VISVESVARAYA TECHNOLOGICAL UNIVERSITY

BELGAUM

PAVEMENT DESIGN

(Subject Code: 18CV825)

LECTURE NOTES

(MODULE-2)

VIII-SEMESTER

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Module - 2
Design Factors

Design Life

The design life or performance period refers to the period of time for which the initially designed pavement structure will last before any rehabilitation is needed.

Traffic and Loading

There are three different approaches for considering vehicular and traffic characteristics, which affects pavement design.

- Fixed traffic: Thickness of pavement is governed by single load and number of load repetitions is not considered. The heaviest wheel load anticipated is used for design purpose. This is an old method and is rarely used today for pavement design.
- Fixed vehicle: In the fixed vehicle procedure, the thickness is governed by the number of repetitions of a standard axle load. If the axle loads is not a standard one, then it must be converted to an equivalent axle load by number of repetitions of given axle load and its equivalent axle load factor.
- Variable traffic and vehicle: In this approach, both traffic and vehicle are considered individually, so there is no need to assign an equivalent factor for each axle load. The loads can be divided into a number of groups and the stresses, strains, and deflections under each load group can be determined separately, and used for design purposes. The traffic and loading factors to be considered include axle loads, load repetitions and tyre contact area.

Factors affecting Design Life of Pavement:

1. Traffic Factors
2. Climatic Factors
3. Road Geometry
4. Subgrade strength and Drainage

1. Traffic Factors:

Wheel load: Pavement wheel load causes stresses and strains in pavement layers and subgrade. The tyre pressure determines the area of application.

Impact: Imperfections in surface and at joints cause additional loads due to impact.

Repetition of wheel loads: Apart from single wheel load design criteria, the cumulative load applications during the design life cause plastic and elastic deformations.

Position of wheel load across pavement: The concentration of wheel load at a localized width of the pavement can cause extra distress.

Iron-tyred vehicles: Bullock carts with iron tyres can cause severe stresses in pavements.

2. Climatic Factors:

Rainfall: Rainfall affects pavement drainage and can thus be a significant factor.

Frost: Frost heave can disrupt pavement structure.

Temperature: Variation of temperature can cause stresses in the pavement.

3. **Road geometry:**

   Horizontal Curves: Pavements on horizontal curves are subjected to extra stresses, pavements at junctions are typical examples.

   Vertical Profile: Pavements on grades are subjected to extra forces due to acceleration, deceleration and braking.

4. **Subgrade Strength and Drainage:**

   Subgrade Strength: Subgrade soil type and compacted density significantly affect pavement design.

   Drainage: Surface and subsurface drainage of pavement and from adjoining land also affect subgrade strength significantly and hence the pavement design.

Equivalent Single Wheel Load (ESWL):
To carry maximum load within the specified limit and to carry greater load, dual wheel, or dual tandem assembly is often used. Equivalent single wheel load (ESWL) is the single wheel load having the same contact pressure, which produces same value of maximum stress, deflection, tensile stress or contact pressure at the desired depth.

The procedure of finding the ESWL for equal stress criteria is provided below. This is a semi-rational method, known as Boyd and Foster method, based on the following assumptions:

- Equilency concept is based on equal stress
- Contact area is circular
- Influence angle is 45°, and
- Soil medium is elastic, homogeneous, and isotropic half space.

Design Wheel Load:
Thickness of the pavement primarily depends upon the design wheel load/higher the wheel load, higher will be the thickness, provided other design factors are the same. As speed increases, the rate of application of stress increases.

Elements of design wheel load:
- Static load on each wheel/dual/dual tandem wheel
- Contact pressure
- Load repetition and dynamic effect of transient loads
- Repetition of loads

DESIGN OF WHEEL LOAD:

i. Maximum Wheel Load:

The way in which a load in given vehicle is applied on a pavement surface depends on the wheel configuration of the vehicle. Therefore, it is important to know the wheel configuration of vehicles.

The Indian Road Congress has specified the maximum legal axle load as 8170kg with a maximum equivalent single wheel load of 4085kg. The total load decides the pavement thickness.

ii. Contact Pressure:

Two important factors to be considered here are tyre pressure and inflation pressure.

The tyre pressure is very high on upper layers of pavements. The tyre pressure diminishes in proportion to the depth of a pavement. Therefore, tyre pressure of high magnitude requires high quality surface course. The tyre pressure is constant. Hence, the stress on the sub grade depends on the total load.

Contact Pressure = Load on wheel / Contact area or area of imprint

iii. Equivalent Single Wheel Load (ESWL):

Dual wheel assembly to rear axles of vehicles improves the load carrying capacity of vehicles. It also helps to maintain maximum wheel load within the specified limit. However, the effect of dual carriage way on the pavement is not equal to two times the load on any one wheel. The effect is in between the load carried by a single wheel and that by a dual wheel.

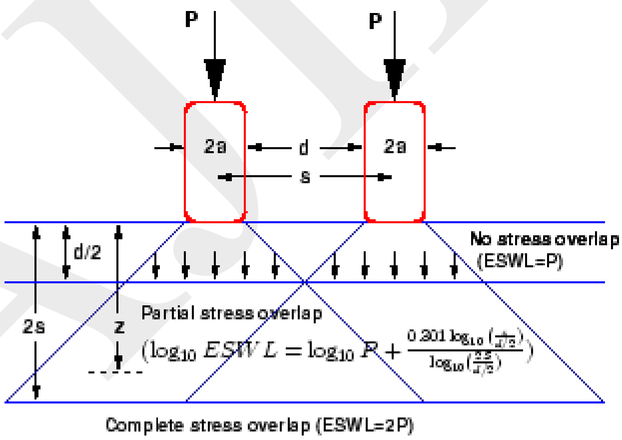


Figure 1: ESWL-Equal stress concept

where s= spacing between the centers of the wheels = (d+2a)

a = radius of the circular contact area of each wheel

d = clear gap between two wheels

P = wheel load

ESWL is used –

- To carry maximum load within the specified limit

- To carry greater load, dual wheel, or dual tandem assembly

The ESWL is given by:

$$\log_{10} ESWL = \log_{10} P + \frac{0.301 \log_{10} [z/(d/2)]}{\log_{10} [2s/(d/2)]}$$

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

At a depth 2s and above, stresses induced are due to the effect of both wheels as the area of overlap is considerable. Therefore, at any depth greater than 2s the stresses due to wheels are considered to be equivalent to a single wheel load of magnitude 2P. There are limitations to carry the loads by wheels heavy wheel load. Near the surface wheel loads act independently. At a greater depth stress overlaps, but become smaller as depth increases until a point reached where the overlap of stresses is negligible. At a depth greater than d/2 wheel stop to act independently and pavement stress result from the combined effect of two wheels. At a depth 2s overlap of stresses becomes negligible. At a depth below 2s, stresses due to wheel load are taken equivalent to 2P.

Determination of ESWL:

a) **Based on equivalent deflection:** The ESWL is the single wheel load having the same contact pressure and producing the same value of stress at a depth equal to the thickness of the pavement.
b) **Based on equivalent stress criteria:** The ESWL is the single wheel load producing the same value of maximum stress at a depth equal to the thickness of the pavement.

ESWL by Equal Stress Criteria (Boussinesq's method):

Stress produced by single wheel load is considered equal to the stresses produced by dual wheel load.

$$Ps \left\{\frac{\sigma_z}{P_s} * 100\right\} = P_d \left\{\frac{\sigma_z}{P_d} * 100\right\}$$

where Ps = Equivalent single wheel load
P_d = Dual wheel load
$\frac{\sigma_z}{P_s} * 100$ = stress at a depth "z" for singe wheel load
$\frac{\sigma_z}{P_d} * 100$ = stress at a depth "z" for dual wheel load

Then,

$$P_s = ESWL = \frac{P_d (\sigma_z / P_d) * 100}{(\sigma_z / P_s) * 100} = \frac{\text{Max stress due to dual wheel load}}{\text{Max stress due to single wheel load}}$$

ESWL by Equal Deflection Criteria:

ESWL is taken in such a way that the single load produces deflection (at a certain depth) = deflection produced by a dual wheel load assembly (at same depth)

$$P_s * F_s = P_d * F_d$$

Where P_s is ESWL

P_d is the load on single wheel

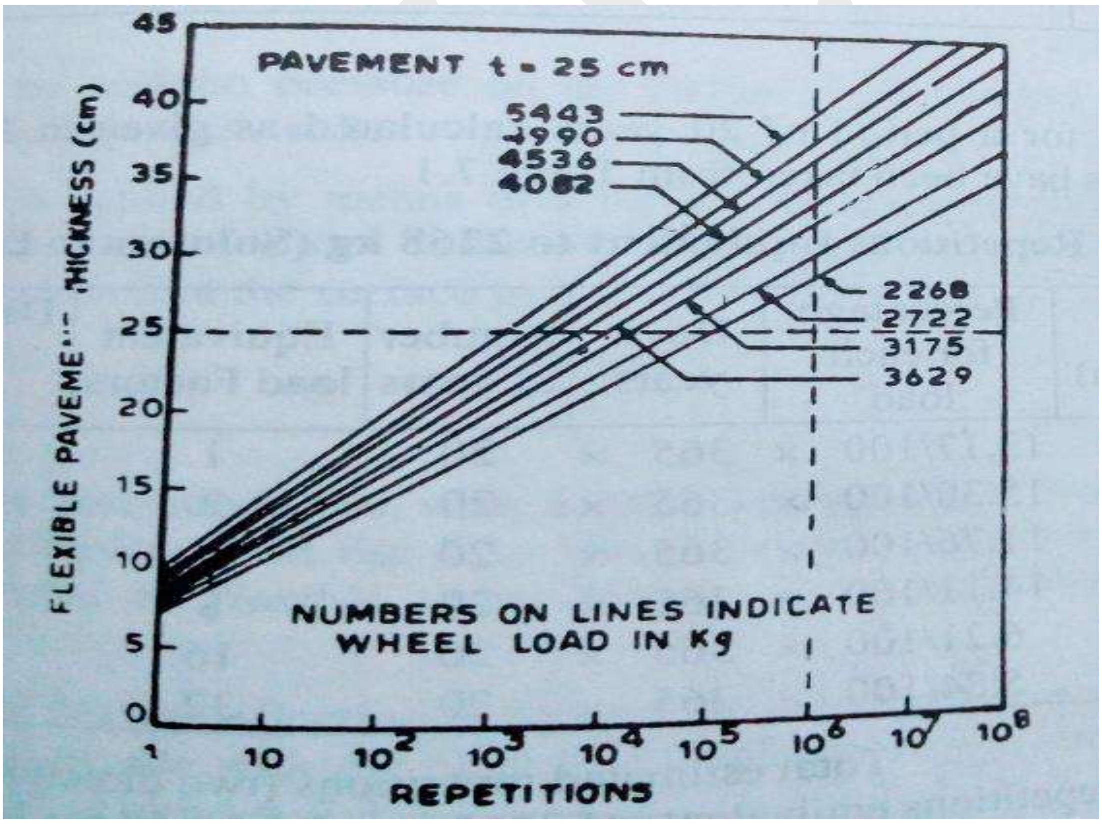
F_d = Max deflection due to dual wheel load

F_s = max deflection due to single wheel load

F_d and F_s are obtained by (z/a) and (r/a) ratio from one layer deflection chart

Repetition of Loads:

Pavement or sub grade may deform little on a single application of wheel load. However, if that load is repeatedly applied, then the elastic and plastic deformations and also accumulated unrecovered deformation increases. This may even result in failure of the pavement. Equivalent wheel load is a single load equivalent to the repeated applications of any particular wheel load on a pavement which requires the same thickness and strength of pavements.



Deformation of pavement or sub grade due to a single application of wheel load is small. Deformation due to repeated application of the load is more. Plastic, Elastic & Permanent deformation may result in pavement due to repetition of loads.

Equivalent Wheel Load (EWL):

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

If the pavement fails with N_1 no. of repetitions of P_1 kg load and if N_2 no. of repetitions of P_2 kg load cause failure of the pavement, then,

$$P_1 * N_I = P_2 * N_2$$

McLeod assumed that pavement thickness which are designed for a given wheel load would support 1 million repetitions of such load during the life of pavement.

Problems:

1. Calculate ESWL of a dual wheel assembly carrying 2044 kg each for pavement thickness of 15, 20 and 25cms. Centre to centre tyre spacing=27cm and distance between the walls of the tyres=11cm.
   Solution: Here P=2044kg, 2P=4088kg, d=11cm, S=27cm
   X and Y points are plotted on the log-log graph between ESWL and pavement thickness
   X has a coordinates(P,d/2)=(2044,5.5)
   Y has a coordinates (2P,2S)= (4088,54)

Pavement thickness	ESWL
15	2760
20	3000
25	3230

2. Calculate ESWL at a depth of 4.5cm, 18.0cm and 40.0cm for a dual wheel carrying 20.5kN each. The centre to centre spacing is 20cm and the clear distance between the two tires is 9cm.

   Solution: P= 20.5kN, s = 20cm and d = 9cm.

   ESWL @ z = 40cm = 2 x P = 2 x 20.5 = 41kN (since, z = 2s ≈40cm)

   ESWL@ z = 4.5cm = P = 20.5kN (since, z = d/2≈ 4.5cm)

$$\log_{10} \text{ESWL @ 18cm} = \log_{10} 20.5 + \frac{0.301 \log_{10} [18/(9/2)]}{\log_{10} [(2x20)/(9/2)]}$$

$$\log_{10} ESWL\ @\ 18cm = \log_{10} 20.5 + \frac{0.301 \log_{10} (4)}{\log_{10} (8.88)}$$

$$\log_{10} ESWL\ @\ 18cm = 1.3117 + \frac{0.301 \times 0.60206}{0.94841}$$

$$= 1.3117 + 0.19107$$

$$= 1.50277$$

Therefore, ESWL @ 18cm depth = $10^{1.50277}$ = 31.8251 kN

Flexible Pavement Design

Assumptions

1) In flexible pavements, under the application of load, none of the layers are overloaded i.e, at any given instance; no section of the pavement structure is subjected to excessive deformation to form differential settlement.
2) The maximum intensity of stress occurs in the top layer. The magnitude of stress occurred at the lower layers are comparatively less. Hence superior pavement materials are used in the top layer of flexible pavement.
3) It is not possible to have rational method of design where in the design process and serviceability behavior of pavement is expressed. In flexible pavement design, they are predicted theoretically by mathematical laws. It is one of the limitations of flexible pavement design.
4) In the design of flexible pavements, the methods employed for design are based on semi-empirical and classical approach. Here for empirical and semi-empirical approach, the knowledge and experience gained on the behavior of the pavement in past are effectively utilized.
5) Some of the methods are directly based on soil classification and California Resistance value, which may be estimated by sieve analysis, CBR test and Plate Bearing test depending upon the condition of the soil. Here the thickness required is directly estimated using the results obtained from the experiments under ideal condition.

Design Methods of Flexible Pavement

The design methods can be grouped into the following three broad groups:

1) Empirical Methods
2) Semi- theoretical Methods
3) Theoretical Methods

Empirical Methods

In this class of methods, soil strength test may or may not be carried out. Group Index Method, California Bearing Ratio Method, etc. falls under this category.

Semi-Theoretical Methods

These methods are based partly on past experience and partly on simplified theories of stress distribution as Boussinesq Analysis and Westergaard Analysis Methods, etc. Actually, Westergaard Method is used for rigid pavements.

Theoretical Methods

These methods are wholly based on mathematical analysis of stress and strains developed in the pavements and subgrade. Burmister Analysis Method falls under this category.

Mc Leod Method

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

Principle:

The test set up consists of a set of plates of diameter 75, 60, 45 and 30cms, a loading device consisting of a reaction frame, proving ring and jack. The load on the plate is exerted by the jack against the reaction of the frame. The settlement of loaded plate is measured by dial gauges attached to a datum frame resting on the ground at a distance from the loaded area. The loading arrangement is as shown below:

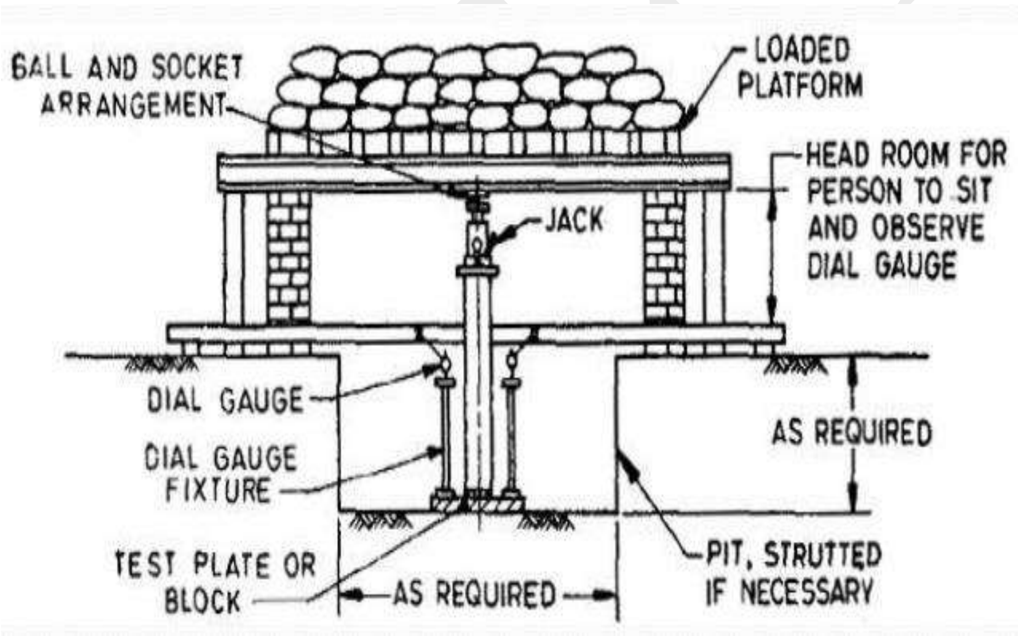


Fig: Plate Load Test

In this procedure after seating the plates, a load sufficient to produce a pressure of $0.7 kg/cm^2$ is applied on the plates in 10 seconds and held in position till the rate of settlement reaches less than 0.05mm per minute. The procedure is repeated till the settlement reaches 0.125cms.

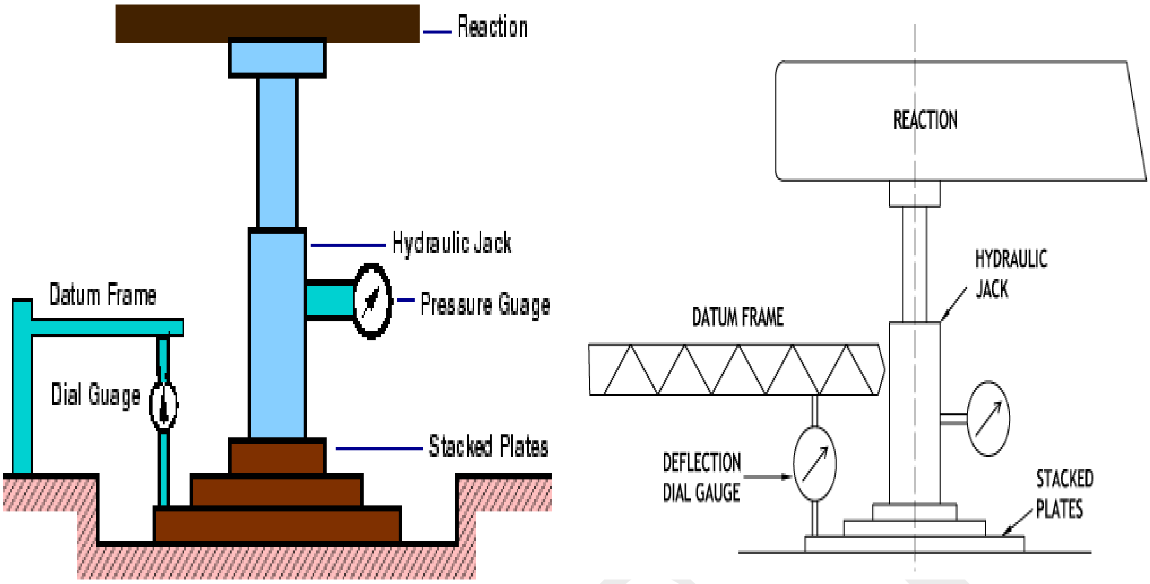


Fig: Plate Load Test

From this test, the modulus of subgrade reaction is determined. The modulus of subgrade reaction may be defined as the pressure sustained per unit deformation of subgrade at specified pressure or deformation using a specified plate. It is denoted by 'K'.

Then, K is given by the relation,

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

From the plate load test results, Mc Leod derives the following relation for thickness of flexible pavement.

$$T = K.\ \log_{10} (P/S)$$

Where, T = Required thickness of the base course in cms.
P = Gross wheel load in kg
S = Total subgrade support in kg (for the same contact area and deflection as for load P)

Thus, if the subgrade support is known from the plate test, the base course thickness can be obtained from above equation. It can be calculated for 30cm diameter plate at 0.5cm deflection and ten repetitions.

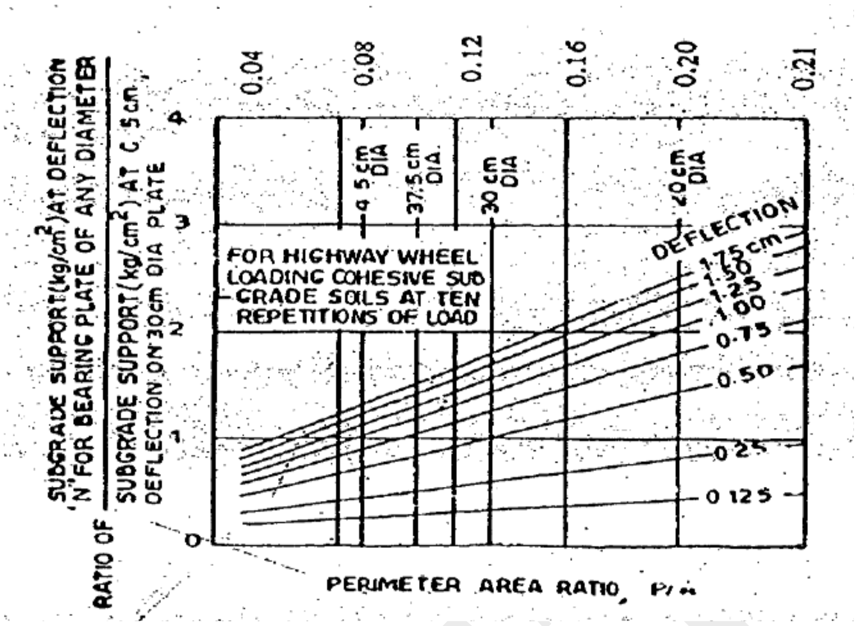


Fig: Relationship of Subgrade Support with P/A ratio

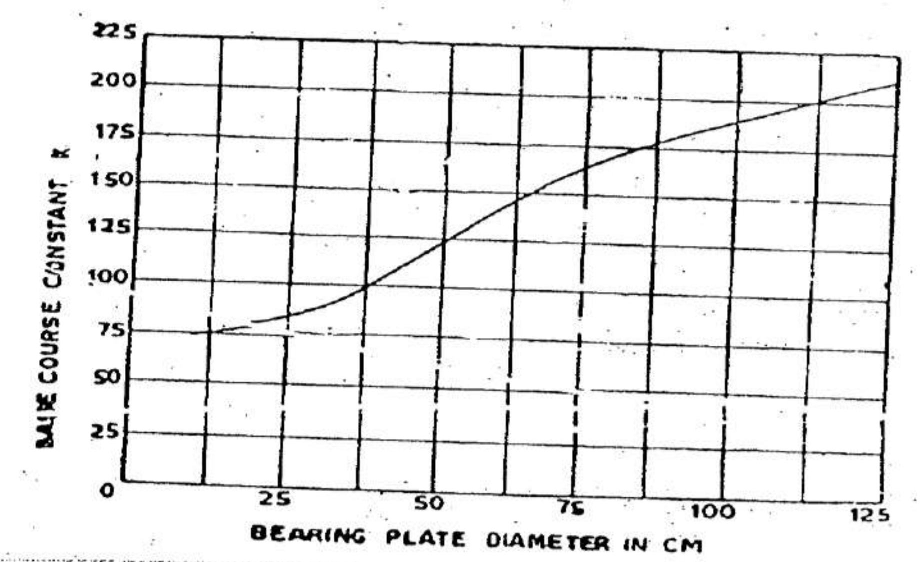


Fig: Relation between Plate Diameter and Base Course Constant

The above graphs can be used for finding the ratio of unit subgrade support for the design wheel load diameter to that on 30cm dia plate at 0.5cms deflection.

Problems

1) Design a highway pavement for a wheel load of 5443kg with a tyre pressure of 6.0kg/cm^2. The plate bearing test carried out on the subgrade soil using 30cm diameter plate yielded a pressure of 2.5kg/cm^2 after 10 repetitions of load at 0.5cm deflection.

   Solution:

   Radius of contact, a = √ (load/ π x tyre pressure)

   a = √ (5443 / π x 6)

= 17cm

Perimeter and area ratio = $2\pi r / \pi r^2 = 2/r = 2/17$

= 0.118

From the graph, the ratio of unit subgrade support on 34cm diameter plate at 0.5cm deflection = 0.96

Thus, unit support at 0.5cm deflection = 0.96 x 2.5

= 2.40kg/cm^2

Therefore, design subgrade support on 34cm diameter plate, $S = 2.4 \times \pi \times \frac{34^2}{4}$

= 2179 kg

From the graph, base course constant K, for 34cm dia plate = 95

Thus, granular pavement thickness, $T = K \log_{10} P/S$

$$T = 0.95 \times \log_{10} \frac{5443}{2179}$$

T = 0.377m = 37.7cm =38cm

Provide 5cm bituminous surfacing out of this 38cm total thickness and 33cm as granular base course.

2) Design a highway pavement of wheel load 4100kg with a tyre pressure of 5kg/cm^2 by Mc Leod Method. Plate bearing test carried out on subgrade soil using 30cm dia plate yielded a pressure of 2.5 kg/cm2 after 10 repetitions of load at 0.5cm deflection.

Solution:

Radius of contact, a = √ (load/ π x tyre pressure)

a = √ (4100 / π x 5)

= 16.2 cm

Perimeter and area ratio = $2\pi r / \pi r^2 = 2/r = 2/16.2$

= 0.123

From the graph, the ratio of unit subgrade support on 32.4cm diameter plate at 0.5cm deflection = 0.96

Thus, unit support at 0.5cm deflection = 0.96 x 2.5

= 2.40kg/cm^2

Therefore, design subgrade support on 32.4cm diameter plate, $S = 2.4 \times \pi \times \frac{32.4^2}{4}$

= 1979 kg

From the graph, base course constant K, for 32.4cm dia plate = 90

Thus, granular pavement thickness, $T = K \log_{10} P/S$

$$T = 0.9 \times \log_{10} \frac{4100}{1979}$$

T = 0.285m = 28.5cm =29cm

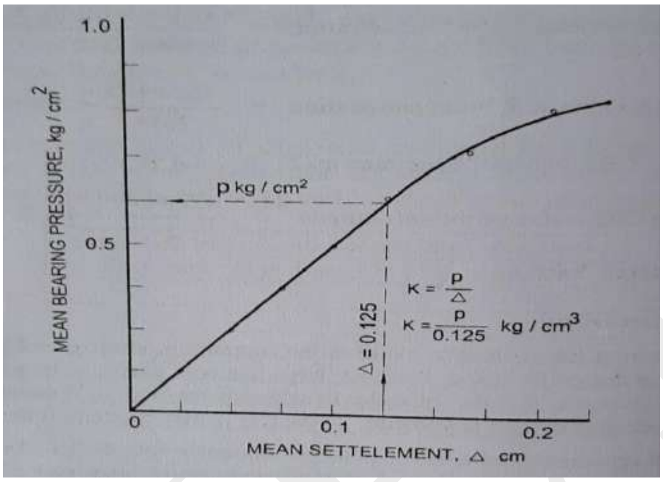
Provide 5cm bituminous surfacing out of this 29cm total thickness and 24cm as granular base course.

3) A plate load test was conducted on a soaked subgrade during monsoon season using a plate diameter of 30cm. The load values corresponding to the mean settlement dial

readings are given below. Determine the modulus of subgrade reaction for the standard plate.

Mean settlement values, mm	0.0	0.24	0.52	0.76	1.02	1.23	1.53	1.76
Load Values, kg	0.0	460	900	1180	1360	1480	1590	1640

Solution:



The load-settlement curve is plotted on a graph and the load value p_1 corresponding mean settlement value of $\Delta = 0.125$cm is determined = 1490kg.
For plate radius of $a_1 = 15$cm,
Unit load, $p_1 = 1490 / (\pi \times 15^2)$ kg/cm^2
Modulus of subgrade reaction K_1 for 30cm diameter plate = $p_1 / \Delta = 1490 / (\pi \times 15^2 \times 0.125)$

$= 16.86$ kg/cm^3

Modulus of subgrade reaction K for standard plate of diameter 75cm = $K_1 a_1 / a$

$= 16.86 \times 30/75$

$= 6.75$ kg/cm^3

Kansas Method or Kansas Triaxial Method

This method relies on triaxial tests of all materials incorporated within the pavement, tested in a saturated condition and adjusted for traffic and anticipated degree of saturation. Based on the Boussinesq's displacement equation for homogeneous elastic single layer, a design method was proposed in 1910 by L.A Palmer and E.S Barber.

$$\Delta = 3pa^2 / 2E\,(a^2 + z^2)^{1/2}$$

The major assumption made in this analysis was replacing the stress function by force function.

W.K.T, $p = P/\pi a^2$ $\quad$ ($A = \pi a^2$)

Now, $\Delta = \dfrac{3\,(P/\pi a^2)\;\; a^2}{2E\,(a^2 + z^2)^{1/2}}$

$$\Delta = \frac{3P}{2\pi E (a^2 + z^2)^{1/2}}$$

$$(a^2 + z^2)^{1/2} = \frac{3P}{2\pi E\Delta}$$

$$a^2 + z^2 = (3P/2\pi E\Delta)^2$$

$$z^2 = (3P/2\pi E\Delta)^2 - a^2$$

$$z = \sqrt{(3P/2\pi E\Delta)^2 - a^2} \longrightarrow (1)$$

Assuming that pavement is incompressible, 'z' becomes 'T_s'

$$T_s = \sqrt{(3P/2\pi E_s\Delta)^2 - a^2} \longrightarrow (2)$$

Where, P = wheel load in kg

E_s = Modulus of elasticity of subgrade in kg/cm^2 obtained from Triaxial test results.

Δ = Design deflection in cm (0.25 cm in almost all cases)

a = Radius of contact area in cm

In the above analysis, pavement and subgrade, both are assumed to have the same value of 'E' i.e., the material characteristic of the structure and soil remains the same, which is relatively not true.

Uses of Triaxial Test

1) The triaxial test is used in determining the value of modulus of elasticity for various materials.
2) A lateral pressure of 1.4 kg/cm^2 is applied to find the value of 'E' of the material. This lateral pressure is arbitrarily assumed as the lateral confinement in the pavement layer by the Kansas State Highway Department of USA.
3) This method further emphasizes the use of certain co-efficient namely,
   - Traffic coefficient, X
   - Saturation coefficient, Y
   - Stiffness factor

The idea of having traffic factor is, all the slabs for all the locations do not release the same value of load. The idea of introducing saturation co-efficient is, all the locations where the slab is proposed, the type of soil, combination of soil, position of water table, nature of surface and sub-surface flow and nature of compaction factor are different from location to location.

Incorporating traffic coefficient (X) and saturation or rainfall coefficient (Y) in equation (2)

$$T = \sqrt{(3PXY/2\pi\Delta E)^2 - a^2}$$

While solving numerical problems depending upon the average rainfall data and average daily traffic data in the given location.

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

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

If the pavement and subgrade are considered to be a two-layer system, stiffness factor has to be introduced to take into account the different values of modulus of elasticity of the two layers.

Stiffness Factor = $(E_1/E_2)^{1/3}$ (or) $(E_S/E_B)^{1/3}$

Actual thickness by Kansas Method is given by,

$$T = \sqrt{(3PXY/2\pi\Delta E_s)^2 - a^2} \times (E_S/E_B)^{1/3}$$

Where, E_S = Modulus of Elasticity of subgrade
E_B= Modulus of Elasticity of base course/ pavement

The thickness of the structure is inversely proportional to the value of Young’s Modulus of Elasticity of subgrade soil raised to the power of 1/3.

Thus, the relationship between the pavement layers of thickness t_B and t_C w.r.t Modulus of elasticity of E_B and E_C is given by,

$$t_B / t_C = (E_C/E_B)^{1/3}$$

Problems

1) Design the pavement section by Triaxial Test method using the following data:

   Wheel load = 4100 kg
   Radius of contact area = 15 cm
   Traffic coefficient, X =1.5
   Rainfall coefficient, Y = 0.9
   Design deflection, Δ = 0.25 cm
   E_S = 100 kg/cm^2
   E_B = 400 kg/cm^2
   E value of 7.5cm thick bituminous concrete surface course = 1000 kg/cm^2

Solution:

Assuming the pavement consists of single layer of base course material only. The pavement thickness is given by,

$$T = \sqrt{\left[\frac{3PXY}{2\pi \Delta E_S}\right]^2 - a^2} \times (E_S/E_B)^{1/3}$$

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

$$T = 65.92\text{cm} \approx 66\text{cm}$$

Let 7.5cm bituminous concrete surface with E_P = 1000kg/cm^2 be equivalent to the thickness 't_B' of base course.

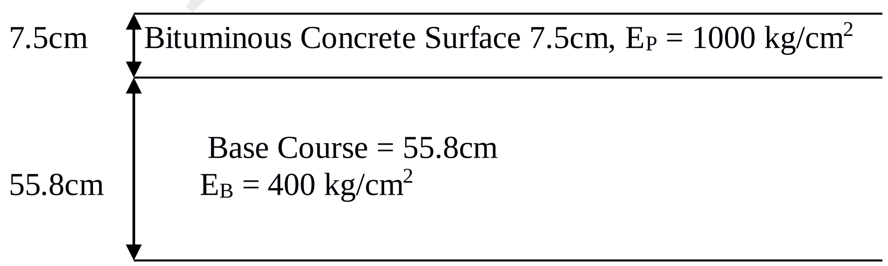
The equivalent replacement t_B is obtained from the relation,

$$\left[\frac{t_B}{t_P}\right] = \left[\frac{E_P}{E_B}\right]^{1/3}$$

$$\left[\frac{t_B}{7.5}\right] = \left[\frac{1000}{400}\right]^{1/3}$$

$$t_B = 10.18\text{cm} \approx 10.2\text{cm}$$

The required base course thickness = 66 – 10.2
= 55.8cm



The pavement section consists of 55.8cm thick WBM base course and 7.5cm thick bituminous concrete surface course as shown in the figure.

2) Calculate the thickness of bituminous surface by Kansas Method.
$E_S = 90\ kg/cm^2$
$E_P = 900\ kg/cm^2$
Wheel load = 5100 kg
Tyre pressure = 7 kg/cm^2
Traffic coefficient, X = 1.25
Saturation coefficient, Y =0.8
Design the thickness of pavement layer, base course and sub-base course are to be provided having 'E' values of 400 kg/cm^2 and 200 kg/cm^2.

Solution: $\Delta = 0.25cm$ (assumed)
Assuming that the pavement consists of single layer,

$$T_B = \sqrt{\left[\frac{3PXY}{2\pi\Delta E_S}\right]^2 - a^2} \times (E_S/E_B)^{1/3}$$

$$T_B = \sqrt{\left[\frac{3x\ 5100x\ 1.25x\ 0.8}{2x\ \pi\ x\ 0.25x\ 90}\right]^2 - \left[\sqrt{\frac{5100}{\pi\ x\ 7}}\right]^2} \times (90/400)^{1/3}$$

$$T_B = 65.17cm \approx 65.2cm$$

Let 7.5cm thick pavement material with E_P = 900kg/cm^2 be equivalent to the thickness 't_B' of base course.
Then,

$$\left[\frac{t_B}{t_P}\right] = \left[\frac{E_P}{E_B}\right]^{1/3}$$

$$\left[\frac{t_B}{7.5}\right] = \left[\frac{900}{400}\right]^{1/3}$$

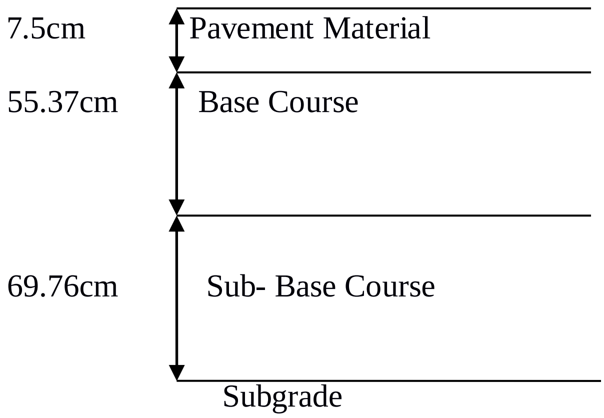
$$t_B = 9.83cm$$

The actual thickness of base course = 65.2 – 9.83
= 55.37 cm

$$\left[\frac{t_B}{t_S}\right] = \left[\frac{E_S}{E_B}\right]^{1/3}$$

$$\left[\frac{55.37}{t_S}\right] = \left[\frac{200}{400}\right]^{1/3}$$

$$t_S = 69.76\ cm$$



3) Design the flexible pavement by triaxial method using the following data:
   E value of subgrade soil = 100 kg/cm^2
   E value of 8cm thick bituminous surface = 1000 kg/cm^2
   E value of base course = 400 kg/cm^2
   Design wheel load = 6000 kg
   Radius of contact area = 15cm
   Traffic coefficient = 1.5
   Rainfall coefficient = 0.6
   Design deflection = 0.25

   Solution:
   Assuming the pavement consists of base and subgrade material only. The pavement thickness is given by,

$$T = \sqrt{\left[\frac{3PXY}{2\pi\Delta E_S}\right]^2 - a^2} \times (E_S/E_B)^{1/3}$$

$$T = \sqrt{\left[\frac{3x\ 6000x\ 1.5x\ 0.6}{2x\ \pi\ x\ 0.25x\ 100}\right]^2 - 15^2} \times (100/400)^{1/3}$$

$$T = 64.28cm \approx 64.3cm$$

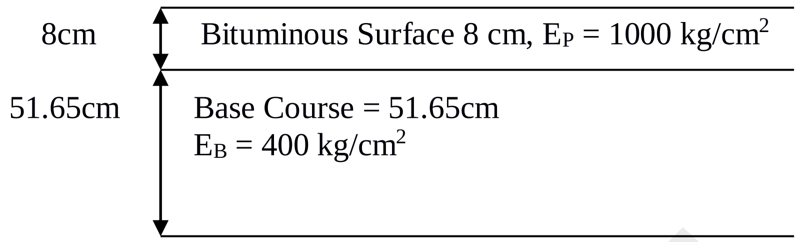
   Let 8cm bituminous surface with E_P = 1000kg/cm^2 be equivalent to the thickness 'T' of base course.
   The equivalent replacement t_B is obtained from the relation,

$$\left[\frac{t_B}{t_P}\right] = \left[\frac{E_P}{E_B}\right]^{1/3}$$

$$\left[\frac{t_B}{8}\right] = \left[\frac{1000}{400}\right]^{1/3}$$

$$t_B = 12.65cm$$

The required base course thickness = 64.3 – 12.65
= 51.65 cm



CBR Method – California Bearing Ratio Method

This method was originally developed in 1928-29 by California Division of Highways (U.S.A) for pavement design. The original curves were developed by O.J. Porter and later modified by U.S Corps of Engineers.

CBR tests were carried out by the California State Highways Department on existing layers including subgrade, sub-base and base course. From the data collected on the existing pavements which behaved satisfactorily and as well as which failed, empirical design curves were developed correlating CBR values and pavement thickness. The original curves as shown in the figure below were developed for 3175kg and 5443kg total wheel loads representing light and heavy traffic.

Later design curves for 4082kg wheel load were designed by interpolation for medium traffic.

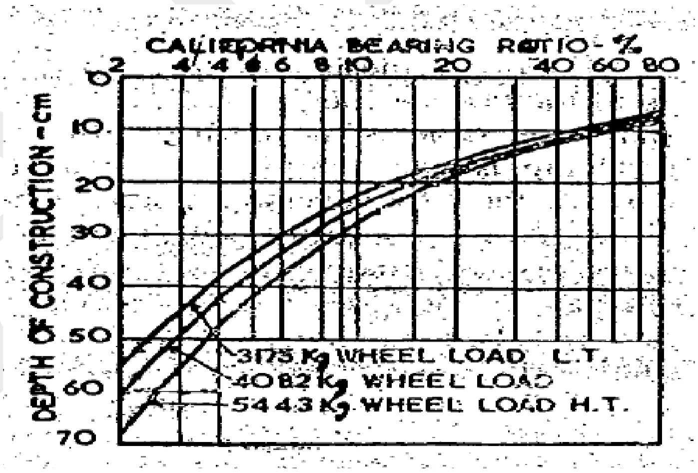


Fig: Original CBR design Chart

It is the most widely used method for all designs of flexible pavements.

Procedure for the Test:

1) The laboratory CBR apparatus consists of a mould 150mm diameter with a base plate and a collar, a loading frame with a cylindrical plunger of 50mm diameter and dial gauges for measuring the expansion on soaking and the penetration values.

2) The specimen in the mould is compacted to a dry density corresponding to the minimum state of compaction likely to be achieved in practice.
3) The specimen is subjected to four days soaking and the swelling and water absorption values are noted.
4) The surcharge weight is placed on the top of the specimen in the mould and the assembly is placed under the plunger of the loading same as shown in the figure.
5) The load values are noted corresponding to penetration values of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0 and 12.5mm.
6) The load-penetration graph is plotted as shown in the graph.
7) Two typical types of load-penetration curves may be obtained as shown in the graph.
8) The normal curve is with convexity upwards as for specimen 1 and the loads corresponding to 2.5- and 5.0-mm penetration values are noted.
9) Sometimes a curve with initial upward concavity is obtained indicating the necessity of correction as can be seen for specimen 2 in the graph.
10) The corrected origin is established by drawing a tangent from the steepest point on the curve to obtain the corrected origin. The load values corresponding to 2.5 and 5.0mm penetration values from the corrected origin are noted.

CBR value is calculated using the relation,

$$\text{CBR \%} = \frac{\left[\begin{array}{l}\text{Load (or pressure) sustained by the} \\ \text{specimen at 2.5 or 5.0mm penetration}\end{array}\right]}{\left[\begin{array}{l}\text{Load (or pressure) sustained by std. aggregates} \\ \text{at the corresponding penetration level}\end{array}\right]} \times 100$$

Normally, the CBR value at 2.5mm penetration is higher than that at 5.0mm and the higher value is reported as the CBR value of the material.

Procedure for Designing:

For designing a pavement, first of all, the CBR value of the soaked material of subgrade is determined and the corresponding total thickness of the pavement required is read from the curve.

The total thickness obtained is further sub-divided into sub-base, base and surfacing by knowing their respective CBR values. The thickness of each layer to the constructed above the particular type of material can be obtained from the curves. It requires that each layer must be of higher quality than the layer just below it.

On the basis of their studies, the U.S. Corps of Engineers have shown that the pavement thickness, wheel load, tyre pressure and CBR have a definite relationship within a limit of 10 to 20% error. Thus, they have suggested the following equation to find out the pavement thickness,

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

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

where, t = pavement thickness in cms
p = tyre pressure in kg/cm^2
P = wheel load in kg
A = area of contact in cm^2

Problem

1) Find out the total thickness of a flexible pavement for the following data using U.S Corps of Engineers formula.
CBR value of subgrade = 4%
Wheel load = 4100kg
Tyre pressure = 6 kg/cm^2

Solution:

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

$$t = \sqrt{4100}\left[\frac{1.75}{4} - \frac{1}{\pi x 6}\right]^{1/2}$$

t = 64 x 0.62

t = 39.7cm ≈ 40cm

IRC Method – IRC: 37-1970

Regarding the use of CBR design method, Indian Road Congress has made certain recommendations. They are:

1) Standard test procedure should be strictly adhered.
2) For design of new pavements, if suitable equipments are available, the subgrade soil samples should be compacted at optimum moisture content to proctor density in the field.
3) For design of new pavements, in areas of heavy rainfall, the CBR test should be performed on samples soaked in water for four days before testing.
4) In areas where rainfall is less than 50cms and water table is too deep to affect the subgrade adversely and when thick and impermeable bituminous surfacing is often provided.
5) 50cms thick top layer of subgrade should be compacted at least upto 95 to 100% of proctor density.
6) The estimated traffic using the pavement at the end of its expected useful life should be estimated on the basis of existing traffic and probable future increase in the traffic. The maximum life of major pavements may be taken as 10 years. For traffic prediction the following formula is used:

$$A = P\,[1 + r]^{n+10}$$

where, A = No. of heavy vehicles per day for design.
P = No. of heavy vehicles per day on the last count.
r = Annual rate of increase of heavy vehicles.
n = No. of years between the last count and the year of completion of construction.

7) For design purposes, the traffic is counted in terms of heavy vehicles per day- in both directions divided into seven groups A, B, C, D, E, F and G as shown in figure below.

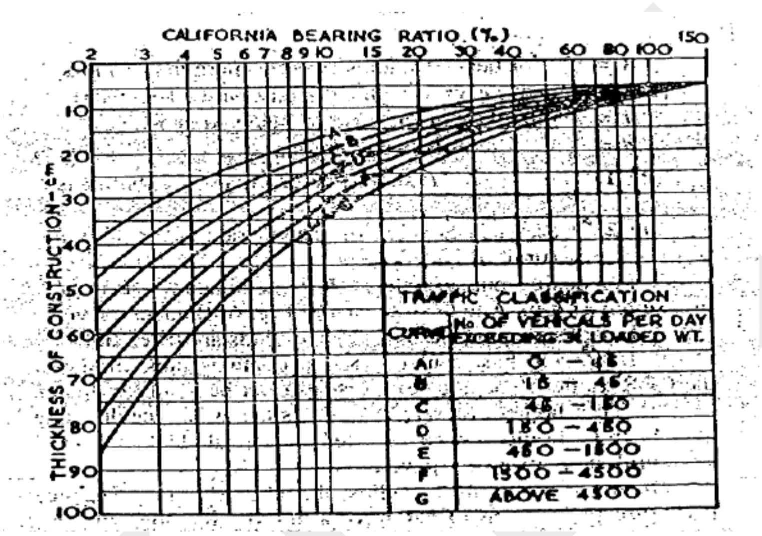


Fig: CBR Design chart (IRC)

8) For design purposes single axle loads are taken upto 8200kg and tandem axle loads upto 14500 kg.
9) If the sub-base course material contains substantial proportion of aggregates of size more than 20mm, the CBR value of such materials would not be valid for design of subsequent layer above them.

Problems

1) Design a flexible pavement for average traffic of about 2000 vehicles exceeding 3 tonnes loaded weight. The CBR of subgrade is 4.0. The compacted sub-base of poorly graded gravel layer has a CBR value as 20.0. The base material has a CBR of 60. The pavement will have a bituminous surfacing.

Solution:

For the given loads, use curve F

i. Total thickness above subgrade for CBR = 4% = 55cm
ii. Thickness above sub-base whose CBR is 20% = 20cm
iii. Thickness above base whose CBR is 60% = 10cm

a) Thickness of sub-base = 55 - 20 = 35cm
b) Thickness of base = 20 - 10 = 10cm
c) Thickness of surfacing = 10cm

2) The penetration test on the subgrade soil of a road project gave the following results.

Load in kg	5	15	25	30	40	50	65	69	85	90	100	107
Penetration in mm	0.8	1.0	1.3	1.5	1.85	2.4	3.0	4.0	5.5	7.1	10.0	12.5

Further the CBR values of different layers were desired as follows:

a) Compacted soil subgrade = 7%
b) Poorly graded gravel layer = 20%
c) Well graded gravel layer = 90%
d) Minimum thickness of bituminous concrete surfacing as 5cms

Design the pavement for 4000 commercial vehicles by IRC Curve.

Solution:
Load at 2.5mm penetration = 62kg
Load at 5mm penetration = 82kg

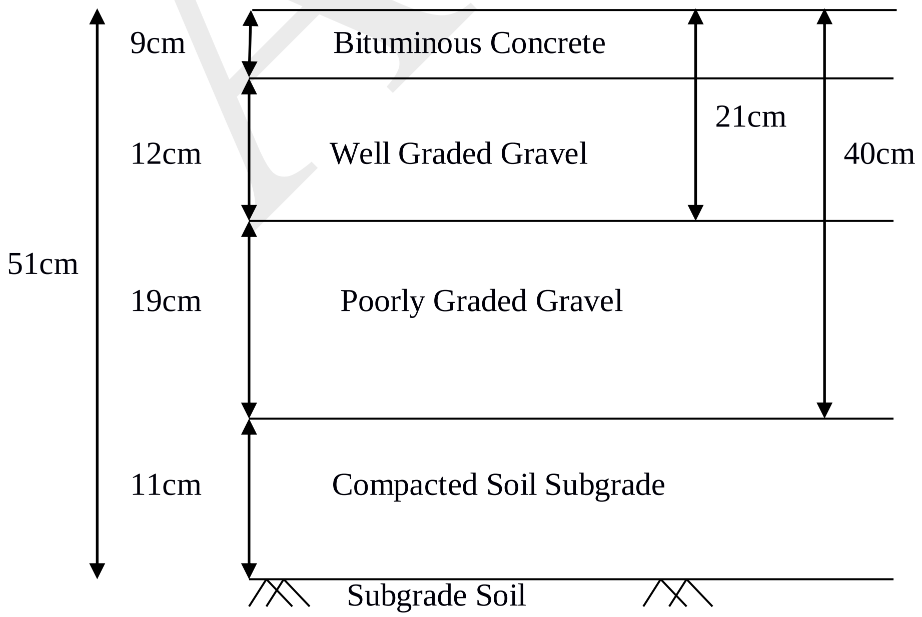
$$\text{CBR at 2.5mm} = \frac{62}{1370} \times 100 = 4.5\%$$

$$\text{CBR at 5mm} = \frac{82}{2055} \times 100 = 4\%$$

Using the higher value, CBR = 4.5% is adopted
For vehicular traffic of 4000, Curve F is used.

The pavement thickness required to curve the subgrade natural soil = 51cm. For compacted soil subgrade having CBR = 7%, thickness = 40cms. Similarly, thickness of cover required for poorly graded gravel having CBR = 20% = 21cm and thickness to cover graded gravel layer having CBR = 90% = 9cm.

i. Total thickness above subgrade = 51cm
ii. Compacted soil subgrade = 51 - 40 = 11cm
iii. Poorly graded gravel layer = 40 – 21 = 19cm
iv. Well graded gravel layer = 21 – 9 = 12cm
v. Bituminous surfacing = 9cm



3) Soil subgrade sample was obtained from the project site and the CBR test was conducted at field density. The following were the results:

Penetration (mm)	0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	7.5	10.0	12.5
Load (kg)	0	5	16.2	28.1	40	53	56.5	67.5	76.5	89	99.5	106.5

It is desired to use the following materials for different pavement layers.

a) Compacted sandy soil with 7% CBR
b) Poorly graded gravel with 20% CBR
c) Well graded gravel with 95% CBR
d) Minimum thickness of bituminous concrete surfacing may be taken as 5cm.

The traffic survey revealed the present ADT of commercial vehicle as 1200. The annual rate of growth of traffic is found to be 8%. The pavement construction is to be completed in 3 years after the last traffic count.

a) Design the pavement section by CBR method as recommended by IRC using all the four pavement materials.
b) Suggest alternate design without using poorly graded gravel.

Solution:

Load at 2.5mm penetration = 53kg

Load at 5mm penetration = 76.5kg

CBR at 2.5 = $\frac{53}{1370} \times 100 = 3.87\% \approx 3.9\%$

CBR at 5.0 = $\frac{76.5}{2055} \times 100 = 3.72\%$

Using the higher value, the CBR value is 3.90%, say 4%

No. of commercial vehicle can be estimated from the relation,

$$A = P\,[1 + r]^{\,n+10}$$

$$A = 1200 \times [1 + (8/100)]^{\,3+10}$$

$$A = 3264 \text{ vehicles/day}$$

The design curve ‘F’ is to be used for design as the design traffic volume is in the range of 1500 – 4500 commercial vehicles/ day.

Therefore, total pavement thickness over the subgrade having a CBR of 4% is obtained as 55cm.

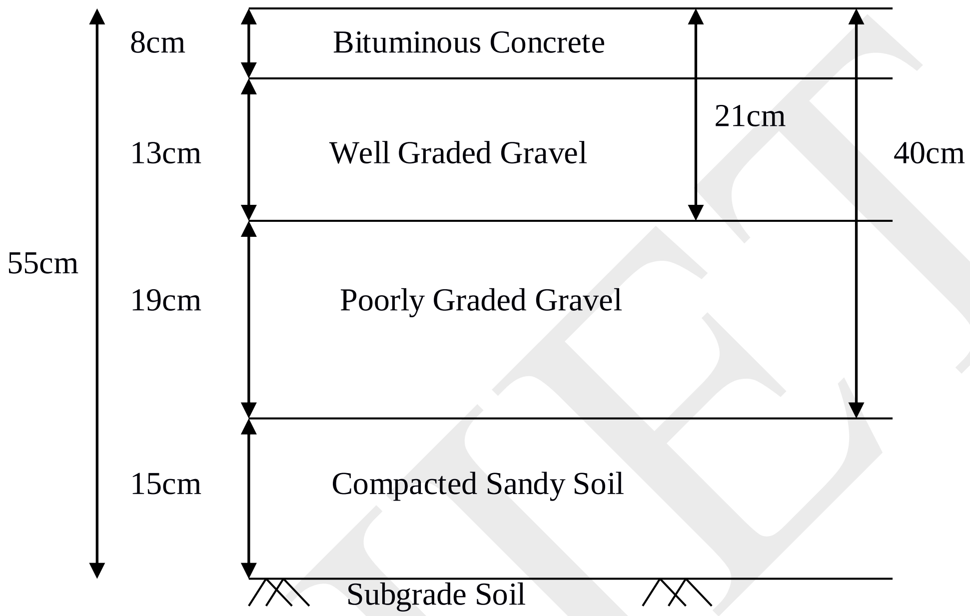
a) To compute the thickness of compacted soil, the design curve F is again used:
   i. Pavement thickness of 40cm is required above the compacted soil subgrade having CBR value of 7%.

      Hence, the actual thickness of this layer = 55 – 40
      = 15cm

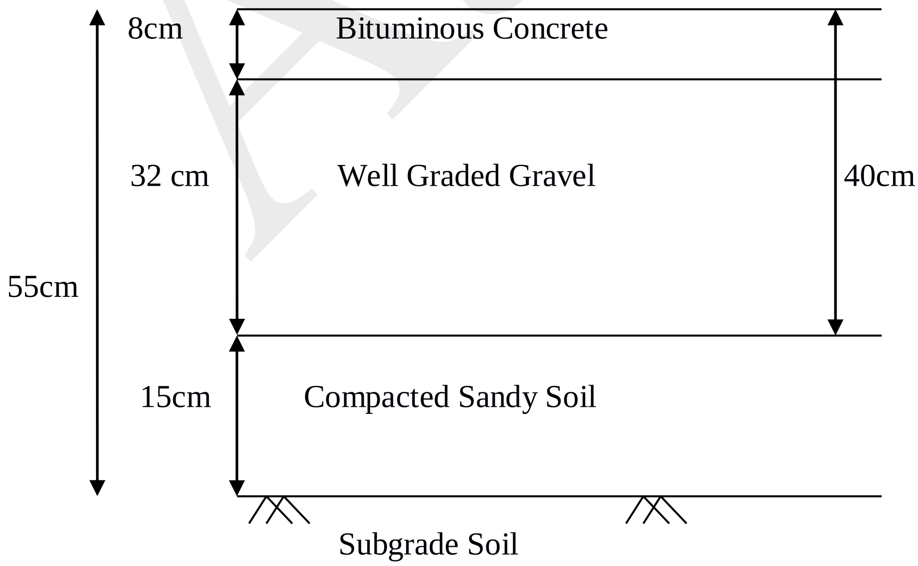
ii. Similarly, the thickness of pavement required over poorly graded gravel of CBR 20% is 21cm
   Hence, Actual thickness = 40 – 21 = 19cm

iii. For well graded gravel with 95% of CBR,
   Thickness of pavement required = 21 – 8
   = 13cm

Take bituminous concrete surfacing between 5 to 8 cm



b) Alternate design without poorly graded gravel i.e., replacing poorly graded gravel by well graded gravel of CBR = 95%



4) Soil subgrade sample was obtained from the project site and the CBR test was conducted at field density. The following were the results:

Penetration (mm)	0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	7.5	10.0	12.5
Load Dial Readings (divisions)	0	8	15	23	29	34	37	43	48	57	63	67

Determine the CBR value of the soil if 100 divisions of load dial represent 190kg in the calibration chart of proving ring chart. It is desired to use the following materials for different layers.

i. Compacted sandy soil, 8% CBR
ii. Poorly graded gravel, 21% CBR
iii. Well graded gravel, 90% CBR

Minimum thickness of bituminous concrete surfacing may be taken as 5cm. The traffic survey revealed that the present ADT of commercial vehicles as 1000. The annual rate of growth of traffic is 7.5%. The pavement construction is to be completed in 3 years after the last traffic count.

Design the pavement section by CBR Method as recommended by IRC: 37-1970 using all the four-pavement material.

Solution:

Penetration (mm)	0	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	7.5	10.0	12.5
Load (kg)	0	15.2	28.5	43.7	55.1	64.6	70.3	81.7	91.2	108.3	119.7	127.3

100 divisions $\longrightarrow$ 190kg

8 divisions $\longrightarrow$? $\quad \frac{8 \times 190}{100} = 15.2$ kg

Load at 2.5 mm penetration = 64.6 kg

Load at 5.0 mm penetration = 91.2 kg

CBR at 2.5 mm = $\frac{64.6}{1370} \times 100 = 4.7\%$

CBR at 5.0 mm = $\frac{91.2}{2055} \times 100 = 4.4\%$

Using the higher value, CBR value is 4.7% ≈ 5%.

No. of commercial vehicle can be estimated from the relation

$$A = P\,[1 + r]^{\,n+10}$$

$$A = 1000 \times [1 + (7.5/100)]^{3+10}$$

$$A = 2561 \text{ vehicles/day}$$

The design curve ‘F’ is to be used for design, as the design traffic volume is in the range of 1500 – 4500 commercial vehicles/ day.

Therefore, total pavement thickness over the subgrade having a CBR of 5% is obtained as 48cm.

a) To compute the thickness of compacted soil, the design curve F is again used,

i. Pavement thickness of 37cm is required above the compacted soil subgrade having CBR value of 8%.

Therefore, Actual thickness of this layer = 48 – 37 = 11cm

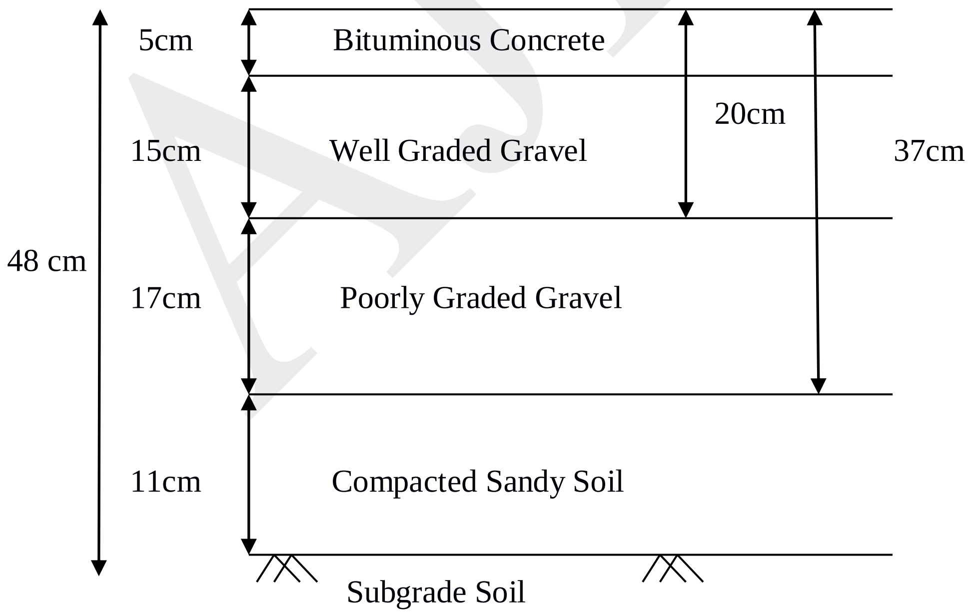
ii. Similarly, the thickness of pavement required over poorly graded gravel of CBR 21% is 20cm.

Therefore, Actual thickness = 37 – 20 = 17cm

iii. For well graded gravel with 90% CBR,

Thickness of pavement required = 20 - 5 = 15cm

Take bituminous concrete surfacing as 5cm.



CSA Method Using IRC: 37-2001

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

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

where, N = Cumulative number of standard axles to be catered for in the design in terms of msa

A = Initial traffic in the year of completion of construction in terms of the number of commercial vehicles per day.

D = Lane Distribution Factor

F = Vehicle Damage Factor

n = Design life in years

r = Annual growth rate of commercial vehicles

The traffic in the year of completion is estimated using the following formula:

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

Where, P = Number of commercial vehicles as per last count.

x = Number of years between the last count and the year of completion of construction

Problems

1) Design a flexible pavement for a full design life of 15 years for the following data as per IRC: 37 – 2001.

i. Two –lane carriageway
ii. Initial traffic = 2000 CV
iii. Growth rate = 8%
iv. Vehicle Damage Factor = 6
v. Design CBR = 4%
vi. No. of years of construction = 2 years

Solution:

i. $A = P (1 + r)^{x}$

$A = 2000 \times (1 + 0.08)^{2}$

$A = 2332.8 \approx 2333$ CVPD

ii. Lane Distribution Factor (LDF), D = 75% = 0.75

iii. Cumulative number of standard axles to be catered for in the design

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

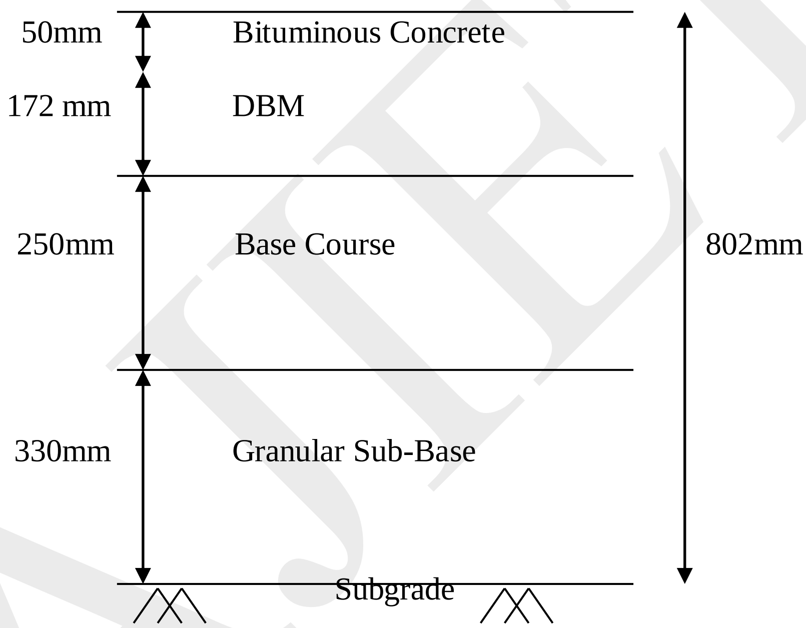
$$N = \frac{365 \times [(1 + 0.08)^{15} - 1]}{0.08} \times 2333 \times 0.75 \times 6$$

$$N = 104 \times 10^6 \text{ sa} = 104 \text{ msa}$$

From figure 2 of IRC: 37- 2001,
Total thickness of pavement = 802mm

From the charts on Pg. 31 of IRC: 37- 2001 corresponding to 4% CBR and 10-150msa range, the thickness of various pavement layers are as follows:

a) Bituminous surfacing = (50 BC + 172 DBM) mm
b) Granular base = 250mm
c) Granular sub-base = 330mm



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

i. Two – lane single carriageway

ii. Initial traffic in the year of completion of construction = 400 CVPD (in both directions)

iii. Traffic growth rate per annum = 7.5 percent = 0.075

iv. Design life = 15 years

v. Vehicle damage factor = 2.5 (std. axles per commercial vehicles)

vi. Design CBR of subgrade soil = 4%

Solution:

i. Lane Distribution Factor (L.D.F), D = 0.75 (pg.13)

ii. Cumulative number of standard axles to be catered for in the design,

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

$$N = \frac{365 \times [(1 + 0.075)^{15} - 1]}{0.075} \times 400 \times 0.75 \times 2.5$$

$$N = 7.15 \times 10^{6} = 7.15 \text{ msa}$$

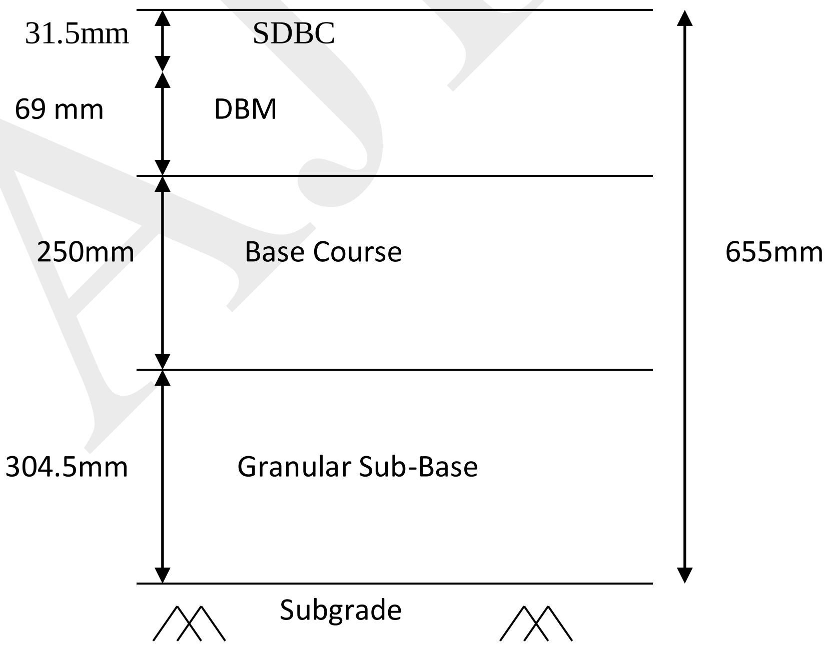
iii. Total pavement thickness for CBR 4% and traffic 7.15msa = 655mm

iv. Pavement Composition

a) Bituminous surfacing = (31.5 SDBC + 69 DBM) mm

b) Granular base = 250 mm

c) Granular sub-base = 304.5 mm



3) It is proposed to widen an existing two – lane NH section to four-lane divided road. Design the pavement for new carriage-way with the following data:

    i. Four-lane divided carriageway
    ii. Initial traffic in both direction in the year of completion of construction = 5600 CVPD
    iii. Design life = 10/15 years
    iv. Design CBR of subgrade soil = 5 percent
    v. Traffic growth rate = 8 percent
    vi. Vehicle damage factor = 4.5 std. axles / CV

Solution:

i. Lane Distribution Factor (L.D.F), D = 0.4

ii. Vehicle Damage Factor, F = 4.5

iii. Cumulative number of standard axles to be catered during

a) Design life of 10 years,

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

$$N = \frac{365 \times [(1 + 0.08)^{10} - 1]}{0.08} \times 5600 \times 0.4 \times 4.5$$

$$N = 53.3 \times 10^{6} \text{ sa} = 53.3 \text{ msa} \approx 53 \text{ msa}$$

b) Design life of 15 years,

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

$$N = \frac{365 \times [(1 + 0.08)^{15} - 1]}{0.08} \times 5600 \times 0.4 \times 4.5$$

$$N = 99.9 \times 10^{6} \text{ sa} \approx 100 \text{ msa}$$

iv. Pavement Composition for CBR = 5%

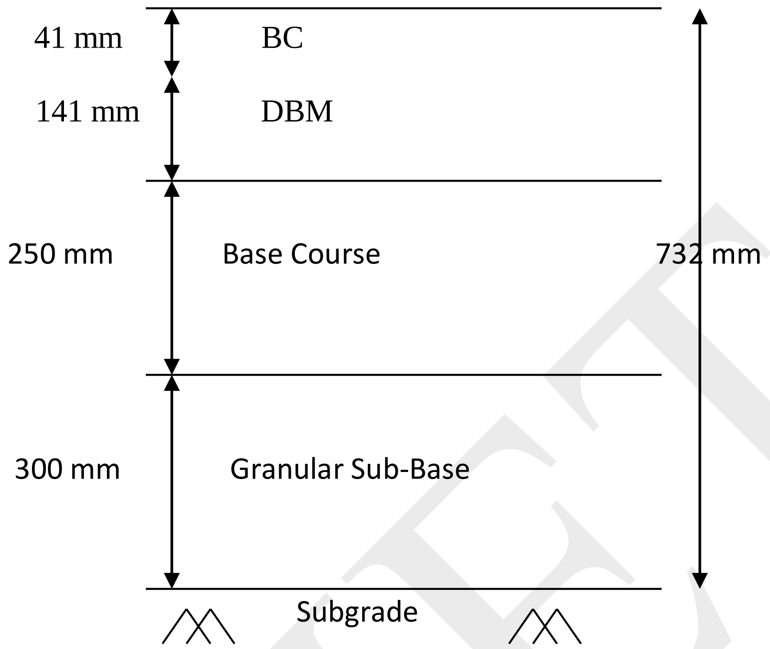
a) Total pavement thickness for 53 msa = 732 mm

Pavement composition:

i. Bituminous surfacing = (41 BC + 141 DBM) mm

ii. Granular sub-base = 300 mm

iii. Granular base = 250 mm



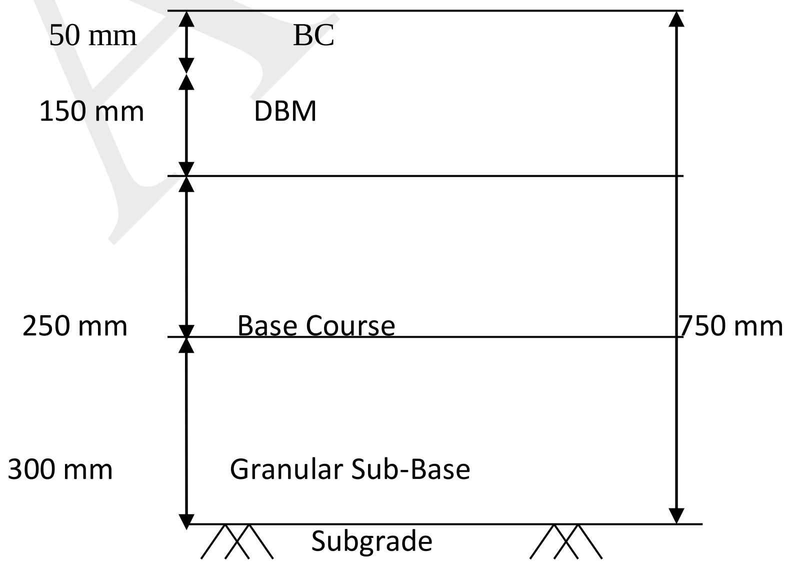
b) Total pavement thickness for 100 msa = 750 mm

Pavement composition:

i. Bituminous surfacing = (50 BC + 150 DBM) mm

ii. Granular base = 250 mm

iii. Granular sub-base = 300 mm



4) Design the flexible pavement as per IRC: 37-2001 for construction of new highway for the following data:

i. No. of commercial vehicle as per last count = 1200 CV

ii. Period of construction = 3 years

iii. Annual growth rate = 7.5%

iv. Design CBR of soil = 10%

v. Two lane carriageways

vi. Design life = 15 years

vii. VDF = 3.5

viii. LDF = 75%

Solution:

i. Initial traffic in the year of completion in terms of CVPD,

$$A = P (1 + r)^{x}$$
$$A = 1200 \times (1 + 0.075)^{3}$$
$$A = 1491 \text{ CVPD}$$

ii. Cumulative number of standard axles to be catered during a design life of 15 years,

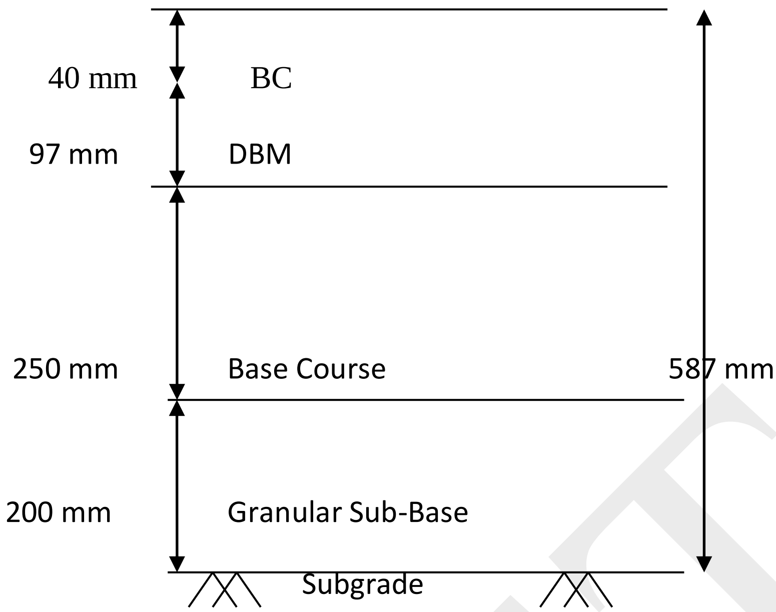
$$N = \frac{365 \times [(1 + r)^{n} - 1]}{r} \times A \times D \times F$$

$$N = \frac{365 \times [(1 + 0.075)^{15} - 1]}{0.075} \times 1491 \times 0.75 \times 3.5$$

$$N = 37.3 \times 10^{6} \text{ sa} \approx 37.3 \text{ msa}$$

iii. From figure 2, for CBR = 10 % and N = 37.3 msa
Total thickness of pavement = 587 mm

iv. Pavement Composition:
a) Bituminous surfacing = (40 BC + 97 DBM) mm
b) Granular base = 250 mm
c) Granular sub-base = 200 mm



5) Design the pavement of a two-way road on a soil of CBR 4% for an initial traffic of 1200 CVPD. The period of construction is 5 years and the design life is 12 years after opening to traffic. The VDF is 2.0. The rate of growth of traffic is 8% per annum.

Solution:

i. Lane Distribution Factor, D = 0.75

ii. Cumulative number of standard axles to be catered for in the design,

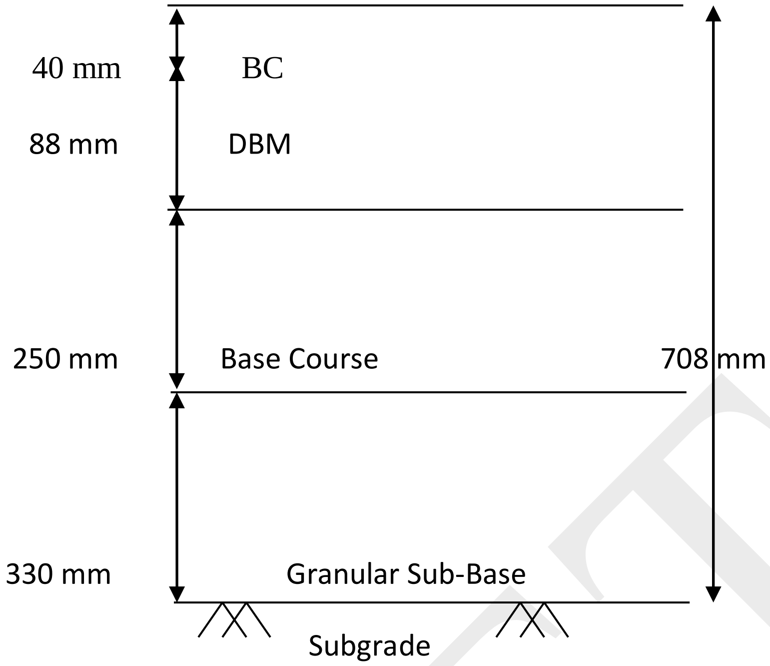
$$N = \frac{365 \times [(1 + r)^{n} - 1]}{r} \times A \times D \times F$$

$$N = \frac{365 \times [(1 + 0.08)^{12} - 1]}{0.08} \times 1200 \times 0.75 \times 2$$

$$N = 12.5 \times 10^{6} \text{ sa} \approx 12.5 \text{ msa}$$

iii. From figure 2, for CBR = 4% and N = 12.5 msa,
Total thickness of pavement = 708 mm

iv. Pavement Composition:
a) Bituminous surfacing = (40 BC + 88 DBM) mm
b) Granular base = 250 mm
c) Granular sub-base = 330mm



6) It is proposed for a NH (four-lane single carriage way road). Design the pavement as per IRC: 37-2001, using the following data:

i. Initial traffic in the year of completion of construction = 6000 CVP
ii. Design life = 10 years
iii. Design CBR of soil subgrade = 4%
iv. Traffic growth rate = 9%
v. Vehicle Damage Factor = 3.5

Solution:

i. Lane Distribution Factor, D = 40% = 0.4
ii. Cumulative number of standard axles to be catered for in the design,

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

$$N = \frac{365 \times [(1+0.09)^{10} - 1]}{0.09} \times 6000 \times 0.4 \times 3.5$$

$$N = 46.58 \times 10^6 \text{ sa} = 46.58 \text{ msa}$$

iii. From figure 2, for CBR = 4% and N = 46.58 msa,
Total thickness of pavement = 775 mm

iv. Pavement Composition:

d) Bituminous surfacing = (40 BC + 155 DBM) mm
e) Granular base = 250 mm
f) Granular sub-base = 330mm