

PAVEMENT

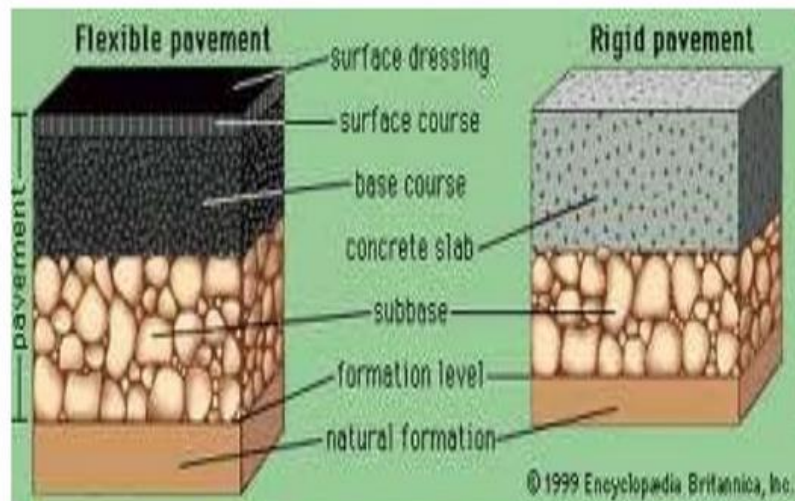
Pavement is the durable surface material laid down on an area intended to sustain vehicular load or foot traffic, such as a road or walkway.

- 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 form 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 amenable 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 times.

- 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 in 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 and 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 characteristics:

- 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 rideability.

- 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) Glare and night visibility:

- Concrete pavements have a gray color which can cause glare under sunlight. Colored cement can reduce the glare.
- 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 plain, 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 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ol style="list-style-type: none"> 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 | <ol style="list-style-type: none"> 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.

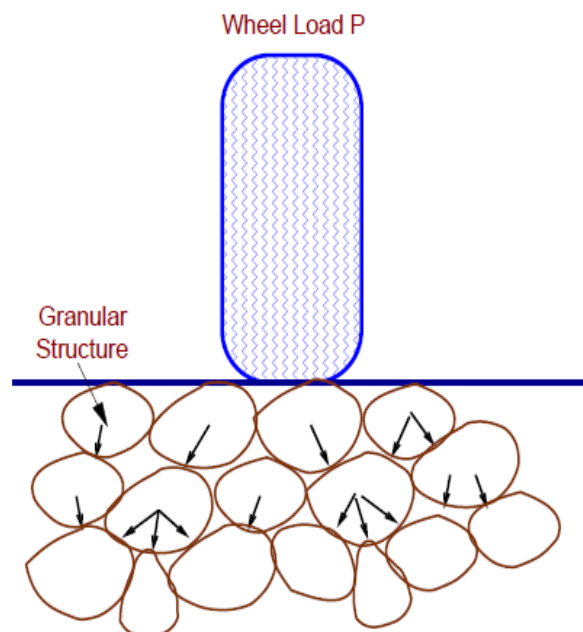


Figure: 3.1 Load transfer in granular structure

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.

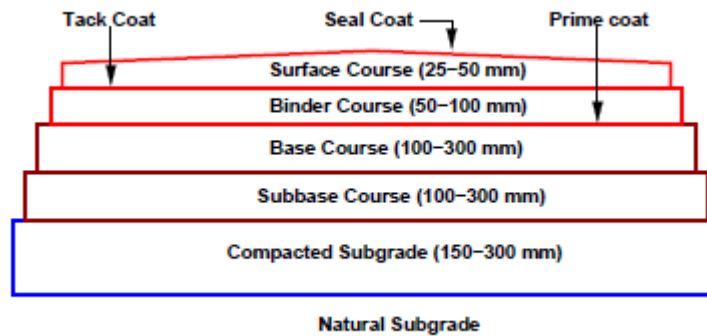


Figure: 3.2 Typical cross section of a flexible pavement

Binder course:

This layer provides the bulk of the asphalt concrete structure. Its 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.

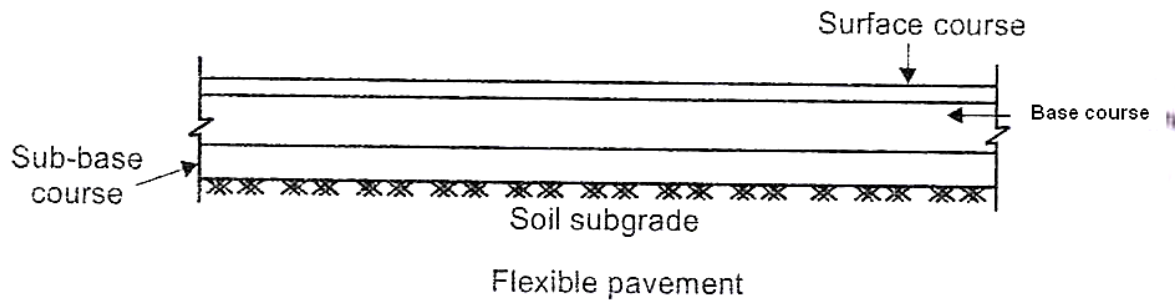
FLEXIBLE PAVEMENTS – COMPONENTS AND THEIR FUNCTIONS:

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.



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.

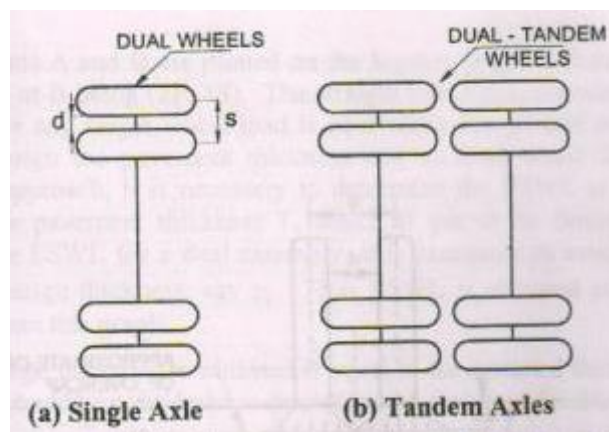
Various wheel load factors are

- 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:

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

Where σ_z = vertical stress at depth z

p = contact pressure of tyre

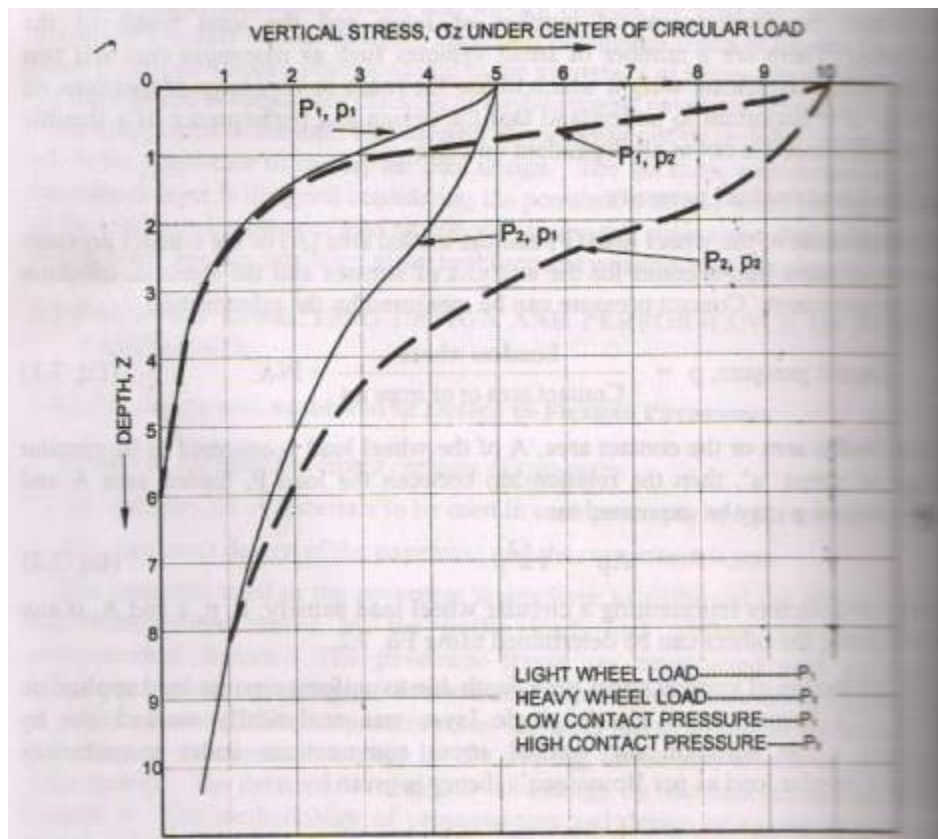
z = depth at which σ_z is computed

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 tyres.

Contact pressure:

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



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. This 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
 - Contact pressure
- } same

$$\text{Contact pressure } p = \frac{\text{Load on wheel}}{\text{Contact area or Area of Im print}} = \frac{P}{A}$$

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/cm².

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°.

Let d = clear gap between the two loads

S = spacing between centers of wheels

a = radius of circular contact area of each wheel

Then $S = d + 2a$

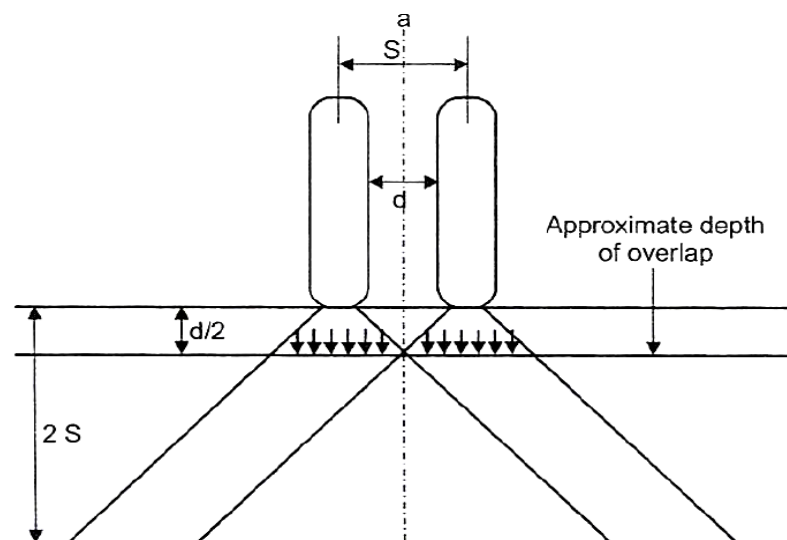


Figure: Stress overlap due to dual wheels

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 $2P$.

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.

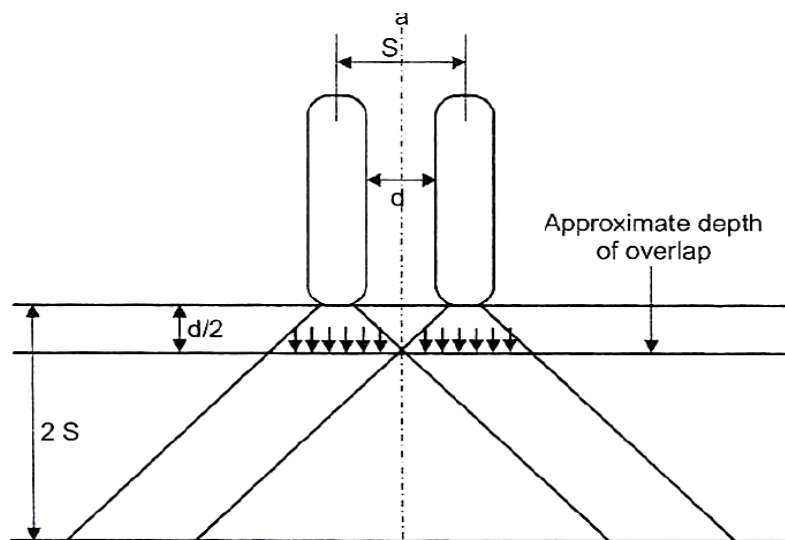


Figure: Stress overlap due to dual wheels

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 dual 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 $2P$.

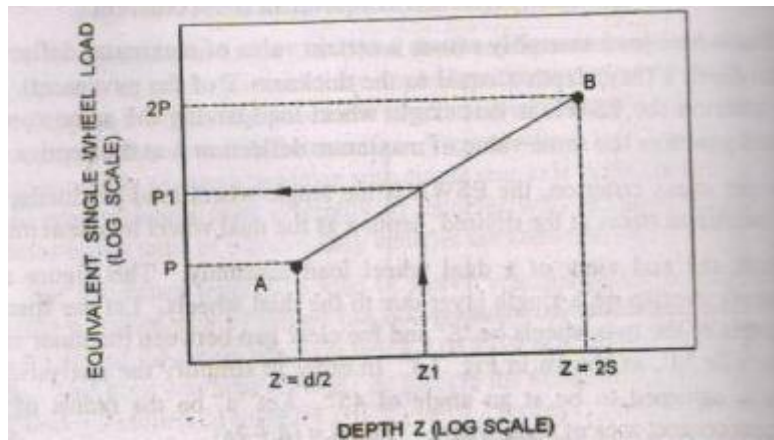


Figure: Graphical method for determination of ESWL

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 % 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 FLEXIBLE PAVEMENTS

There are 3 approaches

1. Empirical method
 - i. Group index method
 - ii. CBR method
 - iii. Stabilometer method
 - iv. McLeod method
2. Semi empirical method
 - i. Burmister method
 - ii. Triaxial method
3. Theoretical method

IRC Recommendations

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 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 following formula may be used:

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

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.

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 exible 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

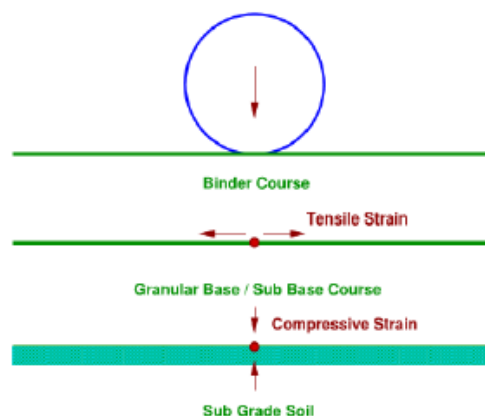


Fig. Critical Locations in Pavement

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 $T_{r1}, T_{r2} \dots$). Here, pavement may first be assumed to consist of single base course layer of known C-value, C_g .
- ii. Pavement thickness fulfilling both R-values and expansion pressure are found by dividing the expansion pressure by average density of pavement which may be assumed as about 2.1 g/cm^3 . The pavement thickness value (Say $T_{e1}, T_{e2} \dots$) 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° 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 of 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.

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.

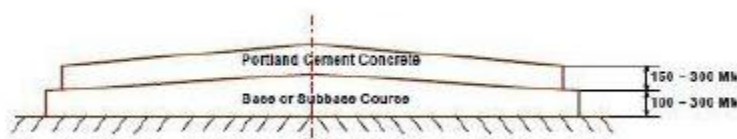


Figure 3.3 Typical cross section of Rigid pavement

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.

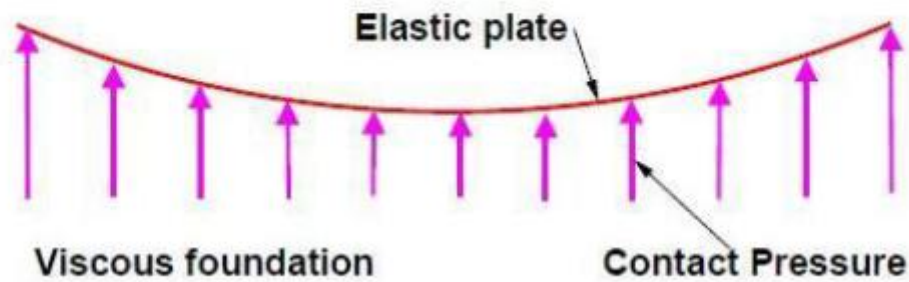
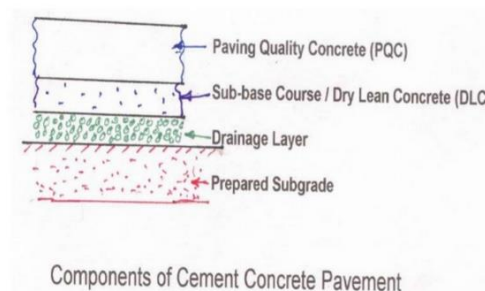


Figure 3.4 Elastic plate resting on Viscous foundation

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.

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 and 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 (3.0×10^5),

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.

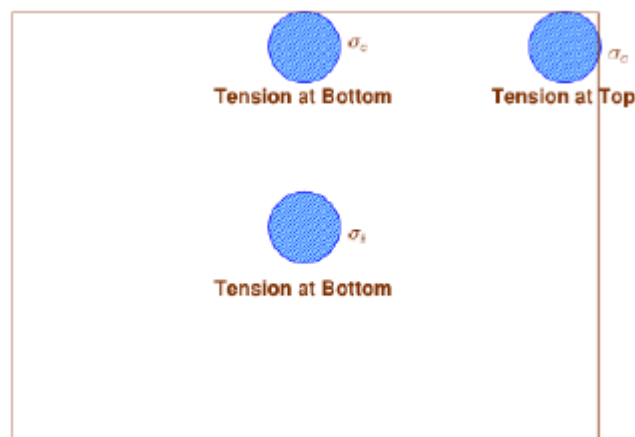


Fig. Critical stress locations

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

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

$$\text{Otherwise } b = a \quad \text{if } a > 1.724h$$

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/cm² 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

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

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 (3×10^5),

e is the thermal coefficient of concrete per $^{\circ}C$ (1×10^{-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

$$S_f = \frac{(WL_e f)}{(2 \times 10^4)}$$

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 thee 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 = $S_e + S_{t_e} - S_f$

- 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 = $S_e + S_{t_e} + S_f$

- 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 = $S_e + S_{t_e}$

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 (CRRRI 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/cm³.

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

| <i>Traffic classification</i> | <i>Design traffic intensity, A_d (number of vehicles of wt > 3 tonnes per day) at the end of design life</i> | <i>Adjustment in design thickness of cement concrete pavement, cm</i> |
|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 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 40kg/cm^3 .

The cube strength of concrete should be 280kg/cm^2 , modulus of elasticity $E = 3 \times 10^5$ and Poisson's ratio = 0.15. These properties may also be determined experimentally.

Co-efficient of thermal expansion may be taken as 10×10^{-6} per $^\circ\text{C}$ 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 Westergaard's 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 above 1. 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 15cm 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 $(L_d + \delta)$. The load bearing capacity of the dowel system is assumed to be 40% of the design wheel load. The dowel bars are 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 joints

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.

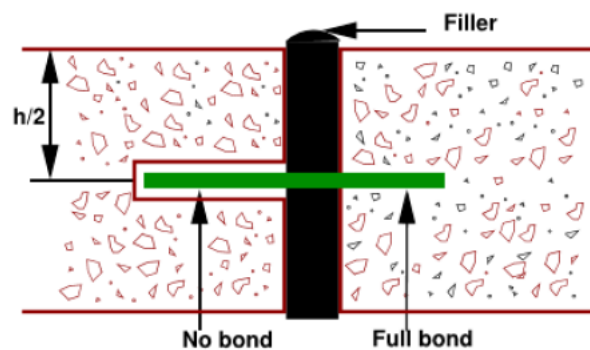
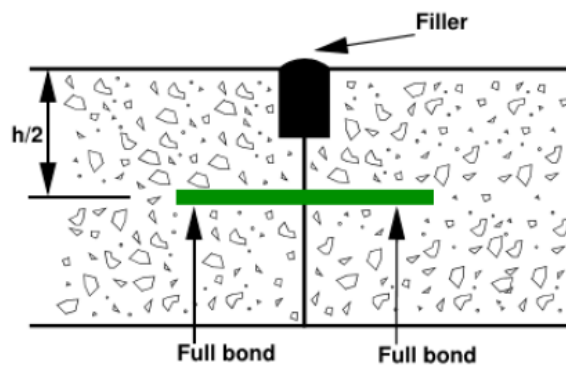


Figure: Expansion joint

Contraction joints



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.

Tie bars

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.

HIGHWAY CONSTRUCTION

Introduction

The science of highway engineering raises some fundamental questions as to what is a road or highway, how is it planned and designed and lastly how is it built. By now in the preceding chapters, depending upon the desired strength of the pavement, the aggregate gradations and the type and proportion of binders are decided. These three basic binder medium give rise to a number of construction methods.

Types of Highway Construction

The highway types are classified as below:

- (i) Earth road and gravel roads
- (ii) Soil stabilized roads
- (iii) Water bound macadam (WBM) road
- (iv) Bituminous or black-top roads
- (v) Cement concrete roads

The roads in India are classified based on location and functions. All the roads do not cater for the same amount of traffic volume or intensity. Since the funds available at hand for financing the construction projects are also meager, it is necessary to have roads which cost less. The adoption of low cost roads is now preferred in developing countries like India where large lengths of roads are to be constructed in the rural areas with the limited finances available in the country. Earth roads and stabilized roads are typical examples of low cost roads. Stabilized soil roads are gaining importance in the form of low cost roads.

EARTHWORK

General

The subgrade soil is prepared by bringing it to the desired grade and camber and by compacting adequately. The subgrade may be either in embankment or in excavation, depending on the topography and the finalized vertical alignment of the road to be constructed.

Excavation

Excavation is the process of cutting or loosening and removing earth including rock from its original position. Transporting and dumping it as a fill or spoil bank. The excavation or cutting mat is needed in soil, soft rock or even in hard rock, before preparing the subgrade.

Embankment

When it is required to raise the grade line of a highway above the existing ground level it becomes necessary to construct embankments. The grade line may be raised due to any of the following reasons

- i) To keep the subgrade above the high ground water table.
- ii) To prevent damage to pavement due to surface water and capillary water.
- iii) To maintain the design standards of the highway with respect to the Vertical alignment.

The design elements in highway embankments are:

- a) Height
- b) Fill material
- c) Settlement
- d) Stability of foundation, and
- e) Stability of slopes

Height

The height of the embankment depends on the desired grade line of the highway and the soil profile or topography. Also the height of the fill is some times governed by stability of foundation, particularly when the foundation soil is weak.

Fill Material

Granular soil is generally preferred as highway embankment material. Silts, and clays are considered less desirable. Organic soils, particularly peat are unsuitable. The best of the soils available locally is often selected with a view to keep the lead and lift as low as possible. At times light-weight fill material like cinder may be used to reduce the weight when foundation soil is weak.

Settlement

The embankment may settle after the completion of construction either due to consolidation and settlement of the foundation or due to settlement of the fill or due to both. If the embankment foundation consists of compressible soil with high moisture content, the consolidation can occur due to increase in the load. The settlement of the fill is generally due to inadequate compaction during construction and hence by proper compaction this type of settlement may be almost eliminated. Whatever be the type of settlement, it is desirable that the settlement is almost complete before the construction of pavement.

Stability of Foundation

When the embankment foundation consists of weak soil just beneath or at a certain depth below in the form of a weak stratum, it is essential to consider the stability of the foundation against a failure. This is all the more essential in the case of high embankments.

- a) The foundation stability is evaluated and the factor of safety is estimated by any of the following approaches:
- b) Estimating the average shear stress and strength at the foundation layers by approximate methods and estimating the factor of safety.
- c) Using theoretical analysis based on elastic theory.

The factor of safety in the case of compressible soil foundation is likely to be minimum just after the completion of the embankment. Later due to consolidation of foundation and consequent gain in strength there will be an increase in the foundation factor of safety.

Stability of Slopes

The embankment slopes should be stable enough to eliminate the possibility of a failure under adverse moisture and other conditions. Hence the stability of the slope should be checked or the slope should be designed providing minimum factor of safety of 1.5. Often much flatter slopes are preferred in highway embankments due to aesthetic and other reasons.

CONSTRUCTION OF PAVEMENTS

Various equipments for construction of the pavements:

1. Bull dozer
2. Scrapper
3. Power shovel
4. Hoe
5. Dragline
6. Clamp shell
7. Pavers

Construction of Flexible pavement

Material for construction Flexible pavement/Bituminous pavement:

The common types of flexible pavements in India is made from wet mix macadam (WMM) and (WBM) water bound macadam.

Wet mix macadam construction procedure

Steps

1. The compaction test is conducted in the laboratory using the selected WMM material.

2. The optimum moisture content of the WMM material is found out in the laboratory under heavy compaction.
3. The selected WMM material is prepared in a pug mill by adding water equal to the optimum moisture content.
4. Then the WMM material is transported to the field and spread over the site by using a paver to attain required slope, thickness & grade.
5. Then the compaction is done using the vibratory roller of minimum weight 10 times and with a rolling speed of 5 Kmph.
6. The WMM layer is checked for defects before the construction of the bituminous surface course.
7. After the WMM layer is dried in a dry weather for 24 hours the bituminous pavement layer is applied & the road is opened for traffic.

WATER BOUND MACADAM CONSTRUCTION

Material used for the WBM construction

- a) Coarse aggregate
- b) Screening
- c) Binding material

Construction process

Steps

1. The soil surface prepared by leveling & filling of the depressions and patching the pot holes up to the required grade and slope.
2. The dust and other loose materials are cleaned.
3. The total boundary for the formation of the pavement was confined by constructing the shoulders.
4. Then the coarse aggregates are properly spread to a uniform profile and thickness.
5. The compaction is done by using power rollers of 3-10 tons by vibration & rolling, starting from the edge towards the center line.
6. After the compaction is over the dry screening are applied on the surface to fill the interspaces in 3-4 applications.
7. The surface is sprinkled with water & rolled. The rolling is done till the coarse aggregates get firmly bonded.
8. The binding material is applied at a uniform & slow rate followed with sprinkling of water. Then rolled to desired level.

9. After the final compaction the layer is allowed for drying 24 hours. The bituminous surfacing is layered which comprises of tar & aggregate of range (1-1.5 cm) in hot condition.
10. Then the rolling is done followed by sprinkling of additional bitumen & after the drying of road completely this is made open to the traffic.

CONSTRUCTION OF CEMENT CONCRETE/RIGID PAVEMENTS

Construction of C.C. pavements can be done in two methods

1. Alternate bay method

Here the C.C slabs are layered alternatively after an interval of 1 week or 2 days in case of rapid hardening cement (High alumina cement).

2. Continuous construction

In this method all the bays of one traffic lane are laid continuously without any break.

Materials required for the construction of C.C. pavements

- a) Cement – OPC & Rapid hardening (High alumina cement)
- b) Coarse aggregate
 - Abrasion value < 35 %
 - Impact value < 30 %
 - Crushing value < 30 %
 - Soundness value < 12

Note: The maximum size of the aggregate used should be $\frac{1}{4}$ th the slab thickness.

- c) Fine aggregate – Natural sand, Crushed gravel/stone
- d) water

Construction procedure

Normally the C.C. pavements are constructed in the dry weather at temperature between (4 – 40° C).

Step 1 Subgrade preparation

The foundation should be compacted & well graded. Generally the subgrade or sub-base preparation is done till a depth of 30 cm.

Step 2 Formwork fixing

Timber/ wood frameworks were previously used as formwork in C.C. pavement construction but now-a-days steel formworks of length 3 m are used. The formworks were made to stand vertically & fixed by the help of stiffeners at the backside and arranged in a straight line. Then the line & levels were ensued.

Step 3 Batching of concrete

The coarse aggregate, fine aggregate and cement are mixed in required preparation by weight in the batching plant properly.

Step 4 Mixing of materials

Concrete mixing is done using power driven mixers for uniform distribution of all materials in mixture. The workability is also determined for the prepared mix.

Step 5 Transportation & spreading

The concrete should be immediately placed between the formwork within 20 minutes after mixing & compacted properly. The concrete should not be dropped from a height of 90 cm (to avoid segregation).

Step 6 Compaction

The compaction must be done by using a vibrating screed while continuing this process over vibration is avoided as to prevent coming of excess mortar & water to the top. This step should be completed within 75 minutes after mixing.

Step 7 Curing

After the final setting time is over. Wet jute mats were placed over the pavement for initial curing of 24 hrs and after that sand is sprayed and watered over the pavement for final curing of 14 days. After 28 days the pavement is opened for traffic.

PAVEMENT FAILURE & MAINTAINANCE

The no. of factors that causes pavement failure are

- Increase in traffic
- Environmental charges
- Design and construction deficiency
- Maintenance deficiency

Pavement failures:

Unsatisfactory performance of a pavement such that it can no longer be serviceable.

Pavement failure may be structural and functional failures.

- Structural failure means the collapse of the pavement
- Functional means the pavement is not able to discharge the traffic freely.

Maintenance of pavements:

Maintenance is the process which tends to keep the pavement in serviceable condition as long as possible.

- For proper inspection & maintenance each state should have a highway maintenance cell which will focus on construction, repair, maintenance & inspection works.

Earth roads:

The usual damages caused in the earth roads needing frequent maintenance are:

- i) Formation of dust in dry weather.
- ii) Formation of longitudinal ruts along wheel path or vehicles
- iii) Formation of cross ruts along the surface after monsoons due to surface water.

Thus, dust nuisance may be remedied by the following methods:

- a) Frequent sprinkling of water
- b) Treatment with calcium chloride
- c) Use of other dust palliatives.

Application of calcium chloride retains some water due to the hygroscopic nature of mix. Oiled earth roads are also common these days.

Periodical maintenance by spreading moist soil along ruts and reshaping of the camber is necessary. Formation of cross ruts may be due to excessive cross slope.

Hence either these ruts should be repaired from time to time during and after the monsoon or a surface treatment or stabilized layer be provided on the top.

Maintenance of earth roads:

- Sprinkling water
- Rolling
- Adding new material over the older one followed by compaction.

Maintenance of WBM roads:

- Spreading a thin binder layer after monsoon.
- Applying surface dressing.
- Using filling materials such as dust.

Maintenance of bituminous surfaces:

Mainly the maintenance works of bituminous surfacing consists of:

- i) Patch repairs
- ii) Surface treatments
- iii) Resurfacing

Patch repairs:

Patch repairs are carried out on the damaged or improper roads surface. Localized depression and pot holes may be formed in the surface layers due to defects in materials and construction.

An inadequate or defective binding material causes removal of aggregates during monsoons. Patching may be done on affected localized area or sections using a cold premix.

Pot holes and repairs:

Pot holes are cut to rectangular shape and the affected materials in the section is removed until the sound materials are encountered.

The excavated patches are cleaned and painted with bituminous binder. A premixed material is then placed in the sections. Generally, cutback or emulsion is used as binder.

Bituminous emulsions could be used even when the pavement surface and the aggregates are wet during monsoons.

The materials so places in the pot hole, is well compacted by ramming to avoid any raveling.

The materials in out holes are places in layers of thickness of 6 cm.

it is however necessary to replace the base course materials with similar new materials if the failure has been detected in the base course layer. The finished level of the patched is kept slightly above original level to allow for subsequent compaction under traffic.

Surface treatment:

Excess of bitumen in the surface materials bleeds and the pavement becomes patchy and slippery. Corrugations or rutting or shoving develop in such pavement surface. It is customary to spread blotting materials such as aggregate chips of maximum size of about 10mm or coarse sand during summer.

Resurfacing:

In the event when the pavement surface is totally worn out and develops a poor riding surface, it may be more economical to provide an additional surface course on the existing surface.

In case of the pavement is of inadequate thickness due to increase in traffic loads and strengthening is necessary, than an overlay of adequate thickness should be designed and constructed.

Maintenance of Bituminous pavements:

- Cutting the defective areas in rectangular shape.
- Cleaning & applying primer.
- Filling the excavated area with premixed material by applying emulsions and compacted.
- Bituminous surface with minute cracks are treated by providing a completely new surface over it.

Maintenance of cement concrete roads:

Various types of cracking have been explained:

Treatment of cracks:

The cracks are developed in cement concrete (CC) may be classified into two groups:

- i) Temperature cracks which are initially fine cracks or hair cracks formed across the slab in between a pair of transverse or longitudinal joints, dividing the slab length into two or more approximately equal parts due to the temperature stresses like the shrinkage stress warping stress etc.
- ii) Structural cracks formed near the edge and corner regions of the slabs, due to combined wheel load and warping stresses in the slab.

The repeated application of heavy wheel loads and the variations in temperature and moisture conditions the cracks get widened and further deterioration becomes rapid.

Once the surface water starts getting into the pavement and the sub grade through the widened cracks, progressive failure of the pavement is imminent.

Therefore before these cracks get wide enough to permit infiltration of water, they should be sealed off to prevent rapid deteriorations

The formation of structural cracks in CC slabs should be viewed seriously and needs immediate attention as these indicate possible beginning of pavement failure. The maintenance work in such a case involves first remedy of the basic cause of the failure and then recasting the failed slabs.

Maintenance of joints:

Joints are the weakest parts in CC pavements. The efficiency of the pavement is determined by the proper functioning of the joint.

During the summer the joint sealer material is squeezed out of the expansion joints due to the expansion of the slabs. Subsequently as the slabs contract during winter, the joint gap opens out and cracks are formed in the old sealer material.

The joint filler material at the expansion joints may get damaged or deteriorated after several years of pavement life. The repair consists of removal of the sealer and deteriorated filler and sealer materials from the expansion joints cleaning up replacement with new filter board and sealing the top of the joints with suitable sealer materials.

Maintenance of concrete roads:

- Wide pavement cracks can be maintained by first cleaning the cracks & applying a coat of kerosene then filled with suitable fillers.
- Slabs may be repaired using epoxy resin sand ratio of 1:8 to 1:10 to a desired level.

Pavement strengthening:

Strengthening of pavement may be remedial & preventive.

For strengthening an extra thickness of pavement known as overlay is provided in 4 different ways such as

- a) Flexible overlay over flexible pavement
- b) Flexible overlay over rigid pavement
- c) Rigid overlay over rigid pavement
- d) Rigid overlay over flexible pavement

PAVEMENT FAILURES:

Some of the general causes of pavement failures needing maintenance measures may be classified as given below:

- a) Defects in the quality of materials used.
- b) Defects in construction method and quality control during construction
- c) Inadequate surface or subsurface drainage in the locality resulting in the stagnation of water in the sub grade or in any of the pavement layers.
- d) Increase in the magnitude of wheel loads and the number of load repetitions due to increase in traffic volume.
- e) Settlement of foundation of embankment of the fill material itself.
- f) Environmental factors including heavy rainfall, soil erosion, high water table, snow fall, frost action etc.

The various items of highway maintenance works may be broadly classified under three heads:

Routine maintenance:

These include filling up of pot holes and patch repairs, maintenance of shoulders and the cross slope, up-keep of the road side drains and clearing choked culverts, maintenance of miscellaneous items like road signs, arboriculture, inspection bungalows etc.

Periodic maintenance:

These include renewals of wearing course of pavement surface and preventive maintenance of various items.

Special repair:

These include strengthening of pavement structure or overlay construction, reconstruction of pavement, widening of roads, repairs of damages caused by floods, providing additional safety measures like islands, signs etc.

DESIGN OF PAVEMENT

The surface of the roadway should be stable & non-yielding, to allow the heavy wheel load of road traffic to move with least possible rolling resistance. The road surface should also be even along the longitudinal profile to enable the design speed. The earth road may not be able to fulfill any of the above requirement, especially during the varying conditions of traffic loads & the weather. At high moisture contents, the soil becomes weaker & soft & starts yielding under heavy wheel loads, thus increasing the tractive resistance discomfort & fatigue to the passengers of fast moving vehicle & cyclists thus a pavement consisting of a few layers of pavement materials is constructed over a prepared soil sub grade to serve as a carriageway.

- Based on the vertical alignment & the environmental conditions of the site, the pavement may be constructed over an embankment, cut or almost at the ground level of the ground water to keep the sub grade relatively dry even during monsoons.

Failures in flexible pavement

A flexible pavement failure is defined by formation of pot holes, ruts, cracks, localized depressions and settlements. The localized depression normally is followed with heaving in the vicinity.

The failure of any one or more components of the pavement structure develops the waves and corrugations on the pavement surface or longitudinal ruts and shoving. Pavement unevenness may itself be considered, as a failure, when it is excessive.

The aging and oxidation of bituminous films lead to the deterioration of bituminous pavements. Deterioration actions in pavements are rapidly increased when excess water is retained in the void spaces of bituminous pavements or in the cracks and joint of the cement concrete pavements.

The cement concrete pavement may develop cracks and deteriorate due to repeated loads and fatigue effects. A rigid pavement failure is observed by the development of structural crack of break resulting in progressive subsidence of some portions of pavement.

Pavements are therefore capable of withstanding slight variations in the underlying support and they bridge the localized gaps moderately.

It is the combination of many factors that induce the failure conditions in the rigid pavement. Due to the temperature effects, the newly constructed cement concrete pavement may also crack even if no vehicle moves on them.

Failures in flexible pavements:

The localized settlement of any one component layer of the flexible pavement structure could be enough to cause pavement failure. This demands that each one of the layers should be carefully designed and laid.

Thus to maintain the stability of the pavement structure as a whole, each layer should be stable within itself and thereby make the total pavement maintain its stability.

In this fig shows the failures in soil subgrade, base course and the surface wearing course. It may see that ultimately there is surface deformation when failure takes place either in sub grade or base or surface.

Failures in sub grade:

One of the prime causes of flexible pavement failure is excessive deformation in sub grade soil. It is the form of excessive undulation or waves and corrugations in the pavement surface and also depressions followed by heaving of pavement surface.

The lateral shoving of pavement near the edge along the wheel path of vehicles is due to insufficient bearing capacity or a shear failure in sub grade soil.

The failure of sub grade maybe attributed due to two basic reasons:

- i) Inadequate stability
- ii) Excessive pavement thickness

Inadequate stability may be due to inherent of the soil and excessive moisture condition and improper compaction. Stability is the resistance to deformation under the stress.

Excessive stress application is due to inadequate pavement thickness or loads in excess of design value.

The deformation due to the load would be elastic or fully recovered when the load is released. In part of the compaction of the layers is not adequate with reference to subsequent loading part of the deformation may be permanent due to compaction of soil this may be called as consolidation deformation.

The applied stress is excessive with respect to the stability and plastic flow takes place as in the case of wet clay soil, this deformation is called plastic deformation.

The type of damage in flexible pavement than can be caused by traffic due to sub grade failure due to inadequate and improper compaction of sub grade and other pavement layers.

Failures in sub base or base course:

Following are the chief types of sub-base or base course failures:

- i) Inadequate stability or strength
- ii) Loss of binding action.
- iii) Loss of base course materials

- iv) Inadequate wearing course
- v) Use of inferior materials and crushing of base course materials
- vi) Lack of lateral confinement for the granular base course.

Failures of wearing course:

Failure of wearing course is observed due to lack of proper mix design. Improper gradation of aggregates, inadequate binder content and inferior type of binder result in a poor bituminous surfacing.

Besides the design project the bituminous construction requires a high degree of quality control since over or under estimated binder content are both greatly damaging to the resulting paving mix including temperature controls.

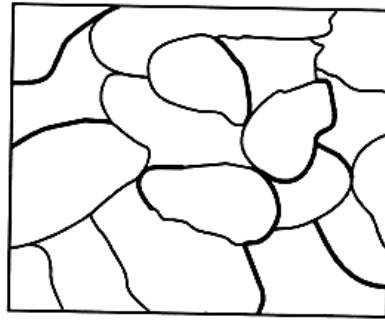
Vocalization and oxidation of binder also makes the bituminous surfacing brittle and cause cracking of the pavement surface which further allows seepage of rain water to harm the underlying layers.

Following are the some of the flexible pavement failures:

- Alligator (map) cracking
- Consolidation of pavement layers
- Shear failure
- Longitudinal cracking
- Frost heaving
- Lack of binding to the lower course
- Reflection cracking
- Formation of waves and corrugation.

Alligator (map) cracking

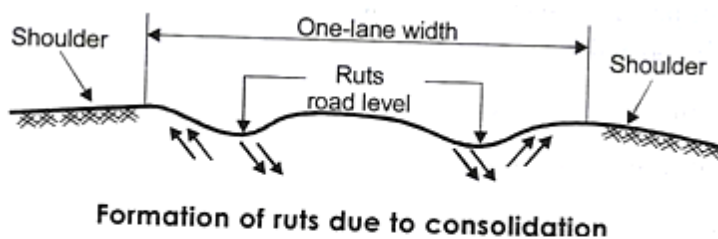
This is the most common type of failure and occurs due to relative movement of pavement layer materials. This may be caused by the repeated application of heavy wheel load resulting in fatigue failure or due to the moisture variations resulting in swelling and shrinkage of sub grade and other pavement materials. Localized weakness in the under laying base course would also cause a cracking of the surface course in this pattern.



Map cracking

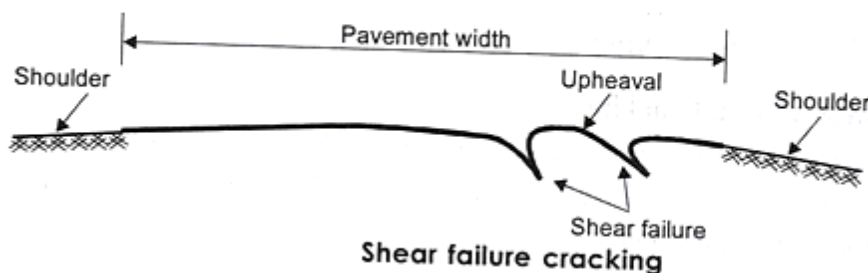
Consolidation of pavement layers

Formations of ruts are mainly attributed to the consolidation of one or more layers of pavement. The repeated application of loads along the same wheel path cause cumulative deformation resulting in consolidation deformation or longitudinal ruts. Shallow ruts on the surfacing course can also be due to wearing along the wheel path. Depending upon the depth and width of ruts, it can be estimated whether the consolidation deformation has been caused in the sub grade or in subsequent layers.



Shear failure and cracking

Shear failures are associated with the inherent weakness of pavement mixtures, the shearing resistance being low due to inadequate stability or excessively heavy loading. The shear failure causes upheaval of pavement materials by forming a fracture or cracking.



Longitudinal cracking

Due to frost action and differential volume changes in sub grade longitudinal cracking is caused in pavement traversing through the fall pavement thickness. Settlement of fill and sliding of side slopes also would cause this type of failure.



Longitudinal cracking due to differential volume change

Frost heaving

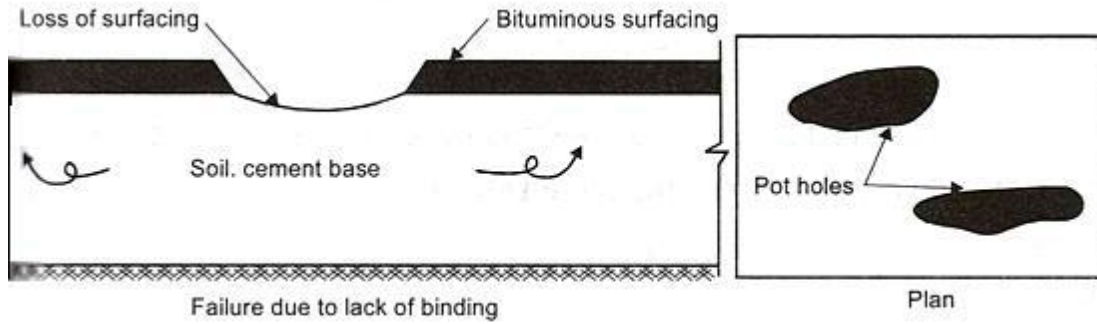
Frost heaving is often misunderstood for shear or other types of failure. In shear failure, the upheaval of portion of pavement is followed with a depression. In the case of frost heaving, there is mostly a localized heaving up pavement portion depending upon the ground water and climate conditions.



Failure due to frost heave

Lack of binding with lower layer

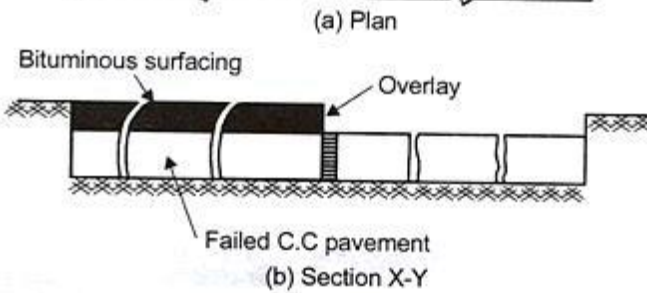
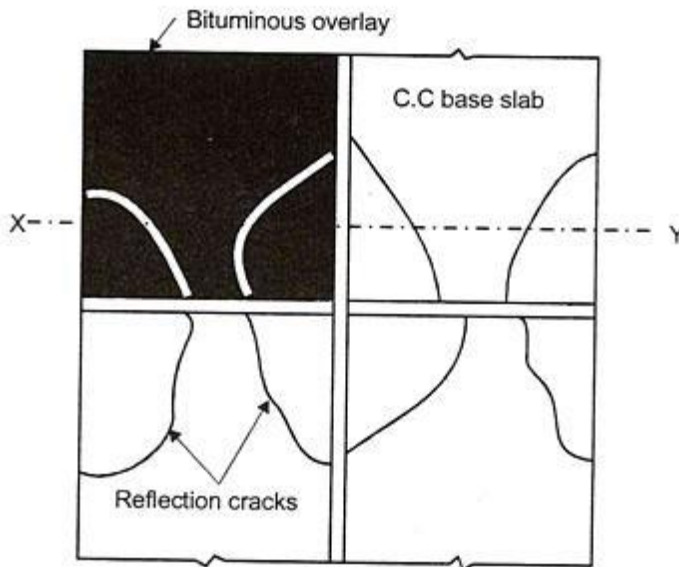
Slipping occurs when the surface course is not keyed/bound with the under laying base. This results in opening up and loss of pavement materials forming patches or pot holes. Such conditions are more frequent in case when the bituminous surfacing is provided over the existing cement concrete base course or soil cement course. This condition is more pronounced when the prime/tack coat in between two layers is lacking.



Reflection cracking

This type of cracking is observed in bituminous overlays provided over existing cement concrete pavements. The crack patterns as existing in cement concrete pavements are mostly reflected on bituminous surfacing in the same pattern. Structural action of the total pavement section is not much influenced by the presence of reflection cracks but since the cracks appear at the surface, these allow surface water to seep through and cause damage to the soil sub grade or resulting in mud pumping.

(a) and (b) show the pattern of reflection cracking.



Reflection cracking

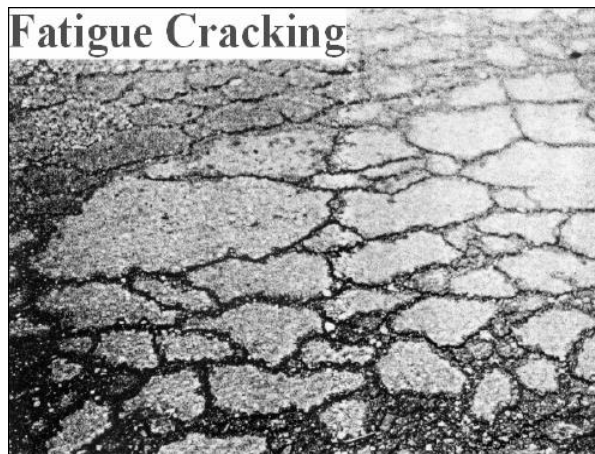
PAVEMENT FAILURE

Pavements fail prematurely because of many factors. When boiled down to the basics, there are four primary reasons pavements fail prematurely:

- Failure in design
- Failure in construction
- Failure in materials
- Failure in maintenance

DIFFERENT TYPE OF PROBLEM

1. **Fatigue Cracking (Alligator Cracking):-** Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue).



2. **Longitudinal Cracking:-** Longitudinal cracks are long cracks that run parallel to the center line of the roadway. These may be caused by frost heaving or joint failures, or they may be load induced. Understanding the cause is critical to selecting the proper repair.



- 3. Transverse Cracking:-** Transverse cracks form at approximately right angles to the centre line of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced (over 20 feet apart). They usually begin as hairline or very narrow cracks and widen with age.



- 4. Block Cracking:-** Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction. Low severity block cracking may be repaired by a thin wearing course.

Block cracking



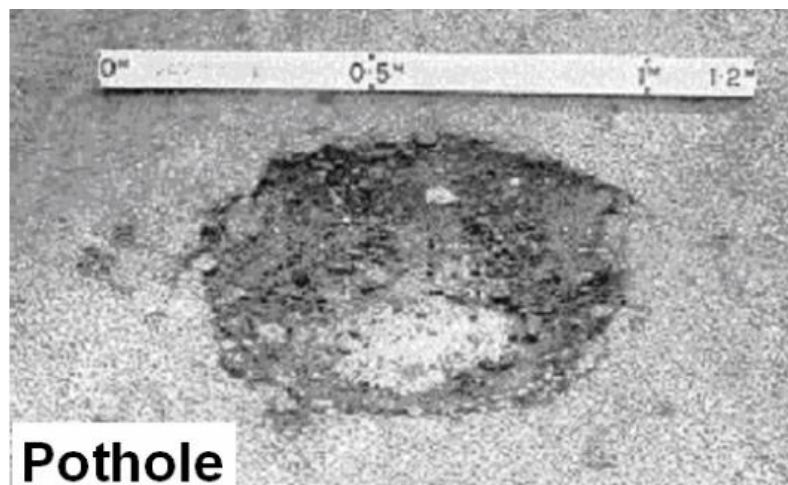
- 5. Edge cracking:-** Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking results from lack of support of the shoulder due to weak material or excess moisture.
- 6. Rutting:-** Rutting is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. Rutting is usually a failure in one or more layers in the pavement. The width of the rut is a sign

of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a sub grade failure.

Rutting



7. **Potholes:-** Potholes are bowl-shaped holes similar to depressions. They are a progressive failure. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage, as seen in Figure Potholes are formed when the pavement disintegrates under traffic loading, due to inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water.



8. **De-lamination:-** De-lamination is a failure of an overlay due to a loss of bond between the overlay and the older pavement. Common causes of de-lamination include: wet or dirty surface during paving of the overlay, failure to use a tack coat, or poor compaction of the overlay. Proper paving techniques, including cleaning the surface and use of tack coat, will reduce the chances of de-lamination.

FAILURE OF RIGID PAVEMENT

Failure in rigid pavement (or cement concrete pavement) can be identified by formation of cracks on the pavement surface. The two prime factors responsible for rigid pavement failure are

1. Use of poor quality material
2. Inadequate stability of the pavement structure

Poor quality of material consist of following items

- Using soft aggregate
- Poor quality of sub-grade soil
- Poor joint filler R sealer materials

Inadequate stability of the pavement structure can be due to following reason

- Inadequate pavement thickness
- Lack of sub-grade support
- Improper compaction of sub-grade
- Improper spacing of joints

TYPES OF FAILURE IN RIGID PAVEMENT

The following 5 form of failures are commonly found in rigid pavement

1. Scaling of cement concrete
2. Shrinkage cracks
3. Joint spalling
4. Warping cracks
5. Pumping

1. SCALING OF CEMENT CONCRETE

Scaling of rigid pavement simply means, peeling off or flaking off of the top layer or skin of the concrete surface. This may be due to the following reasons

- Improper mix design
- Excessive vibration during compaction of concrete
- Laitance of concrete
- Performing finishing operation while bleed water is on surface



2. SHRINKAGE CRACKS

Formation of hairline shallow cracks on concrete slab is the indication of shrinkage cracks. Shrinkage cracks develop on concrete surface during the setting & curing operation. These cracks may form in longitudinal as well as in transverse direction.



3. JOINT SPALLING

Joint spalling is the breakdown of the slab near edge of the joint. Normally it occurs within 0.5 m of the joints. The common reasons for this defect are

- Faulty alignment of incompressible material below concrete slab
- Insufficient strength of concrete slab near joints
- Freeze-thaw cycle
- Excessive stress at joint due to wheel load

4. WARPING CRACKS

In hot weather, concrete slab tends to expand. Therefore the joints should be so designed to accommodate this expansion. When joints are not designed properly, it prevents expansion of concrete slab and therefore results in development of excessive stress. This stress cause

formation of warping cracks of the concrete slab near the joint edge. This type of crack can be prevented by providing proper reinforcement at the longitudinal and transverse joints. Hinge joints are generally used to relieve the stress due to warping.



5. PUMPING

When material present below the road slab ejects out through the joints or cracks, it is called pumping. When soil slurry comes out it is called mud pumping. The common reasons for this defect are

- Infiltration of water through the joints, cracks or edge of the pavement forms soil slurry. Movement of heavy vehicles on pavement forces this soil slurry to come out causing mud pumping.

- When there is void space between slab and the underlying base or sub-grade layer
- Poor joint sealer allowing infiltration of water
- Repeated wheel loading causing erosion of underlying material

Pumping can also lead to formation of cracks. This is because; ejection of sub-grade material below the slab causes loss of sub-grade support.

When traffic movement occurs at these locations, it fails to resist the wheel load due to reduction of sub-grade support and develops cracks. This type of defect can be identified when there is presence of base or sub-grade material on the pavement surface close to joints or cracks.



Maintenance management system

The type and extent of maintenance requirement for a road depend on the serviceability standard laid down, the maintenance needs funds available and the priorities for the maintenance operations. As several interlinked factors are involved in the maintenance works of road network consisting of different categories of road, a system approach is appropriate for the road maintenance management.

The various factors to be included in the maintenance management system are:

- Minimum acceptable serviceability standards for the maintenance of different categories of roads.
- Field surveys for the evaluation of maintenance requirements.
- Various factors influencing the maintenance needs such as sub grade soil, drainage, climate, traffic, environmental conditions.
- Estimation of rate of deterioration of the pavement under the prevailing set of conditions.
- Type and extent of maintenance requirements and various possible alternatives and their economic evaluation.
- Availability of funds.
- Maintenance cost, availability of materials, man power and equipment.