PAVEMENT

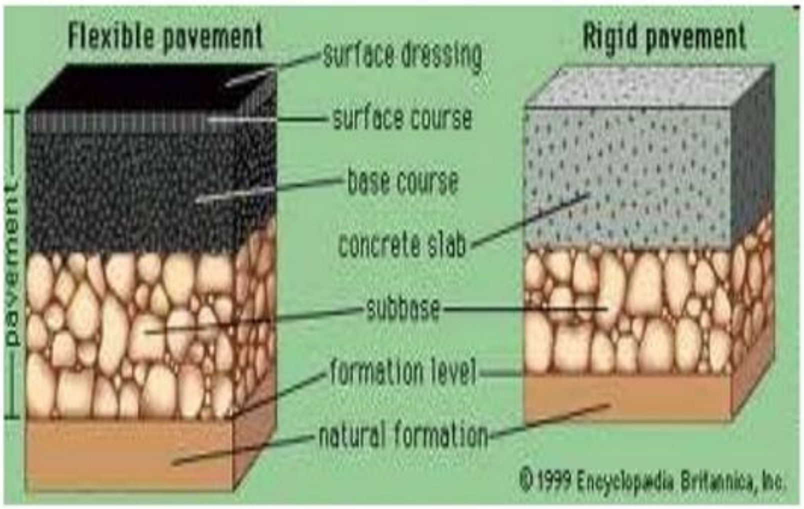
Pavement is the durable surface material laid down on an area intended to sustain vehicular load or foot traffic, such as a road or walkway.

- Pavement means surfacing layer only.
- In terms of highway design, it means the total thickness of road including surfacing, base & surface, if any.
- Thus, pavement includes all the structural layers of road structure lying on subgrade of the road.

It is of two types

- Flexible pavement or bituminous pavement or black top pavement
- Rigid pavement or cement concrete pavement or white surface pavement

Types of Pavements



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 or bituminous pavement or black top pavement, 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 or cement concrete pavement or white surface pavement, 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.

Important Points on Flexible pavement:

- Design of flexible pavement is based on the principle that the wheel loads of vehicle are dissipated to the natural soil through successive layers of granular materials
- The intensity of load decreases with depth as the area of dissipation is increased. Hence the higher quality of material is placed at top.
- The strength of the subgrade decides the thickness of flexible pavement.
- WBM roads, stabilized roads, earth roads, gravel roads etc. consist of layers of road making materials compacted to from an elastic bed are grouped under flexible pavements.

COMPARISON OF FLEXIBLE PAVEMENT & RIGID PAVEMENT

The comparisons are:

i) Design precision

A cement concrete pavement is amerable to a much more precise structural analysis than a flexible pavement. Flexible pavements designs are mainly empirical. Computer aided analysis of layered system is making the flexible pavement design more exact than hitherto.

ii) Life

- Cement concrete slabs of a thin section constructed in the early 1940's are still in existence in India though many of them have cracked badly and a few of them have been ripped open and rebuilt in recent ties.

- A major project in cement concrete road construction between Agra and Mathura. It can safely be said that a well-designed concrete slab has a life of about 40 years.
- Compared to this the life of a flexible pavement generally varies from 10 to 20 years.

iii) Maintenance:

- A well-designed cement concrete pavement needs very little maintenance. The only maintenance needed is I respect of joints.
- The surface is unaffected by spillage of oil and lubricants, bituminous surfaces on the other hand, need great inputs in maintenance.
- The surface is affected by spillage of oil and lubricants. The surface is also affected by natural weathering agents like air, water ad temperature changes.
- A cement concrete pavement on the other hand needs a small amount for maintaining joints.

iv) Initial cost:

- The argument so far used against a cement concrete slab is that it is much more costly than a flexible pavement.
- The latter specifications no doubt represent the rock-bottom needs of a road in India, but these specifications can hardly provide a smooth and durable surface.

v) Stage construction:

- Road construction is generally done adopting a policy of stage construction especially for low volume roads. As traffic grows, additional layers in the form of water bound macadam and superior surfacing are added on.
- Initial outlay is minimum and additional outlays are in keeping with traffic growth. This is a great advantage when dealing with new roads in an atmosphere of austerity.

vi) Availability of materials:

- Cement, bitumen, stone aggregates and gravel/sand are the major materials involved in pavement Construction. Cement has been in serious short supply in the country for the past many decades.
- Bitumen is also not available plentifully in India. There is also the danger of the entire oil reserves in the world shrinking during the next two or three decades.
- In locations where stone aggregates are scarce, cement concrete may have an advantage for flexible pavements

vii) Surface characterstics:

- A good cement concrete surface is smooth and free from rutting, potholes and corrugations. In a bituminous surface it is only the asphaltic concrete surface that can give comparable rideablity.

- A well-constructed cement concrete pavement surface can have a permanent nonskid surface. A bituminous surface can also be designed to have a good skid resistant surface.

viii) Utility location:

- In cement concrete slabs, proper thought has to be given to locate utilities, such as water pipes, telephone lines and electric cables.
- It is difficult to rip open the slab and restore it to be the original condition ,if any changes in the utilities lines are to be made.

ix) Glame and night visibility:

- Concrete pavements have a gray color which can cause glam under sunlight. Colored cement can reduce the grave.
- On the other hand, bituminous roads need more street lighting.

x) Traffic dislocation during construction:

- A cement concrete pavement requires 28 days before it can be thrown open to traffic. On the other hand, a bituminous surface can be thrown open to traffic shortly after it is rolled.

xi) Environmental considerations during construction:

- The process of heating of bitumen and aggregates and mixing them together on hot mix plants, can prove to be much more hazardous to the environment than cement concrete construction where no heating of any material is involved.

xii) Overall economy on a life cycle basis:

- A good road is costly to construct but once constructed such a road requires little maintenance and results in savings in vehicle operating costs.
- The comparative economy of a flexible pavement and a rigid pavement has proved that on overall economic considerations.

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

FLEXIBLE PAVEMENT	**RIGID PAVEMENT**
1.Have low flexural strength 2.Load is transferred by grain-to-grain contact 3.Surfacing cannot be laid directly on the sub grade but a sub base is needed 4.No thermal stresses are induced 5.expansion joints are not needed 6.Design life 10-15 years 7.Initial cost of construction is low 8.Maintenance cost is high 9.Road can be used for traffic within 24 hours 10.Damaged by Oils and Certain Chemicals	1.Have more flexural strength 2.No such phenomenon of grain-to-grain load transfer exists 3.Surfacing can be directly laid on the sub grade 4.Thermal stresses are induced 5.expansion joints are needed 6.Design life 20-30 years 7.Initial cost of construction is high 8.Less maintenance cost 9.Road cannot be used until 14 days of curing 10.No Damage by Oils and other chemicals

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 as shown in figure 3.1. The wheel load acting on the pavement will be distributed to a wider area, and the stress decreases with the depth. Taking advantage of this 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.

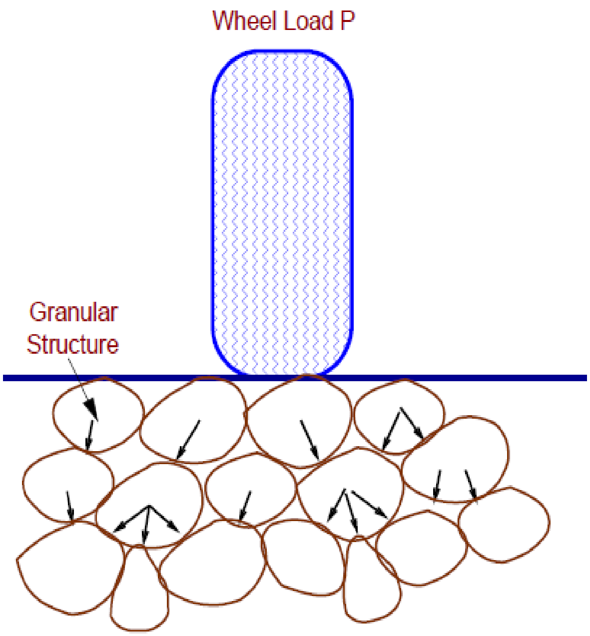


Figure: 3.1 Load transfer in granular structure

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 subgrade. 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 3.2).

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 layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat: Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course:

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded asphalt concrete (AC). The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,

- It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

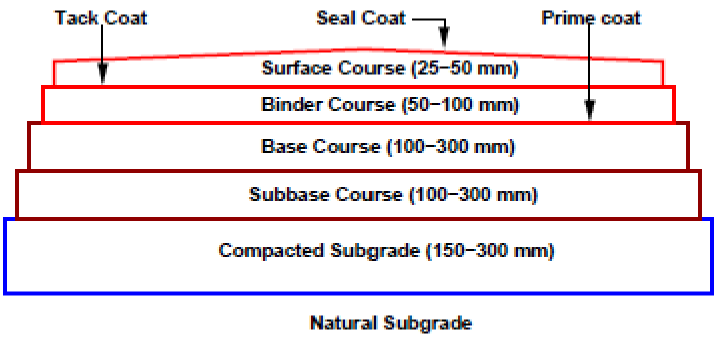


Figure: 3.2 Typical cross section of a flexible pavement

Binder course:

This layer provides the bulk of the asphalt concrete structure. It's chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less asphalt and doesn't require quality as high as the surface course, so replacing a part of the surface course by the binder course results in more economical design.

Base course:

The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

Sub-Base course:

The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course A sub-base course is not always needed or used. For example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

Sub-grade:

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

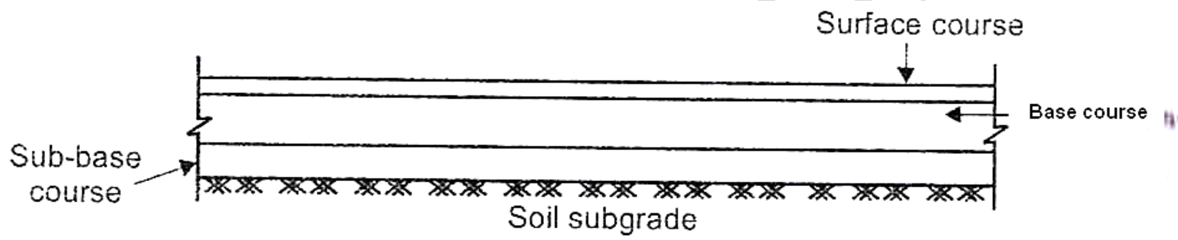
FLEXIBLE PAVEMENTS – COMPONENTS AND THEIR FUNCTIONS:

Components Of The Flexible Pavements

Flexible pavements are those which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the loads. The flexible pavement layers reflect the deformation of the lower layers on to the surface of the layer. Thus if the lower layer of the pavement or soil sub grade is undulated, the flexible pavement surface also gets undulated. A typical; flexible pavement consists of four components:

- Soil sub grade
- Sub base course
- Base course
- Surface course

A typical cross section of a flexible pavement structure is shown in fig.



Flexible pavement

Sub-grade:

It is defined as the supporting structure on which the pavement surface and its special under courses rest.

Main function is to provide sufficient support to the pavement.

Subgrade should possess sufficient stability under adverse climate & loading conditions.

Sub-base:

Economy is the prime factor to be considered in the design of sub base course.

It is generally recommended to use locally available material for sub base.

The main purpose is to permit the construction of pavement at low cost.

Function:

i. To add to the structural support for the overlying layers i.e. base & surface courses.
ii. To improve drainage.
iii. To reduce frost heave in cold weather conditions.

Base course:

It is provide under the wearing course or pavement. They have to satisfy the following requirements

i. Thickness should be adequate to distribute the heavy wheel load pressure gradually to the subgrade through a sub base.
ii. It should have sufficient structural stability so as to resist the vertical pressures & shear stresses due to moving vehicles
iii. It should have enough resistance to weathering.
iv. It should be compacted well to have sufficient density.

Wearing/Surface course:

This course comes into contact with the wheels of vehicles.

The main purpose is to resist the pressure exerted by the tyres and to be smooth so that the vehicles will have large mileage & less wear & tear for tyres.

- It serves as water resistant membrane not allowing the surface water getting into the base & not allowing the capillary water to pass through the wearing course.
- It adds adequate strength to entire pavement structure. Bituminous material as surfacing in flexible pavement. Cement concrete layer act as wearing surface.

Parameters for design of pavements

Design of pavements mainly consists of two aspects

1. Design mix of materials
2. Pavement thickness

Factors governing the structural design of pavements

The various factors to be considered for the design of pavements are given below:

- Design wheel load
- Sub grade soil
- Climatic factors
- Pavement component materials
- Environmental factors
- Special factors

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.

Design wheel load

The thickness design of pavement primarily upon the design wheel load. Higher wheel load obviously need thicker pavement provided other design factors are the same. While considering wheel load, the effects of total static load on each wheel, multiple wheel load assembly, contact pressure, load repetition and the dynamic effects of transient loads are to be taken into account. As the speed increases the rate of application of the stress is also increased in resulting in a reaction in the pavement deformation under the load: but on uneven pavements, the impact increases with speed. Some of the important design factors associated with the traffic wheel loads have been explained in the subsequent article.

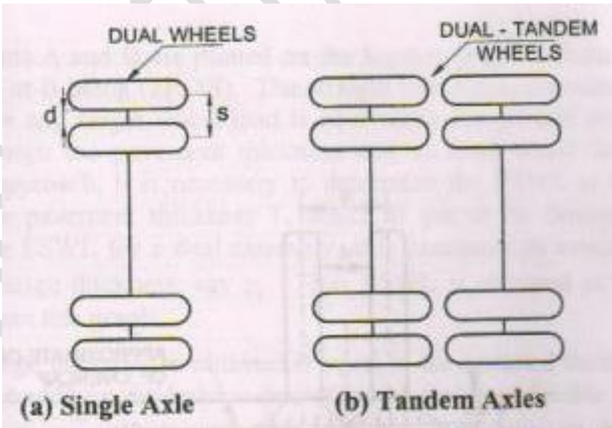
Various wheel load factors are

i. Maximum wheel load
ii. Contact pressure
iii. Dual or multiple wheel loads & ESWL
iv. Repetition of load

Maximum wheel load:

For highways in India, the maximum legal axle load as specified by IRC is 8170 kg with a maximum equivalent single wheel load of 4085 kg.

Total load influences thickness of pavement. Tyre pressure influences quality of surface or wearing course.



The equation for vertical stress computations under a uniformly distributed circular load as per Boussineq's theory is given by:

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

Where σ_z = vertical stress at depth z

p = contact pressure of tyre

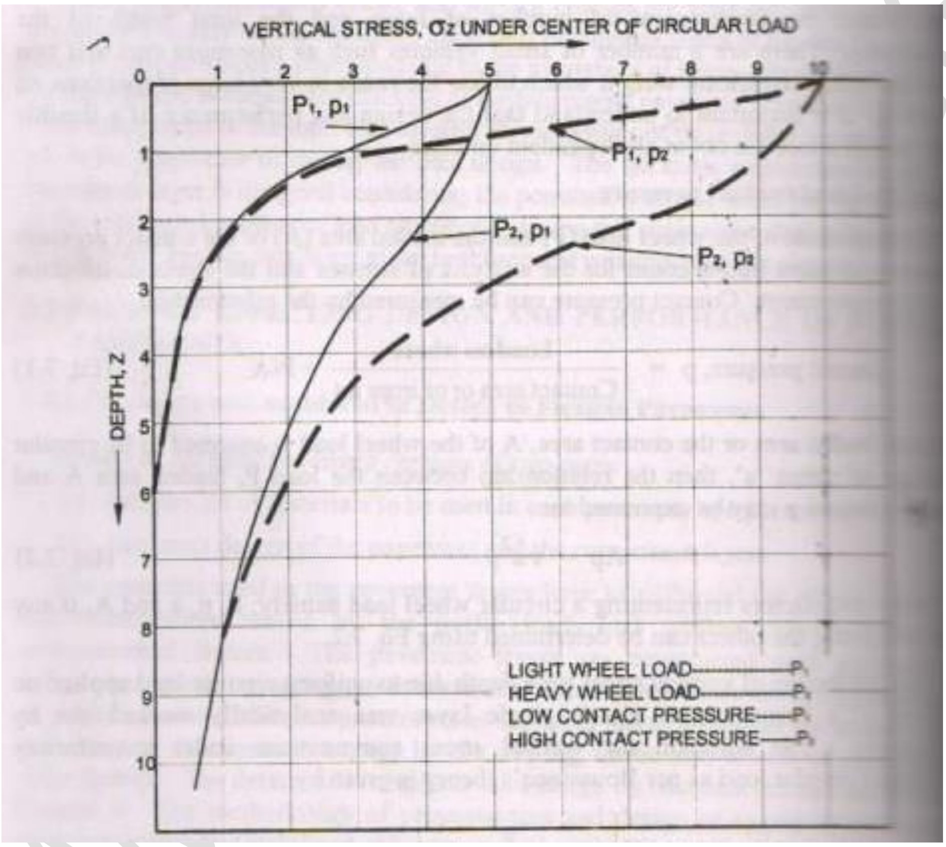
z = depth at which σ_z is computed

a = radius of loaded area

This value is higher than unity for lower tyre pressure& less than unity for tyre pressure higher than 7 kg/cm^2. Rigidity factor depends on the degree of tension developed in the walls of tryes.

Contact pressure:

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



Influence of tyre pressure is predominating in the upper layers. Tyre pressure of high magnitudes therefore demand high quality of materials in upper layers in pavements.

The stresses on the pavement surface under the steel tyred wheels of bullock carts are very high. These demands use of very strong & hard aggregate for the wearing surface of the pavement**.**

Generally, the wheel load is assumed to be distributed over a circular area.

- Tyre pressure
- Inflation pressure } same
- Contact pressure

Contact pressure p = $\frac{Loadonwheel}{ContactareaorAreaof\ \mathrm{Im}\,pr\,\mathrm{int}} = \frac{P}{A}$

Where Wheel load = P

Loaded area = A

The ratio of contact pressure to tyre pressure is defined as Rigidity factor. Value of Rigidity factor is 1 for an average tyre pressure of 7 kg/cm^2.

Equivalent Single Wheel load:

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

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

In order to simplify, the analysis the load dispersion is assumed to be at an angle of 45^0.

Let d = clear gap between the two loads

S = spacing between centers of wheels

a = radius of circular contact area of each wheel

Then S = d + 2a

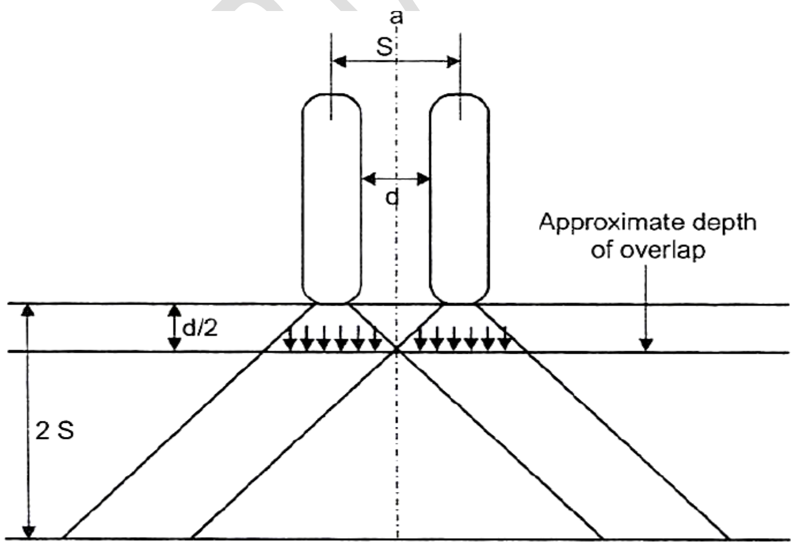


Figure: Stress overlap due to dual wheels

Up to the depth of d/2 each wheel load p acts independently and after this point the stresses induced due to each load begins to overlap. At depth 2S, and above the stresses induced are due to effect of both wheels as the area of overlap is considerable.

So, the total stresses due to dual wheels at any depth greater than 2S is considered to be equivalent to a single wheel load of magnitude 2 P.

Equivalent single axle load

- Legal axle load
- Standard axle load

Repetition of loads:

The deformation of pavement or subgrade due to a single application of wheel load may be small. But due to repeated application of load there would be increased magnitude of plastic and elastic deformations.

Equivalent axle load factor

$$\text{Equivalent single axle load, ESAL} = \sum_{i=1}^{m} F_i n_i$$

Equivalent load factors are employed to convert daily traffic count for each category of wheel load for design purposes.

Sub grade soil

The properties of the sub grade soil are important in deciding the thickness requirements of pavements sub grade with lower stability requires thicker pavement to protect it from traffic loads. The variation in stability and volume of the sub grade soil with moisture changes are to be studied as these properties are dependent on the soil characteristics. The stress strain behaviors of the soil under static and repeated loads have also significance. Apart from the design the pavement performance to a great extent depends on the sub grade soil properties and the drainage.

Climate factors

Among the climate factors, rainfall affects the moisture conditions in the sub grade and the pavement layers. The daily and seasonal variation in temperature has significance in the design and performance of rigid pavements. Where freezing temperature is prevalent during winter, the possibility of frost action in the sub grade and the damping effects should be considered at the design stage itself.

Pavement component materials

The stress distribution characteristic of the pavement components layers depends on characteristics of the materials used. The fatigue behavior of these materials and their durability under adverse conditions of weather should also be given due consideration.

Environmental factors

The environmental factors such as height of embankments and its foundations details. Depth of cutting, depth of sub surface water table, etc. Affect the performance of the pavement. The choice of the bituminous binder and the performance of the bituminous pavement depending on the variations in pavement temperature with the seasons in the region.

Equivalent single wheel load factor

In order to have maximum wheel load, dual wheel assembly is provided to the rear axles of the load vehicles. Because of this, the load due to both the wheels is not to be transferred to the pavement. But there will be overlap pressure after a certain depth. The actual effects is in between a single wheel load and double the load carried by any one wheel. Stress overlap is presented in figure below.

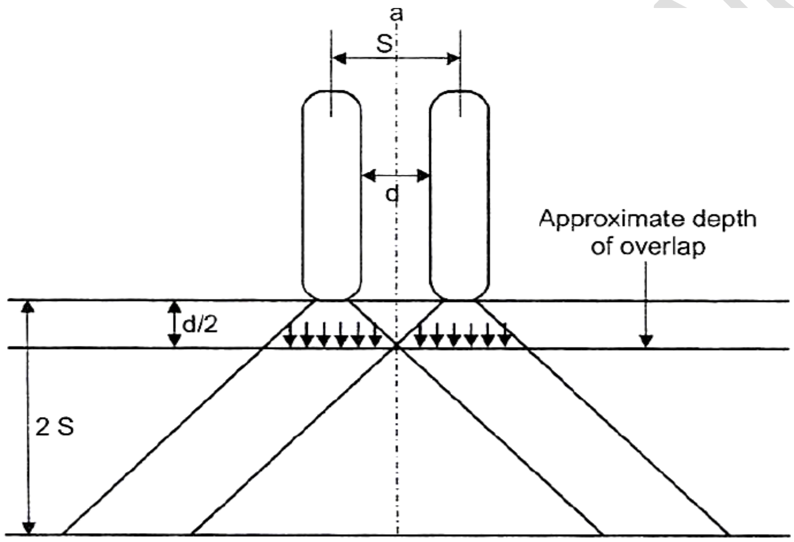


Figure: Stress overlap due to dual wheels

It is assumed that up to a depth of d/2 the loads act independently beyond which the stresses overlap. The area of overlap becomes more beyond a depth of 2S.hence it may be considered that the load the total stress due to the dual wheels at any depth greater than 2S, is to be equivalent to a single wheel load of 2P magnitude. However, this stress due to 2P is to be slightly greater than the duel wheel assembly which is on the safe side.

This equivalent single wheel load can be determined by equivalent deflection or equivalent deflection or equivalent stress criterion. For example, based on deflection criterion it is to state that the maximum deflection caused at a particular depth z (say, depth equivalent to the thickness of pavement) by a dual wheel load Assembly is also caused by an equivalent single wheel load acting at the surface of the pavement.

Similarly by the stress criterion the ESWL producing the same stress value at a depth z as that produced by a dual wheel load assembly.

A linear relationship is assumed between the ESWL and the depth in a log-log scale. A linear plot is got, as shown in fig. By plotting a point A with coordinates z = d/2 and P and point B with coordinates z = 2S and 2P.

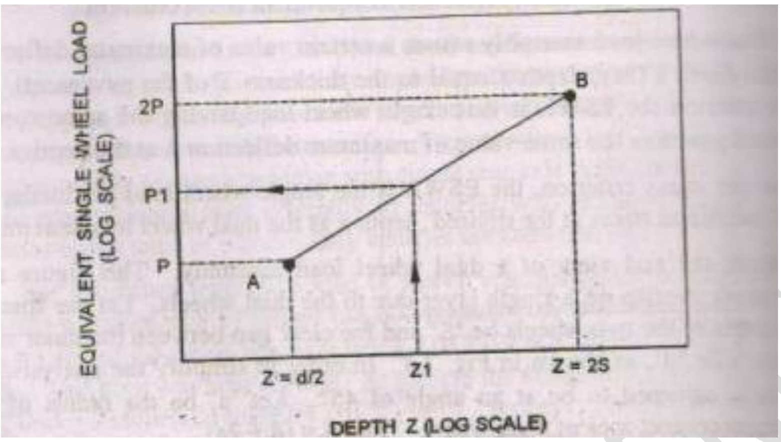


Figure: Graphical method for determination of ESWL

Line AB represents the locus of point where any single wheel load is equivalent to a certain set of dual wheels.

In order to use the graph, for an assumed thickness of pavement and ESWL is got from the graph. This ESWL is used in the design calculations and the thickness of pavement is obtained. If this thickness and assumed thicknesses are same then the ESWL assumed is correct. If not the design is repeated and by trial and error the correct thickness of pavement is obtained. This calculation is valid for the given wheel load configuration. For different wheel load assembly different ESWL plots may be made.

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.

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.

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

STRENGTH CHARACTERISTICS OF PAVEMENT MATERIALS:

1. California Bearing Ratio value
2. Elastic Moduli

California Bearing Ratio

The strength values so obtained for the materials tested are of relative significance and do not provide as absolute measure. These are design methods which employ the CBR strength values of materials used & different pavement layers.

IRC Recommendations CBR test

- Performed in Laboratory only.
- Compaction done by Proctor compaction test
- Top 50 cm of subgrade should be compacted atleast upto 95 to 100 5 of proctor density.
- $A=P(1 + r)^{n+10}$

Where

A = number of heavy vehicles per day for design (laden weight>3 tonnes)

P = number of heavy vehicles per day at least count.

R = annual rate of increase of heavy vehicles

n = number of years between the least count and the year of completion of constructions.

Limitations of CBR method of pavement design

- CBR is an adhoc penetration test which does not consider any of the sub grade properties directly.
- As the method is empirical, it is not essentially related to any particular value of axle load or wheel load repetitions.
- The design curves provided in the method are not meant to be made use of on the basis of traffic immediately carried by the road or that anticipated (in the case of new constructions).
- This method gives the total thickness requirement of the pavement above a sub grade and the thickness is same irrespective of the quantity of materials used in the component layers.

Elastic moduli:

Depending upon the design methods, the elastic moduli of different pavement materials are evaluated

i. Plate bearing test
ii. Tri-axial compression test

The elastic moduli values of the following are determined by plate bearing tests:

i. Subgrade modulus

ii. Elastic moduli of base course and sub base course materials

The maximum deflection, Δ at the surface and the center of a flexible plate is given by

$$\Delta = \frac{1.5pa}{E_s}$$

Where p = uniform pressure on the flexible loaded plate of radius a

E_s = Modulus of elasticity of soil

For rigid plate

$$\Delta = \frac{1.18pa}{E_s}$$

Burmister analysis

$$\Delta = \frac{1.5pa}{E_s} \times F_2 \quad \text{(For Flexible plate)}$$

$$\Delta = \frac{1.18pa}{E_s} \times F_2 \quad \text{(For rigid plate)}$$

Climatic variations:

i. Variation in moisture condition
ii. Frost action
iii. Variation in temperature

Variation in moisture condition:

- Pavement performance is very much affected because of variation in stability and the volume of subgrade soil
- The surface water during rains may enter the subgrade either through pavement edges or through the pavement itself.
- As moisture content of subgrade below the center is often different from that at pavement edges, there can be differential rise or fall of pavement edges w.r.t. center due to swelling and shrinkage of subgrade soil
- It leads to considerable damages to the pavements and will also be progressive and cumulative

Frost action:

It refers to adverse effective due to frost heave, frost melting or thaw & alternate cycles of freezing and thawing.

The freezing and thawing which occurs alternately due to variation in weather causes undulations and considerable damages to the pavement. Hence, the overall effects due to frost heave, frost melting and alternate freeze thaw cycles is called frost action.

Depends on factors such as :

i. Frost susceptible soil
ii. Depressed temperature below freezing point
iii. Supply of water
iv. Cover

Capillary cutoff

Way to reduce the adverse effects of frost action on pavements by soil stabilization.

Variation in Temperature

Temperature stresses of high magnitude are induced in cement concrete pavements due to daily variation in temperature and consequent warping of pavement.

Bituminous pavement become soft in hot weather and brittle in very cold weather.

DESIGN OF FEXIBLE PAVEMENTS

Flexible pavement designs will provide the following:

- Sufficient compaction of the subgrade and of each layer during construction to prevent objectionable settlement under traffic.
- Adequate drainage of base course.
- Adequate thickness above the subgrade and above each layer together with adequate quality of the select material, subbase, and base courses to prevent detrimental shear deformation under traffic and, when frost conditions are a factor, to control or reduce to acceptable limits effects of frost heave or permafrost degradation.
- A stable, weather-resistant, wear-resistant waterproof, non-slippery pavement.

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

(i) Vertical compression strain at the top of the subgrade which can cause subgrade deformation resulting in permanent deformation at the pavement surface.

(ii) Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.

(iii) Pavement deformation within the bituminous layer.

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 critical points are within the allowable limits.

IRC METHOD OF DESIGN OF FLEXIBLE PAVEMENTS

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 up to only 30 million standard axles (msa).

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

- Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.
- Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.
- Pavement deformation within the bituminous layer.

Failure Criteria:

- Fatigue Criteria
- Rutting Criteria

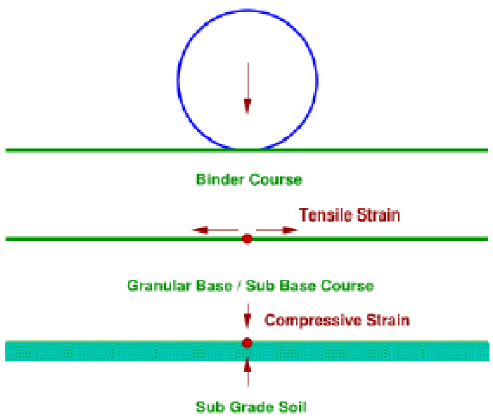


Fig. Critical Locations in Pavement

Failure Criteria:

- Factor responsible for permanent deformation of subgrade is the vertical strain (ε_v) at the top of subgrade. Dominating factor for tensile cracking due to fatigue is the tensile strain (ε_t) at the bottom of bituminous layer.

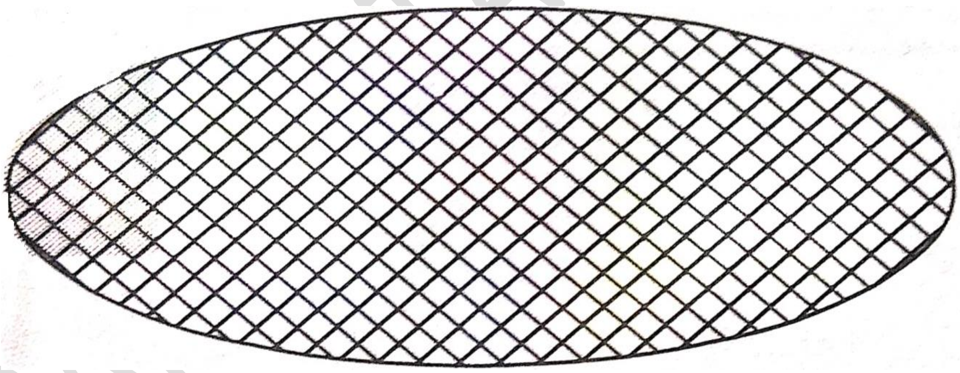
There are two types of failure criteria in case of flexible pavement design.

(i) **Fatigue Criteria:** Bituminous surfacing of pavements display flexural fatigue cracking if the tensile strain at the bottom of the bituminous layer is beyond certain limit. Fatigue cracking in bituminous layer looks like crocodile cracking.

$$N_f = 2.21 \text{ x } 10^{-4} \left(\frac{1}{\varepsilon_t}\right)^{3.89} \left(\frac{1}{E}\right)^{0.854}$$

Where,

- N_f = Number of cumulative standard axle to produce 20 % cracked surface area
- ε_t = Tensile strain at the bottom of the bituminous layer, and
- E = Elastic modulus of the bituminous layer.



Fatigue cracking

(ii) **Rutting Criteria:**

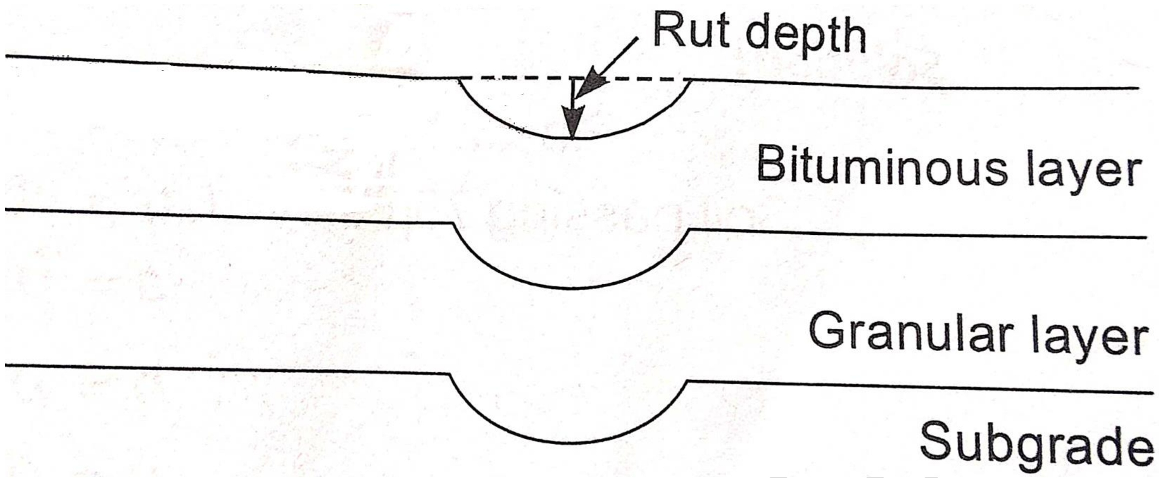
Rutting is the permanent deformation caused mainly due to permanent deformation in subgrade. The allowable number of load repetitions to control permanent deformation can be expressed as

$$N_r = 4.1656 \text{ x } 10^{-8} \left(\frac{1}{\varepsilon_z}\right)^{4.5337}$$

Where,

N_f = Number of cumulative standard axles to produce rutting of 20 mm

ε_v = Vertical subgrade strain at top



Rutting cracking

The flexible pavement is built with number of layers. In the design process it is to be ensured that under the application of load none of the layers is overstressed.

The maximum intensity of stresses occurs in the top layer of the pavement. The magnitude of load stresses reduces at lower layers.

In the design of flexible pavements, it has yet not been possible to have a rational design method wherein design process and service behavior of the pavement can be expressed by mathematical laws.

Flexible pavement design methods are accordingly either empirical or semi empirical. In these methods, the knowledge and experience gained on the behavior of the pavements in the past are usefully utilized.

Various Approaches of Flexible Pavement Design

(i) Empirical methods: They are based on strength pavement of soil subgrade. The group index method, CBR method, and Mcleod method are empirical methods

(ii)Semi Empirical or Semi theoretical method: These methods are based upon the stress strain function, Triaxial test method is an example of semi empirical method.

(iii)Theoretical Methods: These methods are totally depends upon the theoretical analysis and mathematical computations. Burmister method is an example of theoretical method.

Empirical methods are either based on physical properties or strength parameters of soil sub grade. When the design is based on stress strain function and modified base on experience it may be called semi-empirical or semi-theoretical. There are design methods based on theoretical analysis and mathematical computations. Out of the flexible pavement design method available is

i) Group index method

ii) California bearing ratio method

iii) California R value (or) Stabiliometer method

iv) Triaxial test method

v) McLeod method

vi) Burmister method

Group Index Method

D.J. Steel in 1945 suggested the thickness requirement of pavement on the basis of Group Index values. It is just an arbitrary index assigned to the soil depending on the percent fines, liquid limit and plasticity index.

The higher value Group Index represents the weaker soil subgrade, the greater will be the thickness of pavement. The group index values of soils vary from 0 to 20.

Limitations of Group Index Method:

(i) This method does not consider the strength characteristics of the subgrade soil.

(ii) Quality of pavement is not considered, same thickness is required even better quality material is used.

GI is a function of

a. Percentage of material passing through 0.075 mm sieve

b. Liquid limit

c. Plasticity index

By sieve analysis test we can determine Group index value of soil subgrade from below equation

GI = 0.2a + 0.005ac + 0.01bd

Where,

a: portion of material passing 0.075mm sieve greater than 35 and not exceeding 75% (0 to 40)

b: portion of material passing 0.075mm sieve greater than 15 and not exceeding 35% (0 to 20)

c: the value of liquid limit in excess of 40 and less than 60 (0 to 20)

d: the value of plasticity index exceeding 10 and not more than 30 (0 to 20)

Group Index Method of Flexible Pavement Design

Data Required for Flexible Pavement Design

1. Group index of soil subgrade Group index value range of different soils is given below

- For good soil – 0 to 1
- For fair soil – 2 to 4
- For poor soil – 5 to 9
- For very poor soil – 10 to 20

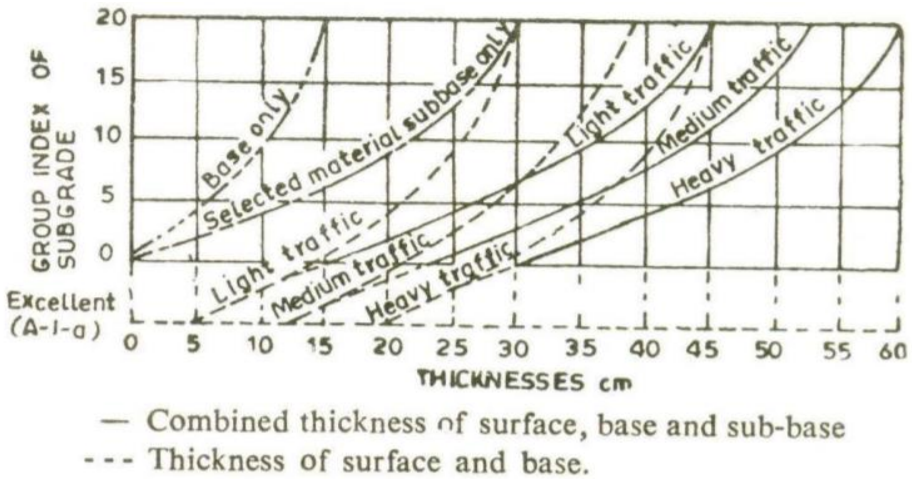
Group index value is an arbitrary index assigned to the soil type in numerical equations base on the percent fines liquid limit and plasticity index. The design chart for group index method for determining the pavement thickness.

- Minimum CBR value of 20% for cumulative traffic upto 2 msa and 30% exceeding 2 msa.

2. Traffic volume It is the measure of Annual average daily traffic, peak-hour traffic. It is denominated by commercial vehicles/day or CVPD. It is classified in three categories. Based on number of vehicles per day. If no. of vehicles per days is

Traffic volume	No of vehicles per day
Light	Less than 50
Medium	50 to 300
Heavy	Over 300

- GI vary in the range of 0 to 20.
- Higher the value of GI, poorer is the soil as sub-grade material.
- For sub-grade, minimum CBR value=10%
- For granular sub-base, Liquid limit: not more than 25% Plasticity index: not more than 6%



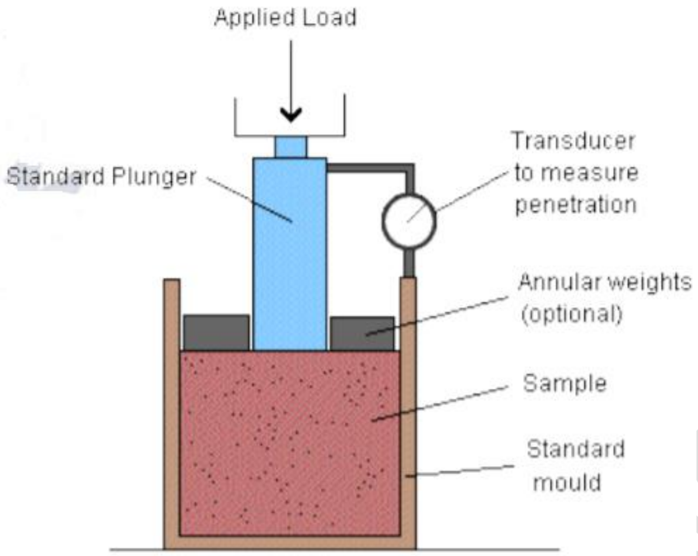
Design Chart by Group Index value

The design of the pavement thickness by this method, first the GI value of the soil is found the anticipated traffic is estimated and is designated as light, medium or heavy as indicated.

The GI method of pavement design is essentially an empirical method based on physical properties of the subgrade soil. This method does not consider the strength characteristics of the subgrade soil and therefore is open to question regarding the reliability of the design based on the index properties of the soil only.

California Bearing Ratio (CBR) Method

- California division of highways in the U.S.A. developed CBR method for pavement design. The majority of design curves developed later are base on the original curves proposed by O.J.porter.
- One of the chief advantages of CBR method is the simplicity of the test procedure. The CBR tests were carried out by the California state highway department on existing pavement layers including subgrade, subbase and base course.
- Based on the extensive CBR test data collected on pavement which behaved satisfactory and those which failed, an empirical design chart was developed correlating the CBR value and the pavement thickness. The basis of the design chart is that a material with a given CBR required a certain thickness of pavement layer as a cover.
- A higher load needs a thicker pavement layer to protect the subgrade. Design curves correlating the CBR value with total pavement thickness cover were developed by the California state highway department for wheel loads of 3175kg and 5443 kg representing light and heavy traffic.



Based on CBR value of any material, over which a flexible pavement is required, thickness of pavement over this is given by

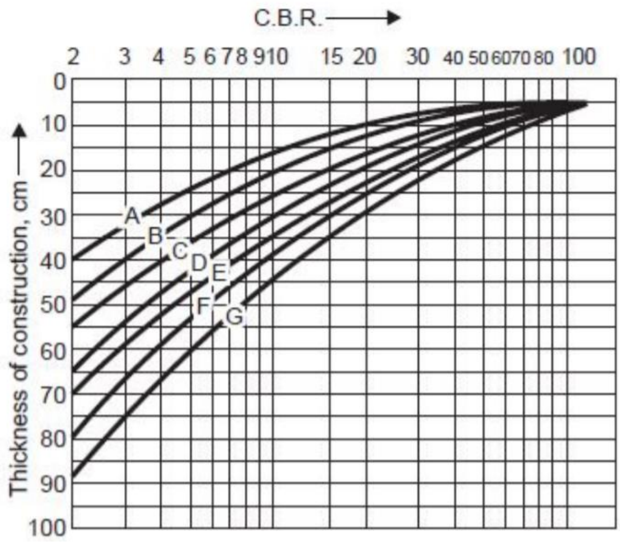
$$t = \sqrt{P}\left[\frac{1.75}{CBR} - \frac{1}{p\pi}\right]^{1/2}$$

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

Where,

- p = P/A
- P= wheel load (kg),
- t = pavement thickness (cm),
- CBR = CBR in %,
- p = Tyre pressure (kg/cm^2),
- A = Contact area (cm^2)

CBR Design Chart



Curve	No. of vehicles day (> 3t)
A	0 – 15
B	15 – 45
C	45 – 150
D	150 – 450
E	450 – 1500
F	1500 – 4500
G	Over 4500

IRC Recommendations for CBR Test

Indian road congress (IRC: 37-1970) has recommended some important aspects to be considered while using the design chart. Following are the recommendations/ Steps involved in the IRC method of design of flexible pavements:

- The specimen to be tested CBR should be remoulded specimen prepared preferably by static compaction wherever possible or dynamic compaction. The standard test procedure should be strictly followed.
- In situ test specimens are not recommended.
- For new roads the sub grade soil specimen should be compacted to proctor density at OMC. If the compaction equipment is not available in the field, the specimen may be compacted to the expected field density.
- For the existing roads the specimen should be compacted to field density of sub grade soil at water content equal to OMC or field moisture content.

- For all new constructions the specimen should be soaked for four days prior to testing. This condition is not mandatory for arid climatic regions or regions with annual rainfall is less than 50cm or the water table is very deep or when thickness of impermeable bituminous surfacing is provided.
- At least three specimens should be tested with identical specimens. If the variation is maximum beyond the norms, then average of six specimens CBR values should be taken.
- The top 50 cm of sub grade should be compacted at least up to 95 to 100 percent of proctor density.
- An estimate of the traffic should be carried by the road pavements at the end of expected in view the existing traffic and probable growth rate of traffic.
- The traffic for the design is considered in units of heavy vehicles per day in both directions and is divided into seven categories A to G. The design thickness is considered applicable for single axle loads up to 8200 kg and tandom axle loads up to 14,500 kg.
- When subbase course materials contain substantial proportion of aggregates of size above 20mm, the CBR value of these materials would not be valid for the design of subsequent layers above them.

Limitations of CBR Method

(i) It does not take fully into account the damaging effects of heavier wheel loads and the their frequency in the wheel load spectrum.

(ii) This method does not consider whether the road is for multi or single lane and single or dual carriageway.

(iii) The CBR method gives the total thickness requirements of the pavement above a subgrade and this thickness requirement of the pavement above a subgrade would remain some irrespective of the quality of material

Note: When a sub base course material contain substantial proportion of aggregates of size above 20 mm, then the CBR value of material would not be valid for the design of subsequent layer above them.

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

The specimen limits of maximum variation in CBR values are

3% for CBR value up to 10%

5% for CBR value 10 to 30%

10% for CBR value 30 to 60%

The top 50cm of sub grade should be compacted with density equal to 95 to 100% of proctor density.

Keeping in view the existing traffic and the anticipated growth in traffic should be calculated for at least 10 years of life period.

The design traffic may be estimated by the following formula

The following formula may be used:

$$A = P\left[1 + r\right]^{(n+10)}$$

A=P (1 + r)$^{n+10}$

Where,

A = number of heavy vehicles per day for design (laden weight>3 tonnes)

P = number of heavy vehicles per day at least count.

R = annual rate of increase of heavy vehicles

n = number of years between the least count and the year of completion of constructions.

The value P has to be found for seven day heavy vehicles obtained from 24 hours count. If a reasonable value of r is not available a value of 7.5% may be assumed for rural roads.

- The traffic obtained from the above equation has to be used in choosing the appropriate design curve (A to G).
- The design thickness corresponding to a single axle load up to 8200kg and tandem axle load up to 14500kg is adopted.
- Substandard sub bases with substantial proportion of aggregates of size above 20mm should not be used in design.
- Thin layers of wearing course such as surface dressing or open graded premixed carpet up to 2.5cm thickness should not be counted towards total thickness as these materials do not contribute to the structural capacity of the pavement.

Modified CBR Method

IRC-37 has revised the guidelines for design of flexible pavement based on the concept of cumulative standard axle rather than total number of all commercial vehicle as done earlier.

In case of roads with design traffic more than 1500 vehicles per day., design traffic is defined in terms of cumulative standard axle loads of 8170 kg carried during the design life of roads.

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.

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.

In this design method it is required to provide a pavement section which satisfies

i. Resistance value of subgrade (R value)
ii. Expansion pressure
iii. Exudation pressure

Design steps:

i. The pavement thickness values required as per the R values of subgrade soil at different moisture contents, are calculated (Say Tr_1,Tr_2 ….Here, pavement may first be assumed to consists of single base course layer of known C- value ,Cg.
ii. Pavement thickness fulfilling both R- values and expansion pressure are found by dividing the expansion pressure by average density of pavement which may assumed as about 2.1 g/cm^2. The pavement thickness value (Say T_{e1} , T_{e2} …) as per expansion pressure at different moisture contents are calculated.
iii. Pavement thickness fulfilling both R value & expansion pressure is found by plotting T_r values against corresponding T_e values from (i) & (ii) above, to the same scale and by drawing 45^0 line.
iv. The exudation pressure of subgrade soil found at various compacting moisture contents are plotted against pavement thickness found from (i) above based on corresponding R values. The pavement thickness corresponding to an exudation pressure of 28 kg /cm^2 is obtained from this graph.
v. Pavement thickness as per California design method, is the higher the values determined in (iii) and (iv) above.
vi. The thickness of other pavement layers are decided and equivalent values of base course thickness replaced are calculated using cohesionmeter values of materials.

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 tones 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.

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 traffic is considered in terms of cumulative number of standard axles (in the lane carrying maximum traffic) to be carried during the design life of pavement using

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

N	The cumulative number of standard axles to be catered for in the design life in terms of msa
A	Initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day
D	Lane distribution factor
F	Vehicle damage factor
n	Design life in years
r	Annual growth rate of commercial vehicles

The traffic in the year of completion is estimated using

$$A = P(1+r)^x$$

P	Number of commercial vehicles as per last count
x	Number of years between the last count and the year of completion of construction

California Resistance Value Method

F.M. Hakeem and R.M. Carmany in 1948 provided design method based on stabilometer R-value and cohesiometer Computer- value.

Based on performance data it was established by Hveem and Carmany that pavements thickness varies directly with R value and logarithm of load repetitions. It varies inversely with fifth root of Computer value.

The expression for pavement thickness is given as by the empirical equation.

$$T = \frac{K(TI)(90 - R)}{C^{1/5}}$$

Where,

T = Total thickness of pavement, cm

K = Numerical constant=0.166

TI = Traffic index = $1.35(EWL)^{0.11}$

R = Stabilometer resistance value

C = Cohesiometer value

Here, equivalent wheel load (EWL) is the accumulated sum of the products of the constants and the number of axle loads. The yearly EWL is obtained by using the data of annual average daily traffic volumes (AADT). Various constants for the different number of axles in group are given below

Number of axles	EWL Constant(Yearly basis)
2	330
3	1070
4	2460
5	4620
6	3040

In the design of flexible pavements based on California resistance value method for the following data are needed:

- R-value of soil subgrade
- TI value
- Equivalent C-value

R value of soil subgrade is obtained from the test using stabilometer. The computation of TI value has been explained.

Equivalent C-Value

The cohesiometer value c is obtained for each layer of pavement material separately from tests. However the composite or equivalent C-value of the pavement may be estimated if the thickness of each component layer and the c-value of the material of the layer are known. while designing a pavement as the thickness of the pavement is not known, it is easier if the pavement is first assumed to consist of any one material like gravel base course with known C-value.

It is not possible to have a composite or equivalent C-value for the total pavement but it may be calculated if the thickness and C-value of the material of the layer is known. The individual thickness of each layer is converted in terms of other material equivalent by using the relationship given below:

$$\frac{t1}{t2} = \left(\frac{C_2}{C_1}\right)^{\frac{1}{5}}$$

Where,

t_1 and t_2 are the thickness values of any two pavement layers. c_1 and c_2 are their corresponding cohesiometer values.

Materials	C value
Soil cement base course	120 – 230
Bituminous concrete	60 – 62
Open graded bituminous mix	22 – 30
Gravel base course	15

Triaxial Test Method

L.A.Palmer and E.S.Barber in 1910 proposed the design method based on Boussinesq's displacement equation for homogeneous elastic single layer. The expression for pavement thickness is given as

The thickness of pavement

$$T_S = \sqrt{\left(\frac{3PXY}{2\pi E_S \Delta}\right)^2 - a^2}$$

Where,

T_s = Pavement thickness, cm

P= wheel load (kg),

E_s = Modulus of elasticity of sub grade from triaxial test result, Kg/cm^2

a = Radius of contact area, cm

Δ = Design deflection (taken equal to 0.25 cm)

X = Traffic coefficient

Y = Saturation coefficient

IRC recommended values of coefficients X and Y

The recommended values of X and Y values with respect to Average Daily Traffic (ADT) and average annual rainfall are tabulated below.

ADT (number)	Traffic coefficient X
40-400	½
401-800	2/3
801-1200	5/6
1201-1800	1
1801-2700	7/6
2701-4000	8/6
4001-6000	9/6
6001-9000	10/6
9001-13500	11/6
13501-20000	12/6

Average annual rainfall (cm)	Saturation coefficient (Y)
38-50	0.5
51-64	0.6
65-76	0.7
77-90	0.8
91-100	0.9
101-127	1.0

If pavement and subgrade are considered as a two layer system, then a stiffness factor $(E_s/E_p)^{1/3}$ has to be introduced to take into account the different values of modulus of elasticity of two layers.

$$T_p = \left[\sqrt{\left(\frac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}\right]\left(\frac{E_s}{E_p}\right)^{1/3}$$

The relation between pavement layers of thickness T_1 and T_2 of elastic modulus E_1 and E_2 is

$$\frac{T_1}{T_2} = \left(\frac{E_2}{E_1}\right)^{1/3}$$

Mcleod Method

This method was developed by Norman W. Mcleod. He performed repetitive plate bearing test on various sizes of plates and gave an empirical design equation. The expression for pavement thickness is given as

$$T = K \log_{10} \frac{P}{S}$$

Where, T = Required thickness of gravel base in cm

P = Gross wheel load in kg

K = Base course constant

S = Total subgrade support in kg

Burmister Method

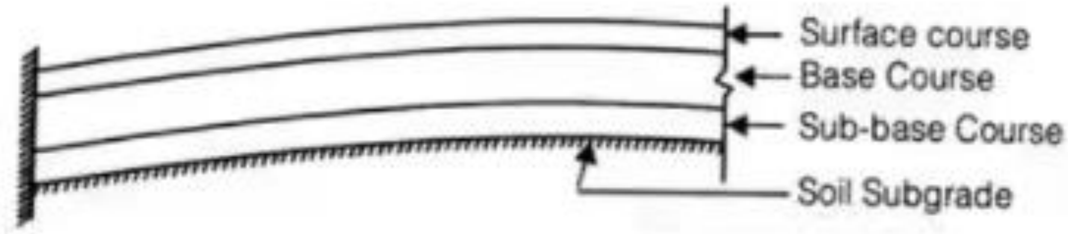
This method is based on young's modulus of elasticity of different layer of pavement.

As flexible pavement composed of layers and elastic modulus of top most layer is maximum.

$E_b > E_{sb} > E_s$ (layered analysis)

Boussinesq's analysis is a special case of Burmister's layered system analysis. He considered

$E_b = E_{sb} = E_s$ (Bousinesq's analysis)



Assumptions involved in Burmister's analysis

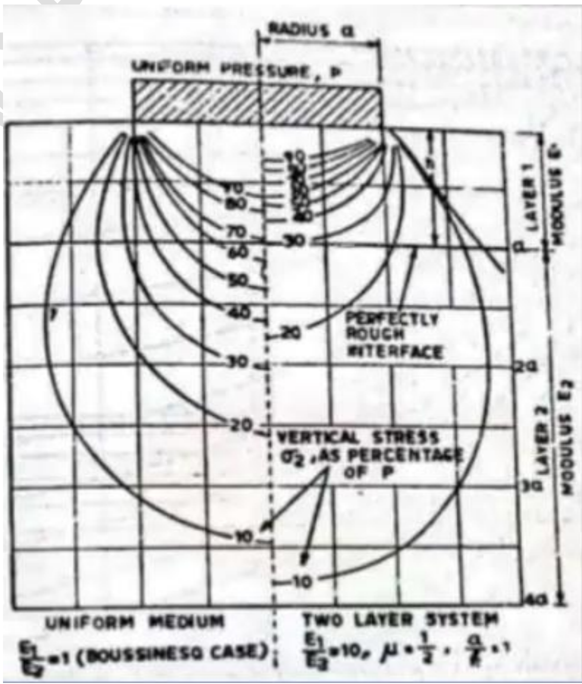
(i) Materials in the pavement layers are isotropic, homogenous and elastic.

(ii) Pavement forms a stiffer reinforcing layer having modulus of elasticity higher than the underlying subgrade.

(iii) Surface layer is infinite in horizontal direction but finite in vertical direction.

(iv) The underlying layer in two layered system is considered infinite in both directions.

(v) The layers are in continuous contact. The top layer is free of shearing and normal stresses outside the loaded area.



Displacement equations given by Burmister are given below

(i) For flexible plate

$$\Delta = 1.5 \frac{paF_2}{E_S}$$

Where, Δ = Design deflection

p = Contact pressure at road surface due to wheel load

a = Radius of contact area

E_s = Modulus of elasticity of soil subgrade

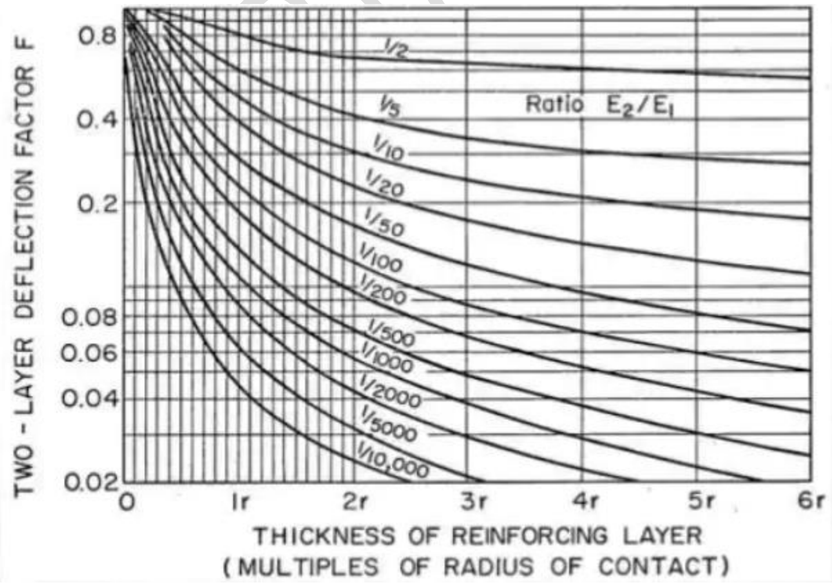
h = Thickness of reinforcing layer

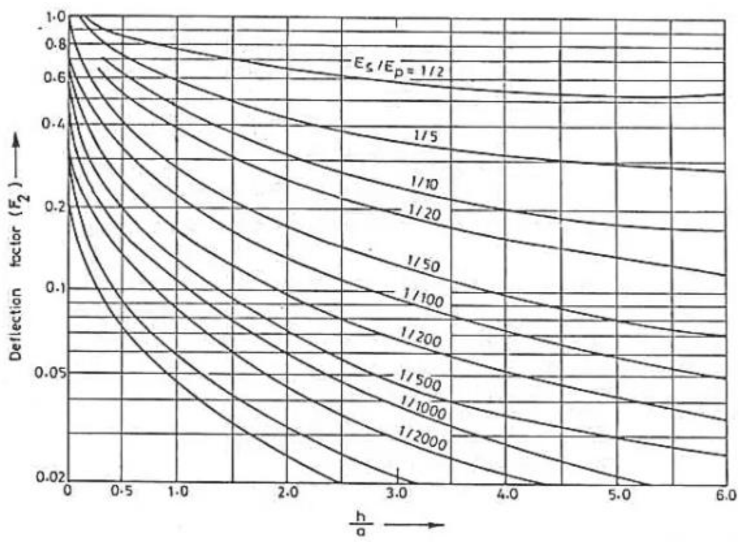
F_2 = Deflection factor based on E_s/E_p and h/a

(ii) For rigid plate

$$\Delta = 1.18 \frac{paF_2}{E_S}$$

For single layer, like in Boussinesq's analysis, h =0, E_s/E_p = 1, therefore F_2 = 1. Poisson's ratio can be taken equal to 0.5 for both subgrade and pavement material. Plate diameter for load test is taken as 30 cm and design deflection as 0.5 or 0.25 cm.





Procedure of Flexible Pavement Design by Burmister's Method

In the Burmister's design process, firstly conduct plate bearing test on the soil. The diameter of plate used is 30cm. now determine the modulus of subgrade soil. In the next step, determine the deflection factor from the below formula

$$F_2 = \frac{\Delta . E_S}{1.18\, p\, a}$$

After obtaining the deflection factor from above formula, now select the value of ratio of modulus of subgrade soil to the modulus of pavement material (E_s/E_p) for the given value of (h/a ratio from the graph. Now for the design load (P) and tire pressure (p) determine the contact radius (a) from the below formula.

$$a = \sqrt{\frac{P}{\pi p}}$$

And again, find the new value of deflection factor F_2 for the design deflection value

$$F_2 = \frac{\Delta . E_S}{1.18\, p\, a}$$

Where Δ = 0.25cm or 0.5cm. For the obtained values of new deflection factor and E_s/E_p ratio, select the appropriate h/a ratio from the above graph.

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 below. Compared to flexible pavement, rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material.

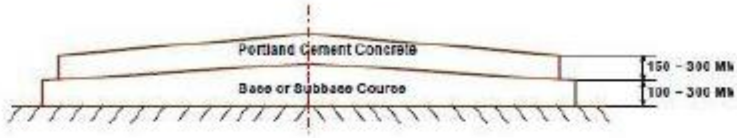


Figure 3.3 Typical cross section of Rigid pavement

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 Rigid pavements are constructed by Portland cement concrete (PCC) and should be analyzed by plate theory instead of layer theory.

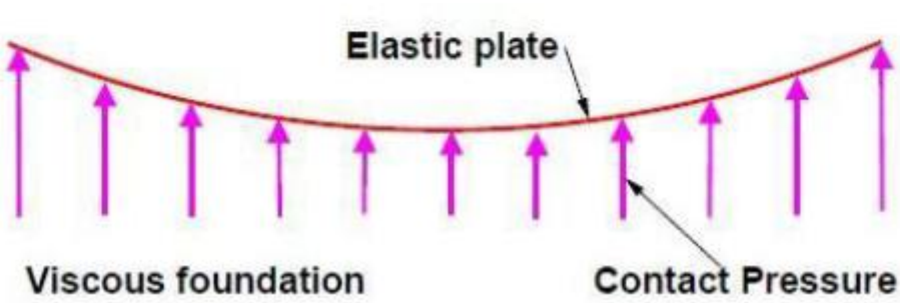
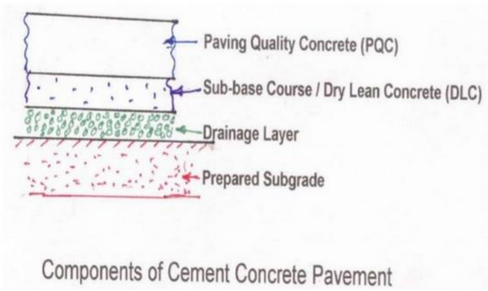


Figure 3.4 Elastic plate resting on Viscous foundation

Components of CC pavement



Types of Rigid Pavements

Rigid pavements can be classified into four types:

- Jointed plain concrete pavement (JPCP),
- Jointed reinforced concrete pavement (JRCP),

- Continuous reinforced concrete pavement (CRCP), and
- Pre-stressed concrete pavement (PCP).

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

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

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

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.

Components of rigid pavement and their Functions:

1. Prepared soil subgrade.
2. Granular sub-base (GSB) or drainage layer.
3. Base course/ (DLC-Dry lean concrete).
4. CC pavement slab using PQC (paving quality concrete).

1. Prepared soil subgrade:

- ❖ The soil subgrade of rigid pavement consists of natural or selected soil from identified borrow pits fulfilling the specified requirements.
- ❖ The soil subgrade is well compacted to the desired density and to the required thickness.
- ❖ The soil subgrade is the lower most layer of the pavement structure which ultimately supports all other pavement layer and traffic loads.
- ❖ A good soil subgrade / well compacted and prepared soil subgrade gives long service life to the pavement.

2. Granular sub-base (GSB) or drainage layer:

- ❖ The GSB course has to serve as an effective drainage layer of the rigid pavement to prevent early failures due to excessive moisture content in the subgrade soil.
- ❖ Crushed stone aggregates are preferred. In the granular subbase course as this material has high permeability and serves as a effective drainage layer.
- ❖ Coarse graded aggregates with low percent of fines (< 5 % finer than 75 micron sieve) will serve as good drainage layer.
- ❖ An effective drainage layer under the CC pavements have the following benefits:

  a. Increases in service life and improved performance of CC pavements.

  b. Prevention of early failures of the rigid pavements due to pumping and blowing.

  c. Protection of the subgrade against frost action in the frost susceptible areas.

3. Base course: (Dry lean concrete):

- ❖ The granular base course is generally provided under the CC pavement slab in low volume roads and also in roads with moderate traffic loads.
- ❖ On roads carrying heavy to very heavy traffic loads high quality base course materials such as dry lean concrete are preferred.
- ❖ In the base course of the CC pavement as they are designed for a life of 30 years or more with good maintenance. The CC pavement are expressed to provide a service life of 40 years or even more.
- ❖ The DLC layer provides a uniform support, high K value and excellent working platform for laying the PQC slab with a sensor paver.
- ❖ The suppression member is spread on the top of the DLC/ base course before laying the CC pavement slab.

4.CC pavement slab: (paving quality concrete (PQC):

- ❖ M-40 cement concrete mix with a minimum flexural strength of 45 kg/cm^2 is recommended by the IRC for use in the CC-pavements of highways with heavy to very heavy traffic loads.
- ❖ The C pavement slab is extended to with stand the flexural stress caused by the heavy traffic loads and the warping effects in the CC pavements due to the temperature variations.
- ❖ The high-quality CC mix with high flexural strength is used for the construction of PQC slab of the CC pavement.
- ❖ The CC pavement slab as considerable flexural strength and spreads the applied load/ wheel loads over a large area by slab action.

- The slab prevents the infiltration of excess surface water in to the sub-base.

FACTORS AFFECTING PAVEMENT DESIGN

Traffic and loading:

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

Contact pressure:

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

Wheel load:

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

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

Moving loads:

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

Repetition of Loads:

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

Environmental factors:

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

DESIGN OF RIGID PAVEMENTS:

Stresses in Rigid Pavement

Rigid pavements are rigid i.e, they do not flex much under loading like flexible pavements. They are constructed using cement concrete. In this case, the load carrying capacity is mainly due to the rigidity ad high modulus of elasticity of the slab (slab action).

Modulus of sub-grade reaction

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil sub-grade, which is assumed as a dense liquid. The upward reaction is assumed to be proportional to the deflection.

Westergaard's Modulus of sub-grade reaction

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

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

where Δ is the displacement level taken as 0.125 cm and p is the pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm.

Radius of relative stiffness (l)

A certain degree of resistance to slab deflection is offered by the sub-grade. The sub-grade deformation is same as the slab deflection. Hence the slab deflection is direct measurement of the magnitude of the sub-grade pressure.

Westergaard defined the radius of relative stiffness which is expressed by the equation

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

where E is the modulus of elasticity of cement concrete in kg/cm^2 (3.0 x 10^5),

μ is the Poisson's ratio of concrete (0.15),

h is the slab thickness in cm and

K is the modulus of sub-grade reaction.

Critical load positions

There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

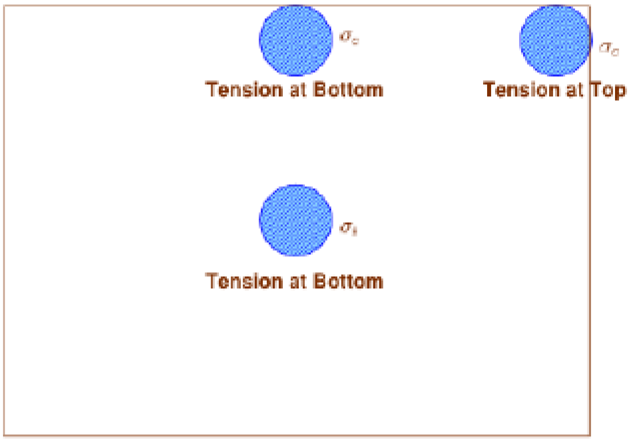


Fig. Critical stress locations

Since the pavement slab has finite length and width, either the character or the intensity of maximum stress induced by the application of a given traffic load is dependent on the location of the load on the pavement surface. There are three typical locations namely the interior, edge and corner, where differing conditions of slab continuity exist. These locations are termed as critical load positions.

Interior loading --- When load is applied in the interior of the slab surface

Edge loading ----- When load is applied in an edge of the slab.

Corner loading ---- When the center of the load application is located on the bisector of the corner angle formed by two intersecting edges of the slab.

Equivalent radius of resisting section

When the interior point is loaded, only a small area of the pavement is resisting the bending moment of the plate. Westergaard's gives a relation for equivalent radius of the resisting section in cm in the equation

b = $\sqrt{1.6a^2 + h^2} - 0.675h$ if a < 1.724h

Otherwise, b = a if a > 1.724h

Where a = the radius of the wheel load distribution in cm

h = the slab thickness in cm.

b = equivalent radius of resisting section in cm

Wheel load stresses - Westergaard's stress equation

The cement concrete slab is assumed to be homogeneous and to have uniform elastic properties with vertical sub-grade reaction being proportional to the deflection. Westergaard developed relationships for the stress at interior, edge and corner regions, denoted as S_i; S_e; S_c in kg/cm^2 respectively and given by the equation

Load stress S_i due to interior loading

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

Load stress S_e due to edge loading

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

Load stress S_c due to corner loading

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

where h is the slab thickness in cm,

P is the wheel load in kg,

a is the radius of the wheel load distribution in cm,

l the radius of the relative stiffness in cm and

b is the radius of the resisting section in cm

Temperature stresses

Temperature stresses are developed in cement concrete pavement due to variation in slab temperature. This is caused by (i) daily variation resulting in a temperature gradient across the thickness of the slab and (ii) seasonal variation resulting in overall change in the slab temperature. The former results in warping stresses and the later in frictional stresses.

Combination of stresses

The cumulative effect of the different stress give rise to the following thee critical cases

- Summer, mid-day: The critical stress is for edge region
- Winter, mid-day: The critical combination of stress is for the edge region given by
- Mid-nights: The critical combination of stress is for the corner region given

Warping stress

The warping stress at the interior, edge and corner regions, denoted as St_i ; St_e ; St_c in kg/cm^2 respectively and given by the equation

Warping stress at interior St_i is given by

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

Warping stress at edge St_e is given by

$$St_e = \frac{C_x Eet}{2}$$

Or $St_e = \frac{C_y Eet}{2}$ whichever is higher

Warping stress at corner St_c is given by

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

where E is the modulus of elasticity of concrete in kg/cm^2 (3X10^5),

e is the thermal coefficient of concrete per ^{o}C (1X10^{-7})

t is the temperature difference between the top and bottom of the slab,

C_x and C_y are the coefficient based on L_x/l in the desired direction and L_y/l right angle to the desired direction,

μ _ is the Poisson's ration (0.15),

a is the radius of the contact area and

l is the radius of the relative stiffness.

Frictional stresses

The frictional stress S_f in kg/cm^2 is given by the equation

$$S_f = \frac{(WL_e f)}{(2\times10^4)}$$

where W is the unit weight of concrete in kg/cm^2 (2400),

f is the coefficient of sub grade friction (1.5) and

L is the length of the slab in meters.

Combination of stresses

The cumulative effect of the different stress give rise to the following three critical cases

a. Summer, mid-day: The critical stress is for edge region given by
   Critical combination of stresses at edge ($S_{critical}$) = load stress + warping stress – frictional stress = $S_e + St_e - S_f$
b. Winter, mid-day: The critical combination of stress is for the edge region given by
   Critical combination of stresses at edge ($S_{critical}$) = load stress + warping stress + frictional stress = $S_e + St_e + S_f$
c. During summer Mid-nights: During summer midnight the critical combination of stress occurs at the corner of the slab on the top when the slab tends to wrap upwards and is resisted by the self-weight.

The Critical combination of stress during night at the corner region = $S_e + St_e$

d. Most critical combination

The most critical combination of stresses is the highest of the three conditions (a),(b) and (c) mentioned above.

Type of concrete used for cement concrete pavement

- Normally M40 grade is used for C.C. pavements.
- Minimum flexural strength of 45 kg/cm^2.
- For low volume roads M35 concrete may be used.

Design approach for rigid pavements

Cement concrete roads provides a highly rigid surface and hence for the success of such roads, following two conditions should be satisfied.

1. They should rest on non-rigid surface having uniform bearing capacity.
2. The total thickness or depth of the concrete pavement & the non-rigid base should be sufficient to distribute the wheel load on a sufficient area of sub-base so that the pressure on unit area remains with the permissible SBC of the soil.

Concrete slab has high modulus of elasticity, high rigidity & flexural strength, so wheel loads are distributed over large areas of subgrade. This leads to small deflections and also leads compressive stresses imposed on the subgrade.

- This leads to fatigue damage in concrete slab in form of development of micro cracks, due to repeated application of traffic loads.
- This is arrested by limiting flexural stresses and increasing the concrete mix grade.

Design steps (parameters)

1. Traffic parameters: Design wheel load, Traffic intensity
2. Environmental parameters: Temperature differential (CRRI table)
3. Foundation strength k (modulus of subgrade reaction)
4. Foundation surface characteristics (As per IRC)
5. Concrete characteristics (IRC:58 -1988)
6. Modulus of elasticity
7. Co-efficient of thermal expansion
8. Design slab thickness

Recommended design procedure for the design of rigid pavements by IRC

Wheel load

The design wheel load may be taken as 4100 kg with a tyre inflation pressure of 5.3 to 6.3 kg/cm^3.

Traffic volume

The growth of traffic volume after 20 years of construction has to be considered in the design. The following formula may be used to estimate the demand

$A_d = P^1(1 + r)^{n+20}$

Where

A_d = number of commercial vehicles per day for laden weight greater than 3 tonnes.

P^1 = the number of commercial vehicles per day at least count.

r = annual rate of increase in traffic intensity

n = number of years between the last traffic count and the commissioning of new cement concrete pavement.

Traffic classification

Traffic classification	*Design traffic intensity, A_d (number of vehicles of wt> 3 tonnes per day) at the end of design life*	*Adjustment in design thickness of cement concrete pavement, cm*
A	0 to 15	– 5
B	15 to 45	– 5
C	45 to 150	– 2
D	150 to 450	– 2
E	450 to 1500	0
F	1500 to 4500	0
G	> 4500	+2

Annual temperature

The mean daily and annual temperature cycles are to be collected. The temperature difference, depending on the place where the road is intended to be constructed is taken from the standard table provided for various states and regions for a given thickness of slab.

Modulus of sub grade reaction

Modulus of sub grade reaction, K, is determined using a 75 cm diameter plate and the pressure corresponding to 0.125cm deflection. If the pavement is to be laid on the sub grade soil then K should be not less than 5.5kg/cm^3 otherwise a suitable sub base course is to be provided.

Properties of concrete

The flexural strength of cement concrete to be used for the pavement should be less than 40 kg/cm^3.

The cube strength of concrete should be 280 kg/cm^2, modulus of elasticity E = 3X10^5 and poisons ratio = 0.15. these properties may also be determined experimentally.

Co-efficient of thermal expansion may be taken as $10x10^{-6}$per ^{o}C for design purpose.

Computation of stresses

- Wheel load stresses at the edge and corner regions are calculated as per modified Westergaard's analysis.
- Temperature stress at the edge region is calculated as per Westergaards analysis using Bradbury's coefficient.

Slab thickness

- The length and width of slab are decided based on the joint spacing's and lane width.
- A trial thickness of slab is assumed. The warping stress at edge region is calculated which is deducted from the allowable flexural stress. The resulting strength in the pavement has to support the edge loads.
- The stress due to load at the edge is calculated. The factor of safety is computed comparing the strength and the edge stress. If the factor of safety is less than one, thickness is increased and the calculations are repeated till the factor of safety is above1.this is the design thickness h.
- The stress due to corner load is computed and checked using the above h. if this stress value is less than allowable flexural stress in concrete then the slab thickness h is adequate. If not the thickness may be suitably increased till the above condition is satisfied.
- The design thickness h is then adjusted for traffic intensity as given in table to obtain the final adjusted slab thickness.

Joint spacing

- For all slab thicknesses with rough foundation the maximum spacings recommended for 25mm wide expansion joint is 140m. For smooth foundation the maximum spacing may be 90m for slab thickness up to 20cm,
- 120m for slab thickness up to 25cm when the construction is made in summer. If the construction is made in winter the spacing may be restricted to 50 and 60m respectively.
- In unreinforced slab for all slab thicknesses the spacing of construction joint is 4.5m.in reinforced slab the spacing is 13m for m15cm thickness slab with steel reinforcement of 2.7kg/cm^2 and 14m spacing for 20cm thick slabs with steel reinforcement of 3.8kg/cm^2.

Dowel bars

- Dowel bars are designed based on Bradbury's analysis for shear, bending and bearing in concrete.
- The minimum dowel length is taken as (L_d + δ). The load bearing capacity of the dowel system is assumed to be 40% of the design wheel load. The dowel bars is considered to be effective 1.8 times the radius of relative stiffness l on the either side of the load position.
- Dowel bars are provided for thickness of slab more than 15cm or more. IRC recommends 2-5cm dia bars of 50cm length with 20cm spacing for 15cm thick slab and spaced at 30cm in case of 20cm thick slab.

Tie bars

Designed for longitudinal joints with permissible bond stress in deformed bars 24.6kg/cm^2 and in plain bars 17.5kg/cm^2. Allowable working stress in tensile steel is taken as 1500kg/cm^2.

Reinforcement

Nominal reinforcement in cement concrete pavements is intended to prevent deterioration of the cracks. It is not provided to increase the flexural strength of uncracked slab. The area of longitudinal and transverse steel required per meter width or length of slab is computed using the following formula.

$A=Lfw/(2S)$

Where

A = area of steel required per meter width or length of the slab, cm^2

L = distance between free transverse joints for longitudinal or transverse steel, m.

w = weight of unit area of pavement slab, kg/cm^2.

The reinforcement is to be provided at 5cm below the surface of slab.it is continued across dummy groove joints to serve the purpose of tie bars. The reinforcement is kept at least 5cm away from the face of joint or edge.

Joints in cement concrete pavements

In general, joints are provided in cement concrete pavements to reduce temperature stresses.

- Expansion joint is provided to permit increase in the length of a slab due to temperature increase.
- Contraction joints are provided (i) to control cracking of the slab resulting from contraction and (ii) to relieve warping stresses.

- Longitudinal joints are provided to prevent the formation of irregular longitudinal cracks and to allow for transverse warping and unequal settlement.
- Construction joints are provided at the abrupt end of a day's work unexpectedly interrupted due to breakdown of plant or onset of bad weather.

Warping joints are provided if expansion joint and contraction joints are not effective.

Expansion joint is designed based on the maximum temperature variations expected and the width of joint. The design of contraction joint is governed by the anticipated frictional resistance and allowable tensile stress in concrete. Longitudinal joints are designed with tie bars.

Design of joint:

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 the factors given above. These joints will then ensure that the stresses developed due to expansion, contraction and warping of the slab are within reasonable limits. The longer the length between joints, the greater is the warping stress and greater is the need for reinforcing steel.

Requirements of Joint

Following are the various objectives of joints:

(i) The joint must permit movement of the slabs without restraint.

(ii) The joint should not underlay weaken the slab structurally and the load should be transferred from one slab to another effectively.

(iii) The joints must be sealed to exclude water, grit and other external matter.

(iv) The riding quality of the pavement should not be impaired.

(v) The construction of the joints must interfere as little at possible with laying of the concrete.

Types of Joints in Rigid Pavements

- Joints are too important for the rigid pavements because the joints are responsible for reducing stresses developed due to temperature variations. There are two type of joints-
- Longitudinal Joints
- Transverse Joints
- The Transverse joints are subdivided into three categories-

- Expansion Joints
- Contraction Joints
- Construction Joints
- Warping or hinged joints.

There are various types of joints in concrete pavement, e.g. contraction joint, construction joint, expansion joint and warping joint. Fig. 3 schematically shows position of various joints. The functions of these joints are as follows:

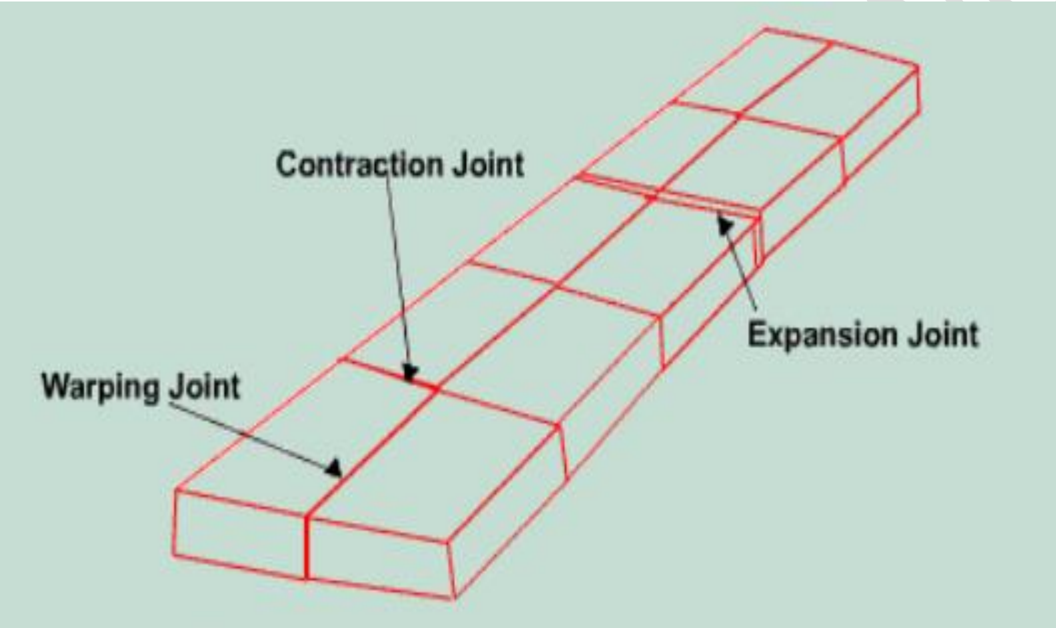


Fig.3 Location of joints in concrete pavement

Expansion joints

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature. The width or gap in expansion joint depends upon the length of the slab. Greater the distance between the expansion joints, the greater is the width required of the gap for expansion. Wide expansion joints are generally not provided as it would be difficult to keep them properly filled in when gap widen during winter season.

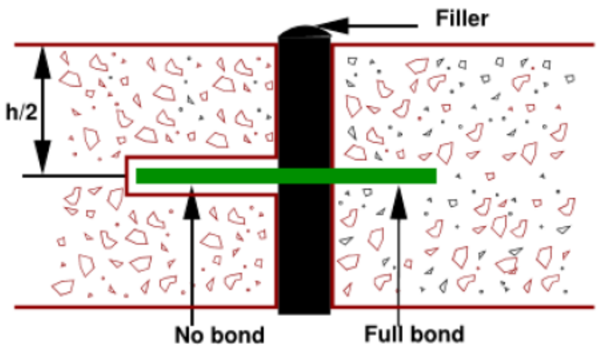


Figure: Expansion joint

The design consideration of expansion joints are:

(i) Provided along longitudinal direction.

(ii) It is recommended not to have a gap more than 2.5 cm in any case.

(iii) IRC has recommended that the maximum spacing between expansion joints should not exceed 140 m.

Hence, $\frac{\Delta}{2} = L\alpha t$

Where, Δ = Width of expansion joint (This gap is such that $\Delta/2$ distance is always maintained after expansion i.e. filler material generally made of cork, Fibre-Board is assumed to be compressed by 50 %)

L = Length of the slab or spacing between transverse joint

A = Thermal coefficient of concrete per ^{0}C

t = Temperature difference in ^{0}C

Features of a suitable design for an expansion joint are:

(i) A space for expansion which is generally 20 mm.

(ii) A joint filling compressible material interposed in the above space.

(iii) A joint sealing arrangement.

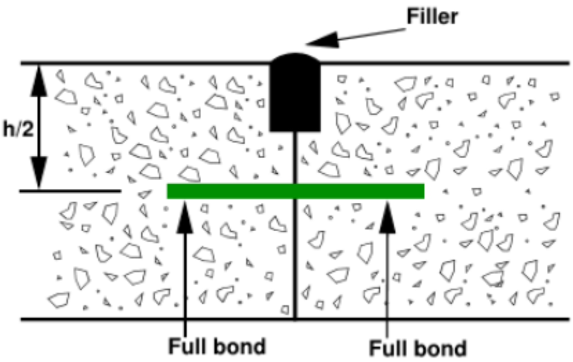
(iv) A dowel bar for load transfer.

(v) Thin coating of bitumen into the expanding portion of the dowel bar to break bond with concrete and permit expansion.

(vi) A card board or metal cap at the expanding end of the dowel bar filled with cotton waste.

Contraction joints

The purpose of contraction joints is to allow the contraction of the slab due to the fall in slab temperature below the construction temperature. If joints are placed at suitable intervals transversely, the appearance of cracks at places other than the joints can be eliminated.



Contraction joint also relieve warping stresses to some extent. The design consideration of contraction joints are:

(i) The movement is restricted by subgrade friction.

(ii) Designing involves the length of the slab when no reinforcement provided is given by

$L = (2x10^4 S_f)/fW$

Where, S_f = Tensile strength developed in concrete and is taken as 0.8 kg/cm^2

W = Unit weight of the concrete which can be taken as 2400kg/cm^3

f = Coefficient of subgrade friction which can be taken as 1.5

(iii) Length of the slabs when bars are provided at contraction joint

Frictional force = Force in bar

$F \times (L/2 \times b \times h \times W) = A_{st}\ \sigma_{st}$

$L = (2\ A_{st}\ \sigma_{st})/fWBh$

Where, σ_{st} = Allowable tensile stress in steel

Dowel bars

The purpose of the dowel bar is to effectively transfer the load between two concrete slabs and to keep the two slabs in same height.

Dowel bars are provided in the direction of the traffic (longitudinal). 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.

Analysis of stresses in dowel bar is given by Bradbury. Following stresses are developed in the dowel bar:

(a) Shear stress
(b) Bending stress
(c) Bearing stress

Objective of Dowel bar

(i) To transfer the load of wheel from one slab to another.
(ii) To reduce the differential deflection between two slabs.

Design Specification of Dowel Bars

(i) Generally, length of dowel bar provided is 0.5 m whose diameter is 25 mm.
(ii) Spacing of dowel bar is of the order of 200 mm for 150 mm thick slab and 300 mm for 200 mm thick slab.
(iii) Dowel bars are not provided for the slab thickness less than 150 mm.
(iv) Maximum load transferred through dowel bars is 40 % of maximum axle load.
(v) Minimum dowel length = $L_d + \Delta$

Load transfer capacity of Dowel bar

(i) For shear in the bar

$P_s = 0.785\, d^2 F_s$

Where, P_s = Load transfer capacity of dowel bar in shear

d = diameter of dowel bar

F_s = Permissible shearing stress in steel

(ii) For bending in the bar

$P_f = (2d^3 F_f)/(L_d + 8.8\Delta)$

Where, P_f = Load transfer capacity of dowel bar in bending

L_d = Length of embedment of dowel bar in cm

F_f = Permissible bending stress in steel

Δ = Joint width in cm

(iii) For bearing in the bar

$P_b = (F_b L_d^2 d)/12.5(L_d + 1.5\Delta)$

Where, P_b = Load transfer capacity of dowel bar in bearing

L_d = Length of embedment of dowel bar in cm

F_b = Permissible bearing stress in steel

Δ = Joint width in cm

Bradbury's analysis gives load transfer capacity of single dowel bar in shear, bending and bearing as follows:

$$P_s = 0.785 d^2 F_s$$

(Shear in the bar)

$$P_f = \frac{2d^3 f_f}{L_d + 8.8\delta}$$

(Bending in the bar)

$$P_b = \frac{d F_b L^2}{12.5(L_d + 1.5\delta)}$$

(bearing on concrete)

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

where as:

- **d** = Diameter of dowel bar, cm
- **L_d** = Total length of embedment of dowel bar, cm
- **δ** = Joint width, cm
- **F_s** = Permissible shear stress in dowel bar, kg/cm^2
- **F_f** = Permissible flexural stress in dowel bar, kg/cm^2
- **F_b** = Permissible bearing stress in concrete, kg/cm^2

Design steps involved in the design of dowel bars

Working procedure of the dowel bars

Step: 1 - Find the length of the dowel bar embedded in slab L_d

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

Step: 2 - Find the load transfer capacities F_s, F_f, and F_b of single dowel bar with the L_d

Step: 3 - Assume load capacity of dowel bar is 40 % wheel load, find the load capacity factor F_s, F_f, and F_b as

Step: 4 - max{0.4P/wheel load}

(the lowest of the F_s, F_f, and F_b is taken as load carrying capacity of dowel bar

Step: 5 - Spacing of the dowel bars.

- Effective distance upto which effective load transfer take place is given by 1.8 l, where l is the radius of relative stiffness
- Assume a linear variation of capacity factor of 1.0 under load to 0 at 1.8 l.
- Assume a dowel spacing and find the capacity factor of the above spacing.
- Actual capacity factor should be greater than the required capacity factor.
- If not, do one more iteration with new spacing.

Design procedure

Step 1 Find the length of the dowel bar embedded in slab L_d by equating Eq. 29.12=Eq. 29.13, i.e.

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

Step 2 Find the load transfer capacities P_s, P_f, and P_b of single dowel bar with the L_d

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

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

Step 4 Spacing of the dowel bars.

- Effective distance upto which effective load transfer take place is given by 1.8 l, where l is the radius of relative stiffness.
- Assume a linear variation of capacity factor of 1.0 under load to 0 at 1.8 l.
- Assume a dowel spacing and find the capacity factor of the above spacing.
- Actual capacity factor should be greater than the required capacity factor.
- If not, do one more iteration with new spacing.

Tie bar

In contrast to dowel bars, tie bars are not load transfer devices, but serve as a means to tie two slabs. Hence tie bars must be deformed or hooked and must be firmly anchored into the concrete to function properly.

Tie bars are used across the longitudinal joint of cement concrete pavement. These bars are not designed to act as load transfer devices. Thus, tie bars are 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. Their length is smaller than the dowel bars and placed at large intervals.

Design of Tie bar