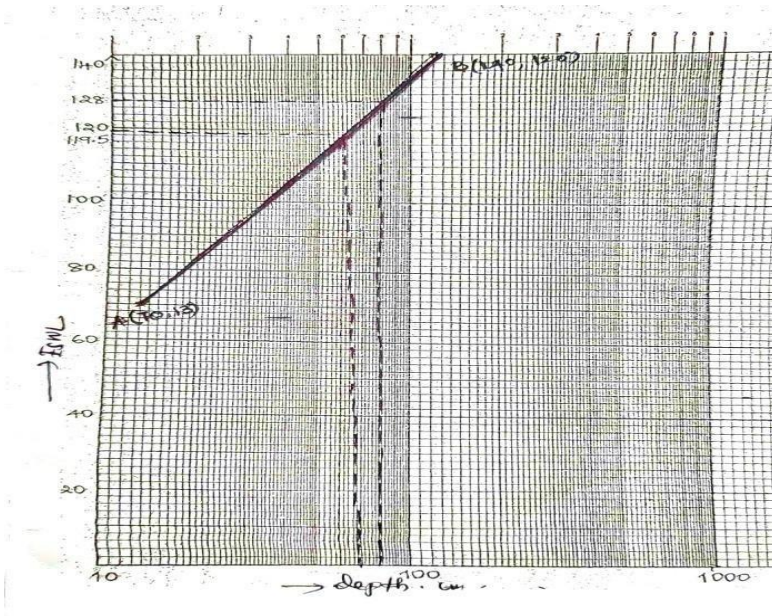
Now, 2P=2x70=140KN

2S=2x60=120cm

d/2=255.28/2=127.64mm=12.76cm=13cm

The co-ordinates are A= (P, d/2) = (70, 13)

B= (2P, 2S) = (140, 120)



Thickness of pavement,cm	ESWL (KN)
60	119.5
80	128.0

EQUIVALENT WHEEL LOAD FACTOR (EWLF)

Equivalent wheel load is a single wheel load equivalent to the repeated application of any particular wheel load on pavement which requires the same thickness and strength of pavement.

If a particular pavement structure fails with N number f repetitions of load $P_{1\ kg}$ and similarly, if N_2 number of repetitions of load P_2 kg can also cause failure of the same pavement structure, then P_1N_1 and P_2 N_2 are considered equivalent.

Based on the experience gained after the AASHO road tests and analysis, “Equivalent wheel load factors (or) Equivalent axle load factors” for vehicles with single axles and tandem axles were generated.

WHEEL LOAD,kg	REPETITIONS TO FAILURE,number	EQUIVALENT TO 2268kg	EQUIVALENT WHEEL LOAD FACTOR, kg
2268	1,05,000	1.0	1
2722	50,000	2.0	2
3175	22,500	4.7	4

3629	13,000	8.2	8
4082	6,500	16.3	16
4536	3,300	32.0	32
4990	1,700	62.0	64
5443	1,000	105.0	128

Generally accepted approach for the conversion of axle loads of different magnitudes in terms of a standard axle is represented as below and is called as the 'fourth power law'

Equivalent wheel load factor = (given wheel load/standard wheel load)^4

EWLF=(P1/p)4

PROBLEMS ON EWLF

1) Determine the equivalent wheel load factor of the following two axle loads in terms of the standard axle load of 8.16t. (a) LCV with rear axle load of 2.0t (b)HCV with rear axle load of 15.5t

   EWLF= $(P_1/p)^4$

(a)EWLF of LCV = $(2.0/8.06)^4$ =0.036

(b) EWLF of HCV= $(15.5/8.16)^4$ =13.02

FLEXIBLE PAVEMENT DESIGN:

ASSUMPTION

- It is not possible to have rational method of design where in the design process and serviceability behavior of pavement is expressed . in flexible pavement design, they are predicted theoretically by mathematical laws. It is one of the limitation of flexible pavement design.
- In flexible pavements, under the application of load , none of the layers are overloaded i.e., at any given instance, no section of the pavement structure is subjected to excessive deformation to form differential settlement.
- Some of the methods are directly based on soil classification and California reistance value, which may be estimated by sieve analysis, CBR test, plate bearing test depending upon the conditions of the soil. Here the thickness required is directly estimated using the results obtained from the experiments under ideal conditions.

MCLEOD METHOD

The Canadian department of transport conducted extensive plate bearing tests to investigate the stability of airfields and pavement under the direction of norman W.Mcleod. the tests were made on surface , base course and subgrade etc.., at large number of locations. On the basis of his test results, he developed a definite design method which is known as Mcleaod method after his name.

Plate Load Test Procedure

The necessary steps to perform plate load test is written below-

1. Excavate test pit up to the desired depth. The pit size should be at least 5 times the size of the test plate (B_p).
2. At the center of the pit, a small hole or depression is created. Size of the hole is same as the size of the steel plate. The bottom level of the hole should correspond to the level of actual foundation. The depth of the hole is created such that the ratio of the depth to width of the hole is equal to the ratio of the actual depth to actual width of the foundation.
3. A mild steel plate is used as load bearing plate whose thickness should be at least 25 mm thickness and size may vary from 300 mm to 750 mm. The plate can be square or circular. Generally, a square plate is used for square footing and a circular plate is used for circular footing.
4. A column is placed at the center of the plate. The load is transferred to the plate through the centrally placed column.
5. The load can be transferred to the column either by gravity loading method or by truss method.

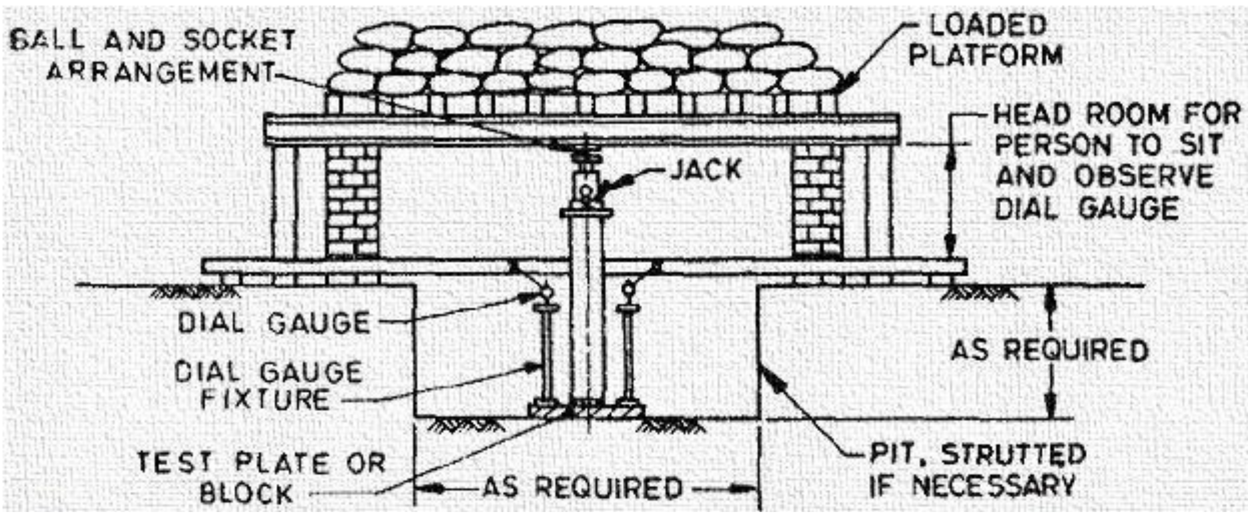


Figure: Test Setup for Plate Load Test

6. For gravity loading method a platform is constructed over the column and load is applied to the platform by means of sandbags or any other dead loads. The hydraulic jack is

placed in between column and loading platform for the application of gradual loading. This type of loading is called reaction loading.

7. At least two dial gauges should be placed at diagonal corners of the plate to record the settlement. The gauges are placed on a platform so that it does not settle with the plate.
8. Apply seating load of .7 T/m^2 and release before the actual loading starts.
9. The initial readings are noted.
10. The load is then applied through hydraulic jack and increased gradually. The increment is generally one-fifth of the expected safe bearing capacity or one-tenth of the ultimate bearing capacity or any other smaller value. The applied load is noted from pressure gauge.
11. The settlement is observed for each increment and from dial gauge. After increasing the load-settlement should be observed after 1, 4, 10, 20, 40 and 60 minutes and then at hourly intervals until the rate of settlement is less than .02 mm per hour. The readings are noted in tabular form.
12. After completing of the collection of data for a particular loading, the next load increment is applied and readings are noted under new load. This increment and data collection is repeated until the maximum load is applied. The maximum load is generally 1.5 times the expected ultimate load or 3 times of the expected allowable bearing pressure.

Calculation of Bearing Capacity from Plate Load Test

After collection of field data, the load-settlement curve is drawn. It is a logarithmic graph where the load applied is plotted on X-axis and settlement in Y-axis. From the graph, the ultimate load for the plate is obtained which is the corresponding load for settlement of one-fifth of the plate width.

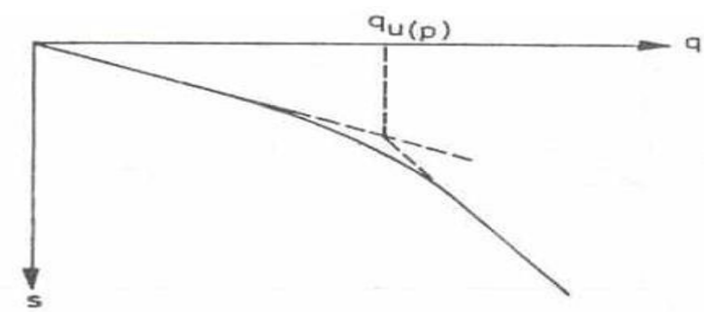


Figure: Load-settlement graph

When the points are plotted on the graph, the curve is broken at one point. The corresponding load to that breakpoint is considered to be the ultimate load on the plate. The ultimate bearing capacity can be calculated from the ultimate load from the plate. The ultimate bearing capacity is then divided by a suitable factor of safety to determine the safe bearing capacity of soil from the foundation.

CBR METHOD

The Californian Bearing Ratio (CBR) test is a penetration test used to evaluate the subgrade strength of roads and pavements. The results of these tests are used with the curves to determine the thickness of pavement and its component layers. This is the most widely used method for the design of flexible pavement.

The CBR test was developed by the California Division of Highways to classify and evaluate soil-sub grade and base coarse materials for flexible pavements. An empirical test, the CBR test has been used to determine the material properties for pavement design. Empirical tests measure the strength of the material and are not a true representation of the resilient modulus. It is a penetration test in which a standard piston, with a diameter of 50 mm (1.969 in), is used to penetrate the soil at a standard rate of 1.25 mm/minute. The pressure up to a penetration of 2.5 mm is measured and its ratio to the bearing value of a standard crushed rock is termed as the CBR.

Although the force increases with the depth of penetration, in most cases, it does not increase as quickly as it does for the standard crushed rock, so the ratio decreases. In some cases, the ratio at 5 mm may be greater than that at 2.5 mm. If this occurs, the ratio at 5 mm should be used. The CBR is a measure of resistance of a material to penetration of a standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered to if a high degree of reproducibility is desired. The CBR test may be conducted on a remolded or undisturbed specimen in the laboratory. The test is simple and has been extensively investigated for field correlations of flexible pavement thickness requirement.

The laboratory CBR apparatus consists of a mould of 150 mm diameter with a base plate and a collar, a loading frame and dial gauges for measuring the penetration values and the expansion on soaking. If a soaked (wet) measurement is desired, the specimen in the mould is soaked in water for four days and the swelling and water absorption values are noted. The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading frame.

Load is applied on the sample by a standard plunger with diameter 50 mm at the rate of 1.25 mm/min. A load penetration curve is drawn. The load values on standard crushed stones are 1,370 kgf (13.44 kN) and 2,055 kgf (20.15 kN) at 2.5 mm and 5.0 mm penetrations respectively.

The CBR value is expressed as a percentage of the actual load causing the penetrations of mm or 5.0 mm to the standard loads mentioned above. The CBR can therefore be mathematically expressed as:

The area of the standard piston is 3.04 in^2, so the results are sometimes converted to pounds per square inch by dividing by 3.

IRC METHOD

Overview

Indian roads congress has specified the design procedures for flexible pavements based on CBR values. The Pavement designs given in the previous edition IRC:37-1984 were applicable to design traffic upto only 30 million standard axles (msa). The earlier code is empirical in nature which has limitations regarding applicability and extrapolation. This guidelines follows analytical designs and developed new set of designs up to 150 msa in IRC:37-2001.

Scope: These guidelines will apply to design of flexible pavements for Expressway, National Highways, State Highways, Major District Roads, and other categories of roads. Flexible pavements are considered to include the pavements which have bituminous surfacing and granular base and sub-base courses conforming to IRC/ MOST standards. These guidelines apply to new pavements.

Design criteria: The flexible pavements has been modeled as a three layer structure and stresses and strains at critical locations have been computed using the linear elastic model. To give proper consideration to the aspects of performance, the following three types of pavement distress resulting from repeated (cyclic) application of traffic loads are considered:

1. vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
2. horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
3. pavement deformation within the bituminous layer.

While the permanent deformation within the bituminous layer can be controlled by meeting the mix design requirements, thickness of granular and bituminous layers are selected using the analytical design approach so that strains at the critical points are within the allowable limits. For calculating tensile strains at the bottom of the bituminous layer, the stiffness of dense bituminous macadam (DBM) layer with 60/70 bitumen has been used in the analysis.

Failure Criteria

Critical locations in pavement:A and B are the critical locations for tensile strains (ϵ_t). Maximum value of the strain is adopted for design. C is the critical location for the vertical subgrade strain (ϵ_z) since the maximum value of the (ϵ_z) occurs mostly at C. *Fatigue Criteria:* Bituminous surfacings of pavements display flexural fatigue cracking if the tensile strain at the bottom of the bituminous layer is beyond certain limit. The relation between the fatigue life of the pavement and the tensile strain in the bottom of the bituminous layer was obtained as

$$N_f = 2.21 \times 10^{-4} \times \left(\frac{1}{\epsilon_t}\right)^{3.89} \times \left(\frac{1}{E}\right)^{0.854} \quad (1)$$

in which, N_f is the allowable number of load repetitions to control fatigue cracking and E is the Elastic modulus of bituminous layer. The use of equation would result in fatigue cracking of 20% of the total area. *Rutting Criteria* The allowable number of load repetitions to control permanent deformation can be expressed as

$$N_r = 4.1656 \times 10^{-8} \times \left(\frac{1}{\epsilon_z}\right)^{4.5337} \quad (2)$$

Where,

N_r is the number of cumulative standard axles to produce rutting of 20 mm.

Design procedure

Based on the performance of existing designs and using analytical approach, simple design charts and a catalogue of pavement designs are added in the code. The pavement designs are given for subgrade CBR values ranging from 2% to 10% and design traffic ranging from 1 msa to 150 msa for an average annual pavement temperature of 35 C. The later thicknesses obtained from the analysis have been slightly modified to adapt the designs to stage construction. Using the following simple input parameters, appropriate designs could be chosen for the given traffic and soil strength:

- Design traffic in terms of cumulative number of standard axles; and
- CBR value of subgrade.

Design traffic

The method considers traffic in terms of the cumulative number of standard axles (8160 kg) to be carried by the pavement during the design life. This requires the following information:

1. Initial traffic in terms of CVPD
2. Traffic growth rate during the design life
3. Design life in number of years
4. Vehicle damage factor (VDF)
5. Distribution of commercial traffic over the carriage way.

Initial traffic Initial traffic is determined in terms of commercial vehicles per day (CVPD). For the structural design of the pavement only commercial vehicles are considered assuming laden weight of three tonnes or more and their axle loading will be considered. Estimate of the initial daily average traffic flow for any road should normally be based on 7-day 24-hour classified traffic counts (ADT). In case of new roads, traffic estimates can be made on the basis of potential land use and traffic on existing routes in the area. **Traffic growth rate** Traffic growth rates can be estimated (i) by studying the past trends of traffic growth, and (ii) by establishing econometric models. If adequate data is not available, it is recommended that an average annual growth rate of 7.5 percent may be adopted. **Design life** For the purpose of the pavement design, the design life is defined in terms of the cumulative number of standard axles that can be carried before strengthening of the pavement is necessary. It is recommended that pavements for arterial roads like NH, SH should be designed for a life of 15 years, EH and urban roads for 20 years and other categories of roads for 10 to 15 years. **Vehicle Damage Factor** The vehicle damage factor (VDF) is a multiplier for converting the number of commercial vehicles of different axle loads and axle configurations to the number of standard axle-load repetitions. It is defined as equivalent number of standard axles per commercial vehicle. The VDF varies with the axle configuration, axle loading, terrain, type of road, and from region to region. The axle load equivalency factors are used to convert different axle load repetitions into equivalent standard axle load repetitions. For these equivalency factors refer IRC:37 2001. The exact VDF values are arrived after extensive field surveys.

Vehicle distribution

A realistic assessment of distribution of commercial traffic by direction and by lane is necessary as it directly affects the total equivalent standard axle load application used in the design. Until reliable data is available, the following distribution may be assumed.

- **Single lane roads:** Traffic tends to be more channelized on single roads than two lane roads and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.
- **Two-lane single carriageway roads:** The design should be based on 75 % of the commercial vehicles in both directions.
- **Four-lane single carriageway roads:** The design should be based on 40 % of the total number of commercial vehicles in both directions.
- **Dual carriageway roads:** For the design of dual two-lane carriageway roads should be based on 75 % of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four-lane carriageway the distribution factor will be 60 % and 45 % respectively.

Design traffic

The design traffic is considered in terms of the cumulative number of standard axles in the lane carrying maximum traffic during the design life of the road. This can be computed using the following equation:

$$N = \frac{365 \times [(1+r)^n - 1]}{r} \times A \times D \times F \quad (3)$$

where N is the cumulative number of standard axles to be catered for the design in terms of million standards axle (msa), A is the initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day, D is the lane distribution factors, F is the vehicle damage factor, n is the design life in years, and r is the annual growth rate of commercial vehicles (r =-0.075 if growth rate is 7.5 percent per annum). The traffic in the year of completion is estimated using the following formula:

$$A = P(1 + r)^x \quad (4)$$

where p is the number of commercial vehicles as per last count, and x is the number of ears between the last count and the year of completion between the last count and the year of completion of the project.

Pavement thickness design charts

For the design of pavements to carry traffic in the range of 1 to 10 msa, use chart 1 and for traffic in the range 10 to 150 msa, use chart 2 of IRC:37 2001. The design curves relate pavement thickness to the cumulative number of standard axles to be carried over the design life for different sub-grade CBR values ranging from 2 % to 10 %. The design charts will give the total thickness of the pavement for the above inputs. The total thickness consists of granular sub-base, granular base and bituminous surfacing. The individual layers are designed based on the the recommendations given below and the subsequent tables.

Pavement composition

Sub-base Sub-base materials comprise natural sand, gravel, laterite, brick metal, crushed stone or combinations thereof meeting the prescribed grading and physical requirements. The sub-base material should have a minimum CBR of 20 % and 30 % for traffic upto 2 msa and traffic exceeding 2 msa respectively. Sub-base usually consist of granular or WBM and the thickness should not be less than 150 mm for design traffic less than 10 msa and 200 mm for design traffic of 1:0 msa and above. **Base** The recommended designs are for unbounded granular bases which comprise conventional water bound macadam (WBM) or wet mix macadam (WMM) or equivalent confirming to MOST specifications. The materials should be of good quality with minimum thickness of 225 mm for traffic up to 2 msa an 150 mm for traffic exceeding 2 msa. **Bituminous surfacing** The surfacing consists of a wearing course or a binder course plus wearing course. The most commonly used wearing courses are surface dressing, open graded premix carpet, mix seal surfacing, semi-dense bituminous concrete and bituminous concrete. For binder course, MOST specifies, it is desirable to use bituminous macadam (BM) for traffic upto o 5 msa and dense bituminous macadam (DBM) for traffic more than 5 msa.

Numerical example

Design the pavement for construction of a new bypass with the following data:

1. Two lane carriage way
2. Initial traffic in the year of completion of construction = 400 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 vehicle
6. Design CBR of subgrade soil = 4%.

Solution

1. Distribution factor = 0.75

2.
$$
\begin{aligned}
N &= \frac{365 \times [(1+0.075)^{n} - 1)]}{0.075} \times 400 \times 0.75 \times 2.5 \\
&= 7200000 \\
&= 7.2\, msa
\end{aligned}
$$

3. Total pavement thickness for CBR 4% and traffic 7.2 msa from IRC:37 2001 chart1 = 660 mm
4. Pavement composition can be obtained by interpolation from Pavement Design Catalogue (IRC:37 2001).
    1. Bituminous surfacing = 25 mm SDBC + 70 mm DBM
    2. Road-base = 250 mm WBM
    3. sub-base = 315 mm granular material of CBR not less than 30 %

MODULE 3

TYPES OF FAILURE

1. Alligator Cracking of Flexible Pavements

Alligator cracks are also called as map cracking. This is a fatigue failure caused in the asphalt concrete. A series of interconnected cracks are observed due to such distress.The tensile stress is maximum at the asphalt surface (base). This is the position where the cracks are formed, i.e. the area with maximum tensile stress. A parallel of longitudinal cracks will propagate with time and reaches the surface. Repeated loading and stress concentration will help the individual cracks to get connected. These will resemble as a chicken wire or similar to the alligator skin. This is termed as the alligator cracking. It is also known as the crocodile cracking.These cracking is observed only in areas that have repeated traffic loading. Alligator cracking is one of the major structural distress. This distress is later accompanied by rutting. The figure-1 below shows alligator cracks formed in the pavement.

Fig.1: Alligator Cracks Formed in Flexible Pavements

2. Depressions in Flexible Pavements: There are certain areas in the pavement that are localized and have a lower elevation compared to the surrounding pavement level. These lowering are depressions found on the pavement. They are mainly noticed only when they are filled with water (After rain).Depressions in flexible pavements are a very common distress found in parking lot construction as well as in overlays. These depressions can be caused either by the foundation soil settlement due to continuous loading or it can be formed during the construction.There are different severity levels that are considered for the depression in the flexible pavement that is constructed for airfield purposes.

Fig.2: Depression Distress

3. Corrugations in Flexible Pavements: The corrugations are distress seen in the pavement at regular intervals in the form of ridges and valleys. These are usually less than 5 feet, along with the direction of the pavement.The ridges form of corrugations will be perpendicular to the traffic direction. Unstable pavement plus traffic will create such distress. Where the traffic starts and stops, this distress are observed.

4. Shoving:A form of plastic movement that is seen in the form of the wave is called as shoving distress. These are also observed perpendicular to the direction of the traffic.

Fig.4: Shoving

5. Potholes

In road surfaces where a portion of the same has broken away, cause a disruption by forming a pothole. These are also called as a kettle. In the Western United States, these are known as chuckhole. The pavement fatigue is the main reason behind the formation of potholes. The occurrence of fatigue cracking will interlock to form alligator cracking. These chunks between the cracks formed in the pavement will become loose and will be picked out under continuous loading and stresses. This will leave a pothole on the pavement. In cold temperatures, the water trapped in the pothole will carry out the freezing and thawing action that leads to additional stresses and crack propagation.

Once the pothole is formed, the distress grows resulting in the continuous removal of pavement chunks. Water entrapped will increase this rate of expansion of distress. The pothole can expand to several feet in width. They don’t develop too much in depth. The vehicle tires are damaged due to large potholes.

Fig.5: Potholes in Pavement

6. Rutting of Flexible Pavements: The depression formed in the surface is called the rutting. This is formed in the wheel path surface. This depression will make the other sides of the wheel to undergo uplift as shown in the figure-6. This pavement uplift is also called as shearing.These ruts like depressions are evident after rain. Where these depressions would be filled with water. There are two types of rutting that can occur;

- Pavement Rutting
- Subgrade Rutting

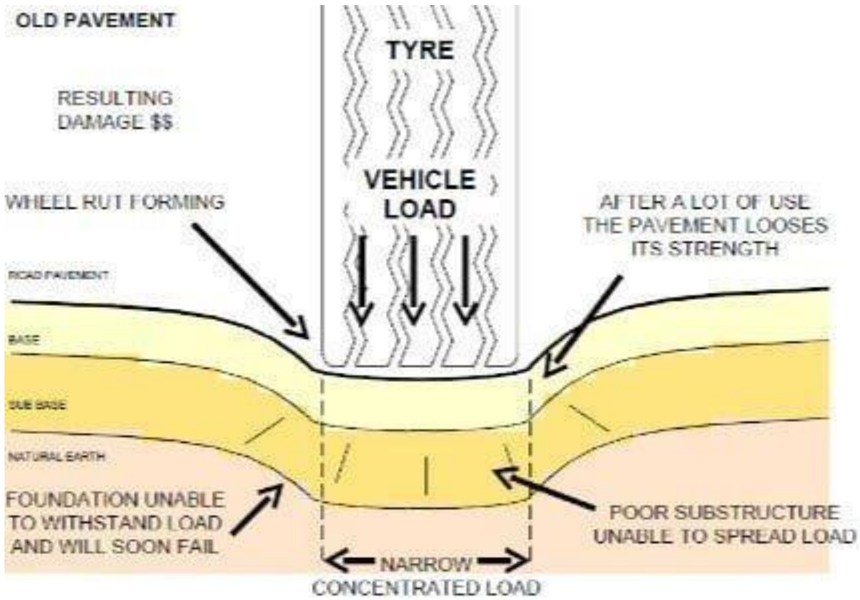


Fig.6: Showing the Rutting Formation under Vehicular Load

Fig.6: Real-Time Formation of Ruts

7. Swelling of Flexible Pavements

These are distress that long and gradual wave. These can be ten feet long. The swelling distress is characterized by the upward bulge in the pavement surface. Surface cracking is the next series of distress that is seen after swelling.The main reason behind swelling in flexible pavement is the frost action in the subgrade. Where frosting results in the swelling of the soil.

Fig.7: Swelling in Road Pavements

CAUSES OF FLEXIBLE PAVEMENT

The 3 common causes of failure of flexible pavement are as follow

1. Failure of subgrade
2. Failure of sub-base or base course
3. Failure of surface or wearing course

1. FAILURE OF SUBGRADE

This is the main cause of flexible pavement failure. When there is excessive deformation in subgrade soil, it will result in failure of whole pavement. The failure of subgrade soil can be detected by the following forms of defects causing unevenness of pavement surface.

- Excessive undulation & corrugation on surface
- Depression followed by heaving at surface
- Lateral shoving of pavement near the edge along the wheel path

The two primary reasons of failure of subgrade soil are

- Inadequate stability
- Excessive stress application

i) Inadequate stability: Stability is the resistance to deformation under stress. When soil used for construction of subgrade is of inferior quality, it will not be able to resist the load coming from wheel, and ultimately it will fail.

Another reason causing loss of stability of subgrade soil is improper compaction of soil during construction. Presence of excessive moisture at subgrade level without proper drainage control also affects the stability of subgrade.

ii) Excessive stress application: Thickness of the pavement should be so designed, that it can distribute the wheel load properly. If pavement thickness becomes less than that of the required value, then it will result in failure of subgrade. Also if the wheel load applied on pavement is in excess of design value, it will result in failure of subgrade.

2. FAILURE OF SUB-BASE OR BASE COURSE

There are 5 primary reasons behind failure of sub-base or base course as described below.

i) Inadequate stability or strength: Role of a sub-base or base course is to transform the wheel load from surface course or wearing course to the subgrade. Therefore the strength of the sub-base or base course is always higher than that of subgrade. Strength of the sub-base or base course can be achieved by taking following measures.

- Using good quality of aggregate
- Proper mix design
- Providing sufficient thickness
- Proper quality control

If there is any deviation occurs in any of the above mentioned factors, it will lead to failure of pavement.

ii) Loss of binding action: When wheel load is repeatedly applied on road surface, it causes internal movement of particles in the sub-base or base course. This results in relative movement between surface course and sub-base or base course. In other word, instead of acting as whole, different layer acts separately. This is the cause of alligator or map cracking on bituminous surface.

Therefore a layer of **tack coat** or **prime coat** is applied on top of the base course before placing surface course. This creates a better bonding of these two layers.

iii) Loss of base course materials: When there is no wearing course or surface course on the base course, or if the wearing course has completely worn out, that will result in loss of base course material. This happens because of suction caused by the tyre and exposed base course materials. Also loss of stone aggregate creates pot holes on surface course.

iv) Inadequate wearing course: If the thickness of wearing course is less, then water will find its way to the base course causing damage to it.

Therefore it is essential to consider type, intensity and volume of traffic before deciding thickness of wearing course.

Use of inferior material**:** The materials to be used for construction of base course should be so chosen in a manner so that it can resist the wheel load and weathering actions. Inferior quality of material should not be used.

3. FAILURE OF WEARING COURSE

Wearing course or surface course is the layer having more strength than all the other pavement layers. This is because the wheel load is directly applied on this layer. Along with the vertical load, it has also to resist the abrading effect of wheel and weathering effect of climate.

Therefore design and construction of wearing course should be done properly. A pervious layer of wearing course can damage all the underlying layers. The following measure should be employed during design and construction of wearing courses

- Proper mix design
- Sufficient thickness
- Good quality of binder

- Proper amount of binder
- Good quality aggregate

High degree of quality control should be employed during construction of wearing course.

Oxidation or aging of binder, also make the bituminous surface brittle and creates cracks on pavement surface. This results in ingress of moisture to underlying layers and weakening of the layers.

Causes for failure in flexible pavement

- Sudden increase in traffic loading especially on new roads where the design is based on lesser traffic is a major cause of cracking.
- Provision of poor shoulders leads to edge failures.
- Provision of poor clayey subgrade results in corrugation at the surface and increase in unevenness.
- Poor drainage conditions especially during rainy season force the water to enter the pavement from the sides as well as from the top surface.

Remedial / maintenance measures in flexible pavement

Remedial measures can be explain for following types of defects

1) Alligator cracking: this type of cracks can be filled with low viscosity binder. Slurry seal or sand bituminous premix patching can be used to fill wide cracks.
2) Longitudinal cracking:
    - fill cracks with bituminous binder
    - A slurry seal or sand bituminous premix patching for wide cracks
    - A fog-real if the cracks are fine and extended over larger area
3) Edge cracking

- Improve the shoulder conditions and give lateral support to pavement
- Seal the cracks using low viscosity binder , a slurry seal, fog seal

4) Center cracking

These types of cracks can be sealed by slurry seal or fog seal

5)Rutting

- Fill the premix dense graded material and compact to the desired levels after applying a prime coat
- If rutting is due to subgrade failure then excavation and rectification of subgrade is done.

6)Potholes

Treatment is done by patch work or patch repairs. To fill pot holes with premix dense graded materials are followed by compaction.

Functional evaluation by visual inspection

Visual inspection is a method of inspecting the pavement surface for detecting and assessing the amount and severity of various types of damage . visual survey conducted from a moving vehicle to the more detailed survey that involves trained engineers and technicians walking the entire length of the selected areas and measuring and mapping out all distresses identified on the pavement surface, shoulders and drainage systems. Recently, automated visual survey techniques have become more common and are being adopted for distress surveys and pavement conditions evaluation.

Evaluation by unevenness measurement

The pavement unevenness may be measured using unevenness indicator, profilograph, profilometer or roughometer. An equipment capable of integrating the unevenness of pavement surface to a cumulative and that gives the unevenness index of the surface in cm/km length of road may be called unevenness integrator. The paverment unevenness criteria to indicate the pavement riding qualities expressed in terms of unevenness index recommended by hollaway is given in below table

In old pavements

Unevenness index cm/km	Riding quality
Below 95	Excellent
95 to 119	Good
120 to 144	Fair
145 to 240	Poor
Above 240	Very poor

In new pavements

Unevenness index cm/km	Riding quality
Below 90	Good
120 to 145	Fair
Above 145	Poor

Structural evaluation by benkleman beam deflection method

The benkleman beam measures the deflections under standard wheel load conditions.
Two kinds of deflection measurements are possible

1) Rebound deflection which is the recoverable deflection on the elastic deflection.
2) Residual deflection which is the non recoverable deflection .

The benkleman beam is a handy instrument which is most measuring deflection pavements. It consists of a lesser 3.66m long pivoted 2.44m from the end carrying the contact point which rests on the surface of the pavement.

The deflection of the pavement surface produced by the test load is transmitted to other end of the beam where it is measured by a dial guage or recorder.
The movement at the dialgauge end of the beam is one half of that at the contact point end. The load on the dual wheel can be in the range 2.7 to 4.1 tonnes

Procedure of measuring the rebound deflection is as follows

- Select 10points along the outer wheel path i.e., 60cm from the pavement edge for each lane

- Bring the rear dual wheel assembly of the truck over the marked point and insert the probe of the beam b/w the dual wheels so that the probe is placed exactly over the point where the deflection is to be measured
- A standard wheel load of 4085kg is used for the test, the tyre pressure being 5.6kg/cm^2
- The dial gauge reading is noted initially (D_0) in the position
- The truck is driven forward at a slow speed and dial gauge readings (D_1 and D_2) are taken when the truck stops at 2.7m and 9m from the measuring point, and when the rate of recovery is equal to 0.0025mm per minute
- Pavement temperature is recorded
- If D_1-D_2 < 0.0025mm, the actual rebound deflection is 2(D_0-D_2). If , however D_1-D_2> 0.0025mm, correction is needed for the vertical movement of the front legs, the truth deflection is obtained by the formula

$$X_T = X_A + 2.91Y$$

Where ,
X_T -- True pavement deflection
X_A – Apparent pavement deflection
Y - vertical movement of the front legs.

Structural evaluation by falling weight deflectometer

Falling weight deflectometer (FWD) is a instrument used to measure the dynamic deflection which drops a weight of 150kg from a variable height on to a spring system. This in turn transmits a load pulse of 28m duration to the road surface through a circular plate. A maximum peak load of 60kn develops a deflected that can be recorded by up to five velocity sensitive transducers arrayed radially from the loaded area. The equipment is carried on a single axle trailer. About 200measurements can be taken daily.

Structural evaluation by ground penetrating radar (GPR)

GPR is a geophysical method that uses radar pulses to image the subsurface. This nondestructive method uses electromagnetic radiation in the microwave band of the radio spectrum and detects the reflects signals from subsurface structures.

GPR have application in pavement evaluation including rock, soil and structures.

GPR, a non-destructive testing method in which electromagnetic radiation in the microwave band. The signals reflected back from the tested subsurface structures helps to detect metamorphism, voids, cracks, fractures, splits in the surface. In this non-destructive testing method, transmitting and receiving antennas are used to record the signals. The transmitting antenna transmits high frequency radiowave in the form of short pulses with penetrate in to the ground or tested subsurface structures. On the other hand, the receiving antenna record the signals reflected from the tested subsurface.

Design factors for runway pavements

- The area served by the airport must be able to generate and attract the estimated passenger and cargo traffic
- Wind velocity, directions, frequency, turbulence have a major influence on the airport operations and safety
- The altitude above mean sea level influences runway length
- Average temperature of the hottest month also influences the runway length
- Visibility conditions, particularly frequency of low visibility conditions due to fog, mist, rain, smoke, low, clouds, dust, storms….etc can affect aircraft landings and take-offs significantly
- Soil condition must be favorable
- The site selected should have a fairly level area with gentle contours.
- The site should be free from features that attracts birds, which cause bird hits.

MODULE 4

STRESSES IN RIGID PAVEMENTS

FACTORS AFFECTING DESIGN

The structural design of rigid pavements is governed by a number of factors, such as:

✓ **Loading**

1. Wheel load and its repetitions
2. Area of contact of wheel
3. Location of load with respect to slab.

✓ **Properties of subgrade**

1. Subgrade strength and properties
2. Sub-base provision or omission.

✓ **Properties of concrete**

1. Strength
2. Modulus of Elasticity
3. Poisson’s ratio
4. Shrinkage properties
5. Fatigue behaviour

✓ **External conditions**

1. Temperature changes
2. Friction between slab and subgrade.

✓ **Joints**

1. Arrangement of joints.

✓ **Reinforcement**

1. Quantity of reinforcement
2. Continuous reinforcement.

LOADING

1. Wheel load and its repetitions

The wheel load induces stresses in the slab. The greater the wheel load, the greater are the stresses. The axle loads on a given highway fall within a wide range. It is required to convert such axle loads in terms of a standard axle load of. In India, the basic design of the slab is done with the 98th percentile axle load.

Load Impact:

Impact can be of serious concern in the design of concrete slabs, especially at the joints. If the load-transferring device (such as dowel bar) at the joints is effective, the impact is minimised. Generally, it is customary, for design purposes, to increase the stresses caused by static wheels by 25 per cent to account for impact when effective load transfer devices are provided. If such load transfer devices are not provided, the stresses are increased by 50 per cent.

2. Area of contact of wheel

The wheel load from the pneumatic tyre is transmitted to the slab over a contact area which is determined by the tyre pressure. The tyre pressure varies from 5.3 to 6.3 kg/cm^2 for most commercial vehicles. In India, a tyre pressure of 0.8 MPa is adopted. The contact area is generally assumed to be circular to simplify the calculations.

3. Location of the load with reference to the slab

Three positions of loading are generally considered for estimating the stresses in a slab in a conventional method of design. They are illustrated in Fig. 1 below. Interior loading produces tensile stresses at the bottom of the slab. Edge loading produces tensile stresses at the bottom of the slab parallel to the edge and another smaller tensile stress at the top of the slab at right angles to the edge. Corner loading produces tensile stresses at the top of the slab parallel to the bisector of the corner angle.

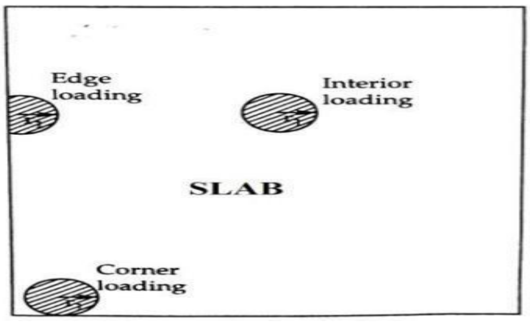


Fig. 1: Loading positions for rigid pavement design

Critical Load Position

Since the pavement slab has finite length and width, 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 are termed as critical load positions.

Interior Loading: When load is applied in the interior of the slab surface at any place remote from all the edges.

Edge Loading: When load is applied on an edge of the slab at any place remote from a corner.

Corner Loading: When the centre of load application is located on the bisector of the corner angle formed by two intersecting edges of the slab, and the loaded area is at the corner touching the two comer edges.

Properties of subgrade

1. **Subgrade strength and properties**

The strength of soil subgrade has an important bearing on the slab design. If the soil has a uniform bearing power, the design is simplified. The supporting power is generally measured by the plate bearing test, using a 75 cm dia. circular plate. The property measured is the "modulus of sub-grade reaction", K, which is a measure of the resistance of the soil to deformation under the pressure caused by the bending slab.

Other properties of the subgrade which affect pavement performance are its drainage characteristics, susceptibility to volumetric changes with changes in the moisture content and susceptibility to frost action.

2. **Sub-base provision or omission**

Sub-base (or sometimes called the base) is the layer of selected granular material placed on the subgrade soil and immediately below the concrete pavement.

The functions of a subbase are:

1. To provide a uniform and reasonably firm pavement support

2. To prevent mud-pumping on clays and silts

3. To prevent or reduce frost action

4. To provide a levelling course on distorted and undulating subgrade

5. To act as a capillary cut-off.

The materials normally used for sub-base are:

1. One layer of flat brick soling under one layer of water-bound macadam.

2. Two layers of water-bound-macadam

3. Well-graded soil-gravel mixtures.

4. Lime or cement stabilised soil, giving a minimum CBR of 50 after 7 days' curing.

5. Lime puzzolana concrete or lean cement concrete.

Properties of concrete

1. Strength of concrete

The design of a concrete pavement slab is dependent upon the strength of the concrete. There are various properties to measure the strength, but the most commonly used property is the crushing strength. Concrete has a very high crushing strength and rarely fails in compression in a pavement. More important is its flexural strength. The flexural strength is generally determined by subjecting a beam of concrete, generally 150 mm x 150 mm square section, and about 700 mm long, to flexure. The span for testing is equal to four times the depth and the load is applied at the third points of the span. The flexural strength is evaluated as the modulus of rupture.

2. Modulus of elasticity

Modulus of Elasticity, E, of concrete increases with its strength. It plays an important role in determining the relative stiffness of the slab and hence is a governing factor in design. This property is

determined by the static method by stress-strain relationship or by the dynamic method. Its value is about 3×10^5 kg/cm^2 (3×10^4 MN/ m^2) for concrete having flexural strength in the range of 38-42 kg/cm^2 (3.8-4.2 MN/ m^2).

3. Poisson's ratio

In the determination of stresses in concrete slabs, its value can be determined by static and dynamic methods, the former value being around 0.15 and the latter around 0.24.

4. Shrinkage properties of concrete

Concrete expands slightly during setting due to hydration of cement, but on subsequent drying, it shrinks. Such a shrinkage causes some stresses. Subsequent changes in moisture content may also cause shrinkage or expansion. Such volumetric changes can result in additional stresses in the slab.

5. **Fatigue behaviour of concrete**

As concrete is subjected to repetitive stresses, progressive permanent internal structural damage takes place. It has been found from research that as the ratio of the flexural stress to the flexural strength (the ratio being termed as stress ratio) increases, the concrete is able to resist fewer and fewer repetitions. It has been found that when the stress ratio does not exceed 0.55, concrete will virtually withstand unlimited stress repetitions without any reduction in load-carrying capacity.

External conditions

1. **Temperature changes**

Changes in temperature affect the stresses in the slab in two ways:

- Changes in the temperature gradient through the slab will cause differential expansion or contraction between the top and bottom of the slab. The slab then tends to warp, but is prevented from warping due to the slab weight and friction at load transferring devices. Stresses are induced due to such restraint.
- The expansion or contraction of the slab due to temperature changes is restrained due to the friction between the subgrade and the slab. This causes stresses in the slab.

2. **Friction between slab and sub-base**

The amount of friction between the slab and the sub-base determines the restraint imposed on expansion and contraction due to temperature changes. The spacing of joints is also affected by this friction. Compacted sand and gravel, covered with waterproof paper, provides a very smooth surface. Water-bound-macadam, soil gravel mix, rolled lean concrete, lime puzzolana concrete etc. give rough surfaces.

Arrangement of joints

Joints are needed for allowing for expansion, contraction and warping of the slab caused by reasons discussed above. The spacing and arrangement of joints govern the stresses induced in the slab.

Reinforcement

A slab can be un-reinforced or reinforced. The amount of reinforcement is an important consideration in design. Recent advances in designing continuously reinforced concrete pavements (CRCP) have changed the design methodologies considerably.

ANALYSIS OF STRESSES

Cement concrete slab design is a complicated subject. Theoretical analysis procedures involve a number of assumptions and some of them are rarely tenable in practice.

The pioneering work in concrete slab design can be attributed to Westergaard, who presented his results in 1925.

Westergard's analysis was based on the following assumptions:

1. The concrete slab is homogeneous and isotropic and has uniform elastic properties.

2. The reaction of the subgrade is vertical only and is proportional to the deflection of the slab. In other words, the support provided by the subgrade is similar to that given by a dense fluid and the subgrade has no shear strength (Fig. 2).

3. The reaction of the subgrade at a point is equal to K x Deflection at that point, the constant K being the Modulus of Subgrade Reaction.

4. The slab is uniform in thickness.

5. The load in the interior and the corner is circular in shape, positioned as indicated in **Fig. 1** The edge loading is semi-circular as in **Fig.1** ***(page 2)***

DESIGN OF RIGID PAVEMENTS

WESTERGAARD ANALYSIS

General Design Considerations

Cement concrete pavements represent the group of rigid pavements. Here the load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab itself i.e., slab action. H. M. Westergaard is considered the pioneer in providing the rational treatment to the problem of rigid pavement analysis.

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil subgrade, which is assumed as a dense liquid. Here it is assumed that the upward reaction is proportional to the deflection, i.e., p = K A, where the constant K is defined as modulus of subgrade reaction. The unit of K is kg/cm^2 per cm deflection i.e., kg/cm^3.

Westergaard's Modulus of Subgrade Reaction

The modulus of subgrade reaction, K is proportional to the displacement. The displacement level is taken as 0.125 cm in calculating K. If p is the pressure sustained in kg/cm^2 by the rigid plate of diameter 75 cm at a deflection =0.125 cm, the modulus of subgrade reaction K is given by:

$$K = \frac{p}{\Delta} = \frac{p}{0.125} \; in\ kg/cm^3$$

Relative Stiffness of Slab to Subgrade

A certain degree of resistance to slab deflection is offered by the subgrade. This is dependent upon the stiffness or pressure-deformation properties of the subgrade material. The tendency of the slab to deflect is dependent upon its properties of flexural strength.

The resultant deflection of the slab which is also the deformation of subgrade is a direct measure of the magnitude of subgrade pressure. The pressure defamation characteristics of rigid pavement is thus a function of relative stiffness of slab to that of subgrade. Westergaard defined this term as the Radius of relative stiffness

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

Here,

l= radius of relative stiffness, cm

E= modulus of elasticity of cement concrete kg/cm^2

μ= Poisson's ratio for concrete = 0.15

h= slab thickness, cm.

K = subgrade modulus or modulus of subgrade reaction, kg/cm^3

The stresses acting on a rigid pavement are;

(i) Wheel load stresses and (ii) temperature stresses.

Critical Load Position

Since the pavement slab has finite length and width, either the character or 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 are termed as critical load positions.

Interior Loading: When load is applied in the interior of the slab surface at any place remote from all the edges.

Edge Loading: When load is applied on an edge of the slab at any place remote from a corner.

Corner Loading: When the center of load application is located on the bisector of the corner angle formed by two intersecting edges of the slab, and the loaded area is at the corner touching the two comer edges.

Equivalent Radius of Resisting Section

Considering the case of interior loading, the maximum bending moment occurs at the loaded area and acts radially in all directions. With the load concentrated on a small area of the pavement, the question arises as to what sectional area of the pavement is effective in resisting the bending moment. According to Westergaard, the equivalent radius of resisting section is approximated, in terms of radius of load distribution and slab thickness,

$$b = \overline{\qquad\qquad} - 0.675h$$

Here,

b=equivalent radius of resisting section, cm when a is less than 1.724 h,

a = radius of wheel load distribution, cm

h = slab thickness, cm

When a is greater than 1.724 h, the value of b = a

Stress equations for wheel loads:

(1) Westergaard's stress equation for wheel loads:

The cement concrete slab is assumed to be a homogeneous, thin elastic plate with subgrade reaction being vertical and proportional to the deflection.

The commonly used equations for theoretical computation of wheel load stresses have been given by Westergaard. He considered three typical regions of the cement concrete pavement slab for the' analysis of stresses, as the interior, edge and the comer regions. The critical stresses Si, Se and Sc at the typical locations i.e. interior, edge and comer are given below,

Interior Loading:

$$S_i = \frac{0.316\,P}{h^2}[4log_{10}(l/b) + 1.069]$$

Edge loading:

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

Corner loading:

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

Where,

Si, Se and Sc = maximum stress at interior, edge and comer loading, respectively in kg/cm^2

h= slab thickness, cm

P =wheel load, kg

a=radius of wheel load distribution, cm

l = radius of relative stiffness, cm

b = radius of resisting section, cm

MODIFIED WESTERGAARD'S EQUATIONS

(2)Evaluation of wheel load stresses for design:

A. MODIFIED WESTERGAARD'S EQUATION USING EQUATIONS:

Westergaard's wheel load stress equations for interior, edge and corner have been modified by various investigators based on their research work on cement concrete pavement slabs. The stresses at the edge and corner regions are generally found to be more critical for the design of rigid pavement for highways. The Indian Roads Congress recommends the following two formulas for the analysis of load stresses at the edge and corner regions and for the design of rigid pavements;

(i) Westergaard's edge load stress formula, modified by Teller and Sutherland for finding the load stress Se in the critical edge region,

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

(ii) Westergaard's corner load stress analysis modified by Kelley for finding the load stress Sc at the critical corner region,

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

where,

Se = load stress at the edge region, kg/cm^2

Sc = load stress at the comer region, kg/cm^2

P =design wheel load, kg

t = thickness of CC pavement slab, cm

n =Poisson's ratio of the CC slab

E =modulus of elasticity of the CC, kg/cm^2

K = reaction modulus of pavement foundations (i.e., base course, sub-base course or subgrade), kg/cm^3

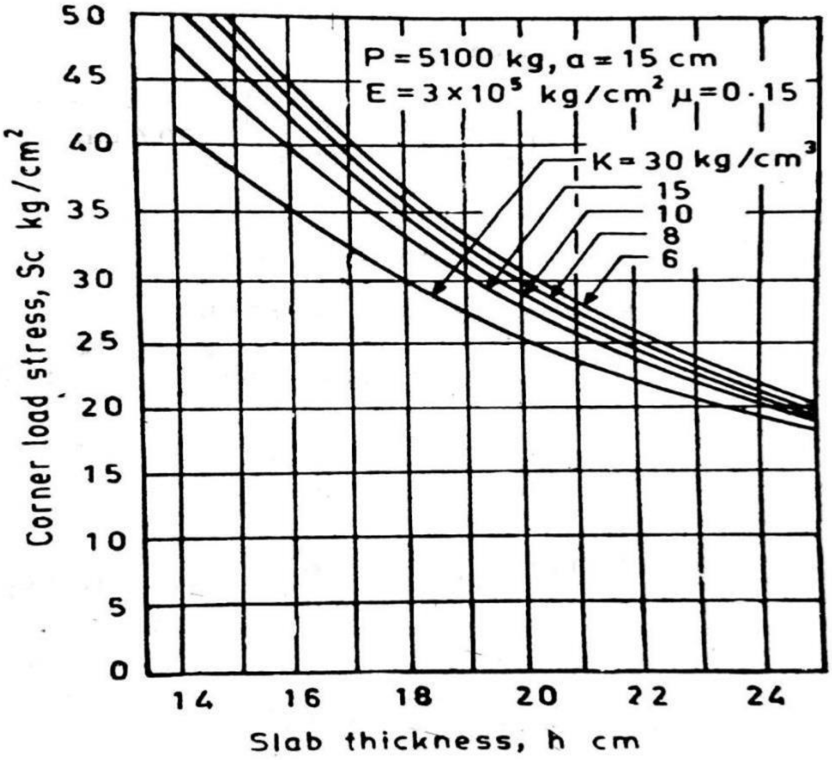
l = radius of relative stiffness, cm

b = radius of equivalent distribution of pressure, cm,

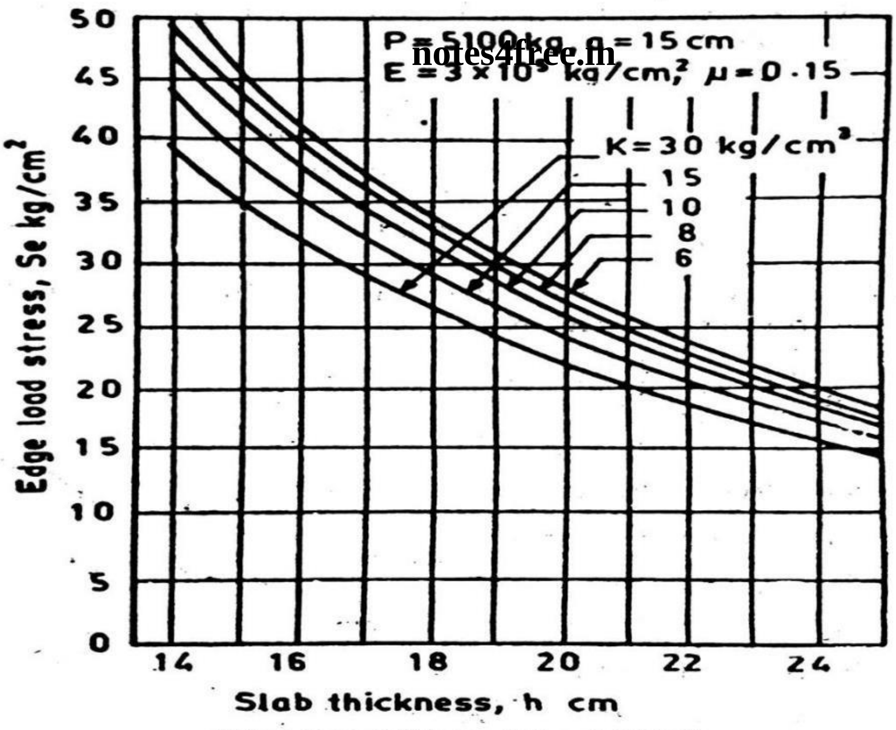
a = radius of load contact, cm (assumed circular in shape)

B. MODIFIED WESTERGAARD'S EQUATIONS USING CHARTS

The above equations for finding load stresses at the edge and corner regions are presented in the form of stress charts by the IRC and these are shown in Fig below. These charts are applicable for a particular set of design parameters only viz**. P= 5100 kg, a = 15 cm, E = 3 x 10^5 kg/cm^2, μ = 0.15;** but different curves are given for different values of K between 6.0 and 30 kg/cm^3. The design curves are for slab thickness values, h = 14 to 25 cm. These stress charts are very handy and save considerable time when the stresses are to be evaluated for various trial thickness of the slab while designing a pavement.



Corner Load Stress Chart (IRC)



Edge Load Stress Chart (IRC)

TEMPERATURE STRESSES

Westergaard's Concept for Temperature Stresses

Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. The variation in temperature across the depth of the slab is caused by daily variation whereas an overall increase or decrease in slab temperature is caused by seasonal variation in temperature.

During the day, the top of the pavement slab gets heated under the sun light when the bottom of the slab still remains relatively colder. The maximum difference in temperature between the top and bottom of the pavement slab may occur at some period after the mid-noon. This causes the slab to warp or bend, as the warping is resisted by the self-weight of the slab, warping stresses are developed late in the evening, the bottom of the slab gets heated up due to heat transfer from the top and as the atmospheric temperature falls, the top of the slab becomes colder resulting in warping of the slab in the opposite direction and there is a reversal in warping stresses at the different regions of the slab. Thus the daily variation in temperature causes warping stresses in reverse directions at the comer, edge and interior regions of the slab.

During summer season as the mean temperature of the slab increases, the concrete pavement expands towards the expansion joints. Due to the frictional resistance at the interface (which depends upon the self-weight of the slab and the coefficient of friction at the interface), compressive stress is developed at the bottom of the slab as it tends to expand. Similarly during winter season, the slab contracts causing tensile stress at the bottom due to the frictional resistance again opposing the movement of the slab. Thus fictional stresses are developed due to seasonal variation in temperature. The frictional stress will be zero at the free ends and at expansion joints and. increases up to a maximum value towards the interior and there-after remains constant.

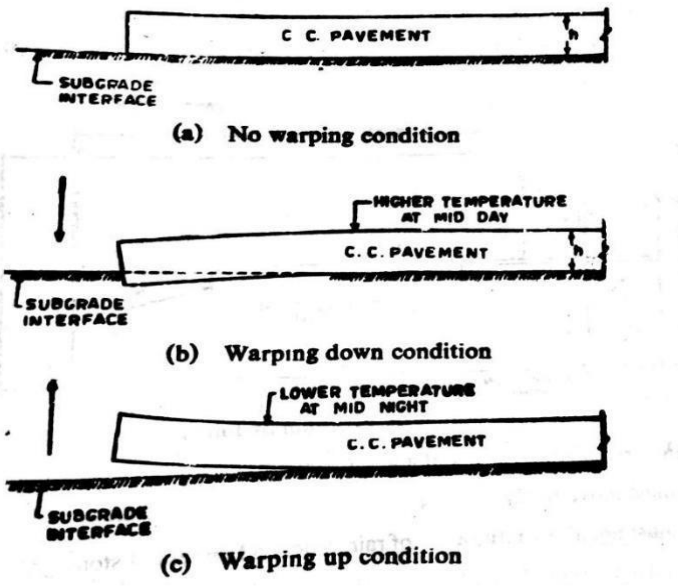
Temperature thus tends to produce two types of stresses in a concrete pavement. These are

(i) Warping stresses and

(ii) Frictional stresses

Warping stresses:

Whenever the top and bottom surfaces of a concrete pavement simultaneously possess different temperatures, the slab tends to warp downward or upward inducing warping stresses.



Warping of cement concrete slab

The difference in temperature between the top and bottom of the slab depends mainly on the slab thickness and the climatic conditions of the region.

By the time the top temperature increases to t_1 degrees, the bottom temperature may be only t_2 degrees and the difference between the top and bottom of the slab would be $(t_1-t_2) = t$ degrees. Assuming straight line variation in temperature across the pavement depth, the temperature at mid depth or average temperature of slab would be $(t_1+t_2)/2$.

If the slab has no restraint then the unit elongation of the top fibres and also unit contraction of the bottom fibre due to relative temperature condition, each would be equal to Eet/2 where e is the thermal coefficient of concrete. Westergaard worked out the stresses due to the warping of concrete slabs.

Now introducing the effect of Poisson's ratio the stresses at the interior, region in longitudinal and transverse directions as given by Bradbury are expressed by the following equations:

$$S_{t(i)} = \frac{Eet}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

Here,

St= warping stress at interior, kg/cm^2

E = modulus of elasticity of concrete, kg/cm^2

e = thermal coefficient of concrete per °C

t = temperature difference between the top and bottom of the slab in °C

Cx = coefficient based on *Lx/l* in desired direction

Cy = coefficient based on *Ly/l* in right angle to the above direction

u = Poisson's ratio (may be taken as 0.15)

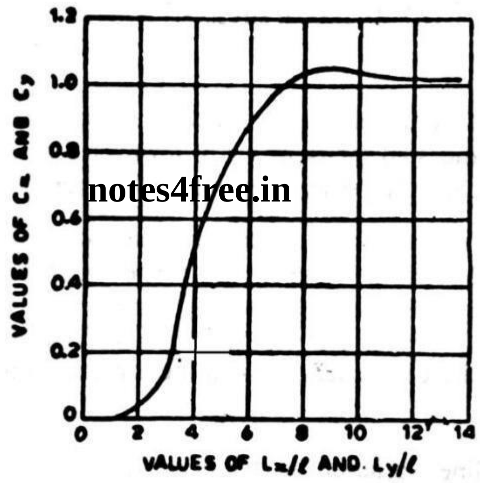
Lx and Ly are the dimensions of the slab considering along X and Y directions along the length and width of slab.

The values of the warping stress coefficients Cx and Cy for cement concrete pavement are taken from the chart developed by Bradbury. See Fig. below

The warping stress at the edge region is given by:

$$S_{e(i)} = \frac{C_x Eet}{2}$$

$$S_{e(i)} = \frac{C_y Eet}{2}, \text{ whichever is higher}$$



Warping Stress Coefficient

Here,

a is the radius o contact and

l= radius of relative stiffness.

The warping stress at the corner region is given by:

$$S_{c(i)} = \frac{Eet}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Here,

a is the radius o contact and

l= radius of relative stiffness.

Frictional stresses:

Due to uniform temperature rise and fall in the cement concrete slab, there is an overall expansion and contraction of the slab. Since the slab is in contact with soil subgrade or the sub-base, the slab movements are restrained due to the friction between the bottom layer of the pavement and the soil layer. This frictional resistance therefore tends to prevent the movements thereby inducing the frictional stress in the bottom fibre of the cement concrete pavement. Stresses in slabs resulting due to this phenomenon vary with slab length. In short, slab stress induced due to this is negligibly small

whereas in long slabs, which would undergo movements of more than 0.15 cm, higher amount of frictional stress develops.

Equating, total force developed in the cross section of concrete pavement due to movement and frictional resistance due to subgrade restraint in half the length of the slab,

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

Here

Sf == unit stress developed in cement concrete pavement, kg/cm^2

W = unit weight of concrete, kg/cm^3 (about 2400 kg/m^3)

f =coefficient of subgrade restraint (maximum value is about 1.5)

L =slab length, **metre**

Critical Combination or Worst combination of Stresses

It is necessary to consider the conditions under which the various stresses in cement concrete pavements would combine to give the most critical combinations.

The following conditions are considered to provide the critical combinations:

(i) During summer: The critical combinations at interior and edge regions during mid-day occurs when the slab tends to warp downward. During this period maximum tensile stress is develop at the bottom fibre due to warping and this is cumulative with the tensile stress due to the loading. However the frictional stress is compressive during expansion. The load stress at edge region is higher than the interior.

Critical combination of stresses = (load stress + warping stress-frictional stress), at edge region.

(ii) During winter: The critical combination of stresses at the above regions occurs at the bottom fibre when the slab contracts and the slab warps downward during the midday. The frictional stress is tensile during contraction.

The critical stress combination = (load stress + warping stress + frictional stress), at edge region.

Since the differential temperature t is of lower magnitude during winter than in summer, the combination (i) may be worst for most of the regions in this country.

(iii) At comer region, the critical combination occurs at the top fibre of the slab, when the slab warps upwards during the midnights. There is no frictional stress at the comer region.

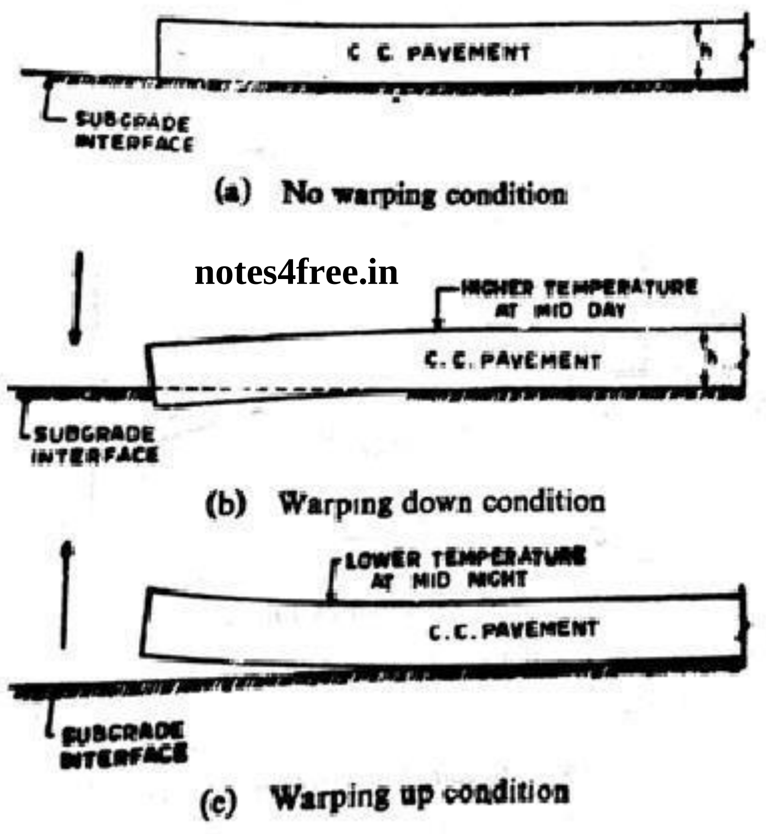
The critical stress combination = (load stress + warping stress), at corner regions.

DESIGN OF RIGID PAVEMENTS

CONSTRUCTION OF JOINTS IN CEMENT CONCRETE PAVEMENTS

Introduction:

Joints are provided in cement concrete roads for expansion, contraction and warping of the slabs due to the variation in the temperature of slabs. Changes in atmospheric temperatures in turn reduce the changes in the temperature of slabs. Such changes of temperature cause expansion of the slab horizontally if there is an increase in the slab temperature above the temperature during which the slab was laid. Similarly there is contraction of slab also when the temperature falls below this temperature. Thus the rise and falls of atmospheric temperatures which is a cyclic phenomenon make the pavement slabs also to expand and contract.



Warping of cement concrete slab

The slab movements also take place in vertical direction which is due to the temperature differential between top and bottom of pavement slab. During the mid-day the top of the pavement slab has higher temperature than the bottom of the slab. This causes the top fibres of the slab to expand more than the bottom fibres, and the slab curls at the edges as shown in **Fig (b).**This phenomenon is known as warping down of the slab.

By about the mid night the temperature of the bottom of the slab is higher than the temperature of the slab top. The slab warps up during this time. See **Fig. (c).**

In reality, the weight of the pavement slab prevents the slab to take a warped shape thereby developing stress in the slab which are known as warping stresses. The magnitude of warping stresses are maximum at the interior region and are minimum at the corner region

When the slab is warped down in the day time, the warping stresses are tensile in nature at the bottom of the slab. In warped up condition, the tensile stresses are developed at the top of the pavement slab. To minimise the temperature stresses in the pavement slab, expansion, contraction and warping joints may be provided transversely across the full width of pavement.

In addition to this, the construction joints are also provided. The compulsory break provided in continuity of the slabs is due to the close of day's job and the commencement of the same the next day with a construction joint. Normally the construction joint is planned to coincide with an expansion joint. It is customary to provide concreting of one lane at a time which may be of width 3.5 m for highway pavements. Thus two lanes are also joined together by a joint known as longitudinal joints. Joints are also classified depending upon their direction of placement:

1. Transverse joints:

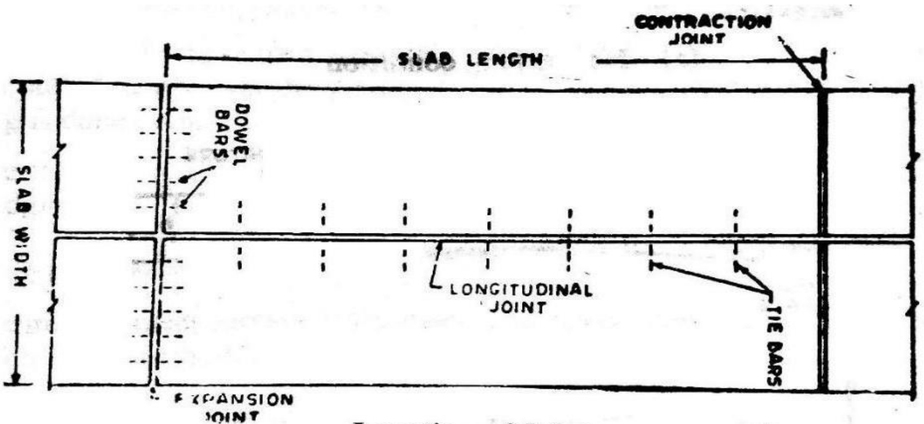
These are further classified as:

(a) Expansion joint

(b) Contraction joint

(c) Warping joint

(d) Construction joint



Location of Joints

2. Longitudinal joints:

The location of these joints is shown in Fig. above.

Following are the requirement of a good joint:

(a) Joint must move freely.

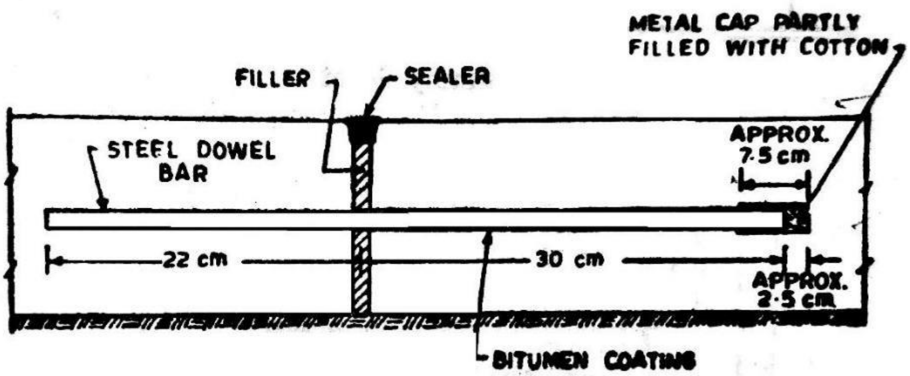
(b) Joint must not allow infiltration of rain water and ingress of stone grits.

(c) Joint must not protrude out the general level of the slab.

1. Transverse joints:

Expansion joints:

These joints are provided to allow for expansion of the slabs due rising in slab temperature above the construction temperature of the cement concrete. Expansion joints also permit the contraction of slabs. Expansion joints in India are provided at interval of 50 to 60 metre for smooth interface laid in winter and 90 to 120 metre for smooth interface laid in summer. However for rough interface the spacing between expansion joints may be 140 m. A typical expansion joint is shown 1n Fig. below. The approximate gap width for this type of joints is from 20 to 25 mm.



Expansion Joint with Dowel Bar

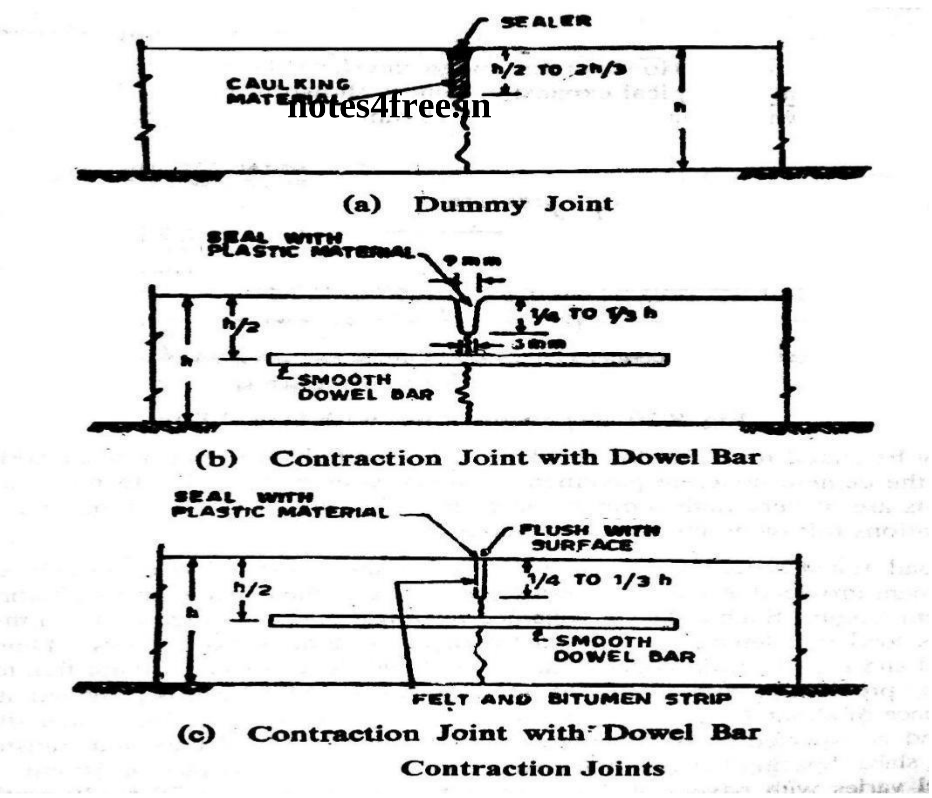
It may be stated here that the break in slab continuity forming a joint adds a weaker plane in the cement concrete pavement. The stresses include due to the wheel loads at such joints are of very high order at the edge and corner regions. In order to strengthen these locations following measures are adopted:

The load transference across the transverse joint is carried out through a system of reinforcement provided at suitable intervals projecting in the concrete in longitudinal direction up to 60 cm length. Such a device is named as dowel bar. In the expansion joint, thus load transference is affected through a system of dowel bars. Dowel bars are embedded and kept fixed in concrete at one end and the other end is kept free to expand or contract by providing a thin coating of bitumen over it. Metal cap is provided at this end to offer a space of about 2.5 cm for movements during expansion. In the design, 40 percent of wheel load is expected to be taken up by the group of dowel bars and transferred to the adjoining slab. Spacing between the dowel bars is generally adopted as 30 cm. The size of the dowel varies with pavement thickness and it ranges between 20 to 30 mm. The total length of dowel bar varies between 40 cm to 73 cm depending upon the dowel diameter.

Contraction Joints:

Contraction joints are provided to permit the contraction of the slab. These joints are spaced closer than expansion joints. Load transference at the joints is provided through the physical interlocking by the aggregates projecting out at the joint faces. As per IRC specifications the maximum spacing of contraction joints in unreinforced CC slabs is 4.5 m and in reinforced slab of thickness 20 cm is 14 m and in reinforced Slab of thickness 20 cm is 14 cm.

Since it is recommended to provide contraction joints at close spacing, there seems to be no need of providing any load transference, as mainly this will be done by the aggregate interlocking. For added safety, some agencies recommended the use of dowel bar which are fully bounded 1n the concrete.



Typical contraction joints are shown in Fig. above

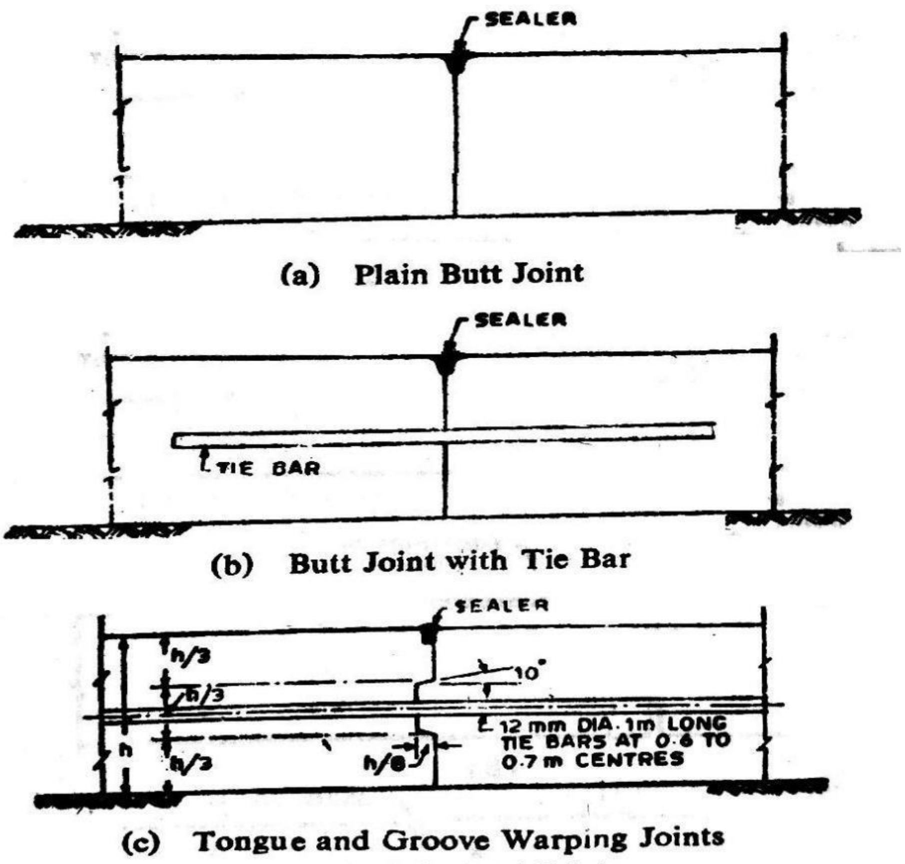
Warping Joints

The warping joints are provided to relieve stresses included due to warping. These are known as hinged joints. Longitudinal joints with tie bars fall 1n this class of joint. These joints are rarely needed if the suitably designed expansion and contraction joints are provided to prevent cracking.

2. Longitudinal Joints

Longitudinal joints are provided in cement concrete roads which have width over 4.5 m. On soil subgrade of clay, such joints are provided to allow differential shrinkage and swelling due to rapid changes in subgrade moisture under the edges than under the centre of road. The longitudinal joints are provided to prevent longitudinal cracking in the cement concrete pavements. This type of joint acts as a hinge and helps to maintain the two slabs together, at the same level.

In the longitudinal joints tie bars are provided to hold the adjacent slabs together. The Various types of longitudinal joints in use are shown in Fig. below. IRC recommends using plain butt with tie bar type of joints.



Longitudinal Joints

A butt joint is the simplest longitudinal joint and is formed by painting the joint faces with bitumen.

The tie bars are also placed in the type of butt joint with tie bar.

Recommended size and spacing of tie bars are as follows:

In cement concrete slab of thickness 20 cm,

(a) 10 mm diameter deformed tie bars of length 35 cm or plain bars of length 45 cm are placed at 45 cm spacing, or

(b) 12 mm diameter deformed bars of length 40 cm or plain bars of length 55 cm are placed at 64 cm spacing.

In slabs of thickness 25 mm, tie bars of diameter 10, 12 or 14 mm and length 35 to 46 cm are placed at 30 to 62 cm spacing.

Arrangement of joints

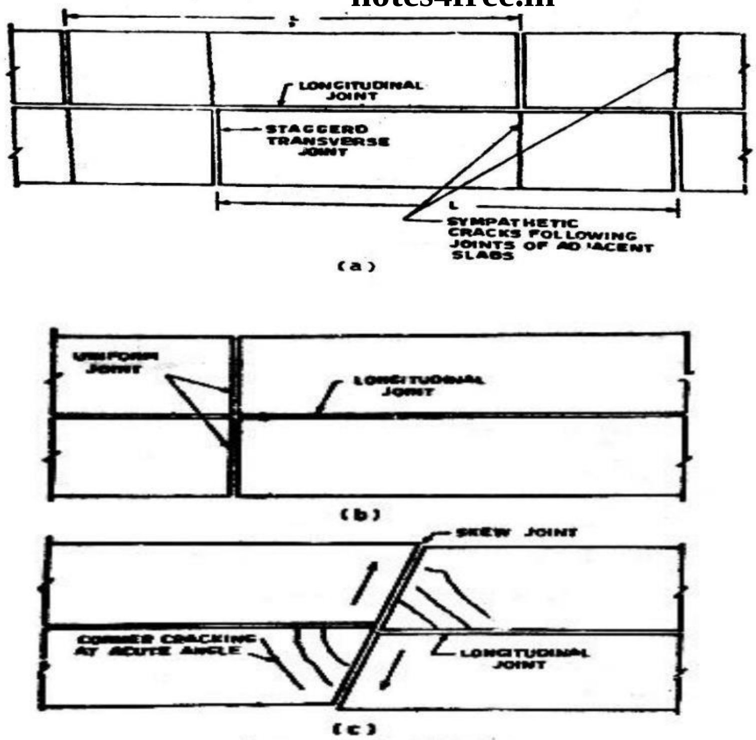
The joints in transverse direction are placed as follows:

(a) Staggered arrangement

(b) Uniform arrangement

(c) Skew arrangement

Figure below shows the arrangement of joints.



Arrangement of Joints

It is observed that where transverse joints are placed, staggered on either side of the, longitudinal joints as shown in Fig. (a), sympathetic Cracks are often formed in line with the transverse joints. It is therefore recommended to provide joints across the longitudinal joint in same transverse alignment as shown in Fig. (b).

It is always attempted to avoid the skew alignment of the joints but in some typical layout at intersections, it may be required to provide skew arrangement. At places where skew arrangement cannot be avoided, the acute corners so formed are strengthened with reinforcement.

DESIGN OF JOINTS IN CEMENT CONCRETE PAVEMENTS:

Various types of joints provided in cement concrete pavements to reduce the temperature stresses are expansion joint, contraction joints and warping joints. If expansion and contraction joints are properly designed and constructed, there IS no need of providing warping joints, in addition. Expansion joint spacing is designed based on the maximum temperature variations expected and the width of joint. The contractionjoint spacing design is governed by the anticipated frictional resistance and allowable tensile stress in concrete during the initial curing period, or the amount of reinforcement, if any. The spacing between the expansion joints is so adjusted that the contraction joints have equal spacing. Dowel bars are provided at expansion joints and sometimes at contraction joints also. The size and spacing of the dowel bars are designed and are also governed by standard specification based on practical considerations. Longitudinal joints in cement concrete pavements are constructed with suitable tie bars. The design considerations include diameter, spacing and length of the bars.

Spacing of expansion joint:

The width or the gap in expansion joint depends upon the length of slab. Greater the distance between the expansion joints, the greater is the width required of the gap for expansion. The use of wide expansion joint space should be avoided as it would be difficult to keep them properly filled in when the gap widens during winter season. The dowels would develop high bending and bearing stresses with wider openings. It is recommended not to have a gap more than 2.5 cm in any case. The IRC has recommended that the maximum spacing between expansion joints should not exceed 140 m for rough interface layer.

If ‘δ’ is the maximum expansion in a slab of length Le with a temperature rise from T_1 to T_2.

$$\text{'}\delta\text{'} = L_e\, C\, (T_2 \text{ to } T_1)$$

Where, C is the thermal expansion of concrete per degree rise in temperature.

The joint filler may be assumed to be compressed up to 50 percent of its thickness and therefore, the expansion joint gap should be twice the allowable expansion in concrete,

i.e., 2δ. From the relation given above, if δ' is half the joint width, the spacing of expansion joint (Le) is given by the equation:

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

Where,

L_e=Expansion joint spacing in m.

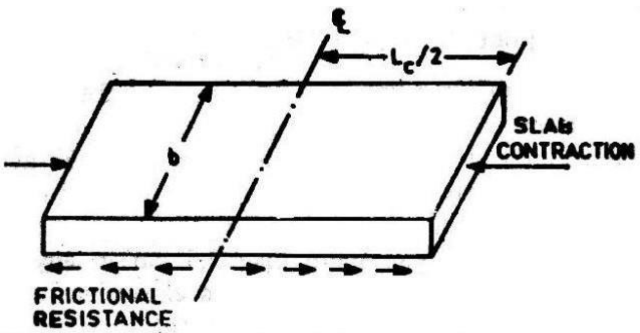
δ'=Half joint width=(δ/2) in cm.

C=Co-efficient of thermal expansion,

T_1 and T_2= Temperature difference (laying temp and slab temp)

Spacing of contraction joints:

The slab contracts due to the fall in slab temperature below the construction temperature. Also during the initial curing period, shrinkage occurs in cement concrete. This movement is resisted by the subgrade drag or friction between the bottom fibre of the slab and the subgrade; see Fig. below. If L_C is the slab length in metre, the maximum stress occurs at half the length.



Slab Contraction and Frictional Resistance

Total frictional resistance up to distance $L_C/2$ = W x b x (L_C/2)

× (h/100) x f Allowable tension in cement concrete = Sc x h x b

x 100

Equating the above two values,

$$\frac{b\,L_C\,h\,f}{200} = 100\,S_C\,h\,b$$

Length of slab to resist the frictional drag, i.e., spacing of contraction joints,

$$L_C = \frac{2\,S_C}{W\,f} \times 10^4$$

Here,
Lc =slab length or spacing between contraction joints, m

h =slab thickness, cm

f = coefficient of friction, (maximum value is about 1.5)

W = unit weight of cement concrete, kg/m3 (2400 kg/m^3)

S_C= allowable stress in tension in cement concrete, kg/cm^2 (0.8 kg/cm^2)

Since the contraction or shrinkage cracks develop mainly during initial period of curing, a very low value of Sc is considered in design. The permissible stress is generally kept as low as about 0.8 kg/cm^2.

Spacing of Contraction Joints when Reinforcement is provided

If it is assumed that the reinforcement takes the entire tensile force in the slab, caused by the frictional resistance of subgrade and hair cracks are allowed, then

$$\mathbf{W \times b \times (L_C/2) \times (h/100) \times f = S_S\, A_S}$$

$$L_C = \frac{200\,S_S\,A_S}{bhWf}$$

Here,

A_S = total area of steel, cm^2 across the slab width

Lc =spacing between contraction joints, m

b = slab width, m

h = slab thickness, cm

W = unit weight of cement concrete, kg/m^3 (2400)

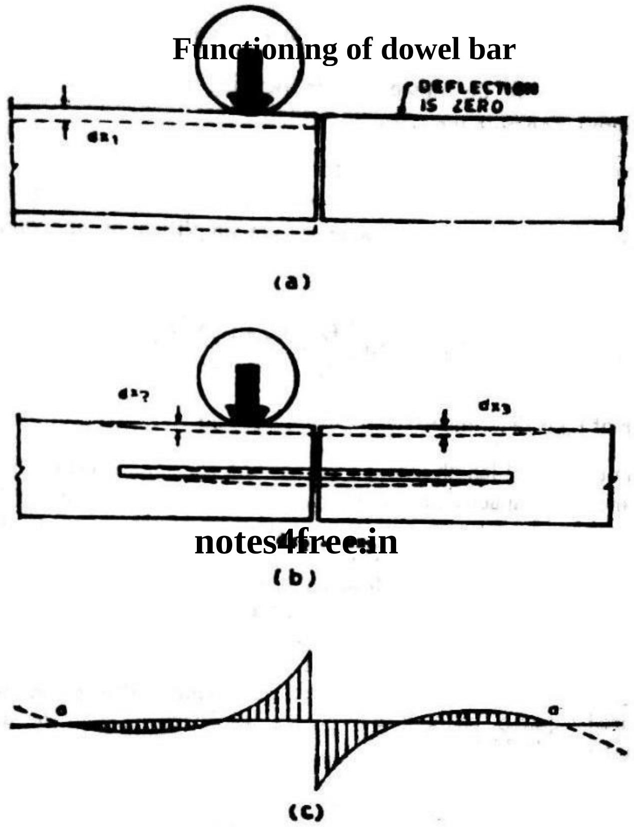
f = coefficient of friction (l .5 max)

S_S= allowable tensile stress in steel, kg/cm^2 (1400)

Design of Dowel Bar:

Dowel bars of expansion joints are mild steel round bars of short length. Half length of this bar is bonded in one cement concrete slab and the remaining portion is embedded in adjacent slab, but is kept free for the movement during expansion and contraction of the slab. The dowel bars allow opening and closing of the joint, maintaining the slab edges at the same level, and the load transference is effected from one slab to the other. This is explained below:

Functioning of dowel bar



Functioning of dowel bar

If dowel bars are not provided at the transverse joint (as in Fig. a) the loaded slab would deflect by say, dx_1 under load P. The adjacent slab across the expansion joint does not participate in load bearing and it does not deflect at all.

When the joint is provided with dowel bar system and the load P is applied on the first slab under the same conditions, the loaded slab deflects by the magnitude say dx_2. (See Fig. b) and the adjacent slab also undergoes a deflection, dx; due to the dowel bar transferring part of the load. Theoretically, if the dowel bars are rigidly embedded in the concrete slabs on both sides, dx_2 should be equal to dx_3. It has however been observed that $dx_3 < dx_2$ and their ratio depends upon the thickness of the slab, size and diameter of dowels and their spacing.

It may be noted that $dx_1 > dx_2$ or dx_3. Accordingly, the stress caused in loaded slab is greater when there are no dowels than the slab joint with dowel bars. This is logical as the stress magnitudes are related with deflections. The pressure distribution along the dowel bar under the load on one slab is illustrated in Fig. 7.27 c as per Friberg's analysis. Points of pressure reversal a, would determine the criterion for determining the length of dowel bars.

In the design of dowels, the load transference is worked out considering the capacity of the dowel system. The capacity depends upon variable like, pavement thickness subgrade modulus, the relative stiffness and spacing and size of dowels.

The IRC recommends that dowel bar system may be designed on the basis of Bradbury's analysis for load transfer capacity of a single dowel bar in shear, bending and bearing in concrete.

These values are given below:

For shear in the bar, $P' = 0.785\, d^2 F_S$

For bending in the bar, $P' = \frac{2d^3 F_f}{L_d + 8.8\delta}$

For bearing on concrete, $P' = \frac{F_b L_d^2 d}{12.5\,(L_d + 1.5\delta)}$

Where,

P' = load transfer capacity of a single dowel bar, kg

d = diameter of dowel bar, cm

Ld = total length of embedment of dowel bar, cm

= joint width, cm

F_f : permissible flexural stress in dowel bar kg/cm^2

F_b = permissible bearing stress in concrete, kg/cm^2.

The load capacity of the dowel bar in bending and bearing depend on the total embedded length Ld on both the slabs.

In order to obtain balanced design for equal capacity in bending and bearing, the length of embedment is first obtained by equating P' values from Eq. 7.33 and 7.34 for the assumed joint width and dowel diameter. On simplification, the value of Ld is given by

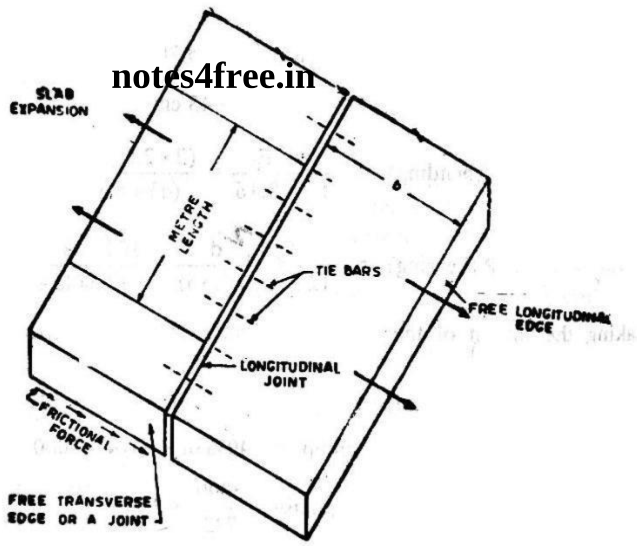
$$L_d = 5d \left[\frac{F_f}{F_b} \times \frac{L_d + 1.5\delta}{L_d + 8.8\delta}\right]^{\frac{1}{2}}$$

The value of Ld is determined by trial from Eq. above.

The minimum dowel length is taken as (Ld + δ), and the lowest of the three values of P' taken as the load capacity of a dowel bar. The load capacity of the dowel system or group is assumed to be 40% of the design wheel load. The required load capacity factor of the dowel group is obtained by dividing the load capacity of the group by the load capacity of one dowel bar, P'. The distance on either side of the load position up to which the group of dowel bars are effective in load transfer is taken as 1.8 times the radius of relative stiffness, ***l***. Assuming linear variation of the capacity factor for a single dowel bar from 1.0 under the load to zero at a distance of 1.8 ***l***, the capacity factors are calculated for the dowel system for the assumed spacing. The spacing which conforms to the required capacity factor is selected as the design value.

Design of tie bars:

Tie bars are used across the longitudinal joints of cement concrete pavements. Tie bars ensure two adjacent slabs to remain firmly together. These bars are not designed to act as load transfer devices. Tie bars are thus designed to withstand tensile stresses, the maximum tensile force in tie bars being equal to the force required to overcome frictional force between the bottom of the adjoining pavement slab and the soil subgrade. The force is considered from the joint location to the subsequent joint or free edge.



Functioning of Tie Bars

Diameter and Spacing:

The diameter and spacing of the tie bars are calculated as explained under:

Area of steel per meter length of joint is obtained by equating the total subgrade friction to the total tension developed in the tie bars.

Thus considering one meter length of the joint,

$$A_S\, S_S = b\frac{h}{100}W\, f$$

$$A_S = \frac{bfhW}{100S_S}$$

Where,

A_S = area of steel per metre length of joint, cm^2

b = distance between the joint and nearest free edge, m

h = thickness of pavement, cm

f = Coefficient of friction between pavement and subgrade (may be taken as 1.5 for rough interface)

W = unit weight of cement concrete, kg/m3 (2400 kg/m^3)

Ss=allowable working stress in tension for steel, kg/cm^2 (1400 kg/cm^2)

Assuming a suitable diameter of the tie bar2 (0.8 to 1.5 cm) the spacing of the tie bar can be found to provide the area of steel as cm per meter length of the slab.

Length of tie bar:

The total length of tie bar should be at least twice the length of embedment required on each slab to develop a bond strength equal to the working stress of the steel.

This is obtained from the consideration that the total tensile force developed in tie bar should not exceed the bond strength between tie bar and the concrete. Therefore considering one Side of the longitudinal joints,

$$a_S S_S = \frac{L_t}{2} P S_b$$

$$L_t = \frac{2a_S S_S}{P\, S_b}$$

Substituting $a_S = \frac{\pi d^2}{4}$ and P= πd

$$L_t = \frac{d\, S_S}{2\, S_b}$$

Hence total length of tie bar L_t

$$L_t = \frac{2a_S S_S}{P\, S_b} = \frac{d\, S_S}{2\, S_b}$$

Here,

$L_f/2$=length of tie bar on one side of slab, cm or half-
length of tie bar S_S = allowable stress in tension, kg/cm^2
(1400 kg/cm^2)

Sb =allowable bond stress in concrete, kg/cm^2 (this is taken as 24.6 kg/cm^2 for deformed bars and 17.5 kg/cm^2 in plain tie bars).

a_s = cross sectional area of one tie bar, cm^2

P = perimeter of tie bar, cm

d = diameter of tie bar, cm

Plate bearing test

The plate bearing tests is used to evaluate the supporting power of subgrade for use in pavement design by using relatively large diameter plates. The plate bearing test was originally devised to find the modulus of subgrade reaction in the Westergaard's analysis for wheel load stress in cement concrete pavements.

The test set up consists of a set of plates of diameter 75, 60, 45 and 30 cm, a loading device consisting of jack and proving ring arrangement and a reaction frame against which the jack can give a thrust to the plate. A datum frame resting far from the loaded area and dial gauges from this frame are used to measure the settlement of the loaded a plate. The loading arrangement is shown in Fig. below.

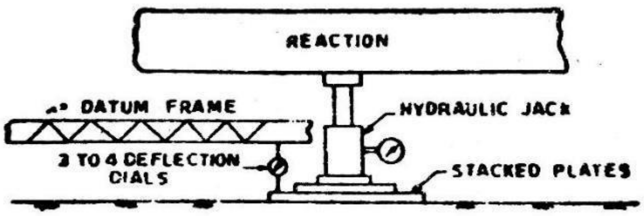


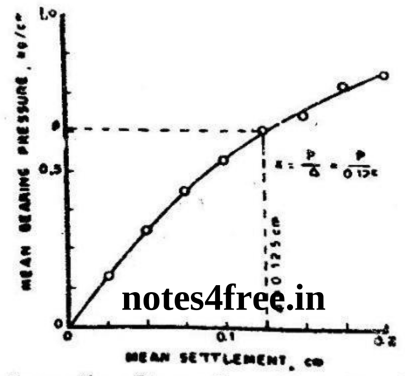
Plate Bearing Test Set Up

Modulus of Subgrade Reaction:

Modulus of subgrade reaction K may be defined as the pressure sustained per unit deformation of subgrade at specified deformation or pressure level, using specified plate size. The standard plate size for finding K-value is 75 cm diameter. But in some tests a smaller plate of 30 cm diameter is also used.

The test site is levelled and the plate is properly seated on the prepared surface. The stiffening plates of decreasing diameters are placed and the jack and proving ring assembly are fitted to provide reaction against the frame. Three or four dial gauges are fixed on the periphery of the plate, from the independent datum frame for measuring settlements. A seating load of 0.07 kg/cm2 (320 kg for 75 cm diameter plate) is applied and released after a few seconds. A load sufficient to cause approximately 0.25 mm settlement is applied and when there is no perceptible increase in settlement or when the rate of settlement is less than 0.025 mm per minute (in the case of clayey soils or wet soils), the readings of the settlement dial gauges are noted and the average settlement is found, and the load is noted from the proving ring dial reading. The load is then increased till settlement increases to a further amount of about 0.25 mm and the average settlement and load are found. The procedure is repeated till the settlement reaches 0.175 cm. A graph is plotted with mean settlement versus mean bearing pressure as shown in Fig. 6.11. The pressure p corresponding to a settlement of 0.125 cm is read and the K-value is calculated by the reaction,

$$K = \frac{p}{0.125}\ kg/cm^2/cm^3$$



Load-Deformation Curve from Plate Bearing Test

Example:

A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter of 30 cm. The load values corresponding to the mean settlement dial readings are given below. Determine the modulus of subgrade reaction for the standard plate.

The load-settlement curve is plotted on a graph paper (similar to the one shown in Fig. above) and the load value p, corresponding mean settlement value of Δ= 0 125 cm is determined=1490 kg.

Unit load p_1

$$p_1 = \frac{1490}{\pi 15^2}$$

= 2.1079 kg/cm2

Modulus of subgrade reaction K_1 for 30 cm diameter plate

$$K_1 = \frac{p_1}{0.125}$$

$$K_1 = \frac{p_1}{\Delta} = \frac{2.1079}{0.125} = 16.86\ kg/cm^3$$

Modulus of subgrade reaction K for standard plate of dia. 70 cm.

$$K = \frac{K_1 a_1}{a} = \frac{16.86 \times 30}{75} = 6.75\ kg/cm^3$$

(Note; As the plate load test was conducted under soaked condition during monsoon season, there is no need to apply correction for subsequent soaking)

Regid pavement failure, maintainance and evaluation.

Failure of regid pavement is recognized mainly by the formation of Structural cracking. The failure are mainly due to two factors.

* Deficiency of pavement materials.
* Structural inadequacy of the pavement system.

Types of failures in Regid pavements.

The different types of destresses responsible for failures in rigid pavements are,

1. Joint spalling.
2. Faulting.
3. Polished aggregate.
4. Shrinkage cracking
5. Pumping
6. Punchout
7. Linear cracking
8. Durability cracking
9. Corner break.

① Joint spalling :

Excessive compressive stress causes deterioration in the joints called as Spalling. Which is caused by the reactive aggregates. Poor quality concrete also result in

Joint spalling. Small edges to large spalls in the back of the slab and down to the joints can be observed.

Causes for joint spalling:

* Joints subjected to excessive stress due to high traffic or by infiltration of any incompressible materials.
* The joint that are constructed with weak concrete.
* Joint that is accumulated with water that results in rapid freezing and thawing.

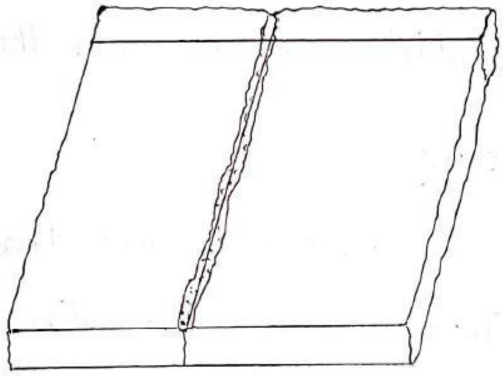


Fig. Joint spalling in rigid pavement slabs.

② Faulting:

The difference in elevation b/w the joints is called as Faulting.

Causes for Faulting:

* Settlement of the pavement that is caused due to soft foundation.
* The pumping or the erosion of material under the pavement, resulting in voids under the pavement slab

causing settlement.

* The temperature changes and moisture changes that cause curling of the slab edges.

3) Polished aggregates

The repeated traffic application leads to this distress. These are the failures in rigid pavements caused when the aggregates above the cement paste in the case of PCC is very small or the aggregates are not rough or when they are angular in shape, that it cannot provide sufficient skid resistance for the vehicles.

4) Shrinkage cracking

These are hairline cracks that are less than 2m in length. They donot cross the entire slab. The setting and curing process of the concrete slab results in such cracks. These are caused due to higher evaporation of water due to higher temperature cracks. Improper curing can also create shrinkage cracks in rigid pavements.

) Pumping effects:

The expulsion of water from the under a layer of the pavement is called as Pumping. The distress is caused due to the active vehicle loads coming over the pavement in repetitive manner. This will result in fine materials present in the subbase to move along with water and get expelled out with the water.

Pumping can be avoided by prevention of water accumulation at the pavement sub-base interface.

6) Punch-out in Rigid pavements:

A localized area of concrete slab that is broken into pieces will be named as punchout distress. This distress can take any shape or form. These are mainly defined by joints and cracks. The joints and cracks will mainly keep 1.5m width.

The main reason behind punchouts is heavy repeated loads, the slab thickness inadequacy, the foundati support loss or the construction deficiency like honeycombing

7) Linear cracking:

These types of failures in rigid pavements divid the slab into two or three pieces. The reason behind such failures is traffic loads at repeated levels, the curling due to thermal gradient and moisture loading repeatedly

8) Durability cracking:

The freezing and thawing action will create regular expansion and contraction which will result in the gradual breakdown of the concrete. This type of distress is patterns of cracks on the concrete surface as layers that are parallel and closer to the joints.

Joints and cracks are the areas where the concrete seem to be more saturated. Here a dark deposit is found and called the 'D' cracks. This failure of rigid pavement will finally result in the complete disintegration of the whole slab.

9) Corner breaks

There are the failures in rigid pavements that is caused due to pumping in excessive rate. When the pumping completely remove the underlying support that no more support exists below to taken the vehicle load, the corner cracks are created. The repair method is either full slab replacement or the repair for the full depth must be carriedout.

Causes for the failure in Rigid pavement:

Following are the chief causes which would give rise to the different failures of cement concrete pavement.

* Soft aggregates.
* Poor workmanship in joint construction.
* Poor joint filler and sealer material.
* Poor surface finish.
* Improper and insufficient curing.

Remedial / Maintainance measures in Rigid pavement.

Maintainance measures taken in Rigid pavement are,

1. Crack filling.
2. Crack sealing.
3. Stitching
4. Partial depth repair
5. Full depth repair
6. Dowel bar retrofit
7. Diamond grinding
8.

① Crack filling:

It is the process of filling crack filler into non-working cracks to substantially reduce the intrusion of incompressible material and the infiltration of moisture in the pavement. Usually cracks less than 2mm and (non working) require crack filling. low viscosity epoxy and polymer modified asphalt are used as Crack filler.

② Crack sealing:

Placement of specialized materials into Working cracks (Cracks more than 2mm) using unique configurations to reduce the intrusion of incompressible material and the infiltration of moisture in the pavement is known as Crack sealing. These cracks can be sealed using epoxy resin mortar.

③ Stitching :

It is a repair technique to maintain aggregate interlock at the point of cracking and to provide added reinforcement and strength to the pavement. Stitching is carriedout for strengthening longitudinal cracks in slabs. There are three types of stitching used,

* Cross stitching
* Slot stitching
* U-bar stitching

Cross stitching is most widely used method.

④ Partial depth repair.

This method is used to correct several distresses. The sequential operations carriedout for this method is,

→ Identification of deteriorated concrete.
→ Demarcation of repair boundaries
→ Removal of distressed concrete.
→ Cleaning
→ Joint preperation.
→ Application of bonding agents.
→ Placing the patching material.
→ Texturing, curing and joint sealing.

Cementatitious grout is usually used as bonding agent.

⑤ Full depth repair :

Structural integrity and functioning of rigid pavements can be restored by full depth repairs. Here full depth of part of the slab is removed and replaced by new concrete patch. The sequence of operations in case of full depth repair are similar to that of partial depth repair but with an addition of provision of load transfer devices, as for most jointed pavements dowel bars are essential for load transfer.

6) Dowel bar retrofit:

The rehabilitation technique is applicable to only jointed concrete pavements. Low load transfer efficiency (<60%) greater faulting and differential deflection of pavement slabs are the reasons for dowel bar retrofitting. Slots of required size are cut using diamond saw slot cutters. Dowel bars are then placed in the prepared slots and then the slots are back filled.

7) Diamond grinding:

Diamond grinding removes a thin layer at the surface of hardened concrete pavement using closely spaced diamond blades. It is used for removing bumps in the newly placed concrete pavement, especially at the transverse construction joints. The level surface is achieved by running the blade assembly at a predetermined level across the pavement surface.

Evaluation of Rigid pavement:

Pavement evaluation involves a thorough study of various factors such as subgrade support, pavement composition and its thickness, traffic loading and environmental conditions.

Evaluation by Visual inspection:

Visual inspection is a method of inspecting the pavement surface for detecting and assessing the amount and severity of various types of damage. Visual survey conducted from a moving vehicle to the more detailed survey that involves trained engineers and technicians walking the entire length of the selected areas and measuring and mappingout all distresses identified on the pavement surface, shoulders and drainage systems. Recently, automated visual survey techniques have become more common and are being adopted for distress surveys and pavement condition evaluation.

Evaluation by Unevenness measurement:

The pavement unevenness may be measured using unevenness indicator, profilograph, profilometer or roughometer. An equipment capable of integrating the

the unevenness of pavement surface to a cumulative scale and that gives the unevenness index of the surface in cm/km Length of road may be called. Unevenness integrator.

The pavement unevenness criteria to indicate the pavement riding qualities expressed in terms of unevenness index recommended by Holloway is given in below table.

In Old pavements

Unevenness index cm/km	Riding quality.
Below 95	Excellent
95 to 119	Good
120 to 144	Fair
145 to 240	Poor
Above 240	Very poor

In new pavements.

Unevenness index cm/km	Riding quality.
Below 120	Good
120 to 145	Fair
Above 145	Poor

Joints:

Requirements of joints:

Some of the requirements of joints are.

* The joint must permit movement of the slabs without restraint.
* The joints should not unduly weaken the slab structurally and the load should be transferred from one slab to another effectively.
* The joints must be sealed to exclude water, grit and other external matter.

* The riding quality of the pavement should not be impaired
* The construction of the joints must interfere as little as possible with laying of the concrete.

Need for Joints:

Concrete pavements are subjected to volumetric changes produced by temperature variations, shrinkage during setting and changes in moisture content. If a long slab is built, it is bound to crack at close intervals because of such factors. A pavement reasonably free from cracks can only be built if it is divided into small slabs by interposing joints. These joints will then ensure that the stresses developed ~~to~~ due to expansion, contraction and warping of the slab are within reasonable limits. The longer the length b/w joints, the greater is the warping stress and greater is the need for reinforcing steel.

Types of joints:

Joints in concrete slabs can be classified into,

① Expansion joints.
② Contraction joints.
③ Warping joints.
④ Construction joints.
⑤ Longitudinal joints.

① Expansion joints:

Expansion joints, as the name itself signifies, are intended to provide space in the pavement for expansion of the slabs. Expansion takes place when the temperature of the slab rises above the value when it was laid. It is normally a transverse joint. Expansion joints also relieve stresses caused by contraction and warping. Expansion joints are omitted altogether in modern practice.

Features of expansion joints are,

* A space for expansion which is generally 20mm.
* A joint filling compressible material interposed in the above space.
* A joint sealing arrangement.
* A dowel bar for load transfer.
* Thin coating of bitumen in the expanding portion of the dowel bar to break bond with concrete and permit expansion.
* A card board or metal cap at the expanding end of the dowel bar filled with cotton waste.

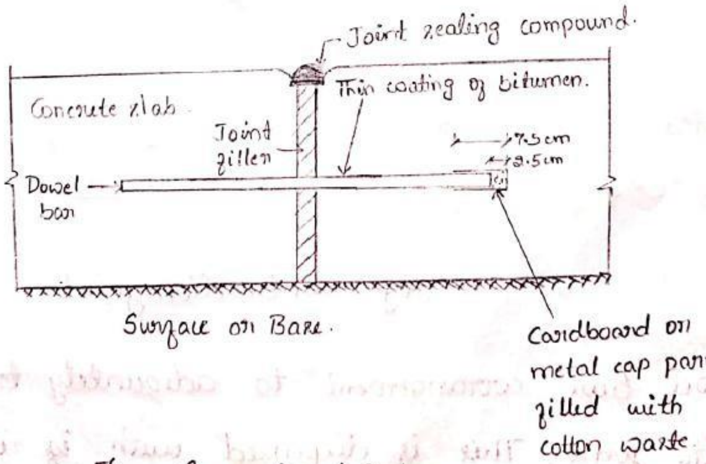


Fig. Expansion joint.

② Contraction joints:

When the temperature of concrete falls below the laying temperature, the slab contracts. If a long length of slab is laid, the contraction induces tensile stresses and the slab cracks. If joints are provided at suitable intervals transversely, the appearance of cracks at places other than the joints can be eliminated. Contraction joints also relieve warping stresses to some extent.

Features of contraction joints are,

* A surface groove formed by driving a flat metal plate when the concrete is green. It is not less than 6mm wide and has a depth equal to one-fourth the depth of the pavement.
* A sealing compound to prevent ingress of external material

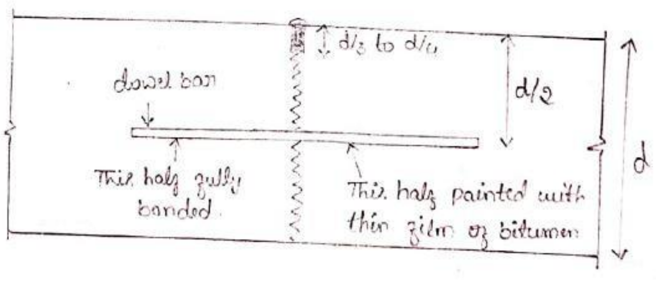


Fig. Contraction joint.

* A dowel bar arrangement to adequately transfer the load across the joint. This is dispensed with if it is considered that the aggregate interlock is able to transfer the load.

③ Warping joints:

Warping joints, also known as hinge joints, are joints which are intended to relieve warping stresses. They permit hinge action but no appreciable seperation of adjacent slabs. Warping joints can be longitudinal or transverse. A major difference b/w the warping joints and the expansion or contraction joints is that in the former appreciable changes in the joint width are prevented. This is achieved by continuation of reinforcing steel through the joint or by the installation of the bars across the joint.

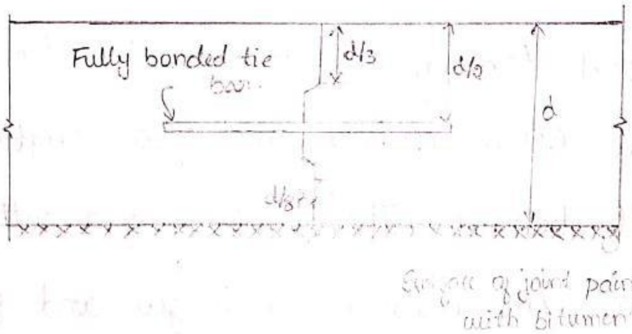


Fig. Warping joint.

④ Construction joint:

A construction joint becomes necessary when work has to be stopped at a point where there would be otherwise no other joint. It is advisable to plan a day's work such that the work stops at a contraction or expansion joint. Such joints should be regular in shape, by placing a cross-form in position. The reinforcement should be continued across the joint. A groove in the joint with a sealing compound will arrest the entry of foreign matter and is desirable.

⑤ Longitudinal joints:

When the pavement width is more than say 5m, it is necessary to provide a longitudinal joint and construct the pavement in strips. These joints allow for warping and uneven settlement of the subgrade.

The very purpose of the longitudinal joints being to reduce warping stresses and uneven settlements, it is very necessary to provide for some form of load transferring device. Load transferring is done by tie-bars (12.5mm to 25mm dia) at 60cm centres and of a length of 1m. Tie bars are fully bonded. The joint is of a butt type as shown in below figure. Alternatively, a tongue and groove joint may be provided with suitable tie rods 12.5 mm dia, 1m long and at 60-75cm centres. The tie rods are fully bonded.

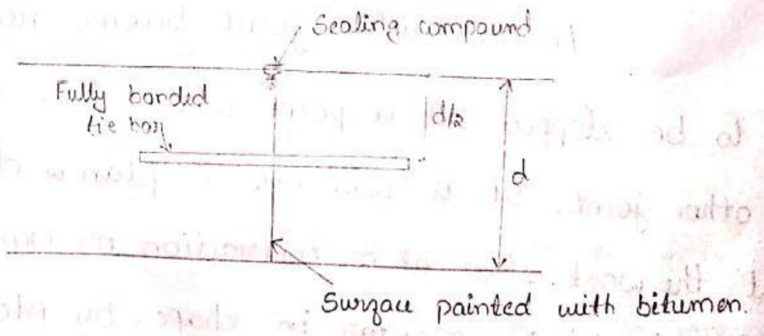


Fig. Butt type longitudinal joint with tie bar.