Spectrum of Axles Approach

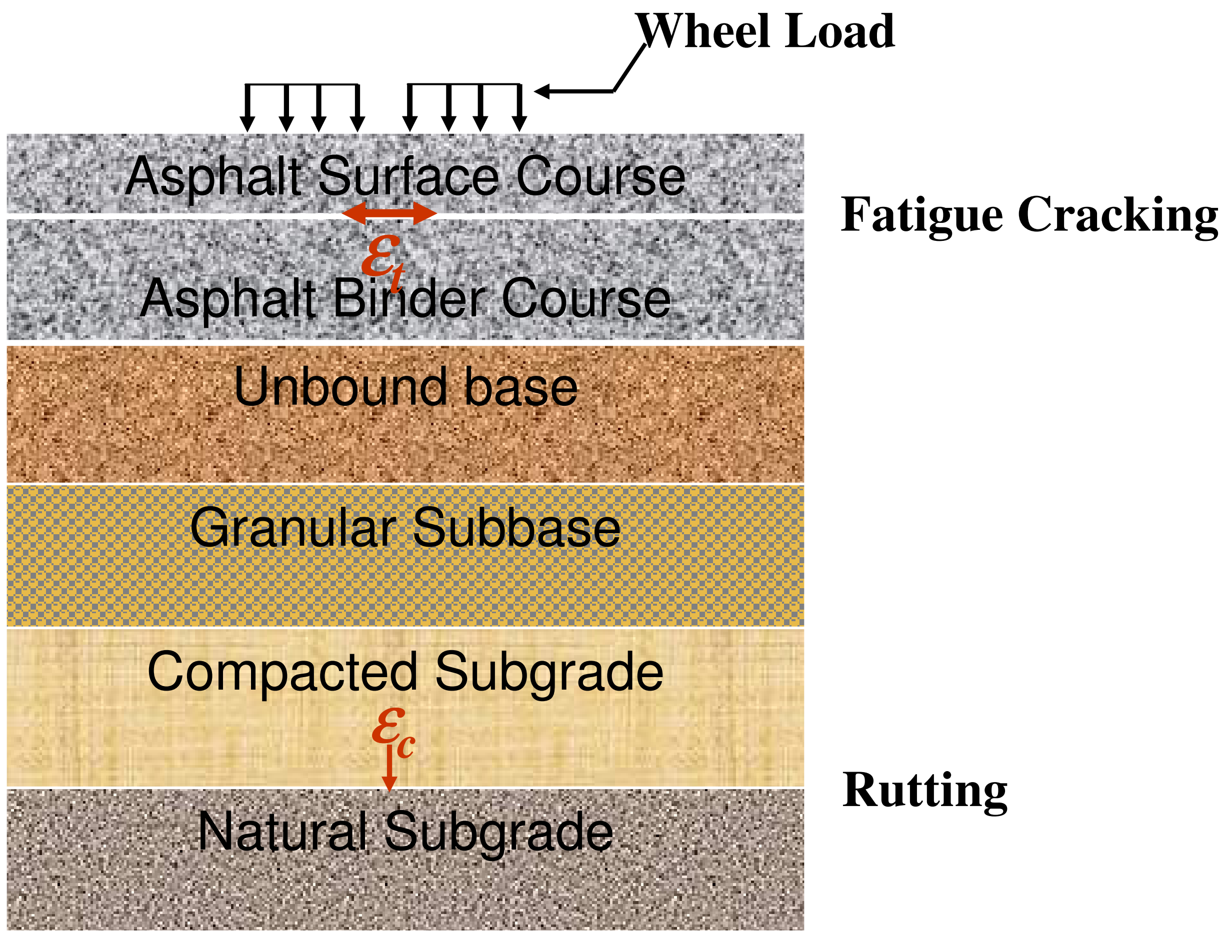
Typical Axle Load Spectrum

Axle Load (kN)	Number of Axles			
	Single	Tandem	Tridem	Quad
50 – 60	5,000	400	100	5
61 – 80	3,000	2,000	500	10
81 – 100	200	5,000	800	30
101 – 120	50	4,000	1,000	80
121 – 140	6	2,000	1,500	100

Distress Model

- Distress models relate the structural responses to various types of distresses
- These are equations relating the allowable number of repetitions of standard axle to the appropriate pavement response as per the failure criteria adopted

Fatigue Cracking and Rutting



Fatigue Cracking Model

$$N_f = k_3 \left[\frac{1}{\varepsilon_t} \right]^{k_1} \left[\frac{1}{E} \right]^{k_2}$$

N_f	=	**No. of cumulative standard axles to produce 20% cracked surface area**
ε_t	=	**Tensile strain at the bottom of Bituminous Concrete layer**
E	=	**Elastic Modulus of Bituminous Surface (MPa)**
k_1, k_2	=	**Laboratory calibrated parameters**
k_3	=	**Transfer parameter**

Rutting Failure Model

$$N_R = k_5 \left[\frac{1}{\varepsilon_c} \right]^{k_4}$$

***N_R* = No. of Repetitions to Rutting failure**

***ε_c* = Vertical subgrade strain**

***k_4, k_5* = Calibrated parameters**

Damage Ratio

- Allowable number of repetitions (N_i) are computed separately for each axle type *i* applying the distress model
- Expected number of repetitions (n_i) of each axle type *i* are obtained from traffic cum axle load survey
- Damage Ratio (DR), which is the ratio between the expected repetitions and allowable repetitions, is worked out for each axle type
- The cumulative DR of all axles should be less than 1

Damage Analysis Considering Seasonal Variations

- Damage Ratio (D_R)

  Ratio between the predicted and allowable number of repetitions computed for each axle type in each season and summed over the year

$$D_R = \sum_i \sum_j \frac{n_{ij}}{N_{ij}}$$

n_{ij}=Predicted number of repetitions of axle type *j* for season *i*

N_{ij}=Allowable number of repetitions of axle type *j* for season *i*

Material Characterisation

subgrade, subbase and unbound bases

Definition of CBR

California bearing ratio is defined as the ratio (expressed as percentage) between the load sustained by the soil sample at a specified penetration of a standard plunger (50 mm diameter) and the load sustained by the standard crushed stones at the same penetration.

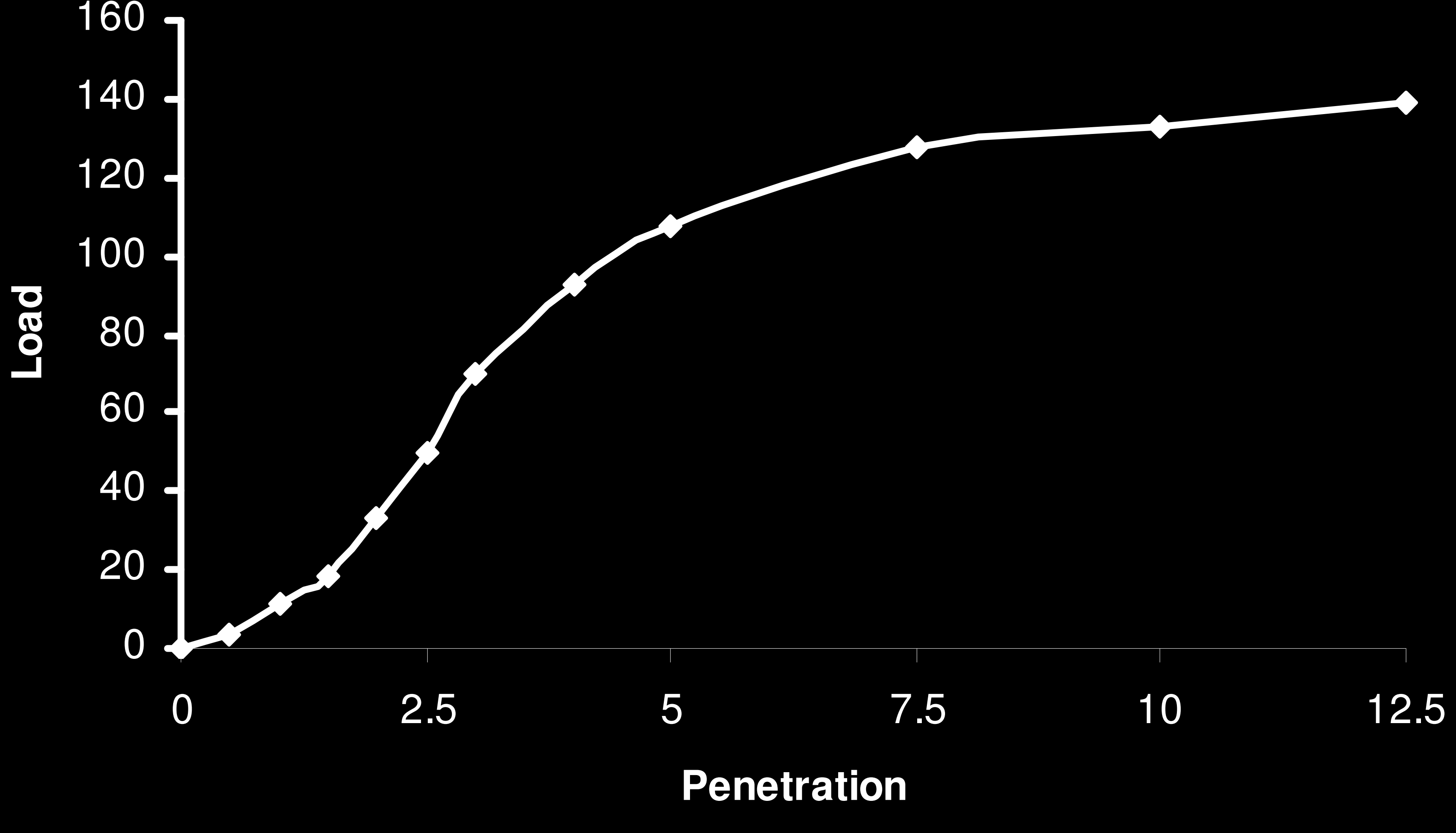
Standard Load values on Crushed Stones for Different Penetration Values

Penetration, mm	Standard Load, kg	Unit Standard Load, kg/cm^2
2.5	1370	70
5.0	2055	105
7.5	2630	134
10.0	3180	162
12.5	3600	183

Basic Test

- This consists of causing a plunger of 50 mm diameter to penetrate a soil sample at the rate of 1.25 mm/min.
- The force (load) required to cause the penetration is plotted against measured penetration.
- The loads at 2.5 mm and 5 mm penetration are recorded.
- This load corresponding to 2.5 mm or 5 mm penetration is expressed as a percentage of standard load sustained by the crushed aggregates at the same penetration to obtain CBR value.

Load Vs Penetration Curve



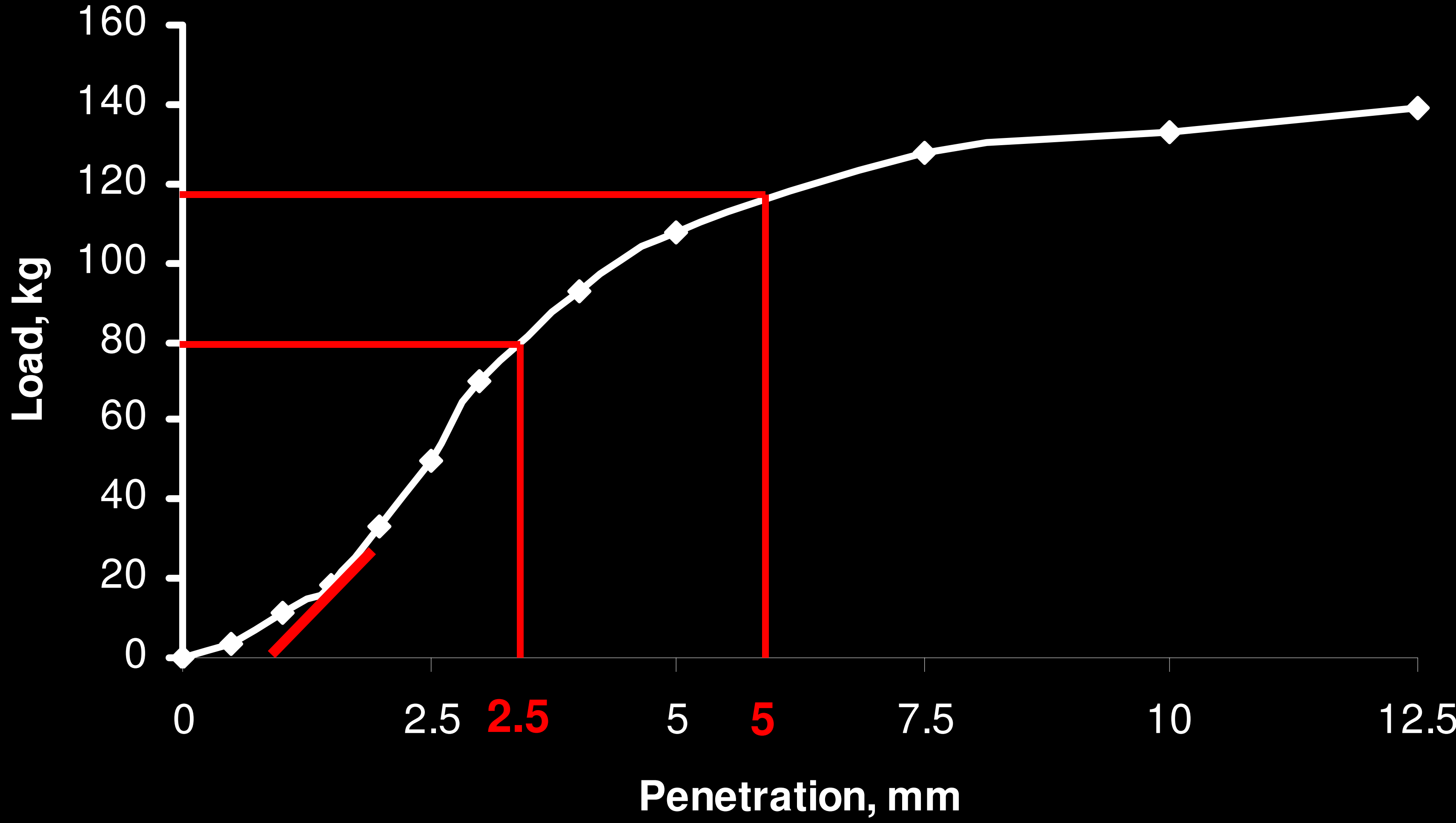
Initial Concavity

- The load – penetration curve may show initial concavity due to the following reasons:
  - The top layer of the sample might have become too soft due to soaking in water
  - The surface of the plunger or the surface of the sample might not be horizontal

Correction

- Draw a tangent to the load-penetration curve where it changes concavity to convexity
- The point of intersection of this tangent line with the x-axis is taken as the new origin
- Shift the origin to this point (new origin) and correct all the penetration values

Corrected Penetration Values



Variation in CBR Values

- At least three samples should be tested on each type of soil at the same density and moisture content to take care of the variation in the values
- This will enable a reliable average value to be obtained in most cases
- Where variation with in CBR values is more than the permissible maximum variation the design CBR value should be the average of six samples and not three

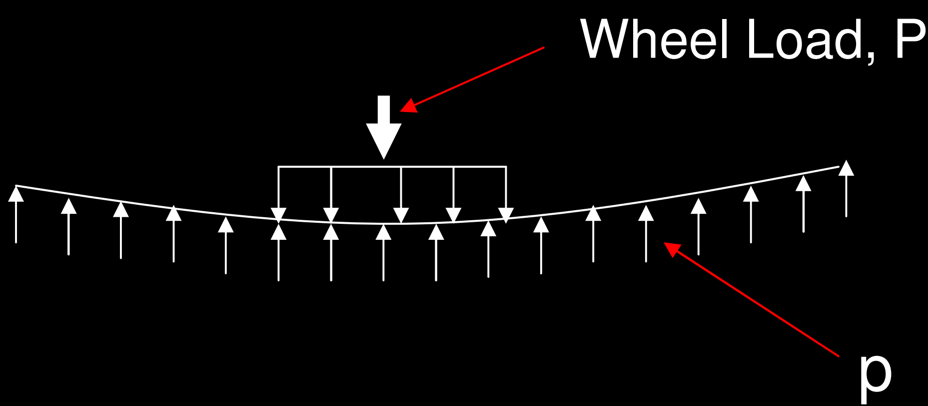
Permissible Variation in CBR Values

CBR (per cent)	**Maximum variation in CBR value**
5	± 1
5-10	± 2
11-30	± 3
31 and above	± 5

Design CBR

- The average CBR values corresponding to 2.5 mm and 5 mm penetration values should be worked out
- If the average CBR at 2.5 mm penetration is more than that at 5 mm penetration, then the design CBR is the average CBR at 2.5 mm penetration
- If the CBR at 5mm penetration is more than that at 2.5 mm penetration, then the test should be repeated. Even after the repetition, if CBR at 5mm is more than CBR at 2.5 mm, CBR at 5 mm could be adopted as the design CBR.

Modulus of Subgrade Reaction



$p \propto \Delta$

$p = K \Delta$

Where, p = reaction pressure

Δ= deflection

K = modulus of subgrade reaction

Definition

- Modulus of subgrade reaction is the reaction pressure sustained by the soil sample under a rigid plate of standard diameter per unit settlement measured at a specified pressure or settlement.
- IRC specifies that the K value be measured at 1.25 mm settlement.

Modulus of Subgrade Reaction

- To calculate the Modulus of Subgrade Reaction, *Plate Bearing Test* is conducted.
- In this a compressive stress is applied to the soil pavement layer through rigid plates of relatively large size and the deflections are measured for various stress values.
- The exact load deflection behavior of the soil or the pavement layer in-situ for static loads is obtained by the plate bearing test.

Modulus of Subgrade Reaction

Apparatus

Bearing Plates: Consist of mild steel 75 cm in diameter and 0.5 to 2.5 cm thickness and few other plates of smaller diameters (usually 60, 45, 30 and 22.5 cm) used as stiffeners.

Loading Equipment: Consists of a reaction frame and a hydraulic jack. The reaction frame may suitably be loaded to give the needed reaction load on the plate.

Modulus of Subgrade Reaction

Apparatus

Settlement Measurement: Three or four dial gauges fixed on the periphery of the bearing plate. The datum frame should be supplied far from the loading area.

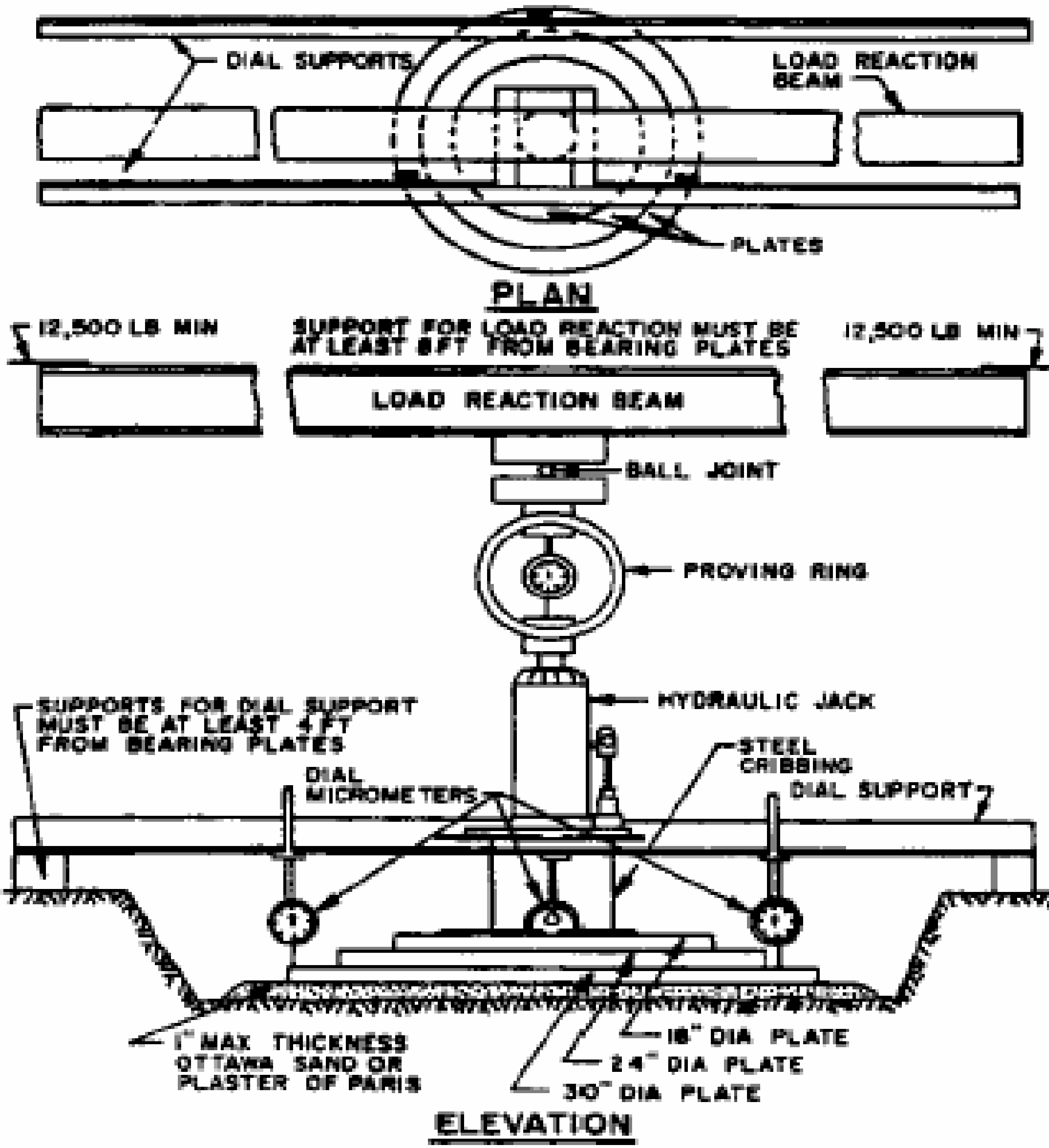


PLATE-BEARING TEST EQUIPMENT

Modulus of Subgrade Reaction

Procedure

- Prepare the test site and remove the loose material so that 75 cm diameter plate rests horizontally in full contact with the soil sub-grade.
- Place the plate accurately and then apply a seating load equivalent to a pressure of 0.07 kg/cm^2 and release it after few seconds.
- The settlement dial readings are adjusted to zero for zero load.

Modulus of Subgrade Reaction

Procedure (Contd…)

- A load is applied by means of the jack, sufficient to cause an average settlement of about 0.25 mm. When there is no perceptible increase in settlement or when the rate of settlement is less than 0.025 mm per minute, the load dial reading and the settlement dial readings are noted.
- The average of the three or four settlement dial readings is taken as the average settlement of the plate corresponding to the applied load.

Modulus of Subgrade Reaction

Procedure (Contd…)

- The load is increased till the average settlement increased to a further amount of about 0.25 mm and the load and the average settlement readings are noted as before.
- The procedure is repeated until the settlement is about 1.75 mm.

Modulus of Subgrade Reaction

Modulus of Subgrade Reaction

Modulus of Subgrade Reaction

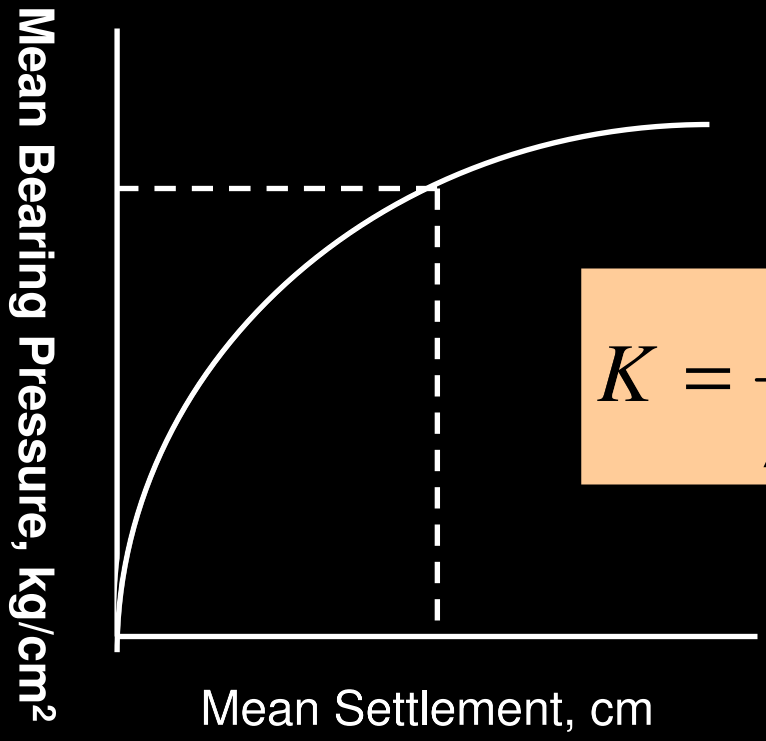
Calculation

A graph is plotted with the mean settlement (mm) on x axis and load (kN/m^2) on y-axis. The pressure *p* corresponding to a settlement of 1.25 mm is obtained from the graph. The modulus of sub-grade reaction K is calculated from the relation

$$K = P/0.00125 \ \ kN/m^2/m \ \text{ or } kN/m^3$$

Modulus of Subgrade Reaction

Calculation



$$K = \frac{p}{\Delta} = \frac{p}{0.125}$$

Bearing Pressure-Settlement Curve

Modulus of Subgrade Reaction

Soil Type: ……………………………… Plate Diameter = ………………

Moisture Content:…… ……………. % Area of Plate = ………………

Settlement Dial, 1 Division = ………….. mm Proving ring calibration factor = ………………

Approximate settlement, mm	Settlement dial readings, division				Average Settlement, Δ mm	Load dial (proving ring dial) Reading, divisions	Load per unit area P kN/mm^2	Remarks
	1	2	3	4				
0.00								
0.25								
0.50								
0.75								
1.00								
1.25								
1.50								
1.75								

Modulus of subgrade $K = \frac{p}{\Delta} = \frac{p}{125}$ kN/mm ^{2}/mm

(p = the pressure corresponding to average settlement; Δ = 1.125 cm, obtained from the graph Δ vs. p values)

Modulus of Subgrade Reaction

Corrections:

(1) Subsequent soaking condition of subgrade:

- The modulus of subgrade found by this method depends on the moisture content of the soil at the time of testing.
- The minimum value of K is obtained at the time of soaking condition.
- For K value in soaking condition, a correction factor must be applied to the K value found at the prevailing field moisture content.

Modulus of Subgrade Reaction

Corrections:

(1) Subsequent soaking condition of subgrade:

(Contd….)

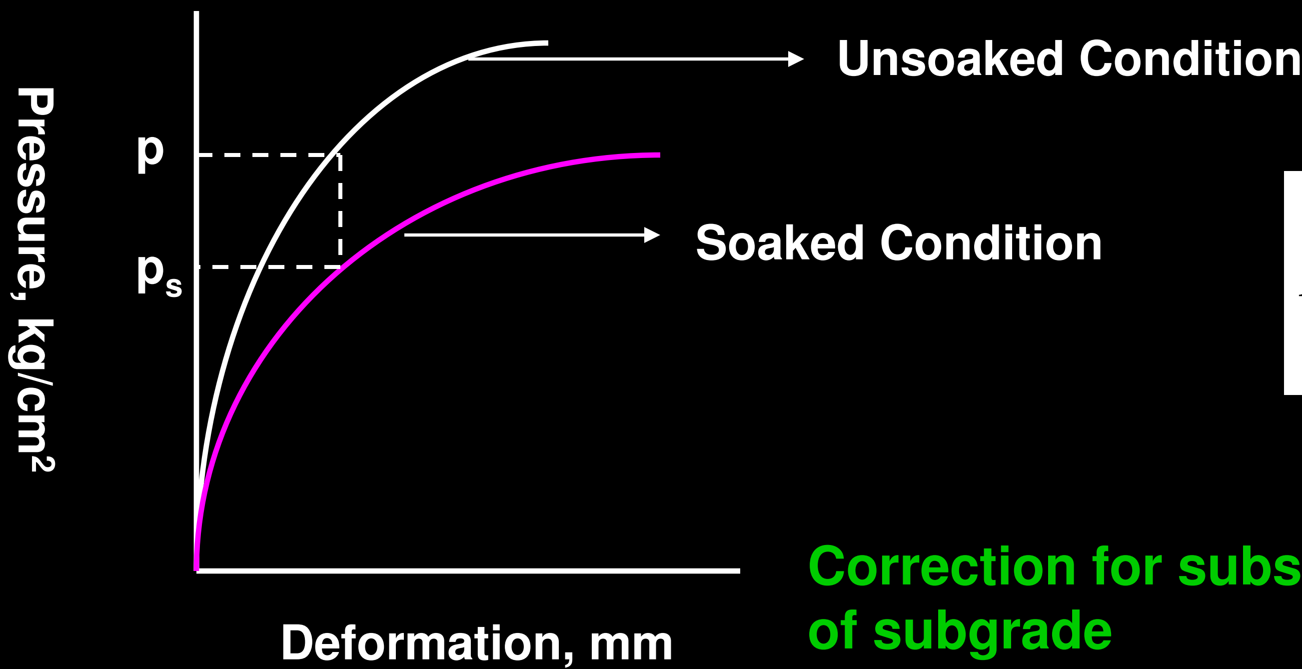
Procedure:

- Two samples are collected from the site where the plate load test was conducted.
- One sample is subjected to laboratory compression test under unsoaked condition and the other in soaked condition.
- Pressure sustained by the soil samples at different settlements is plotted.

Modulus of Subgrade Reaction

Corrections:

(1) Subsequent soaking condition of subgrade:



$$K_s = K \frac{p_s}{p}$$

Correction for subsequent soaking of subgrade

Modulus of Subgrade Reaction

Corrections:

(1) Subsequent soaking condition of subgrade:

(Contd….)

Procedure:

The correction factor for soaking is taken as P_s/P which will be less than 1.0 Therefore, Modulus of Subgrade for soaking condition is

$$K_s = K\frac{p_s}{p}$$

Modulus of Subgrade Reaction

Corrections:

(2) Correction for plate size

- A heavy reaction load is required for soils with high K value when a plate of diameter 75 cm is used for testing.
- If the reaction load is to be reduced a plate of smaller diameter has to be used.

Modulus of Subgrade Reaction

Corrections:

(2) Correction for plate size

If K_1 is the modulus of subgrade of smaller size plate and a_1 is the diameter of the smaller plate, then the K value corresponding to the standard plate (diameter *a) is*

$$K = \frac{K_1 a_1}{a}$$

Data from a Typical Plate Bearing Test

S. No.	Proving Ring Reading (Divs)	Load (kN)	Dial Gauge Reading (mm)			Cumulative Settlement (mm)
			A	B	C	
1	0	0	0	0	0	0
2	30	1.70	0.25	0.31	0.26	0.27
3	62	3.51	0.50	0.57	0.54	0.54
4	80	4.53	0.75	0.92	0.85	0.84
5	91	5.15	1.00	1.30	1.25	1.18
6	100	5.66	1.25	1.59	1.62	1.49
7	105	5.94	1.50	1.87	2.03	1.80
8	107	6.06	1.75	2.18	2.32	2.08

Load – Settlement Curve