CHAPTER 6

# Pavement Design

## INTRODUCTION

The surface of the roadway should be stable and non-yielding to allow the heavy wheel loads of road traffic to move with least possible rolling resistance. The road surface should also be even along the longitudinal profile to enable the fast vehicles to move safely and comfortably at the design speed. The roadway is well designed to provide a stable and even surface for the traffic, the main objective of a well designed and constructed pavement is to keep elastic deformation of the pavement within the permissible limits, so that the pavement can sustain a large number of repeated load applications during the design life.

## 6.1 Types of Pavement Structure

Pavements are generally classified into two categories on the basis of structural behaviour:

(*i*) Flexible pavement (*ii*) Rigid pavement

### 6.1.1 Flexible Pavement

The pavements which have very less flexural strength are called flexible pavements. This type of pavements transmit the load to the lower layer by grain to grain transfer. A typical flexible pavement consists of four components as shown in Figure 6.1.

(*i*) Soil subgrade (*ii*) Sub base course
(*iii*) Base course (*iv*) Surface course

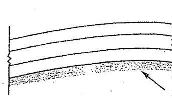



*Figure-6.1 : Components of Flexible Pavement*

Bituminous concrete, granular materials with or without bituminous binders, water bound macadam etc. are common examples of flexible pavement. Neither expansion nor contraction joints are provided in the flexible pavement. Cost of completion of such pavements are less but have high maintenance cost.

**NOTE:** (*i*) IRC – 37 : 2012 : Design code for the design of flexible pavement.
(*ii*) Flexible payement are commonly designed using empirical charts or equations.

### 6.1.2 Rigid Pavement

Rigid pavements are those which possess worthy flexural strength. The rigid pavement transmit the wheel load stresses through a wider area below by the slab action. The rigid pavements are made of portland cement concrete. The plain cement concrete slabs are expected to take up about 40 kg/cm$^2$ flexural stress. Joints are also used in the construction of rigid pavement and has high completion cost but low maintenance cost.

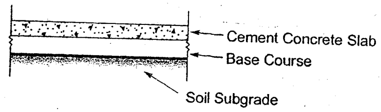



*Figure-6.2 : Components of rigid pavement*

**NOTE:** (*i*) IRC-58 : 2012 : Design code for the design of rigid pavement.
(*ii*) Rigid pavements are designed using elastic theory.

### 6.1.3 Semi Rigid Pavement

A Semi rigid pavement is the intermediate stage between the flexible and the rigid types. It derives strength by both load-spreading and flexural action.

## 6.2 Functions of Pavement Components

(i) **Soil subgrade:** It is a layer of natural soil and the loads on pavement are ultimately received by the soil subgrade. Atleast 50 cm layer of the subgrade soil is well compacted at optimum moisture content and maximum dry density.

Common tests which are used to evaluate the strength of soil subgrade are:

(a) California bearing ratio test
(b) California resistance value test
(c) Plate bearing test
(d) Triaxial compression test

(ii) **Sub base and base course:** They are made up of broken stone aggregates. Base and sub base courses are used under flexible pavements primarily to improve load supporting capacity by the distribution of the load through a finite thickness. Use of smaller size graded aggregates at sub base courses instead of boulder stones is desirable.

Base courses are used under rigid pavement for:

(a) Preventing pumping
(b) Protecting the subgrade against frost action

(iii) **Wearing course:** It's purpose is to provide smooth riding surface. It resists pressure exerted by tyres and takes up wear and tear due to the traffic. It also provides the safety against the unfiltered water. The stability of wearing course is estimated by Marshall stability test where in optimum percentage of bituminous material is worked out based on stability density, VMA and VFB.

Plate bearing test and Benkleman beam test are also sometimes made use for evaluating the wearing course and the pavement as a whole.

## 6.3 Design Factors

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

(i) **Design Wheel Load:** Following are the wheel load factors to be consider in the design of pavement:

(a) Maximum wheel load: Total load influences the thickness requirements of pavements and the tyre pressure influences the quality of surface course. Maximum legal axle load as specified by IRC is 8170 kg with a maximum equivalent single wheel load of 4085 kg. The pressure distribution is bulb shaped as shown in Figure 6.3.

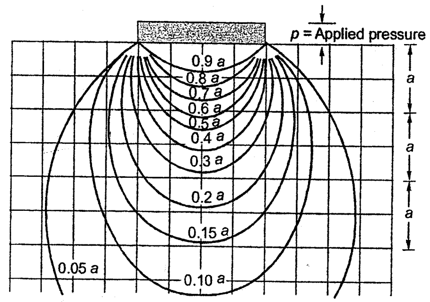
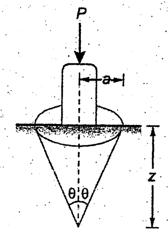



*Figure-6.3 : Pressure distribution bulb*

**NOTE**

Vertical stress under a uniformly distributed circular load based on Boussinesq's theory.

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




Where,

$\sigma_z$ = Vertical stress at depth $z$

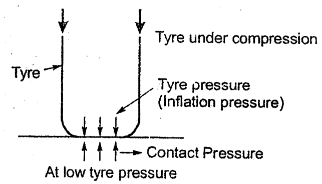
$p = \frac{P}{\pi a^2}$ = Surface pressure

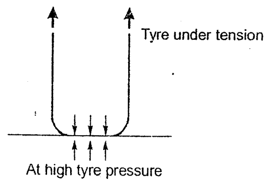
$z$ = Depth at which $\sigma_z$ is computed

$a$ = Radius of loaded area

(b) Contact Pressure and Tyre Pressure or Inflation Pressure: At low tyre pressure the tyre comes under compression. Hence contact pressure is greater than tyre pressure.

Contact Pressure = Load on wheel/Contact area




At high tyre pressure, tyre come under tension. Hence contact pressure is less than tyre pressure.

The contact pressure is found to be more than tyre pressure when the tyre pressure is less than 7 kg/cm$^2$ and it is vice versa when the tyre pressure exceeds this value.

**NOTE:** Tyre pressure effects top surface of the pavement and contact pressure effects the bottom layer.

The variation between tyre pressure and measured contact pressure is shown in **Figure 6.4**.

The ratio of contact pressure to tyre pressure is defined as Rigidity factor.

***Table 6.1*** *Value of rigidity factor*

| Contact Pressure | Tyre Pressure | Rigidity Factor |
|---|---|---|
| 7 kg/cm$^2$ | 7 kg/cm$^2$ | 1 |
| > 7 kg/cm$^2$ | < 7 kg/cm$^2$ | > 1 |
| < 7 kg/cm$^2$ | > 7 kg/cm$^2$ | < 1 |

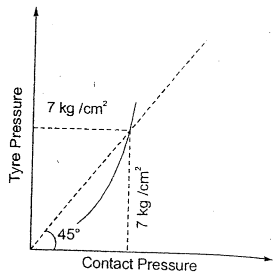



***Figure-6.4 :*** *Relationship between tyre and contact pressure*

(c) **Equivalent Single Wheel Load (ESWL):** It is defined as load on the single tyre which will cause an equivalent magnitude of stress, strain, deflection etc. at a given location to that of multiple wheel load at the same location. To maintain the maximum wheel with in the specified limit, it is necessary to provide dual wheel assembly to the rear axles of road vehicles.

The effect of dual wheel assembly is not equal to two times the load of any wheel. Equivalent single wheel load is calculated by using equal stress criteria. It is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

1. Equalancy concept is based on equal stress
2. Contact area is circular
3. Influence angle is 45°
4. Soil medium is elastic, homogenous and isotropic

In a dual wheel load assembly, let '*d*' is the clear gap between two wheel, '*S*' be the spacing between center of the wheels and '*a*' be the radius of the circular contact area of each wheel.

Therefore, $S = d + 2a$

The ESWL is given by:

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

Where, $P$ = Wheel load

$Z$ = Desired depth

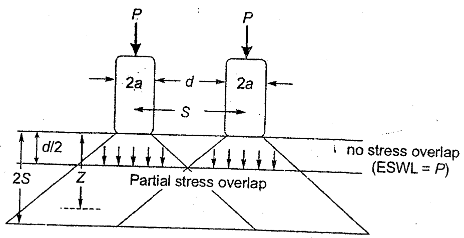



***Figure-6.5 :*** *ESWL stress concept*

Upto a depth of $\frac{d}{2}$, no stress overlap occurs, therefore

$$\text{ESWL} = P$$

and for the depth greater than 2*S*, the effect of overlap is such that we can consider

$$\text{ESWL} = 2P$$

The pressure at any depth lies between single wheel load (*P*) and two times of any one wheel load (2*P*) as shown in **Figure 6.6**.

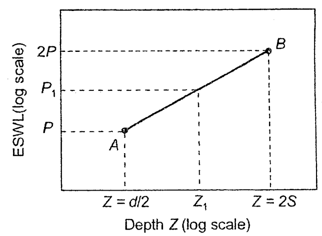



***Figure-6.6 :*** *Graphical representation of ESWL*

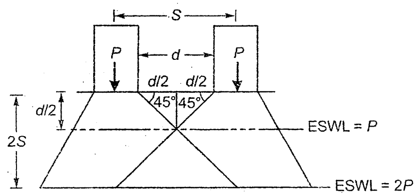
**Example-6.1** What is the equivalent single wheel load of a dual wheel assembly carrying 20,440 N each for pavement thickness of 20 cm? Centre to centre spacing of tyres is 27 cm and the distance between the walls of tyres is 11 cm.

***Solution:***

Given, $S$ = 27 cm

$d$ = 11 cm

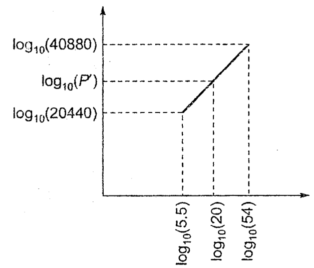
$P$ = 20440 kN




ESWL at $d/2$ depth i.e. at 5.5 cm = 20440 N

ESWL at 2$S$ depth i.e. at 54 cm = 2 × 20440 = 40880 N

$$\log_{10}(P') = \log_{10}(20440) + \frac{\log_{10}(40880) - \log_{10}(20440)}{\log_{10}(54) - \log_{10}(5.5)} \times [\log_{10}(20) - \log_{10}(5.5)]$$




$\Rightarrow$ $P'$ = 30242.26 N

$\therefore$ ESWL = 30242.26 N

(d) **Equivalent Axle Wheel Load:** Vehicles can have many axles which will distribute the load into different axles and in turn to pavement through the wheels. The design of flexible pavement is by layered theory, only the wheels on the side needed to be considered. On the other hand, the design of rigid pavement is by plate theory and hence the wheel load on both sides of axle need to be considered.

**Legal axle load:** The maximum allowed axle load on the roads is called legal axle road. For highways the maximum legal axle load in India recommended by IRC is 10 tonnes.

**Standard axle road:** It is a single axle load with dual wheel carrying 80 kN load and the design of pavement is based on the standard axle load.

(e) **Repetition of Load:** Repetitive application of load will increase the magnitude of plastic and elastic deformations. Equivalent wheel load is single load equivalent to the repeated applications of any particular wheel load on a pavement which requires the same thickness and strength of pavements.

**Remember:** 80 kN single axle is considered to be standards axle load.

Axles that are not equal to 80 kN are converted into equivalent number of standard axle load with the help of Equivalent Load Factor (ELF). According to Mcleod equivalent load factors is given as

$$\text{Equivalent load factor} = \left(\frac{\text{Axle load}}{\text{Standard Axle load}}\right)^4$$

Evaluation of equivalent load factor is also known as fourth Power Law. If the pavement structure fails with $N_1$ number repetitions of $P_1$ kg load and similarly $N_2$ number repetitions of $P_2$ kg load can also cause failure of the some pavement structure, then

$$P_1 N_1 = P_2 N_2$$

**Example-6.2** The result of one day axle load of trucks on a road is given below. Find the number of repetitions of a standard 80 kN axle in a year.

| Axial load range (kN) | Frequency (*n*) |
|---|---|
| 0 - 40 | 60 |
| 40 - 80 | 300 |
| 80 - 120 | 500 |

***Solution:***

| Mid of axial load range (kN) (W) | Frequency (*n*) | $ELF = \left(\frac{W}{80}\right)^4$ | *n* × ELF |
|---|---|---|---|
| 20 | 60 | $\frac{1}{256}$ | $\frac{60}{256}$ |
| 60 | 300 | $\frac{81}{256}$ | $\frac{81}{256} \times 300$ |
| 100 | 500 | $\frac{625}{256}$ | $\frac{625}{256} \times 500$ |
| | | | $\Sigma = 1315.86$ <br> $\simeq 1316$ |

$\therefore$ Number of repetitions of standard axles in one year will be = 1316 × 365 = 480340.

## 6.4 Design of Flexible Pavement

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

(*i*) Vertical compressive strain at the top of the subgrade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.

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

(*iii*) Pavement deformation within the bituminous layer.

Permanent deformation within the bituminous layer can be controlled by meeting the mix design requirements, thickness of granular and bituminous layers are selected using the analytical design approach so that strains at critical points are within the allowable limits.

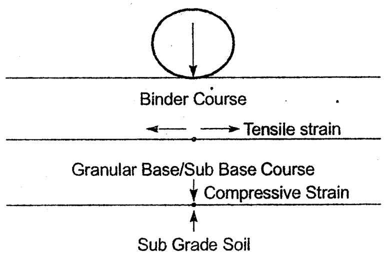



***Figure-6.7 :** Critical Location in Pavement*

### Failure Criteria

Factor responsible for permanent deformation of subgrade is the vertical strain ($\epsilon_v$) at the top of subgrade. Dominating factor for tensile cracking due to fatigue is the tensile strain ($\epsilon_t$) at the bottom of bituminous layer.

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

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

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

Where,

$N_f$ = Number of cumulative standard axle to produce 20% cracked surface area

$\epsilon_t$ = Tensile strain at the bottom of bituminous layer

$E$ = Elastic Modulus of bituminous layer

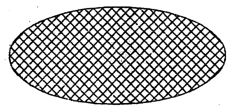


***Figure-6.8 :** Fatigue cracking*

**(ii) Rutting Criteria:** Rutting is the permanent deformation caused mainly due to permanent deformation in subgrade. The allowable number of load repetitions to control permanent deformation can be expressed as

$$N_f = 4.1656 \times 10^{-8} \times \left(\frac{1}{\epsilon_v}\right)^{4.5337}$$

Where;

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

$\epsilon_v$ = Vertical subgrade strain at top

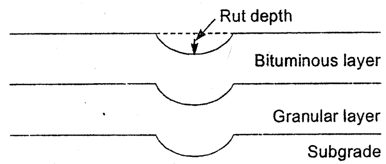



***Figure-6.9 :** Rutting*

### Various Approaches of Flexible Pavement Design

**(i) Empirical methods:** They are based on strength pavement of soil subgrade. The Group Index Method, CBR method and Mcleod method are empirical methods.

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

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

### 6.4.1 Group Index Method

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

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

**Limitations of Group Index Method**

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

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

$$GI = 0.2a + 0.005ac + 0.01bd$$

Where,

$a$ = % finer passing 75μ sieve = $p - 35 \not> 40$

$b$ = % finer passing 75μ sieve = $p - 15 \not> 40$

$c = W_L - 40 \not> 20$

$d = I_P - 10 \not> 20$

$W_L$ = Liquid limit

$I_P$ = Plasticity Index

**NOTE:** (*i*) $a$ and $b$ are expressed as whole number between 0 – 40.
(*ii*) $c$ and $d$ are expressed as whole number between 0 – 20.

**Example-6.3** A soil subgrade has following data:

1. Soil passing 75 μ sieve is 60%
2. Liquid limit = 45%
3. Plastic limit = 20%

Find out the thickness of pavement.

| *G.I.* | Thickness (cm) |
|---|---|
| 0 | 30 |
| 05 | 45 |
| 10 | 62 |
| 15 | 78 |
| 20 | 90 |

***Solution:***

Plasticity Index ($I_P$) = $W_L - W_P$ = 45% – 20% = 20%

Soil passing 75μ sieve ($p$) = 60%

$a = p - 35 = 60 - 35 = 25 < 40$

$b = p - 15 = 60 - 15 = 45 \nless 40$

∴ $b = 40$

$c = W_L - 40 = 45 - 40 = 5 < 20$

$d = I_P - 10 = 25 - 10 = 15 < 20$

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

$G.I. = 0.2 \times 25 + 0.005 \times 25 \times 5 + 0.01 \times 40 \times 15$

$G.I. = 11.625$

Thickness ($t$) of pavement corresponding to $G.I.$ = 11.625 is interpolated as

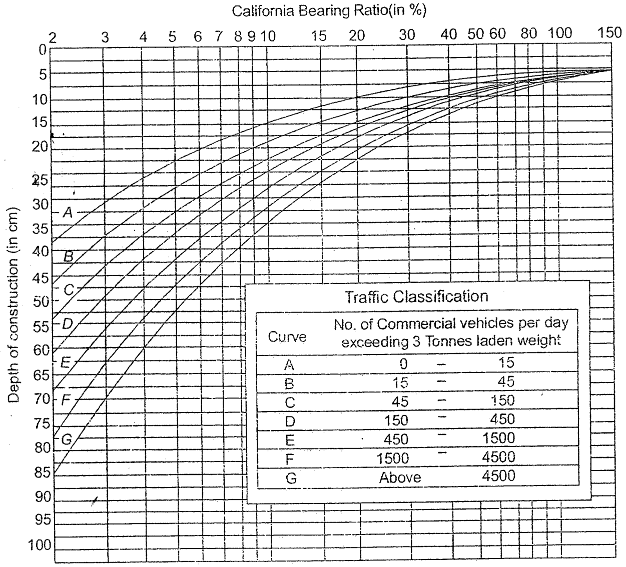
$$t = 62 + \left(\frac{78-62}{15-10}\right) \times (11.625 - 10) = 67.2 \text{ cm}$$

### 6.4.2 California Bearing Ratio Method

This method is based on the strength parameters of subgrade soil and subsequent pavement material. In this method, first the soaked CBR values of the soil subgrade is calculated and then appropriate design curve as shown in Figure 6.10 is chosen.

Thickness of sub base = Total thickness – Thickness over sub base

Thickness of base = Thickness over sub base – Thickness over base




Traffic Classification

| Curve | No. of Commercial vehicles per day exceeding 3 Tonnes laden weight |
|---|---|
| A | 0 – 15 |
| B | 15 – 45 |
| C | 45 – 150 |
| D | 150 – 450 |
| E | 450 – 1500 |
| F | 1500 – 4500 |
| G | Above 4500 |

***Figure-6.10 :** CBR design curves as per IRC-37*

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

$$T(\text{cm}) = \sqrt{\frac{1.75P}{CBR(\%)} - \frac{P}{p\pi}}$$

Where, $P$ = Wheel load in kg

$p$ = Tyre pressure in kg/cm²

**NOTE:** The above formula is more appropriate for the CBR value of subgrade less than 12%.

**IRC Recommendations for CBR Test**

(*i*) CBR test must be performed in laboratory, in situ tests are not recommended.

(*ii*) The soil should be compacted to optimum moisture content to achieve maximum dry density.

(*iii*) These samples should be soaked for 4 days (96 hours) before testing.

(*iv*) Minimum three samples should be tested on each type of soil at the same moisture content.

(*v*) Top 50 cm of subgrade should be compacted upto 95 – 100% of maximum dry unit weight.

(*vi*) Pavement of major roads to be designed for 10 years of life span.

(*vii*) The design thickness is applicable for single axle load upto 8200 kg and tandem axial load upto 14500 kg.

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

**Limitations of CBR Method**

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

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

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

**Example 6.4** CBR test was conducted for soil subgrade and the following results were found.

| Load | Penetration |
|---|---|
| 60 kg | 2.5 mm |
| 82 kg | 5.0 mm |

Following materials are required to be used over soil subgrade:

1. Compacted soil (CBR = 6%)
2. Poorly graded gravels (CBR = 12%)
3. Well graded gravel (CBR = 60%)
4. Bituminous surface of thickness 4 cm

Assume wheel load as 4085 kg and tyre pressure as 7 kg/cm$^2$.

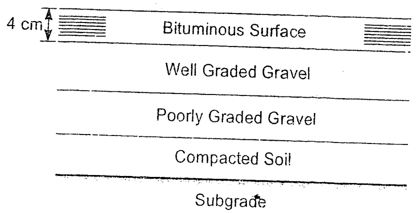
***Solution:***

$$P = 4085 \text{ kg} \quad \text{and} \quad p = 7 \text{ kg/cm}^2$$

| Load (kg) | Penetration (mm) | Standard load (kg) | CBR (%) |
|---|---|---|---|
| 60 | 2.5 | 1370 | 4.38 |
| 82 | 5.0 | 2055 | 3.99 |

CBR value choosed for the design purpose is the maximum of above two

$\therefore$ CBR = 4.38%




Now, thickness of pavement above soil subgrade

$$= \sqrt{\frac{1.75P}{CBR(\%)} - \frac{P}{p\pi}} = \sqrt{\frac{1.75 \times 4085}{4.38} - \frac{4085}{7 \times \pi}} = 38.1 \text{ cm}$$

Thickness of pavement above compacted soil $= \sqrt{\frac{1.75 \times 4085}{6} - \frac{4085}{7\pi}} = 31.7$ cm

$\therefore$ Thickness of compacted soil = 38.1 – 31.7 = 6.4 cm.

Thickness of pavement above poorly graded soil $= \sqrt{\frac{1.75 \times 4085}{12} - \frac{4085}{7\pi}} = 20.24$ cm

$\therefore$ Thickness of poorly graded gravel = 31.7 – 20.24 = 11.46 cm

Thickness of well graded gravel = 38.1 – 11.46 – 6.4 – 4 = 16.24 cm

### 6.4.3 Modified CBR Method

IRC-37 has revised the guidelines for design of flexible pavement based on the concept of cumulative standard axle rather than total number of all commercial vehicle as done earlier. In case of roads with design traffic more than 1500 vehicles per day, design traffic is defined in terms of cumulative standard axle loads of 8170 kg carried during the design life of roads.

Number of cumulative standard axle ($N_s$) are computed with the help of expression given below:

$$N_s = \frac{365\left[\left(1+\frac{r}{100}\right)^n - 1\right] \times A \times D \times F}{\left(\frac{r}{100}\right)}$$

Where,
$A$ = Number of commercial vehicle per day when pavement construction is completed.
$r$ = Rate of growth of traffic (generally taken as 7.5%)
$n$ = Design life of pavement (10 – 20 years)
$F$ = Vehicle Damage Factor
$D$ = Lane Distribution Factor
$N_s$ = Number of cumulative standard axle

$$A = P\left(1+\frac{r}{100}\right)^x$$

$P$ = Number of vehicles per day at last count
$x$ = Number of years between last count and completion of pavement construction

**Vehicle Damage Factor**

It is defined as a equivalent number of standard axles per commercial vehicle. The vehicle damage factor is used to convert the number of commercial vehicles of different axle loads and axle configuration to the number of standard axle load repetitions.

The vehicle damage factor for any axle load is given as:

(*i*) Single axle load, $VDF = \left(\frac{\text{Axle load in kg}}{8200}\right)^4$

(*ii*) Tendem axle load, $VDF = \left(\frac{\text{Axle load in kg}}{14500}\right)^4$

When the information regarding the axle load is missing, then the following value of vehicle damage factor is used given in **Table 6.2** depending upon the topography and initial traffic volume

**Table-6.2 :** IRC recommended values of VDF

| Initial traffic volume in terms of number of commercial vehicle per day | Terrain | |
|---|---|---|
| | Rolling plain | Hilly |
| 0 – 150 | 1.5 | 0.5 |
| 150 – 1500 | 3.5 | 1.5 |
| > 1500 | 4.5 | 2.5 |

**NOTE:** In a two way carriageway, if Vehicle Damage Factor in one direction is higher, then the traffic in direction of higher Vehicle Damage Factor is considered.

**Example-6.5** A two lane single carriageway road is at present carrying a traffic of 1500 commercial vehicle per day. It is to be strengthened for the growing traffic needs. The vehicle damage factor has been found to be 3.0. The rate of growth of traffic is 10% per annum. The period of construction is 10 years. The pavement is to be designed for 15 years after completion. Calculate the cumulative standard axles to be used in design.

***Solution:***

Present traffic = 1500 cvpd

Traffic after completion of construction = $1500(1+0.1)^{10} = 3891$ cvpd

Number of commercial vehicles per day in design land = 0.5 × 3891 = 1946 cvpd

$$\text{Cumulative standard axles} = \frac{365\left[(1+0.1)^{15}-1\right]\times 3\times 1946}{0.1} = 67.7 \text{ msa}$$

**Lane Distribution Factor**

Distribution of commercial traffic in each direction is required for determining the total equivalent standard axle load. If no data is given then lane distribution value will be taken as for

(i) **Single-lane road:** Traffic tends to be more channelised on single lane roads then 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. Hence lane distribution factor is 1.

(ii) **Two-lane single carriageway:** The design should be based on 50% of the total number of commercial vehicle in both direction. Hence, lane Distribution factor is 0.5

(iii) **Four-lane single carriageway:** Design should be based on 40% of the total number of commercial vehicle. Hence, lane distribution factor is taken as 0.40.

(iv) **Dual carriageway roads:** Design of dual two way carriage way roads should be based on 75% for the commercial vehicle in each direction. Hence, lane distribution factor will be equal to 0.75.

**Example-6.6** Initial traffic = 1213 commercial vehicle per day, traffic growth rate ($r$) = 8% per annum, Design life ($n$) = 12 years, $VDF$ = 2.5, $LDF$ = 1.0, find out cumulative number of standard axle in msa.

(a) 13.0
(b) 17.0
(c) 21.0
(d) 35.0

***Ans. (c)***

$$N_s = 365\left[\left(1+\frac{r}{100}\right)^n - 1\right] A\times D\times F$$

$$N_s = \frac{365\left[(1+0.08)^{12}-1\right]\times 1213\times 2.5\times 1}{0.08} = 21.0 \text{ msa}$$

**Example-6.7** Find the vehicle damage factor for a pavement having design traffic of 100 msa for a newly developing National Highway as per IRC-37.

Informations regarding the highway design:

1. Design life = 20 years
2. Commercial vehicle count before pavement construction = 4500 vehicles per day
3. Annual traffic growth rate = 10%

***Solution:***

$A$ = 4500 cvpd, $r$ = 10%, $N_s$ = 100 msa, $n$ = 20 years

Cumulative number of standard axle,

$$N_s = \frac{365\left[\left(1+\frac{r}{100}\right)^n - 1\right]\times A\times D\times F}{\frac{r}{100}}$$

$$100\times 10^6 = \frac{365\left[(1+0.1)^{20}-1\right]\times 4500\times F}{0.1}$$

∴ $F = 1.0629$

Hence, Vehicle Damage Factor is 1.0629.

### 6.4.4 California Resistance Value Method

In 1948 Hveem and Carmany gave design method based on stabilometer $R$-value and cohesiometer $C$-value. The expression for pavement thickness is given as

$$T = \frac{k(\text{T.I.})(90-R)}{C^{1/5}}$$

Where,
$T$ = Total thickness of pavement in cm
$k$ = Numerical constant = 0.166
T.I. = Traffic Index = $1.35\,(EWL_{avg})^{0.11}$
$R$ = Stabilometer Resistance Value
$C$ = Cohesiometer Value

Here, EWL (Equivalent Wheel Load) is the accumulated sum of the products of the constants and number of axle loads. The yearly EWL is obtained by using the data of annual average daily traffic volumes (AADT). Various constants for the different number of axles in a groups are given in **Table 6.3**.

**Table-6.3 :** Equivalent wheel load constant

| Number of axles | EWL constants |
|---|---|
| 2 | 330 |
| 3 | 1070 |
| 4 | 2460 |
| 5 | 4620 |
| 6 | 3040 |

## Equivalent C-Value

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

$$\frac{T_1}{T_2} = \left(\frac{C_2}{C_1}\right)^{1/5}$$

**Example-6.8** Calculate 10 years EWL and traffic index value using following data.

| No. of Axle | AADT |
|---|---|
| 2 | 3750 |
| 3 | 470 |
| 4 | 320 |
| 5 | 120 |

Assume 60% increase in traffic in next 10 years. Calculate thickness of pavement required, if $R = 48$ and $C = 16$.

***Solution:***

| No. of Axle | EWL Constant | AADT | Total EWL Value |
|---|---|---|---|
| 2 | 330 | 3750 | 1237500 |
| 3 | 1070 | 470 | 502900 |
| 4 | 2460 | 320 | 787200 |
| 5 | 4620 | 120 | 554400 |
| | | | $\Sigma = 3082000$ |

EWL after 60 years$=1.6 \times 3082000 = 4931200$

$$\text{Traffic Index, (T.I.)} = 1.35\,(\text{EWL})^{0.11} = 1.35\left(4931200 + \frac{308200}{2}\right)^{0.11} = 7.188$$

$$\text{Now, Thickness of pavement, } T = \frac{k(\text{T.I.})\,(90-R)}{(C)^{1/5}} = \frac{0.166 \times 7.188 \times (90-48)}{(16)^{1/5}} = 28.785 \text{ cm}$$

**Example-6.9** Calculate equivalent $C$-value of a 3 layered pavement section having individual $C$-values as follows:

| Material | Thickness | C-Value |
|---|---|---|
| Bituminous pavement | 12.5 cm | 62 |
| Cement treated base | 25 cm | 180 |
| Well graded gravel | 20 cm | 25 |

***Solution:***

Total thickness of pavement = 12.5 + 25 + 20 = 57.5 cm

As we know that, $\dfrac{T_1}{T_2} = \left(\dfrac{C_2}{C_1}\right)^{1/5}$

Now, calculated the thickness of pavement if only well graded gravels are used in the construction.

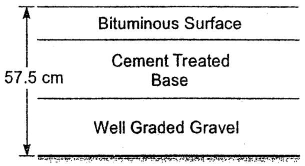
$$T_G = T_{CTB}\left(\frac{C_{CTB}}{C_G}\right)^{1/5} + T_{BP}\left(\frac{C_{BP}}{C_G}\right)^{1/5} + 20$$

$$T_G = 25\left(\frac{180}{25}\right)^{1/5} + 12.5\left(\frac{62}{25}\right)^{1/5} + 20 = 37.10 + 14.9 + 20 = 72.1 \text{ cm}$$

Now, $\dfrac{T_{pavement}}{T_G} = \left(\dfrac{C_G}{C_{pavement}}\right)^{1/5}$

$\Rightarrow \dfrac{57.5}{72.1} = \left(\dfrac{25}{C_{pavement}}\right)^{1/5}$

$\therefore C_{pavement} = 77.5$




### 6.4.5 Triaxial Test Method

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

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

Where,

$T$ = Pavement thickness in cm
$P$ = Wheel load in kg
$E_s$ = Modulus of elasticity of subgrade from triaxial test results in kg/cm$^2$
$a$ = Radius of contact area in cm
$\Delta$ = Design deflection (taken equal to 0.25 cm)
$X$ = Traffic coefficient
$Y$ = Saturation coefficient

The recommended values of coefficients $X$ and $Y$ based on ADT of design traffic and rainfall are given in Table 6.4.

**Table-6.4 :** IRC recommended values of coefficients $X$ and $Y$

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

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

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

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

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

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

**Example-6.10** Design the pavement section by triaxial test method using the following data:

1. Wheel load = 4100 kg
2. Radius of contact area = 15 cm
3. Traffic coefficient, $X = 1.5$
4. Rainfall coefficient, $Y = 0.9$
5. Design deflection, $\Delta = 0.25$ cm
6. E-value of subgrade soil, $E_s = 100$ kg/cm²
7. E-value of base course material, $E_b = 400$ kg/cm²
8. E-value of 7.5 cm thick bituminous concrete surface course = 1000 kg/cm²

***Solution:***

Assuming the pavement to consist of single layer of base course material only, the pavement thickness is given by

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

$$= \left\{\sqrt{\left(\frac{3\times 4100\times 1.5\times 0.9}{2\pi\times 100\times 0.25}\right)^2 - 15^2}\right\}\left(\frac{100}{400}\right)^{1/3} = 65.9 \text{ cm}$$

Let, 7.5 cm bituminous concrete surface with $E_c = 1000$ kg/cm² be equivalent to the thickness $t_b$ of base course. The equivalent replacement $t_b$ is obtained from the relation:

$$\frac{t_b}{t_c} = \left(\frac{E_c}{E_b}\right)^{1/3}$$

$$t_b = 7.5\times\left(\frac{1000}{400}\right)^{1/3} = 10.2 \text{ cm}$$

∴The required base course thickness = 65.9 − 10.2 = 55.7 cm

The pavement section consists of 55.7 cm thick WBM base course and 7.5 cm thick bituminous concrete surface course.

### 6.4.6 Mcleod Method

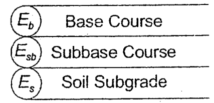
This method was developed by Norman W. Mcleod. He performed repetitive plate bearing test on various sizes of plates and gave an empirical design equation. The expression for pavement thickness is given as

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

Where,
- $T$ = Required thickness of gravel base in cm
- $P$ = Gross wheel load in kg
- $K$ = Base course constant
- $S$ = Total subgrade support in kg

**NOTE:** The subgraded support 'S' for the design of highway pavement is calculated from the support measured or calculated for 30 cm diameter plate at 0.5 cm deflection and 10 repetitions.

### 6.4.7 Burmister Method




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

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

$$E_b > E_{sb} > E_s$$

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

$$E_b = E_{sb} = E_s$$

**Assumptions involved in Burmister's analysis:**

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

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

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

(*iv*) Underlying layer is infinite in both the directions.

(*v*) The layers are in continuous contact.

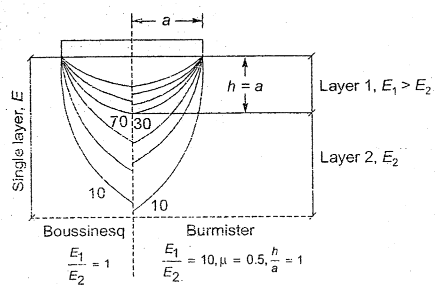



***Figure-6.11 :** Comparison of vertical stress Distribution*

Displacement equations given by Burmister are given below.

(*i*) **For Flexible Plate**

$$\Delta = 1.5\frac{pa}{E_s}\times F_2$$

Where,
- $\Delta$ = Design deflection
- $p$ = Contact pressure at road surface due to wheel load
- $a$ = Radius of contact area
- $E_s$ = Modulus of elasticity of soil subgrade
- $h$ = Thickness of reinforcing layer
- $F_2$ = Deflection factor based on $\frac{E_s}{E_p}$ and $\frac{h}{a}$

(*ii*) **For Rigid Plate**

$$\Delta = 1.18\frac{pa}{E_s}\times F_2$$

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

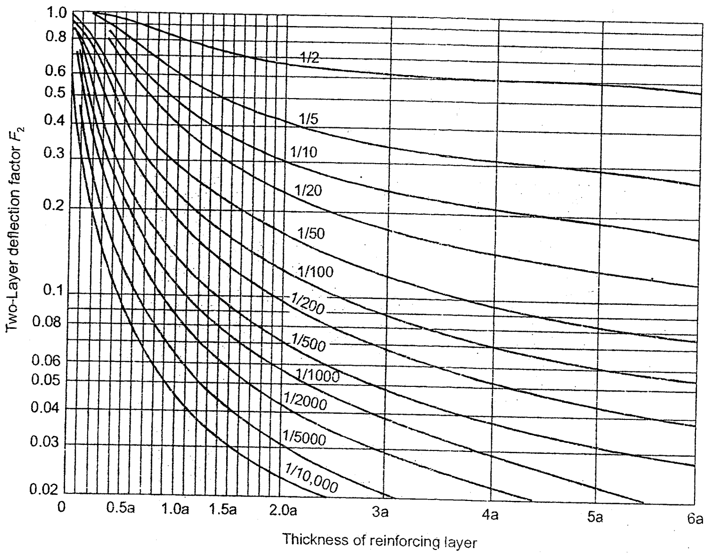



***Figure-6.12 :** Relationship of $F_2$ and h in a two-layer system*

**NOTE**

- When Wheel load test is conducted over surface then flexible plate case is considered.

$$\Delta = 1.5\frac{pa}{E_s}\times F_2$$

- When plate load test is conducted over soil subgrade or any flexible pavement material then rigid plate case is considered.

$$\Delta = 1.18\frac{pa}{E_s}\times F_2$$

**Example-6.11** Plate Bearing Test is conducted with 30 cm diameter plate on a soil subgrade yielded a pressure of 1 kg/cm² at 5 mm deflection. A test is carried out over 15 cm base course yielded a pressure of 6 kg/cm² at 5 mm deflection. Design the pavement section for the wheel load of 4200 kg with a tyre pressure of 6 kg/cm² and allowable deflection of 5 mm. Use Burmister method.

***Solution:***

**Step-1:** Plate load test conducted over soil subgrade

Diameter = 30

Radius of contact area, $a = 15$ cm

Pressure, $p = 1$ kg/cm²

Deflection, $\Delta = 5$ mm

As it is a single layered system,

$$F_2 = 1$$

Now, using rigid plate formula

$$\Delta = 1.18\frac{pa}{E_s}\times F_2$$

$$0.5 = \frac{1.18\times1\times15}{E_s}\times1$$

$$E_s = 35.4 \text{ kg/cm}^2$$

**Step-2:** Plate load test over base course

Base course thickness = 15 cm

$E_s = 35.4$ kg/cm²

$p = 6$ kg/cm²

$\Delta = 5$ mm

Now, again using rigid plate formula

$$\Delta = 1.18\frac{pa}{E_s}\times F_2$$

$$0.5 = \frac{1.18\times6\times15}{35.4}\times F_2$$

$$F_2 = 0.17$$

$$\frac{h}{a} = \frac{15}{15} = 1.0$$

Now, from **Figure 6.12** by using $F_2$ and $h/a$ value, find the value of $E_s/E_p$

$$\therefore \quad \frac{E_s}{E_p} = \frac{1}{100}$$

$$\Rightarrow \quad E_{\text{Base Course}} = E_P = 100\times E_s = 3540 \text{ kg/cm}^2$$

**Step-3:** Wheel load test over base course

$P = 4200$ kg

Tyre pressure = 6 kg/cm²

Allowable deflection, $\Delta = 5$ mm

Now, using flexible plate formula

$$p = \frac{P}{A} \quad \text{or} \quad A = \frac{P}{p}$$

$$\Rightarrow \quad \pi a^2 = \frac{4200}{6} = 700 \Rightarrow a = 15 \text{ cm}$$

$$\therefore \quad \Delta = 1.5\frac{pa}{E_s}F_2 \Rightarrow 0.5 = \frac{1.5\times6\times15}{35.4}\times F_2$$

∴ $F_2 = 0.13$

From Figure 6.12 we find, $\frac{h}{a} = 1.9$

$h = 1.9 \times 15 = 28.5$ cm

Hence, the thickness of pavement section for elastic modulus 3540 kg/cm² is 28.5 cm.

## 6.5 Design of Rigid Pavement

As the name implies, rigid pavements are rigid i.e. they do not bend much under loading like flexible pavement. Cement concrete pavements represent the group of rigid pavements. In this case, the load carrying capacity is mainly due to the rigidity and high modulus of elasticity of the slab. H.M. Westergaard is considered the pioneer in providing the rational treatment of the rigid pavement analysis.

### 6.5.1 Factors Affecting Design

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

**(i) Loading:**
- (a) Wheel load and its repetition
- (b) Area of contact of wheel
- (c) Location of load with respect to slab

**(ii) Properties of subgrade:**
- (a) Subgrade strength and properties
- (b) Sub-base provision

**(iii) Properties of concrete:**
- (a) Strength
- (b) Modulus of elasticity
- (c) Poisson's ratio
- (d) Shrinkage properties
- (e) Fatigue

**(iv) External conditions:**
- (a) Temperature changes
- (b) Friction between slab and subgrade

**(v) Joints:**
- (a) Arrangements of joints
- (b) Spacing of joints

**(vi) Reinforcement:**
- (a) Quantity of reinforcement
- (b) Continuous reinforcement

### 6.5.2 Modulus of Subgrade Reaction

Westergaard considered the rigid pavement slab as a thin elastic plate resting on soil subgrade which is assumed as a dense liquid. Modulus of subgrade reaction is found out by using the plate load test or plate bearing test.

Westergaard defined a modulus of subgrade reaction ($k$) in kg/cm³ given as:

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

Where, $\Delta$ = Deflection (taken equal to 0.125 cm)

$p$ = Pressure sustained by the rigid plate of 75 cm diameter at a deflection of 0.125 cm

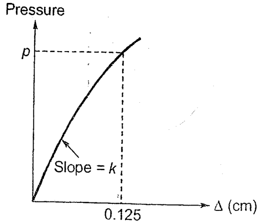



*Figure-6.13 : Plate bearing test graph*

Assumptions involved in the analysis of westergaard

(i) The concrete slab is homogenous, isotropic and has uniform elastic properties.

(ii) The upward reaction is proportional to the deflection.

(iii) Slab is uniform in thickness.

(iv) The load in the interior and the corner is circular in shape while the edge loading is semicircular.

**Example-6.12** A plate bearing test was carried out on a subgrade using a 76 cm diameter rigid plate. A deflection of 1.25 mm was caused by a pressure of 0.84 kg/cm². The modulus of subgrade reaction in kg/cm³ is _____.

***Solution:***

The modulus of subgrade reaction for 76 cm diameter rigid plate

$$k_1 = \frac{P}{\Delta} = \frac{0.84}{0.125} = 6.72 \text{ kg/cm}^3$$

∴ Modulus of sub-grade reaction for standard plate of radius 75 cm

$$k = \frac{k_1 a_1}{a} = \frac{6.72 \times 76}{75} = 6.81 \text{ kg/cm}^3$$

### 6.5.3 Relative Stiffness of slab to subgrade

A certain degree of resistance to slab deflection is offered by the sub-grade and the subgrade deformation is same as the slab deflection. Slab deflection is direct measurement of the magnitude of the subgrade pressure. Relative stiffness of slab with respect to subgrade is represented by radius of relative stiffness ($l$) in cm is given as

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

Where, $E$ = Modulus of elasticity of cement concrete in kg/cm² ($3.0 \times 10^5$)

$h$ = Slab thickness in cm

$\mu$ = Poisson's ratio of concrete (0.15)

$k$ = Modulus of subgrade reaction in kg/cm³

**Example-6.13** Compute the radius of relative stiffness of 20 cm thick cement concrete slab from the following data:

1. Modulus of elasticity of cement concrete = $2.1 \times 10^5$ kg/cm²
2. Poisson's ratio for concrete = 0.15
3. Load sustained by rigid plate = 2000 kg

***Solution:***

Let, Diameter of plate used = 75 cm

$$\text{Contact area of rigid plate} = \frac{\pi}{4}(75)^2 = 4417.86 \text{ cm}^2$$

$$\text{Pressure sustained by 75 cm} = \frac{\text{Load}}{\text{Contact Area}} = \frac{2000}{4417.86} = 0.453 \text{ kg/cm}^2$$

Now, the modulus of subgrade reaction,

$$k = \frac{p}{\Delta} = \frac{0.453}{0.125} = 3.62 \text{ kg/cm}^3$$

Therefore, relative stiffness of slab to subgrade,

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = \left[\frac{2.1\times10^5\times(20)^3}{12\times3.62\times(1-0.15^2)}\right]^{1/4}$$

$$= 79.31 \text{ cm}$$

Hence, relative stiffness of slab to subgrade is 79.31 cm.

### 6.5.4 Critical Load Positions

Since the pavement slab has finite dimension therefore the intensity of maximum stress induced due to application of traffic load is dependent on the location of the load on the pavement surface. There are mainly three critical load locations:

(*i*) Interior
(*ii*) Edge
(*iii*) Corner

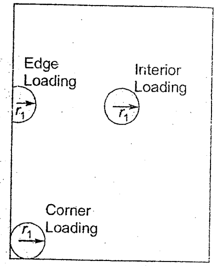



***Figure-6.14 :** Loading positions for rigid pavement design*

### 6.5.5 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 ($b$) in cm

$$b = \begin{cases}\sqrt{1.6a^2 + h^2} - 0.675h & \text{if } a < 1.72\,h \\ a & \text{if } a \geq 1.72\,h\end{cases}$$

Where, $a$ = Radius of the wheel load distribution in cm
$h$ = Slab thickness in cm

**Example-6.14** Find the equivalent radius of resisting section of 20 cm slab, if the contact area is 707 cm².

***Solution:***

$h = 20$ cm and $A = 707$ cm²

As, $A = \pi a^2$

$$707 = \pi a^2 \Rightarrow a = \sqrt{\frac{707}{\pi}} = 15 \text{ cm}$$

$$\frac{a}{h} = \frac{15}{20} = 0.75 < 1.724$$

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

$$= \sqrt{1.6\times15^2 + 20^2} - 0.675\times20 = 14.07 \text{ cm}$$

Hence, equivalent radius of resisting section is 14.07 cm.

**NOTE:** Maximum stress produced by a wheel load at corner does not exist around the load, but it occurs at a distance $X$ from apex of slab corner to section of maximum stress along the corner bisector in cm i.e. $X = 2.58\sqrt{al}$

### 6.5.6 Wheel Load Stresses - Westergaard's Stress Equations

Westergaard developed relationships for the stress at interior, edge and corner regions denoted as $S_i$, $S_e$ and $S_c$ in kg/cm² respectively and given by the equation.

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

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

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

Where, $h$ = Slab thickness in cm
$P$ = Wheel load in kg
$a$ = Radius of wheel load distribution in cm
$l$ = Radius of the relative stiffness in cm
$b$ = Radius of the resisting section in cm

The above formulae were modified subsequently by Westergaard and by Teller and Sutherland, which are given below:

$$S_i = 0.275(1+\mu)\frac{P}{h^2}\left[\log_{10}\left(\frac{Eh^3}{kb^4}\right) - 54.54\left(\frac{l}{C_1}\right)C_2\right]$$

$$S_e = 0.529(1+0.54\mu)\frac{P}{h^2}\left[\log_{10}\left(\frac{Eh^3}{kb^4}\right) - \log_{10}\left(\frac{b}{1-\mu^2}\right) - 1.0792\right]$$

$$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{12(1-\mu)^2 k}{Eh^3}\right)^{0.3}(a\sqrt{2})^{1.2}\right]$$

Where, $C_1$ and $C_2$ are correction factors to allow for a redistribution of subgrade reactions.

Gerald Pickett presented two formulae, one for protected corner and the other for unprotected corner. A protected corner is one in which provision has been made to transfer atleast 20% of the load from one slab corner to the other by some mechanical device or aggregate interlocking. While an unprotected corner is one which does not fulfill the above criteria, and the formulae are given below.

For protected corners:

$$S_c = \frac{3.36P}{h^2}\left[1 - \frac{\sqrt{a/l}}{0.925 + 0.22\,a/l}\right]$$

For unprotected corners:

$$S_c = \frac{4.2P}{h^2}\left[1 - \frac{\sqrt{a/l}}{0.925 + 0.22\,a/l}\right]$$

IRC also recommends the formulae for wheel load stresses at interior, edge and corner.

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

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

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

### 6.5.7 Temperature Stresses

Temperature stresses are developed in cement concrete pavement when they curl upward or downward due to variation in slab temperature. These stresses are caused due to

(*i*) daily variation resulting in a temperature gradient across the thickness of the slab.

(*ii*) seasonal variation resulting in overall change in the slab temperature.

Daily variation will lead to development of warping stress and seasonal variations results in frictional stress.

**Warping Stress**

The warping stress expressions developed by Bradbury at the interior, edge and corner regions, denoted as $S_{t_i}, S_{t_e}, S_{t_c}$ in kg/cm² respectively are given below.

$$S_{t_i} = \frac{E\alpha t}{2}\left[\frac{C_x+\mu C_y}{1-\mu^2}\right]$$

$$S_{t_e} = \text{Maximum}\left(\frac{C_x E\alpha t}{2}, \frac{C_y E\alpha t}{2}\right)$$

$$S_{t_c} = \frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{l}}$$

Where, $E$ = Modulus of elasticity of concrete in kg/cm² (3 × 10⁵)

$\alpha$ = Thermal coefficient of concrete per °C (1 × 10⁻⁷)

$t$ = Temperature difference between the top and bottom of the slab

$C_x$ and $C_y$ = Coefficient based on the $\frac{L_x}{l}$ and $\frac{L_y}{l}$

$\mu$ = Poisson's ratio of concrete (0.15)

$a$ = Radius of contact area

$l$ = Radius of relative stiffness

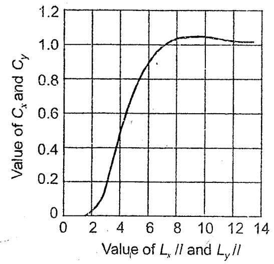



***Figure-6.15 :** Warping stress coefficient*

**Frictional Stress**

If the slab tries to expand due to temperature rise in summer then the slab tries to move outward and the frictional stress is developed as shown in Figure 6.16. The frictional stress $S_f$ in kg/cm² is given by the equation

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

Where,

$W$ = Unit Weight of concrete in kg/cm³ (about 2400 kg/m³)

$f$ = Coefficient of subgrade restraint (Maximum value is about 1.5)

$L$ = Length of the slab in metres

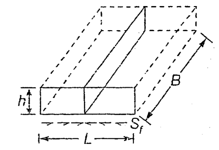
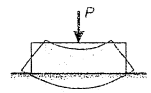



***Figure-6.16 :** Frictional Stress*

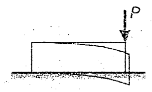
### 6.5.8 Nature of Stresses

**(i) Wheel load stress**

(a) At interior and edge
Top surface = Compression
Bottom surface = Tension

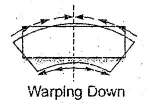



(b) At corner
Top surface = Tension
Bottom surface = Compression

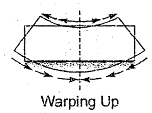



**(ii) Warping stress**

(a) During Day Time
Top surface = Compression
Bottom surface = Tension

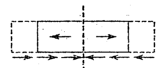



(b) During Night Time
Top surface = Tension
Bottom surface = Compression




**(iii) Frictional Stress**

(a) During Summer
Top and bottom surface = Compression



(b) During Winter
Top and bottom surface = Tension

**NOTE:** Generally frictional stresses are assumed to be constant along length, but in reality it is zero at ends and maximum at centre of slab.

### 6.5.9 Combination of stresses

There is no frictional stress at the corner region. Out of various wheel stresses

(*i*) Corner stress is maximum as there is discontinuity in both direction.

(*ii*) Interior stress is minimum.

(*iii*) Edge stress is in intermediate range.

Temperature stress is critical at the edge and interior and it is minimum at corner. At the corner, resistance due to weight is minimum, hence warping stress is minimum. In combination of wheel load and temperature, edge region is most critical, hence designing is done using edge region stress and however checking is done for corner region.

**Table-6.5 :** Nature of Stress at different locations

| Location | Portion | Load Stress | Warping Stress | | Frictional Stress | |
|---|---|---|---|---|---|---|
| | | | Day | Night | Summer | Winter |
| Interior | Top<br>Bottom | C<br>T | C<br>T | T<br>C | C<br>C | T<br>T |
| Edge | Top<br>Bottom | C<br>T | C<br>T | T<br>C | C<br>C | T<br>T |
| Corner | Top<br>Bottom | T<br>C | C<br>T | T<br>C | C (= 0)<br>C (= 0) | T (= 0)<br>T (= 0) |

### 6.5.10 Critical Cases of Stress Combination

In combination of wheel load and temperature, edge region is most critical, hence designing is done using edge region stress and however checking is done for corner region.

(*i*) Summer, mid-day: The critical stress for edge region is given by

$$S_{\text{critical}} = S_e + S_{t_e} - S_f$$

(*ii*) Winter, mid day: The critical combination of stress for the edge region is given by

$$S_{\text{critical}} = S_e + S_{t_e} + S_f$$

(*iii*) Mid-nights: The critical combination of stress for the corner region is given by

$$S_{\text{critical}} = S_c + S_{t_c}$$

Worst combination of stresses on the basis of location:

(*i*) At interior: During Day time + Winter Season + At Bottom

(*ii*) At edge: During Day time + Winter Season + At Bottom

(*iii*) At corner: During Night time + Winter Season + At Top

## 6.6 Design of Joint

Concrete pavements are subjected to volumetric changes produced by temperature variations, shrinkage during setting and changes in moisture content. If a long slab is built, it is bound to crack at close intervals because of the factors given above. These joints will then ensure that the stresses developed due to expansion, contraction and warping of the slab are within reasonable limits. The longer the length between joints, the greater is the warping stress and greater is the need for reinforcing steel.

### 6.6.1 Requirements of Joint

Following are the various objectives of joints:

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

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

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

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

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

### 6.6.2 Types of Joints

Various types of the joints provided in the cement concrete pavement are:

(*i*) Transverse Joint

(a) Expansion Joint

(b) Contraction Joint

(c) Construction Joint

(d) Warping Joint

(*ii*) Longitudinal Joint

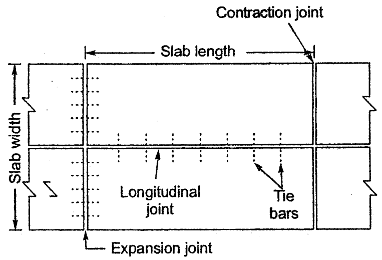



***Figure-6.17 :** Locations of joint*

**Expansion Joint**

The purpose of the expansion joint is to allow the expansion of the pavement due to rise in temperature with respect to construction temperature.

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

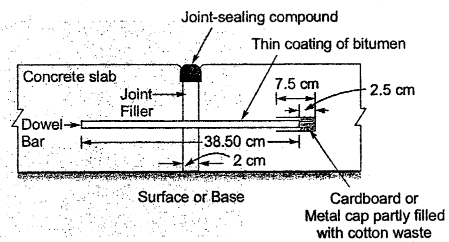



***Figure-6.18 :** Expansion joint*

The design consideration of expansion joints are:

(*i*) Provided along longitudinal direction.

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

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

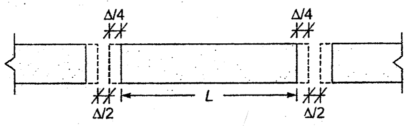



***Figure-6.19 :** Spacing of expansion Joint*

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

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

$L$ = Length of the slab or spacing between transverse joint

$\alpha$ = Thermal coefficient of concrete per °C

$t$ = Temperature difference in °C

Features of a suitable design for an expansion joint are:

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

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

(*iii*) A joint sealing arrangement.

(*iv*) A dowel bar for load transfer.

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

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

**Example-6.15** The width of expansion joint gap is 2.5 cm. In a cement concrete pavement. If the lagging temperature is 10°C and maximum slab temperature in summer is 54°C, calculate the spacing between expansion joints. Assume coefficient of thermal expansion of concrete as $10 \times 10^{-6}$/°C.

***Solution:***

Data given, $T_1 = 10\,°C$; $T_2 = 54\,°C$

The joint filler may be assumed to be compressed upto 50% of its thickness

$$\therefore \quad \delta' = \frac{\delta}{2} = \left(\frac{2.5}{2}\right) = 1.25 \text{ cm}$$

$$\delta' = L_e \alpha (T_2 - T_1) \Rightarrow 1.25 \times 10^{-2} = L_e \times 10 \times 10^{-6} (54 - 10)$$

$$\therefore \quad L_e = \frac{1.25 \times 10^{-2}}{(10 \times 10^{-6} \times 44)} = 28.409 \text{ m}$$

**Contraction Joint**

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

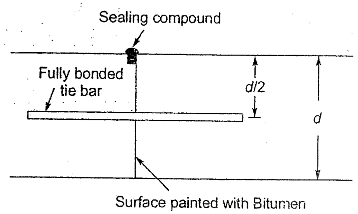


***Figure-6.20 :** Contraction joint*

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

(*i*) The movement is restricted by the subgrade friction

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

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

where, $S_f$ = Tensile strength developed in concrete and is taken as 0.8 kg/cm²

$W$ = Unit weight of the concrete which can be taken as 2400 kg/cm³

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

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

Frictional Force = Force in Bar

$$f \times \left(\frac{L}{2} \times B \times h \times W\right) = A_{st}\,\sigma_{st}$$

$$L = \frac{2A_{st}\sigma_{st}}{fWBh}$$

where, $\sigma_{st}$ = Allowable tensile stress in steel

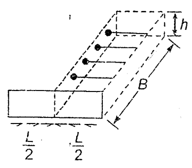


***Figure-6.21 :** Bars in contraction joint*

**Example-6.16** Determine the spacing between contraction joints for 3.5 m slab width having thickness of 20 cm and $f = 1.5$. For the following two cases

(*i*) For plain cement concrete, allowable $S_c = 0.8$ kg/cm²

(*ii*) For reinforced cement concrete with 1.0 cm diameter bars at 0.30 m spacing

***Solution:***

(*i*) We know that,

$$\left(b \times \left(\frac{L_c}{2}\right) \times \frac{h}{100} \times \gamma\right) \times f = S_c \times b \times h \times 100$$

$$\therefore \quad L_c = \left(\frac{2S_c \times 10^4}{\gamma \times f}\right) = \frac{2 \times 0.8 \times 10^4}{(2400 \times 1.5)} = 4.44 \text{ m}$$

(*ii*) Total cross sectional area of steel,

$$A_{st} = \left(\frac{3.5}{0.3}\right) \times \frac{\pi}{4} \times (1)^2 = 9.16 \text{ cm}^2$$

Spacing between contraction joints,

$$L_c = \frac{200 \times A_{st} \times \sigma_{st}}{fbh\gamma} = \frac{200 \times 1200 \times 9.16}{1.5 \times 3.5 \times 20 \times 2400} = 8.72 \text{ m}$$

**Longitudinal Joint**

Longitudinal joints are provided along the length of pavement. They are provided if pavement width is more than 4.5 m. It reduces the warping stress and uneven settlement of subgrade. Tie bars are generally provided across longitudinal joints to transfer the load.

### 6.6.3 Tie Bar

Tie bars are used across the longitudinal joint of cement concrete pavement. These bars are not designed to act as load transfer devices. Thus tie bars are designed to withstand tensile stresses. The maximum tensile force in tie bars being equal to the force required to overcome frictional force between the bottom of the adjoining pavement slab and the soil subgrade. Their length is smaller than the dowel bars and placed at large intervals

**Design of Tie Bar**

**(i) Diameter and Spacing:** The diameter and spacing is first found out by equating the total sub-grade friction to the total tensile stress for a unit length. Hence, the area of steel per one metre in cm² is given by:

$$A_{st} \times \sigma_{st} = fW \times B \times 1 \times h$$

$$A_{st}\,(\text{per m length}) = \frac{fWBh}{\sigma_{st}}$$

where, $B$ = Width of pavement panel in m

$h$ = Depth of pavement in cm

$W$ = Unit weight of concrete

$\sigma_{st}$ = Allowable working tensile stress in steel (assume 1750 kg/cm²)

**NOTE:** (a) Diameter of dowel bar should not exceed 20 mm.

(b) Spacing of tie bars should not be more than 75 mm.

**(ii) Length of tie bar:** The length of the tie bar ($L_t$) is twice the length needed to develop bond stress equal to the working tensile stress and is given by:

$$L_t = 2\,L_d = 2 \times \frac{\phi \sigma_{st}}{4\tau_{bd}}$$

$$\therefore \quad L_t = \frac{\phi \sigma_{st}}{2\tau_{bd}}$$

where, $\phi$ = Diameter of the bar

$\sigma_{st}$ = Allowable tensile stress in kg/cm²

$\tau_{bd}$ = Allowable bond stress (=17.5 kg/cm² for plain bar and 24.6 kg/cm² for deformed bar)

**Example-6.17** Design the tie bars for a cement concrete pavement of thickness 18 cm, has two lanes of 7.2 m with a joint. (Take allowable tensile stress in steel = 1750 kg/cm²)

***Solution:***

Given, $h$ = 18 cm, $B = \frac{7.2}{2}$ = 3.6 m, $\sigma_{st}$ = 1750 kg/cm², $W$ = 2400 kg/cm², $f$ = 1.5, $\tau_{bd}$ = 24.6 kg/cm²

Step-1: Diameter and spacing

$$A_{st} = \frac{fWBh}{\sigma_{st}} = \frac{1.5 \times 2400 \times 3.6 \times 18}{1750 \times 100} = 1.33 \text{ cm}^2/\text{m}$$

Assume, $\phi$ = 1 cm $\Rightarrow$ A = 0.785 cm²

$$\therefore \quad \text{Spacing} = \frac{100 \times 0.785}{1.33} = 59 \text{ cm say } 55 \text{ cm}$$

Step-2:

Length of the bar, $$L_t = \frac{\phi\,\sigma_{st}}{2\tau_{bd}} = \frac{1 \times 1750}{2 \times 24.6} = 36.0 \text{ cm}$$

Hence, use 1 cm $\phi$ tie bars of length of 36 cm at 55 cm c/c.

### 6.6.4 Dowel Bar

Dowel bars are provided in the direction of the traffic (longitudinal). Half length of this bar is bonded in one cement concrete slab and the remaining portion is embedded in adjacent slab, but is kept free for the movement during expansion and contraction of the slab.

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

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

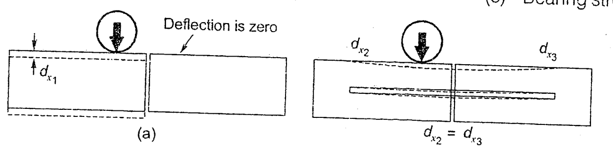



***Figure-6.22:** Functioning of Dowel Bar*

**Objective of Dowel Bar**

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

**Design Specification of Dowel Bars**

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

**Load Transfer Capacity of Dowel Bar**

(i) For shear in the bar

$$P_s = 0.785\, d^2 F_s$$

where, $P_s$ = Load transfer capacity of dowel bar in shear
$d$ = Diameter of dowel bar
$F_s$ = Permissible shearing stress in steel

(ii) For Bending in the bar

$$P_f = \frac{2d^3 F_f}{L_d + 8.8\Delta}$$

where, $P_f$ = Load transfer capacity of dowel bar in bending
$F_f$ = Permissible bending stress in steel
$L_d$ = Length of embedment of dowel bar in cm
$\Delta$ = Joint width in cm

(iii) For Bearing in the bar

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

where, $P_b$ = Load transfer capacity of dowel bar in bearing
$F_b$ = Permissible bearing stress in steel

**NOTE:** Allowable bearing stress on concrete, $F_B = (10.16 - d)\, f_{ck}/9.525$

**Design Steps Involved in the Design of Dowel Bars**

Step-1: Development length ($L_d$) of the dowel bar is decided by equating strength in bending and bearing i.e.

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

Step-2: Find the load transfer capacity of dowel bar $P_s$, $P_f$ and $P_b$.

**Step-3:** Assume load capacity of dowel bar as 40% of wheel load, find the load capacity factor '$f$' as

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

where, $P$ = Wheel load

**Step-4:** The capacity factor of a dowel bar is assumed to be 1, just below the wheel and it is assumed to be zero at a distance of 1.8 $l$ from the wheel as shown in **Figure 6.23**.

where, $l$ = Radius of relative stiffness.

Load capacity

$$= 1+\frac{(1.8l-\Delta)}{1.8l}+\frac{(1.8l-2\Delta)}{1.8l}+\left(\frac{1.8l-3\Delta}{1.8l}\right)+\ldots$$

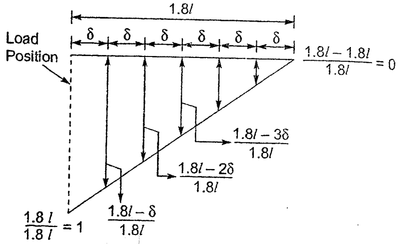



***Figure-6.23 :** Capacity factor distribution*

**Step-5:** Spacing of the dowel bars:

(*i*) Effective distance upto which effective load transfer take place is given by 1.8$l$, where '$l$' is the radius of relative stiffness.

(*ii*) Assume a linear variation of capacity factor of 1.0 under load to zero at 1.8$l$.

(*iii*) Assume a dowel spacing and find the capacity factor of the above spacing.

(*iv*) Actual capacity factor should be greater than the required capacity factor.

(*v*) If not, do one more iteration with new spacing.

**Example-6.18** **Design size and spacing of dowel bars at an expansion joint of concrete pavement of thickness 25 cm. Given the radius of relative stiffness of 80 cm. Design wheel load 5000 kg. Load capacity of the dowel system is 40% of design wheel load. Joint width is 2.0 cm and the permissible stress in shear, bending and bearing stress in dowel bars are 1000, 1400 and 100 kg/cm² respectively.**

***Solution:***

Given, $P$ = 5000 kg, $l$ = 80 cm, $h$ = 25 cm, $\Delta$ = 2 cm, $F_s$ = 1000 kg/cm², $F_f$ = 1400 kg/cm² and $F_b$ = 100 kg/cm² and assume diameter = 2.5 cm

**Step-1:** Length of dowel bar,

$$L_d = 5d\sqrt{\frac{F_f(L_d+1.5\Delta)}{F_b(L_d+8.8\Delta)}} = 5\times2.5\times\sqrt{\frac{1400}{100}\times\frac{(L_d+1.5\times2)}{(L_d+8.8\times2)}} = 12.5\times\sqrt{14\times\frac{(L_d+3)}{(L_d+17.6)}}$$

Solve for $L_d$ by trial and error:

Put, $L_d$ = 45.00 ⇒ $L_d$ = 40.95

Put, $L_d$ = 45.95 ⇒ $L_d$ = 40.50

Put, $L_d$ = 45.50 ⇒ $L_d$ = 40.50

Minimum length of the dowel bar is $L_d + \Delta$ = 40.5 + 2.0 = 42.5 cm

So, Provide 45 cm long and 2.5 cm diameter

∴ $L_d$ = 45 − 2 = 43 cm

**Step-2:** Find the load transfer capacity of single dowel bar

$$P_s = 0.785\, d^2 F_s = 0.785\times(2.5)^2\times1000 = 4906 \text{ kg}$$

$$P_f = \frac{2d^3F_f}{L_d+8.8\Delta} = \frac{2\times(2.5)^3\times1400}{43+8.8\times2\Delta} = 722 \text{ kg}$$

$$P_b = \frac{F_bL_d^2d}{12.5(L_d+1.5\Delta)} = \frac{100\times(43)^2\times2.5}{12.5(43+1.5\times2)} = 804 \text{ kg}$$

Therefore, the required load transfer capacity

$$= \max\left\{\frac{0.4\times5000}{4906}, \frac{0.4\times5000}{722}, \frac{0.4\times5000}{804}\right\}$$

$$= \max\{0.41, 2.77, 2.487\} = 2.77$$

**Step-3:** Required spacing:

Effective distance of load transfer = 1.8 × $l$ = 1.8 × 80 = 144 cm

Assuming spacing of 35 cm

$$\text{Actual capacity} = 1+\frac{144-35}{144}+\frac{144-70}{144}+\frac{144-105}{144}+\frac{144-140}{144}$$

$$= 2.57 < 2.77 \text{ (the required capacity)}$$

Therefore assume 30 cm spacing and now the actual capacity is

$$= 1+\frac{144-30}{144}+\frac{144-60}{144}+\frac{144-90}{144}+\frac{144-120}{144}$$

$$= 2.92 > 2.77 \text{ (the required capacity)}$$

∴Provide 2.5 cm diameter mild steel dowel bars of length 45 cm at the spacing of 30 cm center to center.

## Illustrative Examples

**Example-6.19** Find out the number of standard axles for a new road in plain terrain with a two-lane single carriageway; given the following data:

(*i*) Initial traffic volume in the year of completion of construction 500 vehicles per day (cvpd)

(*ii*) Traffic growth rate per annum = 7.5%

(*iii*) Design life = 12 years

***Solution:***

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

Here, $r$ = 7.5% = 0.075, $n$ = 12 years, $A$ = 500 cvpd, $D$ = 0.75, $F$ = 3.5

Substituting the values,

$$N = \frac{365[(1+0.075)^{12}-1]}{0.075}\times500\times0.75\times3.5$$

$$= \frac{365(2.382-1)}{0.075}\times500\times0.75\times3.5$$

$$= \frac{365\times1.382\times500\times0.75\times3.5}{0.075} = 8827525 = 8.83 \text{ msa}$$

**Example-6.20** Using Boussinesq's analysis, calculate the vertical stress beneath a circular tyre imprint at a depth of 37.5 cm for the following conditions:

(*i*) Gross load on tyre = 20,000 kg

(*ii*) Tyre pressure = 7 kg/cm²

Also determine the elastic deformation if the subgrade has a modulus of deformation of 56 kg/cm² and the thickness of pavement is 40 cm.

***Solution:***

Neglecting effect of side walls of tyre,

Radius of tyre imprint, $a = \sqrt{\dfrac{20{,}000}{\pi \times 7}} = 30.16$ cm

$$\sigma_z \text{ at depth of 37.5 cm} = p\left[1 - \frac{z^3}{(a^2+z^2)^{3/2}}\right] = 7\left[1 - \frac{37.5^3}{\{(30.16)^2 + (37.5)^2\}^{3/2}}\right]$$

$$= 7(1-0.473) = 3.69 \text{ kg/cm}^2$$

Further, $\Delta = \dfrac{pa}{E}F$

where, $$F = \frac{3}{2}\frac{1}{\left[1+\left(\frac{z}{a}\right)^2\right]^{1/2}} = \frac{3}{2}\frac{1}{\left[1+\left(\frac{40}{30.16}\right)^2\right]^{1/2}} = 0.90$$

∴ $$\Delta = \frac{7 \times 30.16}{56} \times 0.9 = 3.39 \text{ cm}$$

**Example-6.21**

| Penetration (mm) | 0.0 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 4.0 | 5.0 | 7.5 | 10.0 | 12.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (kg) | 0.0 | 4.0 | 14.0 | 30.0 | 41.0 | 50.0 | 58.0 | 70.0 | 77.5 | 93.2 | 102.5 | 110.8 |

The different pavement materials available near the construction site are as follows:

(*i*) Sandy soil with CBR value = 10%

(*ii*) Soil-kankar mix with CBR value = 25%

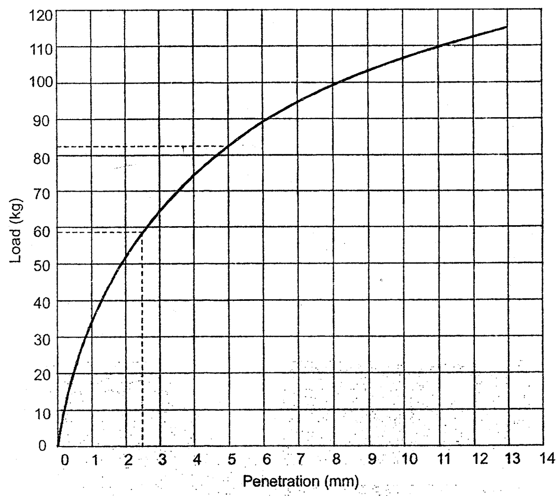
(*iii*) Broken stone and gravel with CBR value = 90%

(*iv*) Bituminous concrete for surfacing = Minimum 5 cm thick

Design the pavement structure for commercial vehicles of 2000 per day.

***Solution:***

To determine the CBR value of the subgrade soil, a graph is plotted between the load in kg and the penetration in mm. After applying corrections due to concavity, the load at 2.5 and 5.0 mm penetrations are 58 and 82 kg respectively.




∴ Bearing value at 2.5 mm penetration $= \dfrac{\text{Load}}{\text{Area of plunger}} = \dfrac{58}{19.35}$ kg/cm²

$$\text{CBR value at 2.5 mm penetration} = \frac{\text{Bearing value at 2.5 mm penetration}}{\text{Standard unit load}} \times 100$$

$$= \frac{58}{19.35} \times \frac{100}{70} = 4.21\%$$

$$\text{CBR value at 5.0 mm penetration} = \frac{82}{19.35} \times \frac{100}{105} = 4.04\%$$

Adopt CBR value of 4.21% say 4%

For 2000 commercial vehicles per day, use curve *F*

Depth of construction for CBR of 4 = 55.0 cm

Depth of construction for CBR of 10 = 32.5 cm

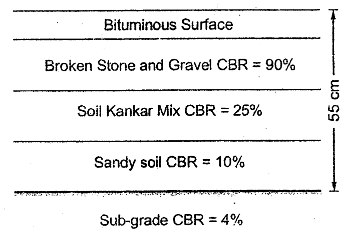
Depth of construction for CBR of 25 = 20.0 cm

Depth of construction for CBR of 90 = 7.5 cm

Depth of sandy soil = 55 − 32.5 = 22.5 cm

Depth of soil kankar mix = 32.5 − 20.0 = 12.5 cm

Depth of broken stone and gravel = 20 − 7.5 = 12.5 cm




**Example-6.22** Estimate the thickness of cement concrete pavement using Pickett's corner load stress equation (for unprotected corner) from the following data:

Modulus of elasticity of concrete = $4 \times 10^5$ kg/cm²

Modulus of rupture of concrete = 50 kg /cm²

Design factor of safety = 2
Poisson's ratio of concrete = 0.15
Modulus of sub - grade reaction = 3 kg/cm³
Wheel load = 4200 kg
Type pressure = 7 kg/cm²

***Solution:***

Modulus of rupture of concrete = 50 kg/cm²
Factor of safety = 2

$\therefore$ Allowable stress is concrete $= \frac{50}{2} = 25$ kg/cm²

Assume slab thickness = 17.5 cm

Radius of contact area, $a = \sqrt{\frac{P}{p\pi}} = \sqrt{\frac{4200}{7\pi}} = 13.82$ cm

Radius of relative stiffness, $l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}} = \sqrt[4]{\frac{3\times10^5\times17.5^3}{12(1-0.15^2)3}} = 82.22$ cm

According to Pickett, corner load stress (for unprotected corner) is given by

$$S_c = \frac{4.2P}{h^2}\left[1-\frac{\sqrt{a/l}}{0.925+0.22\frac{a}{l}}\right] = \frac{4.2\times4200}{17.5^2}\left[1-\frac{\sqrt{\frac{13.82}{82.22}}}{0.925+\frac{0.22\times13.82}{82.22}}\right]$$

$$= 57.6\left[1-\frac{0.41}{0.925+0.037}\right] = 57.6(1-0.426) = 33.05 \text{ kg/cm}^2$$

Which is unsafe, since the allowable stress is 25 kg/cm².

Try slab thickness of 20 cm, $l = \sqrt[4]{\frac{3\times10^5\times20}{12(1-0.15^2)3}} = 90.88$ cm

$$\therefore \quad S_c = \frac{4.2\times4200}{20\times20}\left[1-\frac{\sqrt{\frac{13.82}{98.88}}}{0.925+\frac{0.22\times13.82}{90.88}}\right]$$

$$= 44.1\left[1-\frac{0.39}{0.925+0.033}\right] = 44.1(1-0.41)$$

= 26.02 kg/cm², which is still unsafe

Try slab thickness of 21 cm,

$$l = \sqrt[4]{\frac{3\times10^5\times21^3}{12(1-0.15^2)3}} = 94.26 \text{ cm}$$

$$\therefore \quad S_c = \frac{4.2\times4200}{21\times21}\left[1-\frac{\sqrt{\frac{13.82}{94.26}}}{0.925+\frac{0.22\times13.82}{94.26}}\right] = 40\left(1-\frac{0.383}{0.957}\right)$$

$$= 40(1-0.4) = 24 \text{ kg/cm}^2$$

Which is within the allowable stress limit. Hence, slab thickness = 21 cm.

**Example-6.23** Show that the design thickness of a concrete pavement slab is safe for combined load and temperature stresses for longitudinal end conditions, given the following data:

Design thickness = 20 cm
Maximum wheel load = 4080 kg
Impact factor = 10%
Modulus of elasticity of concrete = $3\times10^5$ kg/cm²
Modulus of subgrade reaction = 6 kg/cm³
Poisson's ratio of concrete = 0.2
Type pressure = 7 kg/cm²
Slab dimensions = 4.5 m x 3.8 m
Thermal coefficient of concrete = $8\times10^{-6}$ per °C
Temperature difference during the day = 0.5°C/cm
Allowable flexural strength of concrete = 35 kg/cm²

***Solution:***

Radius of relative stiffness, $l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}} = \sqrt[4]{\frac{3\times10^5\times20^3}{12(1-0.2^2)6}} = 86.33$ cm

Design load $= 4080+\frac{10}{100}\times4080 = 4488$ kg

Radius of contact area, $a = \sqrt{\frac{P}{p\pi}} = \sqrt{\frac{4488}{7\pi}} = 14.29$ cm

Since the radius of the circular area '$a$' = 14.29 cm is less than 1.724 h =- 1.724 x 20 = 34.48 cm ; the special theory has to be applied.

Equivalent radius of resisting section

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

$$= \sqrt{1.6\times14.29^2+20^2} - 0.675\times20 = 26.96 - 13.50$$

$$= 13.46 \text{ cm}$$

According to IRC (Westergaard formula modified by Teller and Sutherland) the tensile stress at the unbroken edge of the slab

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

$$= \frac{0.529\times4488}{20^2}[1+0.54\times0.2]\left[4\log_{10}\frac{86.33}{13.46}-\log_{10}13.46-0.4048\right]$$

$$= \frac{0.529\times4488}{20^2}\times1.108\times3.9527 = 26.00 \text{ kg/cm}^2$$

$$S_t = \frac{CE\alpha t}{2}$$

$$\frac{L}{l} = \frac{4.5\times100}{86.33} = 5.21 \qquad \left(\frac{L}{l}=5.21, C=0.75\right)$$

$$\therefore \quad S_t = \frac{0.75 \times 3 \times 10^5 \times 8 \times 10^{-6} \times 0.5 \times 20}{2} = 9 \text{ kg/cm}^2$$

Combined Stress = Load Stress + Warping Stress = 26.00 + 9.00 = 35.00 kg/cm$^2$

This is equal to the allowable flexural strength of 35 kg/cm$^2$. Hence the slab thickness of 20 cm is safe.

**Example-6.24** The results of an one-day axle load survey of trucks on a road are tabulated in Table. Determine the number of repetitions of a standard 80 kN axle in a year.

| Weight in tonnes | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 | 5 - 6 | 6 - 7 | 7 - 8 | 8 - 9 | 9 - 10 | 10 - 11 | 11 - 12 | 12 - 13 | 13 - 14 | 14 - 15 | 15 - 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of axles ($N$) | 14 | 76 | 77 | 70 | 28 | 18 | 10 | 11 | 11 | 11 | 12 | 15 | 7 | 3 | 1 |

***Solution:***

The working is facilitated in a tabular from as

| Weight in tonnes | Mid-Point in tonnes | Mid-point in kN($L$) | Number of axles ($N$) | $\left(\frac{L}{80}\right)^4$ | $\left(\frac{L}{80}\right)^4 \times N$ |
|---|---|---|---|---|---|
| 1 - 2 | 1.5 | 15 | 14 | 0.0012 | 0.02 |
| 2 - 3 | 2.5 | 25 | 76 | 0.0095 | 0.72 |
| 3 - 4 | 3.5 | 35 | 77 | 0.0366 | 2.82 |
| 4 - 5 | 4.5 | 45 | 70 | 0.1001 | 7.01 |
| 5 - 6 | 5.5 | 55 | 28 | 0.2234 | 6.26 |
| 6 - 7 | 6.5 | 65 | 18 | 0.4358 | 7.84 |
| 7 - 8 | 75 | 75 | 10 | 0.7725 | 7.72 |
| 8 - 9 | 8.5 | 85 | 11 | 1.2744 | 14.02 |
| 9 - 10 | 9.5 | 95 | 11 | 1.9885 | 21.87 |
| 10 - 11 | 10.5 | 105 | 11 | 2.9675 | 32.64 |
| 11 - 12 | 11.5 | 115 | 12 | 4.2700 | 51.24 |
| 12 - 13 | 12.5 | 125 | 15 | 5.9605 | 89.41 |
| 13 - 14 | 13.5 | 135 | 7 | 8.1021 | 56.76 |
| 14 - 15 | 14.5 | 145 | 3 | 10.7922 | 32.38 |
| 15 - 16 | 15.5 | 155 | 1 | 14.0918 | 14.09 |
| | | | $\Sigma = 364$ | | $\Sigma = 344.8$ |

$\therefore$ Number of 80 kN axles per year = 344.8 × 365 = 128852

## Summary

- **Flexible pavement** transmits the load by grain to grain transfer while in rigid pavement load is transferred through the slab action.
- Purpose of wearing course is to provide smooth riding surface and to prevent wear and tear due to traffic.
- IRC specified **maximum legal axle** load as 8170 kg with a maximum equivalent single wheel load of 4085 kg.
- Load on the single tyre which will cause an equivalent magnitude of stress, strain, deflection etc. at a given location to that of multiple wheel load at the some location is known as equivalent single wheel load.
- The higher value of group index represents the weaker soil subgrade.
- Design of flexible pavement based on the concept of cumulative standard axle rather than total number of all commercial vehicle.
- The load carrying capacity of a rigid pavement is mainly due to the rigidity and high modulus of elasticity of the slab.
- Slab deflection is direct measurement of the magnitude of the subgrade pressure.
- **Temperature stresses** are caused due to daily variation and seasonal variation of temperature.
- The longer is the length between joints, the greater is the warping stress and greater is the need for reinforcing steel.
- The main purpose of **expansion joint** is to allow the expansion of the pavement due to rise in temperature.
- **Contraction joint** relieve warping stresses upto some extent.
- **Tie bars** are provided across longitudinal joints not a to transfer the load.
- **Dowel bars** are provided along the direction of traffic.

## Important Expressions

1. Equivalent single wheel load, $\log_{10} \text{ESWL} = \log_{10} P + \dfrac{0.301 \log_{10}\left(\dfrac{Z}{d/2}\right)}{\log_{10}\left(\dfrac{2S}{d/2}\right)}$

2. California bearing ratio test, $T(\text{cm}) = \sqrt{\dfrac{1.75P}{CBR(\%)} - \dfrac{P}{p\pi}}$

3. Number of cumulative standard axle, $N_s = \dfrac{365\left[\left(1+\dfrac{r}{100}\right)^n - 1\right] \times A \times D \times F}{\left(\dfrac{r}{100}\right)}$

4. California resistance value method, $T = \dfrac{k(\text{T.I.})\,(90-R)}{C^{1/5}}$

5. Triaxial test method, $T = \sqrt{\left(\dfrac{3PXY}{2\pi E_s \Delta}\right)^2 - a^2}$

6. Mcleod method, $T = k \log_{10} \dfrac{P}{S}$

7. Relative stiffness of slab, $l = \left[\dfrac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$

8. Westergaard's stress equations, $S_i = \dfrac{0.316P}{h^2}\left[4\log_{10}\left(\dfrac{l}{b}\right) + 1.069\right]$

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

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

9. Frictional stress, $S_f = \frac{fWL}{2\times10^4}$

10. Length of tie bar, $L_t = \frac{\phi\sigma_{st}}{2\tau_{bd}}$

## Objective Brain Teasers

**Q.1** Main drawback of CBR method is that it
(a) does not consider the strength characteristics of subgrade soil.
(b) is a complex method.
(c) gives the total thickness which remains the same irrespective of the quality of materials used in the component layers.
(d) does not give the thickness of individual layers.

**Q.2** If in a Dorry abrasion test the loss in weight is 21 gm, then the coefficient of hardness is
(a) 9.5 (b) 13
(c) 17 (d) 21

**Q.3** RC-2, MC-2 and SC-2 correspond to
(a) Same viscosity
(b) Viscosity in increasing order from RC-2 to SC-2
(c) Viscosity in decreasing order from RC-2 to SC-2
(d) None of the above

**Q.4** In cement concrete pavements, tie bars are provided:
(a) Near the top of the slab across expansion joints.
(b) Near the bottom of slab across contraction joints.
(c) At mid depth of slab across longitudinal joints.
(d) Near the bottom of slab across longitudinal joints.

**Q.5** If the width of the pavement slab is 7.5 m, thickness 20 cm and working stress 1400 kg/cm$^2$, spacing of 10 mm tie bars for the longitudinal joint is,
(a) 10 cm (b) 30 cm
(c) 40 cm (d) 50 cm

**Q.6** Find the area of steel required per metre width of pavement, having thickness of 20 cm, for a length of 20 m for design wheel load 6300 kg and permissible tensile stress in steel is 1400 kg/cm$^2$.
(a) 3.74 cm$^2$/m (b) 4.26 cm$^2$/m
(c) 5.14 cm$^2$/m (d) 6.32 cm$^2$/m

**Q.7** A plate load test is carried out on subgrade soil using a 300 mm radius rigid plate. A load of 5 tonnes resulted in a deflection of 1.2 mm. Determine the stiffness modulus of the soil, if the Poisson's ratio is 0.5.
(a) 73.38 MPa (b) 66 MPa
(c) 52.16 MPa (d) 50.6 MPa

**Q.8** Two closely separated wheels of load 20.5 kN each and tyre pressure 0.7 MPa are acting on a pavement section. If the two wheels are replaced by a single wheel with the some tyre pressure, calculate the radius of the tyre imprint (idealized as circle) of the single wheel.
(a) 0.096 m (b) 0.136 m
(c) 0.018 m (d) 0.108 m

**Q.9** Design a suitable bituminous pavement for a two lane road with a single carriageway by using the following information.
1. Traffic expected in both directions = 500 cvpd
2. Vehicle damage factor = 1.9
3. Traffic growth rate = 7.5%
4. Design life of pavement = 12 years.
(a) 6.39 msa (b) 7.89 msa
(c) 5.69 msa (d) 4.79 msa

**Q.10** In the context of flexible pavement design, the ratio of contact pressure to tyre pressure is called the Rigidity Factor. This factor is less than unity when the tyre pressure is
(a) less than 0.56 N/mm$^2$
(b) equal to 0.56 N/mm$^2$
(c) equal to 0.7 N/mm$^2$
(d) more than 0.7 N/mm$^2$

**Q.11** 10 cm bituminous concrete having cohesion-meter value 60 is equivalent to 7.5 cm of cement treated base. The cohesion-meter value of cement treated base is
(a) 180.6 (b) 214.8
(c) 252.8 (d) 310.6

**Q.12** The following data pertains to the number of commercial vehicles per day for the design of a flexible pavement for a national highway as per IRC:37-1984:

| Type of commercial vehicle | Number of vehicle per day considering the number of lanes | Vehicle Damage Factor |
|---|---|---|
| Two axle trucks | 2000 | 5 |
| Tandem axle trucks | 200 | 6 |

Assuming a traffic growth factor of 8% per annum for both the types of vehicles, the cumulative number of standard axle load repetitions (in million) for a design life of ten years is
(a) 46.4 (b) 59.2
(c) 64.6 (d) 78.7

**Q.13** The CBR value of a subgrade soil is 10%. The wheel load is 4000 kg and the tyre pressure is 6 kg/cm$^2$. The thickness (in cm) of the pavement that should be constructed is
(a) 22.08 (b) 35.55
(c) 44.16 (d) 55.48

**Q.14** What is the ratio of deflection at the centre for a flexible plate and rigid plate of same diameter?
(a) 0.79 (b) 1.18
(c) 1.27 (d) 1.5

**Q.15** Maximum stress produced by a wheel load at corner does not exist around the load, but it occurs at some distance along the diagonal. If radius of wheel load distribution and radius of relative stiffness are 15 cm and 65 cm respectively, then the location (in cm) from the corner of the slab, where the crack is likely to be developed due to corner loading, is
(a) 43.36 (b) 54.18
(c) 67.72 (d) 80.56

**Q.16** A circular load of radius 20 cm with uniform contact pressure of 8.0 kg/cm$^2$ is applied on the surface of a homogeneous elastic mass. The vertical stress under the centre of the load at a depth of 50 cm from the surface is ___ kg/cm$^2$.
(a) 3.0 (b) 2.4
(c) 1.9 (d) 1.6

**Q.17** The spacing between the contraction joint of a cement concrete pavement is 4.8 m. If the coefficient of friction between the bottom of pavement and the supporting layer is 1.25 and unit weight of cement concrete is 2500 kg/m$^3$, then the tensile stress developed in the cement concrete pavement due to contraction is _____ kg/cm$^2$.
(a) 1.00 (b) 0.75
(c) 0.50 (d) 0.25

**Q.18** The total thickness of flexible pavement assuming single layer elastic theory, using the following data, will be _____ cm.
Design wheel load = 5200 kg
Tyre pressure = 7.2 kg/cm$^2$
Elastic modulus = 160 kg/cm$^2$
Permissible deflection = 0.25 cm

(a) 54.6 (b) 60.2
(c) 66.8 (d) 70.4

**Q.19** A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter of 30 cm. The load value corresponding to mean settlement value of 0.125 cm is 1490 kg. What is the modulus of subgrade reaction (in kg/cm³) for the standard plate having 750 mm diameter?
(a) 6.75 (b) 4.02
(c) 3.57 (d) None of these

**Q.20** What is the gravel equivalent C-value of a three layout pavement section having individual C-values as given below ?
[Use California resistance value method]

| Materials | Thickness | C-Value |
|---|---|---|
| Bituminous concrete | 15 cm | 75 |
| Cement treated base | 20 cm | 200 |
| Gravel sub base | 10 cm | 20 |

(a) 93 (b) 99
(c) 106 (d) None of these

**Q.21** The width of expansion joint gap is 3 cm in a cement concrete pavement. The spacing (in m) between expansion joint for a maximum rise in temperature of 30°C is
[Assume coefficient of thermal expansion of concrete as $10 \times 10^{-6}$ per degree C
(a) 25 (b) 50
(c) 75 (d) 100

**Q.22** The number of commercial vehicles in the year of completing overlay construction is estimated to be 3000 per day with an average growth rate of 8 percent per year. If the average vehicle damage factor is 6, what is the design traffic in terms of msa (million standard axle), for 15 year design period?
[Assuming a lane distribution factor of 0.75]
(a) 54.55 (b) 66.895
(c) 109.1 (d) 133.79

**Q.23** In a pavement slab of thickness 18 cm the modulus of elasticity of concrete and Poisson's ratio are $3 \times 10^5$ kg/cm² and 0.15 respectively. Plate bearing test shown the pressure of 1.2 kg/cm² corresponding to 1.25 mm penetration. What is the radius (in cm) of relative stiffness of pavement slab?
(a) 250 (b) 78
(c) 125 (d) 63

**Q.24** The number of load cycles ($N_i$) to cause the failure of a pavement is proportional to ($P$ is respective applied load)
(a) $P^4$ (b) $P^{-4}$
(c) $P^2$ (d) $\frac{1}{P}$

**Q.25** If the load, warping and frictional stresses in a cement concrete slab are 210 N/mm², 90 N/mm² and 10 N/mm² respectively, the critical combination of stresses during summer midday is
(a) 290 N/mm² (b) 390 N/mm²
(c) 450 N/mm² (d) 590 N/mm²

**Q.26** For a 25 cm thick cement concrete pavement, analysis of stresses gives the following values: Wheel load stress due to edge loading 30 kg/cm², wheel load stress due to corner loading 32 kg/cm², warping stress at corner region during summer 9 kg/cm², warping stress at corner region during winter 7 kg/cm², warping stress at edge region during summer 8 kg/cm², warping stress at edge region during winter 6 kg/cm², frictional stress during summer 5 kg/cm², frictional stress during winter 4 kg/cm². The most critical stress value for this pavement is
(a) 40 kg/cm² (b) 42 kg/cm²
(c) 44 kg/cm² (d) 45 kg/cm²

**Q.27** Which one of the following statements is correct with respect to rigid pavements?
(a) Vertical stress is transmitted to the lower layer through the point of contact in granular structure.
(b) Vertical compressive stress is maximum on the pavement directly under wheel load.
(c) Lower layers have to take lesser magnitude of stress.
(d) Stress on rigid pavements are transmitted to wider area of sub-grade.

**Q.28** A cement concrete pavement of slab thickness 20 cm is placed over a soil with coefficient of friction as 1.2 the length of the pavement between two successive contraction joints is 4 m, width of the slab panel is 3 m, the density of concrete is 2400 kg/m³. The frictional stress developed during peak winter is
(a) 0.58 kg/cm²
(b) 0.82 kg/cm²
(c) 0.98 kg/cm²
(d) 1.1 kg/cm²

**Q.29** The corrected modulus of sub-grade reaction for standard diameter plate is 6.0 kg/cm³. What would be the modulus of sub-grade reaction of the soil when tested with a 30 cm diameter plate?
(a) 15 kg/cm³ (b) 25 kg/cm³
(c) 30 kg/cm³ (d) 60 kg/cm³

**Q.30** The plate load test conducted with a 75 cm diameter plate on soil subgrade yielded a deflection of 2.5 mm under a stress of 800 N/cm². The modulus of elasticity of the subgrade soil, in kN/cm² is
(a) 141.6 (b) 154.6
(c) 160.0 (d) 185.4

**Q.31** Match List-I (Method of design for flexible pavement) with List-II (Principle) and select the correct answer using the codes given below the lists:
List-I
A. Group index method
B. CBR method
C. US Navy method
D. Asphalt institute method
List-II
1. Semi-theoretical
2. Quasi-rational
3. Empirical method using soil classification test
4. Empirical method using soil strength test

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 3 | 1 | 4 | 2 |
| (b) | 2 | 4 | 1 | 3 |
| (c) | 3 | 4 | 1 | 2 |
| (d) | 2 | 1 | 4 | 3 |

**Direction:** Each of the following question consists of two statements, one labelled the **'Assertion (A)'** and the other labelled the **'Reason (R)'**. Examine the two statements carefully and decide if the Assertion (A) and Reason (R) are individually true and if so whether the Reason (R) is correct explanation of the Assertion (A). Select your answers to these questions using the codes given below:
**Codes:**
(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not a correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

**Q.32** **Assertion (A):** Dowel bars are provided at expansion joints and sometimes also at contraction joints in cement concrete slabs.
**Reason (R):** Longitudinal joints in cement concrete pavements are constructed with tie bars.

**Q.33** **Assertion (A):** The critical combination of stresses on a cement concrete pavement during summer is given by: load stress – warping stress + frictional stress.
**Reason (R):** The critical combination of stresses in a cement concrete pavement during winter is given by: load stress + warping stress + frictional stress.

**Q.34** **Assertion (A):** The most widely used test for design of rigid pavements is the California Bearing Ratio (CBR) test.
**Reason (R):** CBR test can be used for evaluating soil strength properties such as cohesion and internal friction.

### Answers

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. (c) | 2. (b) | 3. (a) | 4. (c) | 5. (c) | 6. (c) | 7. (c) | 8. (b) | 9. (a) | 10. (d) | 11. (c) | 12. (b) | 13. (a) | 14. (c) | 15. (d) | 16. (d) | 17. (b) |
| 18. (b) | 19. (a) | 20. (a) | 21. (b) | 22. (d) | 23. (d) | 24. (d) | 25. (a) | 26. (a) | 27. (d) | 28. (a) | 29. (a) | 30. (a) | 31. (c) | 32. (b) | 33. (d) | 34. (d) |

## Conventional Practice Questions

**Q.1** A set of dual tyres has a total load of 4090 kg, a contact radius of 11.4 cm and center to center tyre spacing of 34.3 cm. Find the equivalent single wheel load for a depth of 34.3 cm.

**[Ans.** 3369.3 kg]

**Q.2** Determine the thickness of flexible pavement by Burmister's two layer theory for a wheel load of 40 kN and a tyre pressure of 0.5 MN/m$^2$. The modulus of elasticity of the pavement material is 120 MN/m$^2$ and the subgrade is 12 MN/m$^2$. The value of $F_w$ for $E_1/E_2$ of 10 can be taken as under:

| Thickness of top layer | $F_w$ |
|---|---|
| 0.5 a | 0.8 |
| 1.0 a | 0.5 |
| 2.0 a | 0.3 |

The allowable deflection is 0.5 cm

**[Ans.** 16 cm]

**Q.3** A two-lane two-way carriageway carries a traffic of 1500 cvpd. The rate of growth of traffic is 5 percent per annum. The design life is 15 years. The vehicle damage factor is 2.5. The CBR value of the soil is 6. Calculate: (*i*) the cumulative number of standard axles to be catered in the design (*ii*) the total pavement thickness (*iii*) and composition of the pavement.

**Ans.** (*i*) 22.15 msa
(*ii*) T = 580 mm,
(*iii*) 40 mm BC + 100 mm DBM + 250 mm WBM + 190 mm sub-base

**Q.4** The axle load distribution of commercial vehicles on a highway is as under:

| | |
|---|---|
| 0 – 0.5 tonnes | 10 % |
| 2.5 – 5.0 tonnes | 15 % |
| 5.0 – 7.5 tonnes | 25 % |
| 7.5 – 10.0 tonnes | 40 % |
| 10.0 – 12.5 tonnes | 10 % |

Calculate the cumulative standard axles to be used in design for strengthening the pavement when the current traffic on a two-lane two-way road is 2000 commercial vehicles per day. The rate of growth of traffic is 10 percent per annum and the period of construction is 3 years. The design life is 15 years after construction.

**[Ans.** 24.6 msa]

**Q.5** Estimate the wheel load stress at interior and edge of cement concrete pavement of 21 cm thickness, using stress coefficient given in graph. Modulus of elasticity of concrete = $2\times10^7$ kN/m$^2$. Poisson's ratio of concrete = 0.15. Modulus of sub-grade = $3.6\times10^4$ kN/m$^3$. Wheel load = 40.8 kN. Tyre pressure = 600 kN/m$^2$.

**Ans.** 1202.72 kN/m$^2$ and 1850.34 kN/m$^2$

**Q.6** In a cement concrete pavement of 20 cm thickness, the maximum increase in temperature is 20°C after construction. If the expansion joint gap is 2.0 cm, calculate the spacing between the expansion and contraction joints. The coefficient of thermal expansion of concrete is $10\times10^{-6}$ per°C, unit weight of concrete is 24 kN/m$^3$, allowable stress in tension is 0.1 N/mm$^2$, coefficient of friction of interface is 1.25.

**[Ans.** 4.5 m and 50 m]