G. S. Mandal's
Maharashtra Institute of Technology, Aurangabad.
Department of Civil Engineering

Highway Engineering (CED 403)

(Class : B. Tech. final year)

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Design of Flexible & Rigid Pavement

Contents:

A. Design of Flexible pavement.

- *Design parameter.*
- *Equivalent Single wheel load (ESWL).*
- *Group Index Method.*
- *CBR & Modified CBR Method.*

Difference between Flexible & Rigid Pavement

Sr. No.		Flexible Pavement	Rigid Pavement
1	IRC Code	• IRC: 37	• IRC: 58
2	Layers	1. Surface Coarse (BC) 2. Base Coarse (WBM or WMM) 3. Subbase Coarse (GSB) 4. Subgrade (C-ϕ Soil).	1. Surface Coarse (PCC or RCC) 2. Base Coarse (DLC or WMM) 3. Subgrade (C-ϕ Soil).
3	Load Transformation	• Load Transformation is grain to grain.	• Load Transformation is layer to layer.
4	Failure Nature	• If there is any failure at bottom layer then the failure will be appear at top.	• If there is any failure at bottom layer then for small cavity slab will act as a bridge over it.
5	Joints	• Joints are absent.	• Joints are present.
6	Cost	• Initial cost is low but maintenance cost is high.	• Initial cost is high but maintenance cost is low.

Semi Rigid Pavement:

- *If subbase & base coarse of flexible pavement is replaced by Pozzolanic concrete (Lime + Fly Ash + Aggregate), then the strength of pavement is increases, is known as Semi Rigid Pavement.*
- *Strength of semi rigid pavement is more than flexible pavement but less than rigid pavement.*

Composite Pavement:

- *If Bituminous layer is provided as the top layer over cement concrete pavement, it is known as Composite pavement.*

Design of Flexible pavement

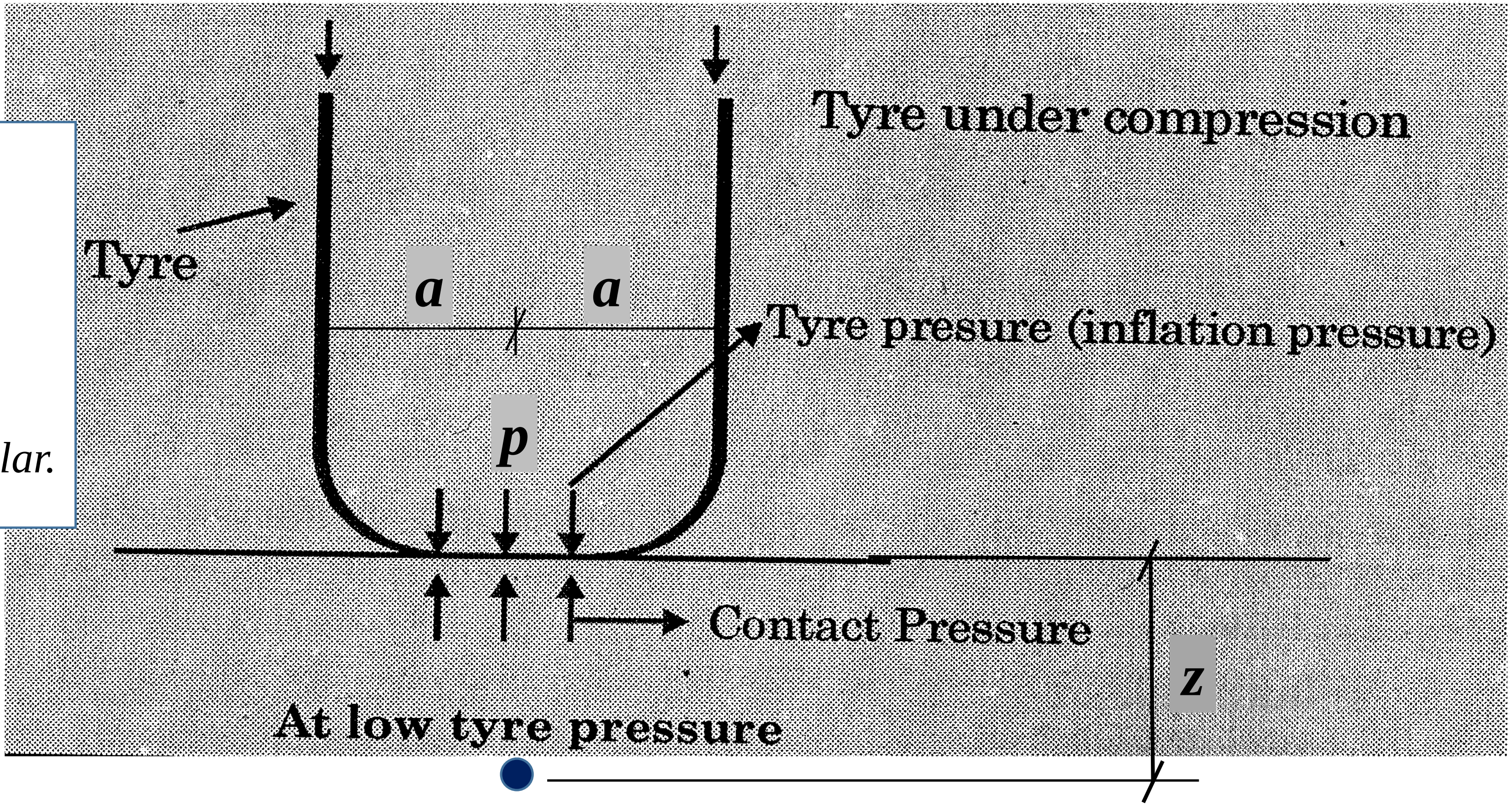
Design Parameter:

1. *Standard Axle Load:*

- *Maximum legal axle load = 8170 kg = 8.2 tonnes (For Single wheel assembly)*
- *Maximum legal axle load = 10.2 tonnes (For dual wheel assembly)*

2. *Stress at any depth (z):*

Where,
z = Depth below tyre pressure;
p = Contact Pressure or Tyre pressure
a = Radius of Contact area.
Assumed Contact Area: Circular
Actual Contact Area: Elliptical or Rectangular.



3. Rigidity Factor (R.F.) = It is the ratio of Contact Pressure and Tyre Pressure

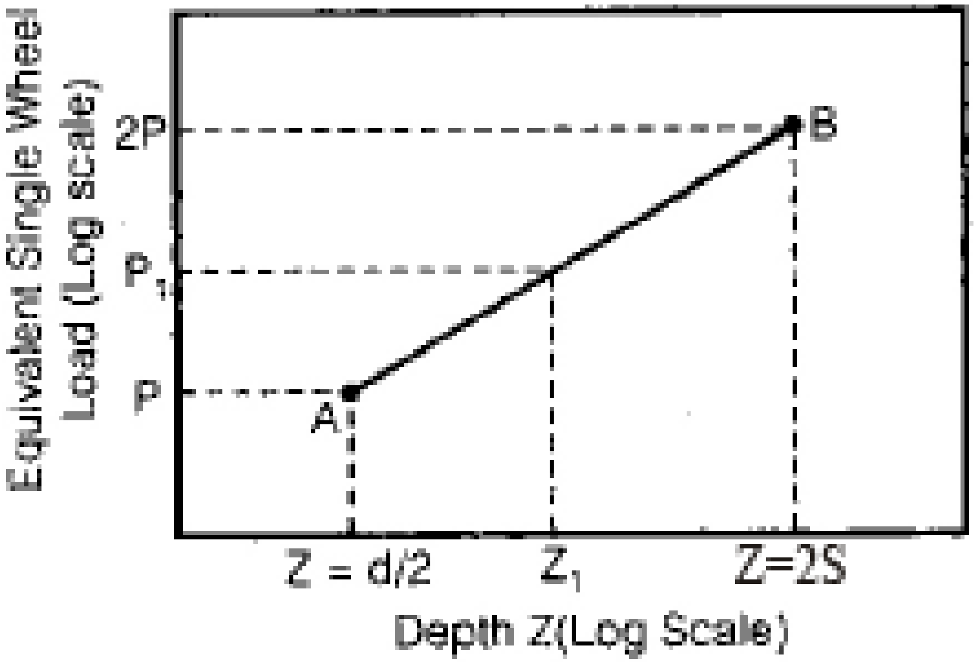
For the design, Contact pressure = Tyre pressure = 7 kg/cm2

= Wheel load / Contact Area

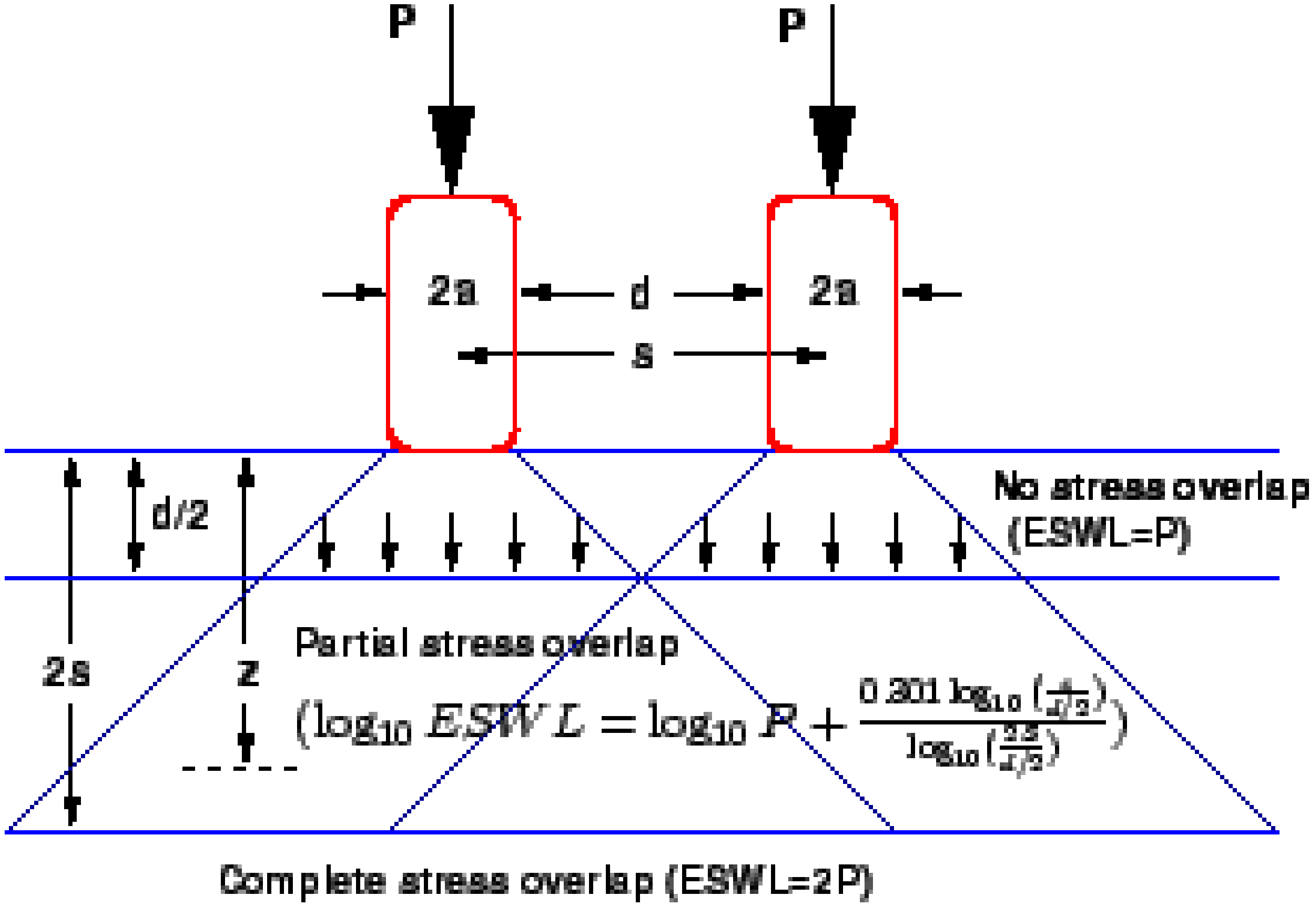
- *At high tyre pressure, tyre come under tension. Hence contact pressure is less than tyre pressure.*
- *Rigidity factor = Contact pressure/tyre pressure*
- *Generally for design purpose,*
- *Tyre pressure = 0.7 Mpa, Rigidity factor = 1*
- *Tyre pressure > 0.7 Mpa, Rigidity factor < 1*
- *Tyre pressure < 0.7 Mpa, Rigidity factor > 1*

Equivalent Single Wheel Load (ESWL):

- *At any depth (z), from graph*
- $\frac{\log(2P)-\log(P)}{\log(2S)-\log(d/2)} = \frac{\log(Pz)-\log(P)}{\log(z)-\log(d/2)}$



Graphical Method for ESWL



Question:

- *Calculate ESWL of a dual wheel assembly carrying 2050 kg load on each wheel for pavement thickness of 5 cm & 15 cm with center to center spacing between tyre is 30 cm and clear distance is 12 cm.*

Answer:

- *Given, P = 2050 kg, d = 12 cm, S = 30 cm*
- *Up to (d/2)= 12/2 = 6 cm, ESWL = 2050 kg*

a. At z = 5 cm < 6 cm , Hence ESWL = 2050 kg

b. At z = 15 cm (In between d/2 & 2S)

- $\frac{log(2P)-log(P)}{log(2S)-log(d/2)} = \frac{log(Pz)-log(P)}{log(z)-log(d/2)}$
- $\frac{log(4100)-log(2050)}{log(60)-log(6)} = \frac{log(Pz)-log(2050)}{log(15)-log(6)}$
- *Log (Pz) = 3.43*
- *Pz = 2701 kg*

Group Index Method

- *It is based on Index Properties of soil.*
- *Index properties are those which are used only for classification of soil such as liquid limit, Plastic limit etc.*

Group Index = 0.2 a + 0.005 ac + 0.01 bd

- *Where, p = % finer passing 75 micron sieve.*

  Wl = Liquid Limit.

  Ip = Plasticity Index (Wl – Wp)

$$a = p - 35 \le 40$$
$$b = p - 15 \le 40$$
$$c = Wl - 40 \le 20$$
$$d = Ip - 10 \le 20$$

- ***Limitation:*** *The quality of pavement material is not considered. Same thickness required even if better quality of material used.*

Note:

- *Group Index value lies between 0 to 20.*
- *An Empirical method based on the physical properties of subgrade soil.*
- *Higher the Group Index value poorer the soil. Hence higher thickness of pavement is require.*
- *Total thickness of pavement depends upon group index value, however thickness of surface coarse and base coarse depends upon GI value and traffic volume both.*

Question:

- *A soil subgrade has following data, Soil portion passing 75 micron sieve = 60 % Liquid limit = 45 % & Plastic limit = 20 %. Find out the thickness of pavement required for above soil subgrade.*

Group Index	**0**	**5**	**10**	**15**	**20**
Thickness (cm)	30	45	62	78	90

Answer:

- *Given, a = p – 35 = 60 – 35 =* ***25 %*** $\leq$ *40*

  b = p – 15 = 60 – 15 = 45 % $\leq$ *40 ……. Take* ***b = 40***

  c = Wl – 40 = 45 – 40 = ***5 %*** $\leq$ *20*

  d = Ip – 10 = (Wl – Wp) – 10

  = (45 – 20) – 10 = ***15 %*** $\leq$ *20*

Group Index = 0.2 a + 0.005 ac + 0.01 bd

*= (0.2 * 25) + (0.005 * 25 * 5) + (0.01 * 40 * 15)*

= ***11.625***

By interpolation method,

Group Index	***Thickness***
X1 = 10	*Y1 = 62*
X2 = 15	*Y2 = 78*
X = 11.625	*Y = ?*

- $\frac{(y-y1)}{(x-x1)} = \frac{(y2-y1)}{(x2-x1)}$
- $\frac{(y-62)}{(11.625-10)} = \frac{(78-62)}{(15-10)}$
- *Y = 67.2 cm*
- *The thickness of pavement layer road above surface layer = 67.2 cm*

California Bearing Ratio Test

IS 2720(Part 16):1987 & RDSO/2009/GE: G-0014

Aim & Objective:

- *To determine the California bearing ratio (CBR) of a compacted soil sample.*
- *CBR is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm (5 cm) diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material.*
- *The ratio is usually determined for penetration of 2.5 mm and 5 mm.*
- *When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.*
- *The following table gives the standard loads adopted for different penetrations for the standard material with a C.B.R. value of 100%.*
- *For Railway Formation purpose, the test is performed on remoulded specimens which are compacted dynamically.*
- *The methodology covers the laboratory method for the determination of C.B.R. of remoulded/compacted soil specimens in soaked state.*

Apparatus:

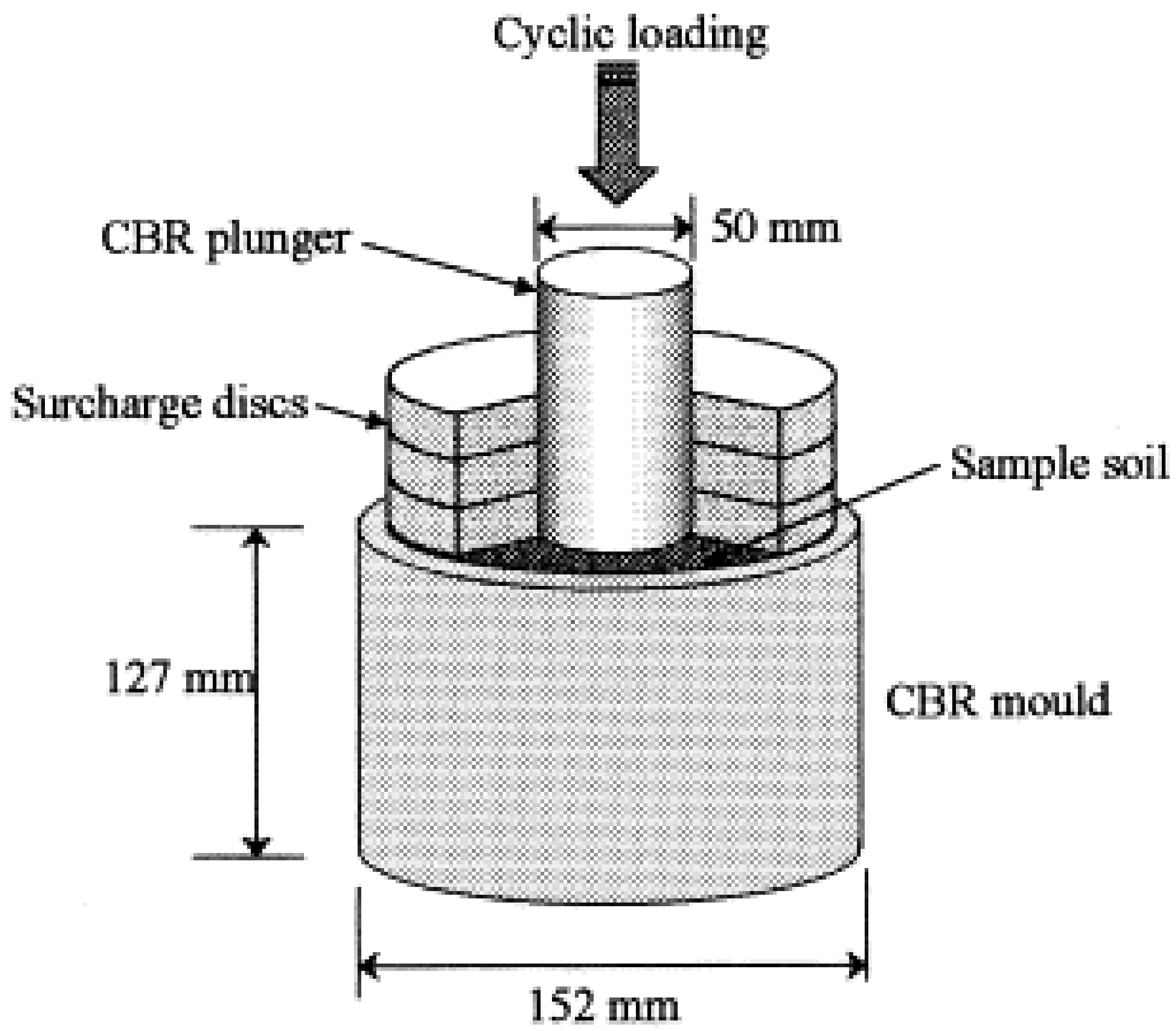
- *CBR Test Apparatus Consisting of Loading machine with capacity of at least 5000 kg and equipped with a movable head or base which enables Plunger of 50 mm dia. to penetrate into the specimen at a rate of 1.25 mm/minute.*
- *CBR Mould with Base Plate, Stay Rod and Wing Nut Cylindrical mould: Inside dia. 150 mm and height 175 mm with a detachable perforated base plate of 235 mm dia. and 10 mm thickness.*
- *Cylindrical mould of net capacity 2250 ml; conforming to IS-9669:1980 (Reaffirmed-2016).*
- *Collar A detachable extension collar of 60 mm height. Spacer Disc 148 mm in diameter and 47.7 mm in height along with handle.*
- *Weights One annular metal weight and several slotted weights weighing 2.5 kg each, 147 mm in diameter, with a central hole 53 mm in diameter.*
- ***Compaction Rammer Weight:***

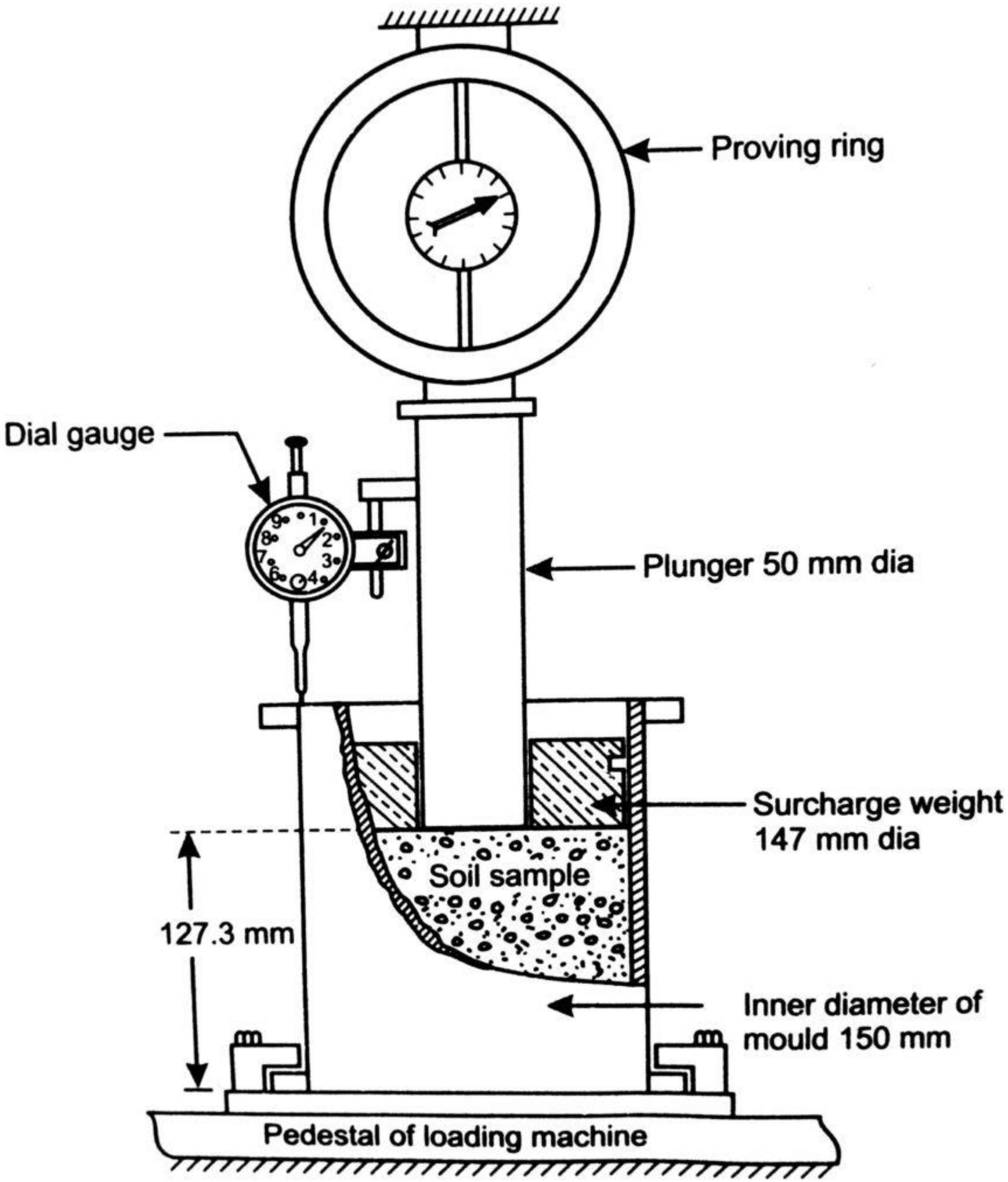
a. *Static Compaction: Compacting soil in loading machine. (Gradually increase load)*
b. *Dynamic Compaction: Compacting soil by specified rammer. (Impact load)*

- *Light Compaction: 2.6 kg with a drop of 310 mm.*
- *Heavy Compaction: 4.89 kg with a drop of 450 mm.*

Theory:

- *The C.B.R test developed by California division of highways as a method of classifying and evaluating soil subgrade and base course materials for flexible pavements.*
- *The C.B.R. is a measure of shearing resistance of the material under controlled density and moisture conditions. The C.B.R. is defined as the ratio of the test load to the standard load, expressed as percentage, for a given penetration of plunger.*
- *Where standard load is the penetration resistance of the plunger into a standard sample of crushed stone for the corresponding penetration.*
- *The Indian Road congress recommends that the test must always be performed on remoulded samples of soil using static compaction whenever possible instead of dynamic compaction.*
- *The CBR values are usually calculated for penetrations of 2.5mm and 5mm and the greater value is used for the design. Generally, the CBR value for 2.5mm penetration will be greater than that at 5mm penetration. However if the CBR value corresponding to a penetration of 5mm exceeds that for 2.5mm, the test is repeated. If identical results follow, the CBR value corresponding to 5mm penetration is taken for design.*


Cyclic loading
CBR plunger
50 mm
Surcharge discs
Sample soil
127 mm
CBR mould
152 mm


Proving ring
Dial gauge
Plunger 50 mm dia
Surcharge weight
147 mm dia
Soil sample
127.3 mm
Inner diameter of
mould 150 mm
Pedestal of loading machine

Test Procedure consist of two parts:

1. *Preparing test specimen.*
2. *Penetration test.*

Preparation Of Test Specimen:

- *Remoulded specimen: The test material should pass 20 mm IS sieve and retained on 4.75 mm IS sieve.*
- *The dry density for a remoulding shall be either the field density or the value of the maximum dry density estimated by the compaction test (Heavy Compaction Test as per IS 2720 (Part-8) -1983, for Railway Formation).*
- *The water content used for compaction shall be the optimum water content or the field moisture as the case may be.*
- *Dynamic Compaction: A representative sample of the soil weighing approximately 4.5 kg or more (5 kg) for fine grained soil and 5.5 kg or more for granular soil shall be taken and mixed thoroughly with water.*

- *If the soil is to be compacted to the maximum dry density at the optimum moisture content, the exact mass of the soil required shall be taken and the necessary quantity of water added so that the water content of the soil sample is equal to the determined optimum moisture content.*
- *Fix the extension collar and the base plate to the mould.*
- *Insert the spacer disc over the base.*
- *Place the filter paper on the top of the spacer disc.*
- *Apply Lubricating Oil to the inner side of the mould.*
- *Compact the mix soil in the mould using heavy compaction. i.e. compact the soil in 5 layers with 56 blows to each layer by the 4.89 kg rammer.*
- *Remove the extension collar and trim the compacted soil carefully at the level of top of mould, by means of a straight edge.*

- *Any holes developed on the surface of the compacted soil by removal of the coarse material, shall be patched with the smaller size material.*
- *Remove the perforated base plate, Spacer disc and filter paper and record the mass of the mould and compacted soil specimen.*
- *Place a disc of coarse filter paper on the perforated base plate, invert the mould and compacted soil and clamp the perforated base plate to the mould with the compacted soil in contact with the filter paper.*
- *Place a filter paper over the specimen and place perforated plate on the compacted soil specimen in the mould.*
- *Put annular weights to produce a surcharge equal to weight of base material and pavement, to the nearest 2.5 kg.*

- *Immerse the mould assembly and weights in a tank of water and soak it for 96 hours.*
- *Mount the tripod for expansion measuring device on the edge of the mould and record initial dial gauge reading.*
- *Note down the readings every day against time of reading.*
- *A constant water level shall be maintained in the tank throughout the period.*
- *At the end of soaking period, note down the final reading of the dial gauge and take the mould out of water tank.*
- *Remove the free water collected in the mould and allow the specimen to drain for 15 minutes.*
- *Remove the perforated plate and the top filter paper.*
- *Weigh the soaked soil sample and record the weight.*

Procedure For Penetration Test:

- *Place the mould assembly with test specimen on the lower plate of penetration testing machine.*
- *To prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight shall be placed on the soil surface prior to seating the penetration plunger after which the remainder of the surcharge weights shall be placed.*
- *Seat the penetration piston at the center of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the piston on the sample is established.*
- *Set the load and deformation gauges to read zero.*
- *Apply the load on the piston so that the penetration rate is about 1.25 mm/min.*
- *Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10 and 12.5 mm.*
- *Raise the plunger and detach the mould from the loading equipment. Take about 20 to 50 g of soil from the top 30 mm layer and determine the moisture content.*

Observation & Recording:

Penetration of Plunger (mm)	*Standard Load (kg)*
2.5	***1370***
5.0	***2055***
7.5	*2630*
10.0	*3180*
12.5	*3600*

- *Proving ring constant = 2.33 kg/Division*

- *Total Energy Ratio or Compaction Ratio:*

$$= \frac{Heavy\ Test}{Light\ Test}$$

$$= \frac{5 * 4.89 * 45 * 56}{3 * 2.6 * 31 * 56} = \mathbf{4.56}$$

Penetration (mm)	*Applied load (kg)*
0.0	*0.0*
0.5	*39.6*
1.0	*81.6*
1.5	*121.2*
2.0	*142.1*
2.5	*156.1*
3.0	*170.1*
4.0	*193.4*
5.0	*214.4*
7.5	*268.0*
10.0	*314.6*
12.5	*358.8*

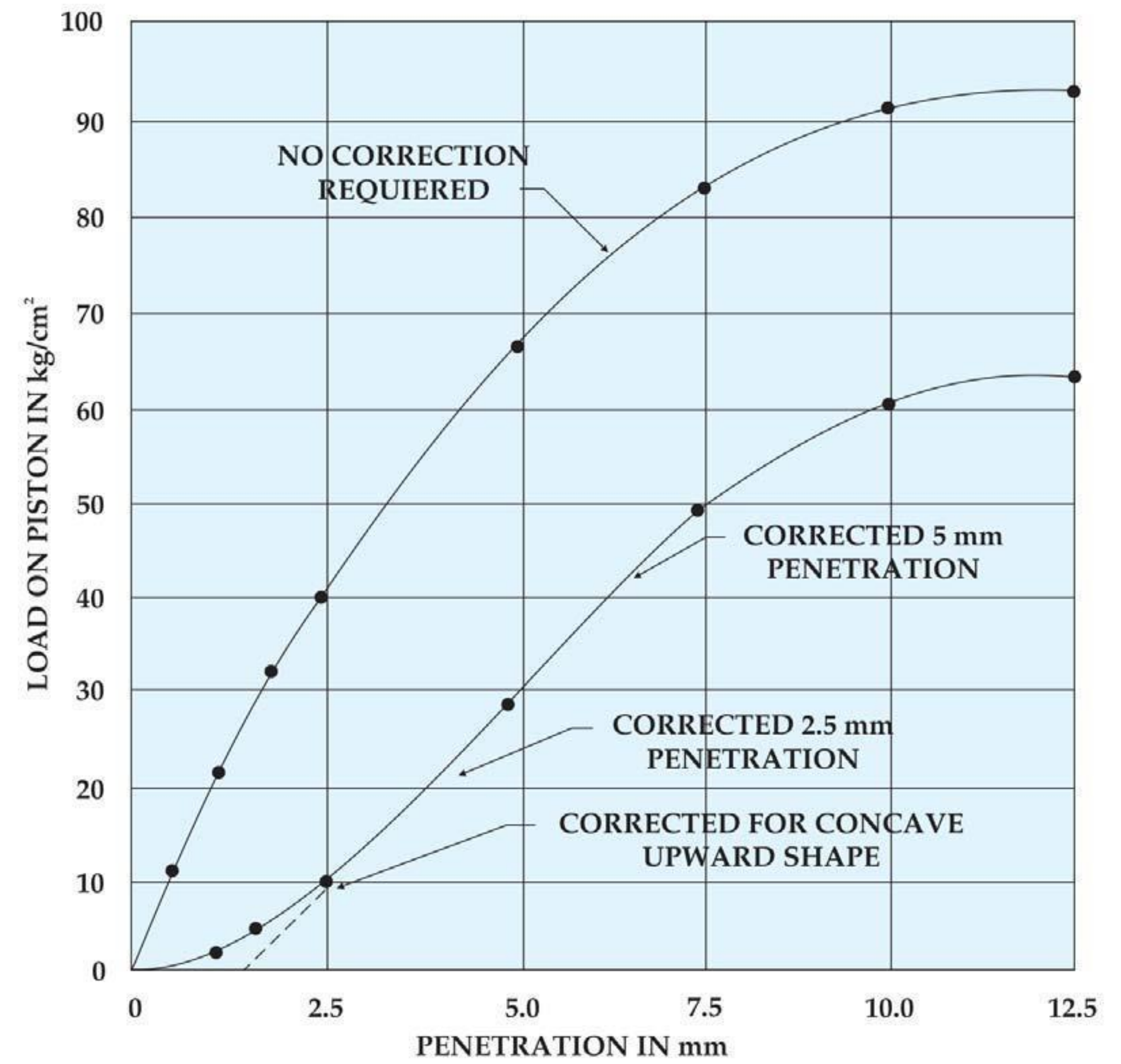
Calculations & Result:

- *If the initial portion of the curve is concave upwards, apply correction by drawing a tangent to the curve at the point of greatest slope and shift the origin.*
- *Find and record the correct load reading corresponding to each penetration.*
- ***C.B.R.*** $= \dfrac{\textbf{\textit{Corrected test load}}}{\textbf{\textit{Standard load}}} * 100$
- *CBR at 2.5 mm (%)* $= \dfrac{156.4}{1370} \times 100 = \mathbf{11.4\%}$
- *CBR at 5.0 mm (%)* $= \dfrac{214.4}{2055} \times 100 = 10.4\%$
- *Therefore, the California bearing ratio of sample = 11.4%*
- *The C.B.R. values are usually calculated for penetration of 2.5 mm and 5 mm. Generally the C.B.R. value at 2.5 mm will be greater than at 5 mm and in such a case/the former shall be taken as C.B.R. for design purpose.*
- *If C.B.R. for 5 mm exceeds that for 2.5 mm, the test should be repeated. If identical results follow, the C.B.R. corresponding to 5 mm penetration should be taken for design.*

Graph:

Plot the load penetration curve. If the curve is convex upwards, no correction is required. On the other hand if the initial portion of the curve is concave upwards a correction should be applied by drawing a tangent to the curve at the point of greatest slope and the point where this tangent meets the abscissa is the new origin.

Dynamic Compaction	**Light Compaction**	**Heavy Compaction**
• *No. of layers*	*03 layers*	*05 layers*
• *Rammer weight*	*2.6 kg*	*4.89 kg*
• *Free fall height*	*31 cm*	*45 cm*
• *No. of Blows*	*56 blows*	*56 blows*



Penetration Depth	*Unit Standard Load*	*Total Standard Load*
(I)	(2)	(3)
m.m	kg/cm²	kgf
2.5	70	1 370
5.0	105	2 055

Design of thickness of pavement by CBR method:

- *Thickness required above the test layer*
- $T = \sqrt{\dfrac{1.75\,P}{CBR\ (\%)} - \dfrac{P}{\pi p}}$
- *Where,* $\dfrac{P}{\pi p} = \dfrac{P}{\pi(P/A)} = \dfrac{A}{\pi} = \dfrac{\pi a^2}{\pi} = a^2$
- *P = Wheel load in kg*
- *p = Tyre pressure or Contact pressure (kg/cm^2)*

Limitation:

- *Quality of material is not considered.*
- *This relation is not valid for higher value of CBR. (CBR ≤ 12 %)*

Question:

- *CBR test was conducted over soil subgrade and following results were obtained.*
- *Assume curve throughout convex, following material are required to be used over the soil subgrade.*

Penetration (mm)	**2.5**	**5.0**
Load (kg)	*60*	*82*

- *Compact soil (CBR = 6%)*
- *Poorly graded gravel (CBR = 12 %)*
- *Well graded gravel (CBR = 60 %)*
- *Bituminous surface (thickness = 4 cm)*
- *Design the pavement using CBR, if wheel load is 4100 kg & tyre pressure is 7 kg/cm^2.*

Answer:

- *Given, P = 4100 kg*

  p = 7 kg/cm^2

- *CBR value for subgrade,*
- *CBR @ 2.5 mm =* $\left(\frac{60}{1370}\right) * 100 =$ *4.39 %*
- *CBR @ 5.0 mm =* $\left(\frac{82}{2055}\right) * 100 =$ *3.99 %*
- *Therefore, the CBR value for subgrade is 4.39 %.*

Bituminous coarse
Well graded (CBR = 60 %)
Poorly graded (CBR = 12 %)
Compacted Soil (CBR = 6 %)
Subgrade (CBR = 4.39 %)

Step-1: *Thickness required above subgrade.*

- *T1 =* $\sqrt{\frac{1.75\,P}{CBR\ (\%)} - \frac{P}{\pi p}}$
- *T1 =* $\sqrt{\frac{1.75 * 4100}{4.39} - \frac{4100}{\pi * 7}}$ *= 38.15 cm*

Step-2: *Thickness required above compacted layer.*

- *T2 =* $\sqrt{\frac{1.75 * 4100}{6} - \frac{4100}{\pi * 7}}$ *= 31.77 cm*

Step-3: *Thickness required above poorly graded gravel.*

- *T3 =* $\sqrt{\frac{1.75 * 4100}{12} - \frac{4100}{\pi * 7}}$ *= 20.28 cm*

Step-4: Thickness of Individual layers.

- *Compacted layer = T1 – T2 = 38.15 – 31.77 = 6.38 cm*
- *Poorly graded gravel = T2 – T3 = 31.77 – 20.28 = 11.49 cm*
- *Well graded gravel = T3 – 4 = 20.28 – 4 = 16.28 cm*
- *Bituminous coarse = 4 cm.*

Bituminous coarse = 4 cm
Well graded (CBR = 60 %) = 16.28 cm
Poorly graded (CBR = 12 %) = 11.49 cm
Compacted Soil (CBR = 6 %) = 6.38 cm
Subgrade (CBR = 4.39 %)

Modified CBR Method:

- *IRC 37:1980 has revised the guide line for the design of flexible pavement based on the concept of cumulative standard axle rather than total number of commercial vehicle as carrier.*
- *In case of road for design traffic more than 1500 vehicle/day, pavement is design in terms of cumulative standard axle load of 8.2 tonnes carrying during the design life of road.*
- *The cumulative number of standard axle load repeatation (Ns)*
- $Ns = \dfrac{365\,A\,((1+r)^n - 1)}{r * 10^6} * D * F * LSF$ **……….. *In MSA***
- *csa = Cummulative std. axle*
- *msa = Millions std. axle =* 10^6 *csa*
- *Any vehicle with gross weight ≥ 3 tonnes, known as Commercial vehicle.*

- *IRC 37: 1984 is applicable to design traffic up to 30 msa*
- *IRC 37: 2001 is applicable to design traffic up to 150 msa*
- *A = Initial traffic in the year of completion of road construction in CVPD.*

  = No. of commercial vehicle per day after the completion of construction.

  = Estimated traffic at the end of design life of pavement.

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

Where,

x = Construction period.

P = Present traffic volume in (vehicle/day)

r = Annual rate of growth of traffic in (% year)

n = Design life of road.

LSF = Load safety factor. (If not given then, LSF = 1)

D = Lane distribution factor.

F = Vehicle damage factor.

Vehicle Damage Factor (F):

- *It is defined as the equipment to number of standard axle per commercial vehicle.*
- *It is a factor which convert number of commercial vehicle of different axle load to the number of repetition of standard axle load.*
- *If (L1) load is repeated N1 times & (L2) load repeated N2 times & so on, then number of repetition on standard axle in terms of (Ls) is known as vehicle damage factor.*
- $F = N = N1(\frac{L1}{Ls})^4 + N2(\frac{L2}{Ls})^4 + N3(\frac{L3}{Ls})^4 + \ldots\ldots\ldots + Nn(\frac{Ln}{Ls})^4$

  $= \textit{Equivalent daily number of repetition}$
- *Ls = 8.2 tonnes (Standard value)*
- *In terms of frequency,*
- $F = f1(\frac{L1}{Ls})^4 + f2(\frac{L2}{Ls})^4 + f3(\frac{L3}{Ls})^4 + \ldots\ldots\ldots + fn(\frac{Ln}{Ls})^4$

- ***Vehicle damage factor: (F)***

Initial Traffic Value (CVPD)	***Terrain (As per IRC 37: 2018)***	
	Plain	*Mountainous*
0 to 150	*1.7*	*0.6*
150 to 1500	*3.9*	*1.7*
> 1500	*5.0*	*2.8*

Lane Distribution factors (D):

1. *Single lane road: D = 1*
2. *Two lane single carriageway (No divider): D = 0.75*
3. *Four lane single carriageway: D = 0.4*

- *In the above three, two directional flow of traffic is taken.*
- *Dual Carriageway: (Traffic moving in one direction)*

1. *Dual two lane road: D = 0.75*
2. *Dual three lane road: D = 0.60*
3. *Dual four lane road: D = 0.45*

Question:

- *It is proposed to widen and strengthen existing two lane National highway as a divided highway. Find out the number of standard axle load if the existing traffic in one direction is 2500 CVPD. Construction will take one year, r = 8%, vehicle damage factor (F) = 3.5, lane distribution factor = 0.75 & design life of 10 year.*

Answer:

- *Given, n = 10 year, r = 8%, F = 3.5, D = 0.75, x = 1 year, P = 2500 CVPD*
- $A = P\,(1 + r)^x = 2500\,(1 + 0.08)^1 = 2700$ *vehicle/day*
- $Ns = \frac{365\,A\,((1+r)^n - 1)}{r} * D * F * LSF$
- $Ns = \frac{365 * 2700\,((1+0.08)^{10} - 1)}{0.08} * 0.75 * 3.5 * 1$
- $Ns = 3.747 * 10^7$ *csa* $= 37.47 * 10^6$ *csa* = ***37.47 msa***

Thank You