Soils

Pavement Design Factors

Wheel Loads Applied to Pavement

Magnitude of Wheel Loads

Type of Wheel Loads (Single or Tandem Axles)

Number of Wheel Load Applications

Changes over Time

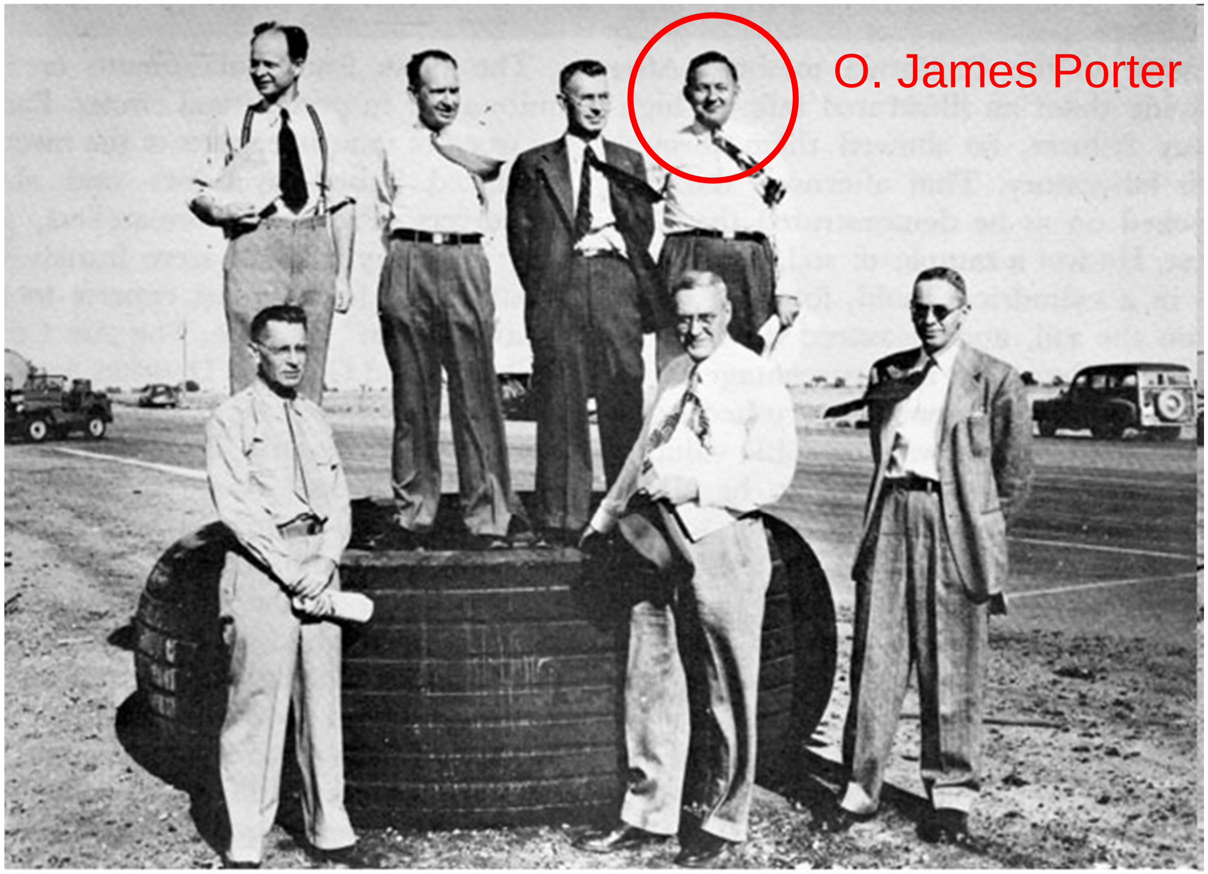
Subgrade Support Provided

Seasonal Changes in Subgrade Support

Subgrade Support

California Bearing Ratio (CBR)

CBR Inventor

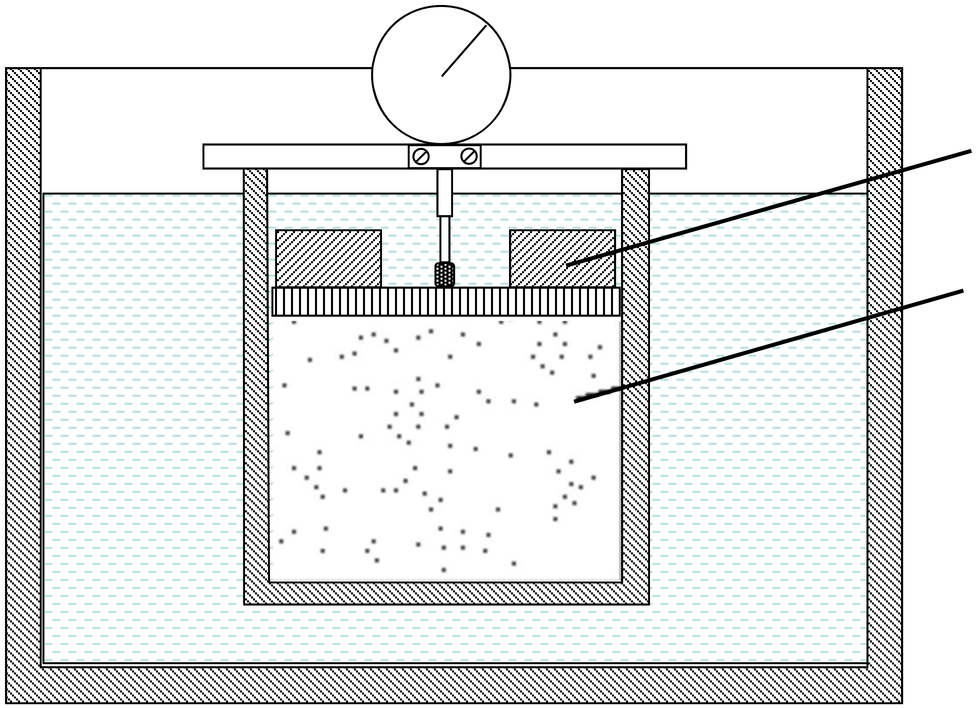


CBR Conference at Stockton Test Track, California. Front row (left to right): Colonel Henry C. Wolfe, Harald M. Westergaard, Philip C. Rutledge. Back row (left to right): Arthur Casagrande, Thomas A. Middlebrooks, James L. Land, O. James Porter

Source: http://gsl.erdc.usace.army.mil/gl-history/images/gl_img_25r.jpg

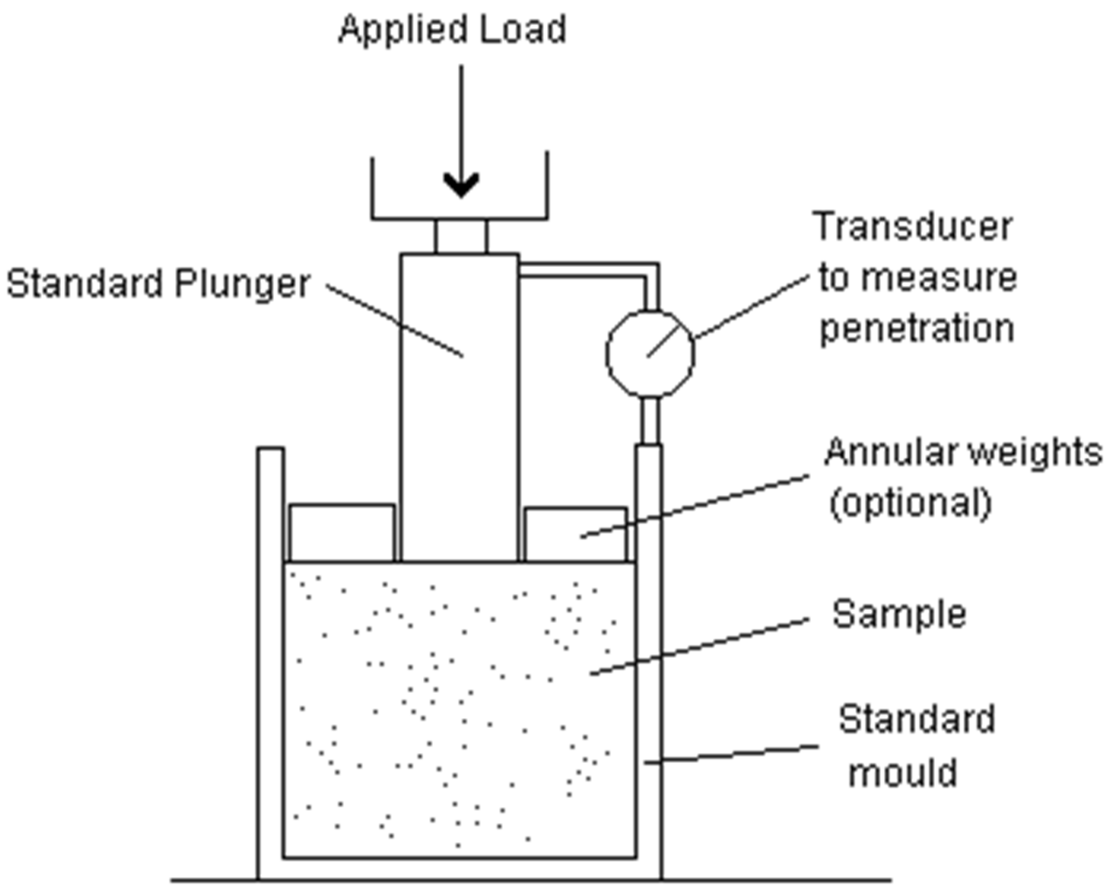
Soaking CBR Sample

4 days



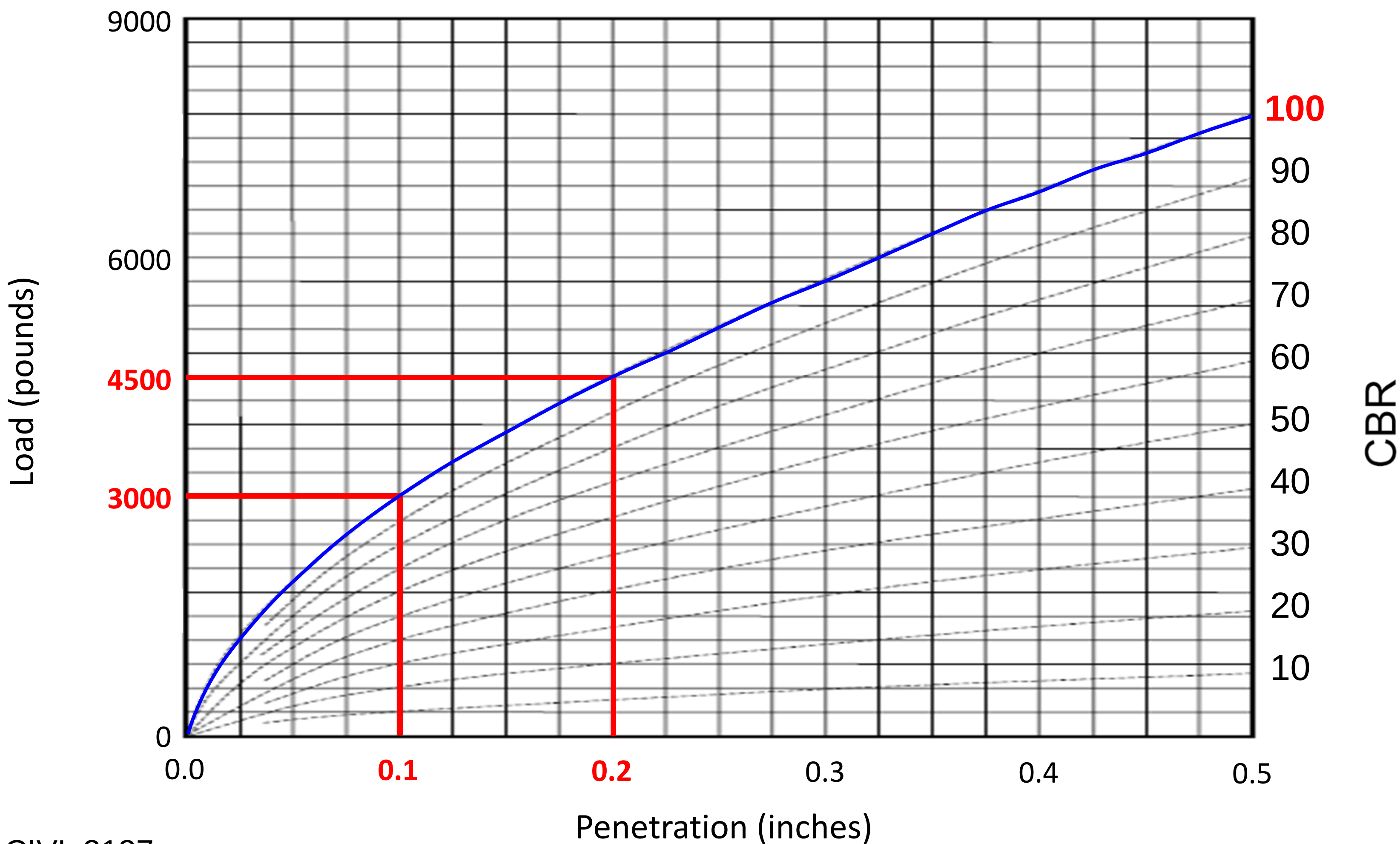
Source: **http://www.archive.official-documents.co.uk/document/ha/dmrb/index.htm**

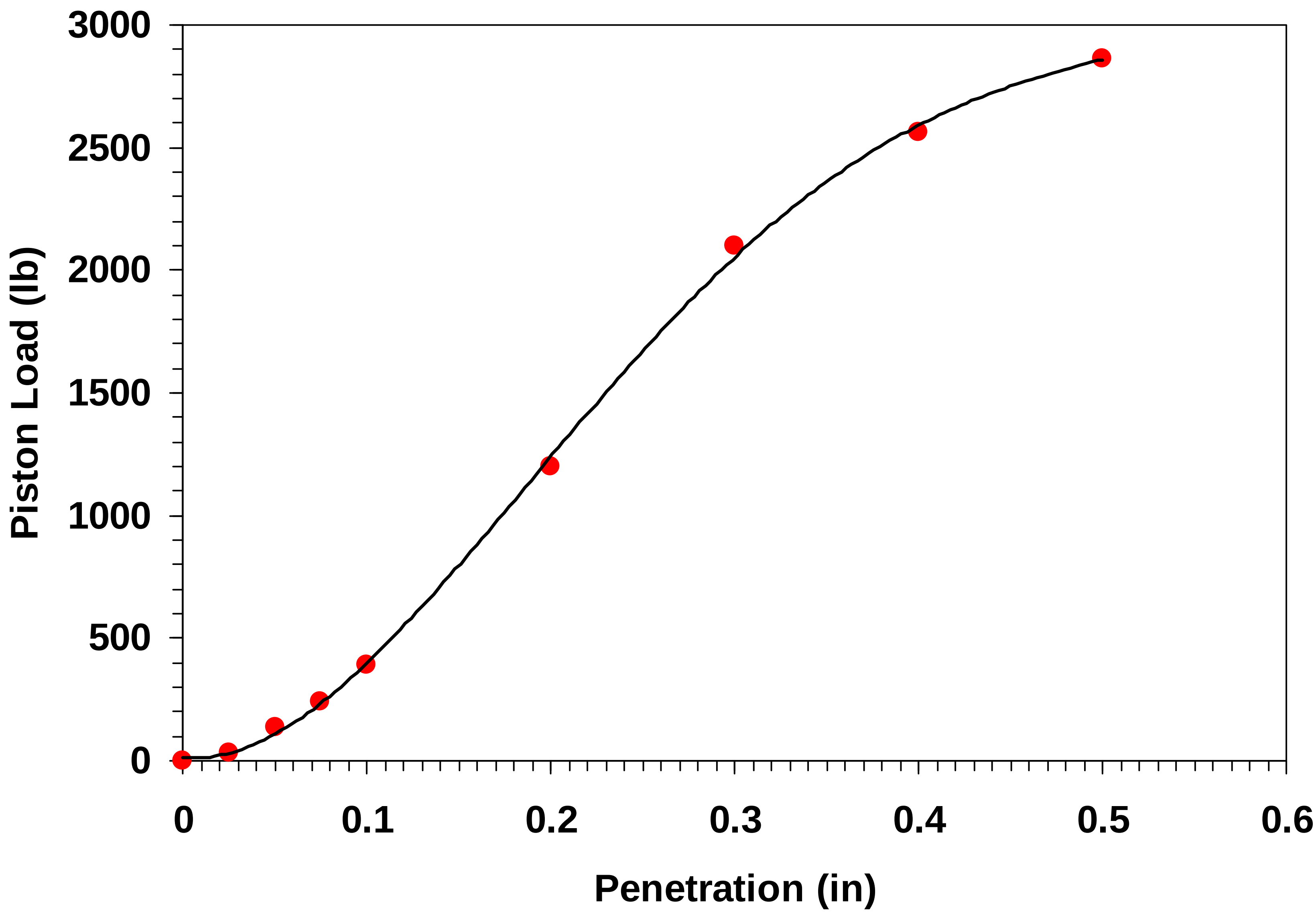
CBR Test Setup



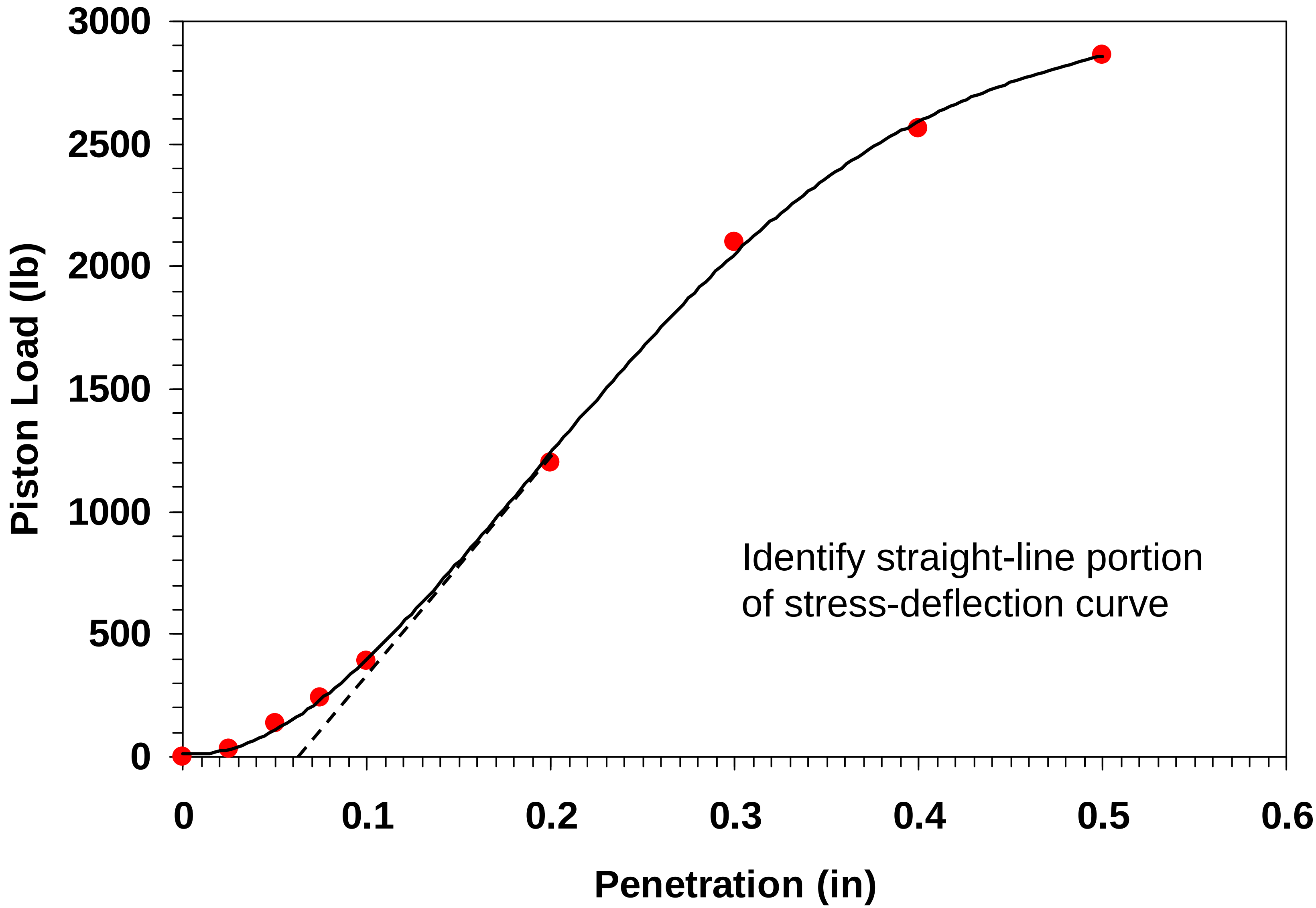
Source: http://www.archive.official-documents.co.uk/document/ha/dmrb/index.htm

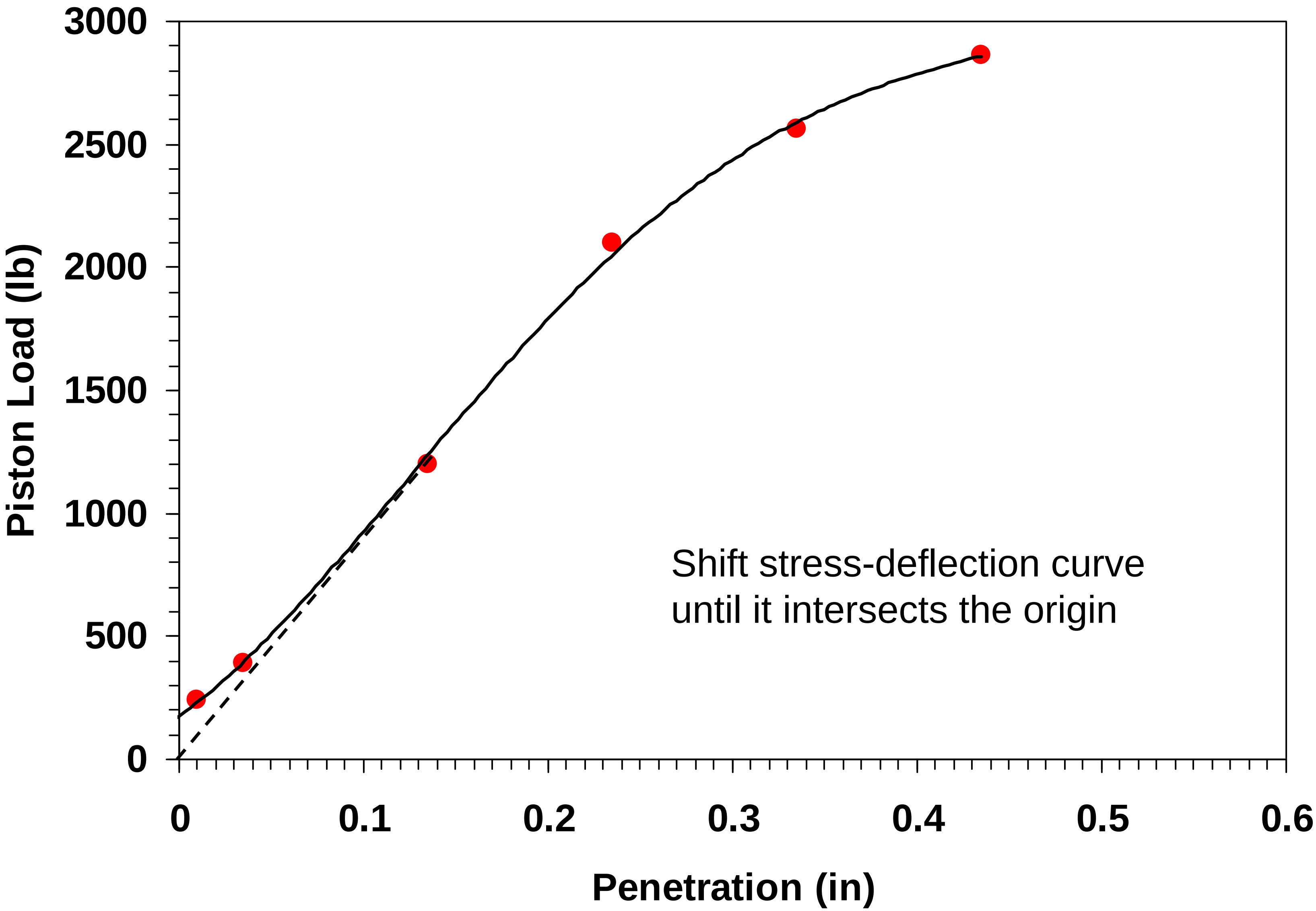
California Bearing Ratio



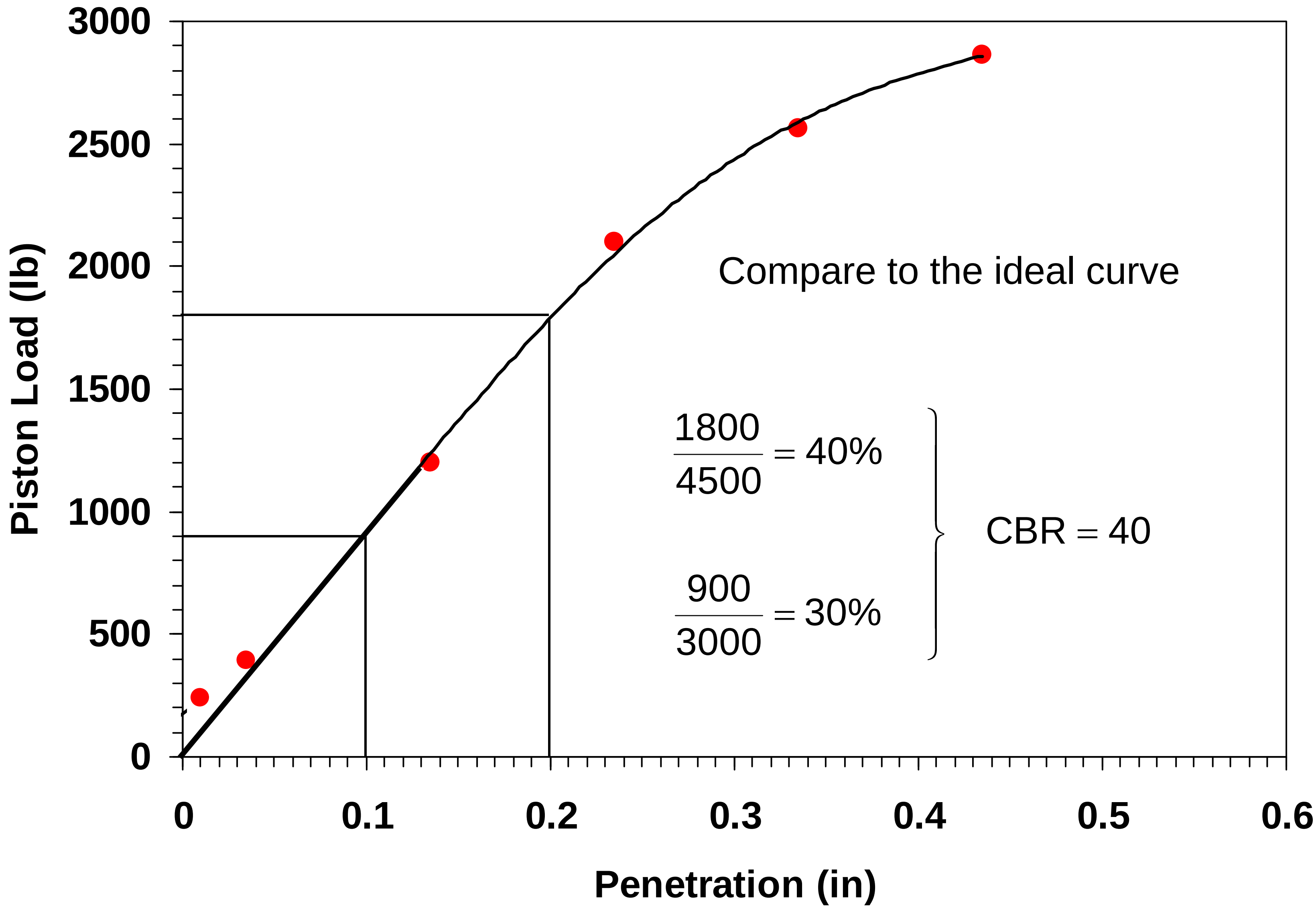


Piston Load (lb)
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Penetration (in)


3000
2500
2000
1500
1000
500
0
Piston Load (lb)
0
0.1
0.2
0.3
0.4
0.5
0.6
Penetration (in)
Identify straight-line portion
of stress-deflection curve



Piston Load (lb)
3000
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Penetration (in)
Shift stress-deflection curve
until it intersects the origin



3000
2500
2000
1500
1000
500
0
Piston Load (lb)
0
0.1
0.2
0.3
0.4
0.5
0.6
Penetration (in)
Compare to the ideal curve
$\frac{1800}{4500} = 40\%$
$\frac{900}{3000} = 30\%$
CBR = 40

Typical Values of CBR

Material	CBR	Elastic Modulus (psi)
Crushed Stone (GW, GP, GM)	20 - 100	20,000 - 40,000
Sandy Soils (SW, SP, SM, SC)	5 - 40	7,000 - 30,000
Silty Soils (ML, MH)	3 - 15	5,000 - 20,000
Clayey Soils (CL, CH)	3 - 10	5,000 - 15,000
Organic Soils (OH, OL, PT)	1 - 5	< 5,000

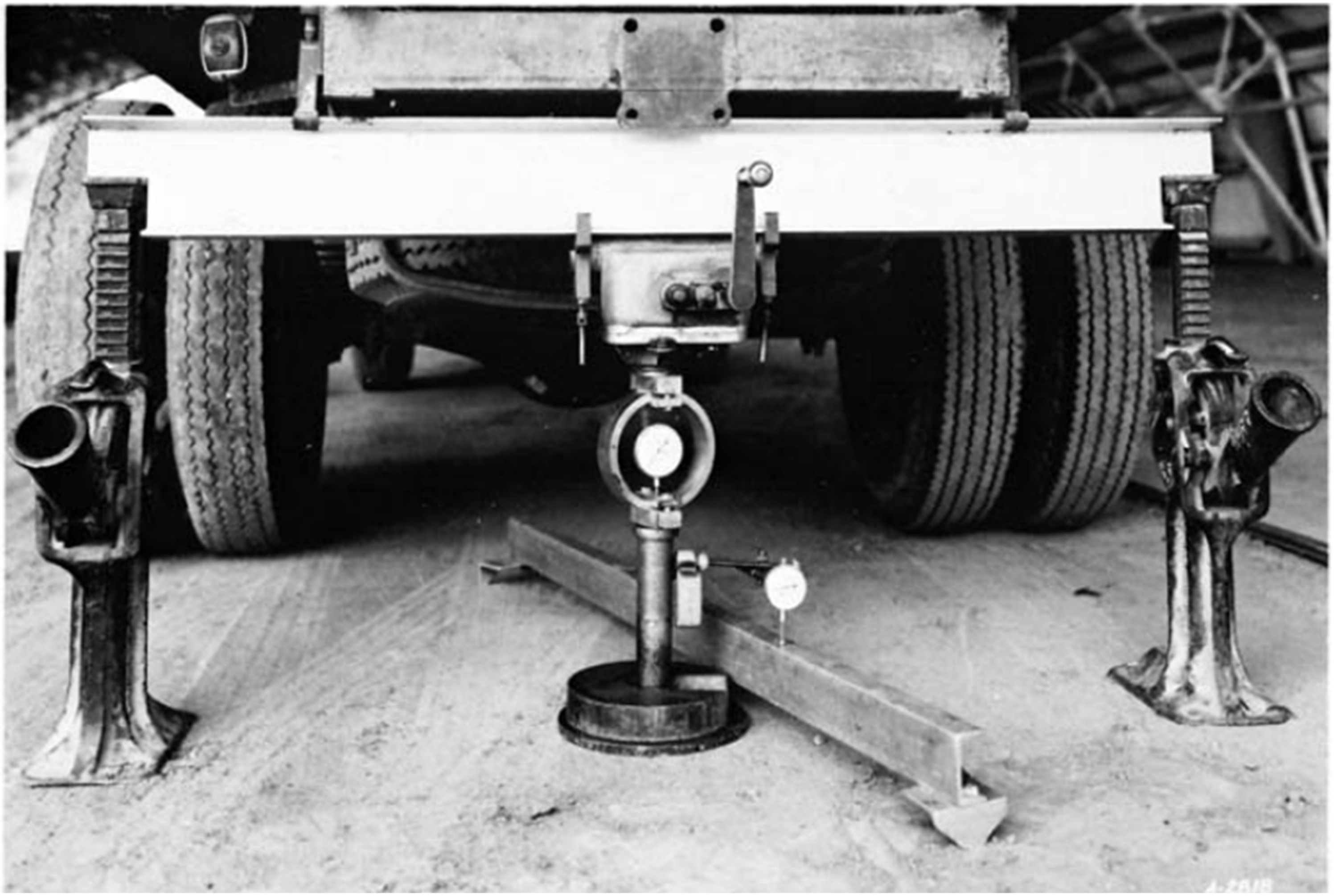
Source: WSDOT Pavement Guide Interactive CD-ROM

Typical Values of CBR

General Soil Type	USC Soil Type	CBR Range
Coarse-grained soils	GW	40 - 80
	GP	30 - 60
	GM	20 - 60
	GC	20 - 40
	SW	20 - 40
	SP	10 - 40
	SM	10 - 40
	SC	5 - 20
Fine-grained soils	ML	$\leq$ 15
	CL	$\leq$ 15
	OL	$\leq$ 5
	MH	$\leq$ 10
	CH	$\leq$ 15
	OH	$\leq$ 5

Source: WSDOT Pavement Guide Interactive CD-ROM

Field CBR Test



Source: *ASTM Standards on Disc*, Vol. 04.03, Designation D 4429 - 04, June 2007

Field CBR

Source: http://www.ele.com/geot/cali.htm

LABORATORY CALIFORNIA BEARING RATIO (CBR) TEST DATA

1. PROJECT					2. DATE	
3. EXCAVATION NUMBER		4. SAMPLE NUMBER			5. CONDITION ☐ DISTURBED ☐ UNDISTURBED	
COMPACTION DATA	6. MOLD NUMBER		7. NUMBER OF LAYERS		8. BLOWS PER LAYER	
	9. PERCENT OF 3/4 in MATERIAL REPLACED		10. WEIGHT OF HAMMER *(lb)*		11. HEIGHT OF DROP *(in)*	
PROVING-RING DATA	12. NUMBER	13. CONSTANT	14. CAPACITY	15. SURCHARGE WEIGHT	16. SOAKING *(lb)*	17. PENETRATING *(lb)*
18. SWELL DATA *(Initial / Final)*	a. DATE	b. TIME	c. ELAPSED TIME	d. DIAL READING	e. INITIAL HEIGHT	f. SWELL PERCENT
			0.0			*(d / e x 100)*

19. PENETRATION DATA

a. PENETRATION *(in)*	b. STANDARD UNIT LOAD *(psi)*	c. PROVING RING DIAL READING *(in)*	d. CORRECTED RING DIAL READING *(in)*	e. TOTAL LOAD *(lb)*	f. UNIT LOAD *(psi)* *(e / 3.0)*	g. CORRECTED UNIT LOAD *(psi)*	h. CBR (%) *(g / b x 100)*
0.025	250						
0.050	500						
0.075	750						
0.100	1000						
0.125	1125						
0.150	1250						
0.175	1375						
0.200	1500						
0.300	1900						
0.400	2300						
0.500	2600						

WATER CONTENT AND UNIT WEIGHT DATA

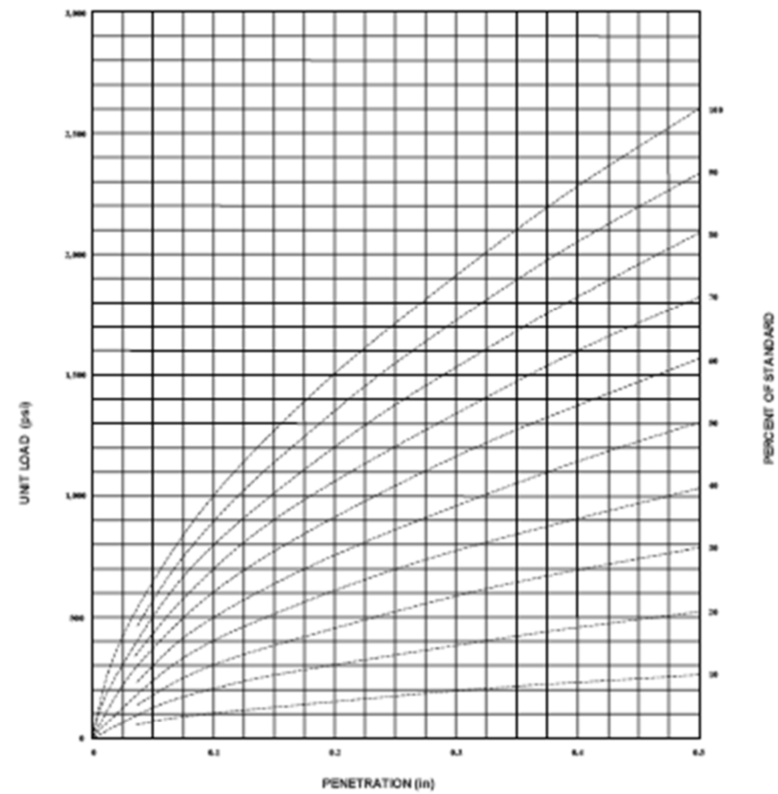
SAMPLES TAKEN	UNITS	BEFORE SOAKING		AFTER SOAKING	
20. WEIGHT OF MOLD + WET SOIL	Grams				
21. WEIGHT OF MOLD	Grams				
22. WEIGHT OF WET SOIL *(20 - 21)*	Grams				
23. WET UNIT WEIGHT, γ wet *([22 / 453.6] / 0.075)*	Pcf				
24. TARE NUMBER / SAMPLE TAKEN		BEFORE COMPACTION	AFTER COMPACTION	TOP 1 INCH	FROM MOLD
a. WEIGHT OF TARE + WET SOIL	Grams				
b. WEIGHT OF TARE + DRY SOIL	Grams				
c. WEIGHT OF WATER, W_w *(a - b)*	Grams				
d. WEIGHT OF TARE	Grams				
e. WEIGHT OF DRY SOIL, W_s *(b - d)*	Grams				
f. WATER CONTENT, $w = \frac{W_w}{W_s} \times 100$ *(c / e x 100)*	Percent				
25. AVERAGE WATER CONTENT	Percent				
26. DRY UNIT WEIGHT, $\gamma d = \frac{\gamma\ wet}{1 + (w / 100)}$	Pcf				

EDITION OF AUG 57 IS OBSOLETE.

Reset

CBR TEST GRAPH

(Plot test curve below to obtain corrected unit load)

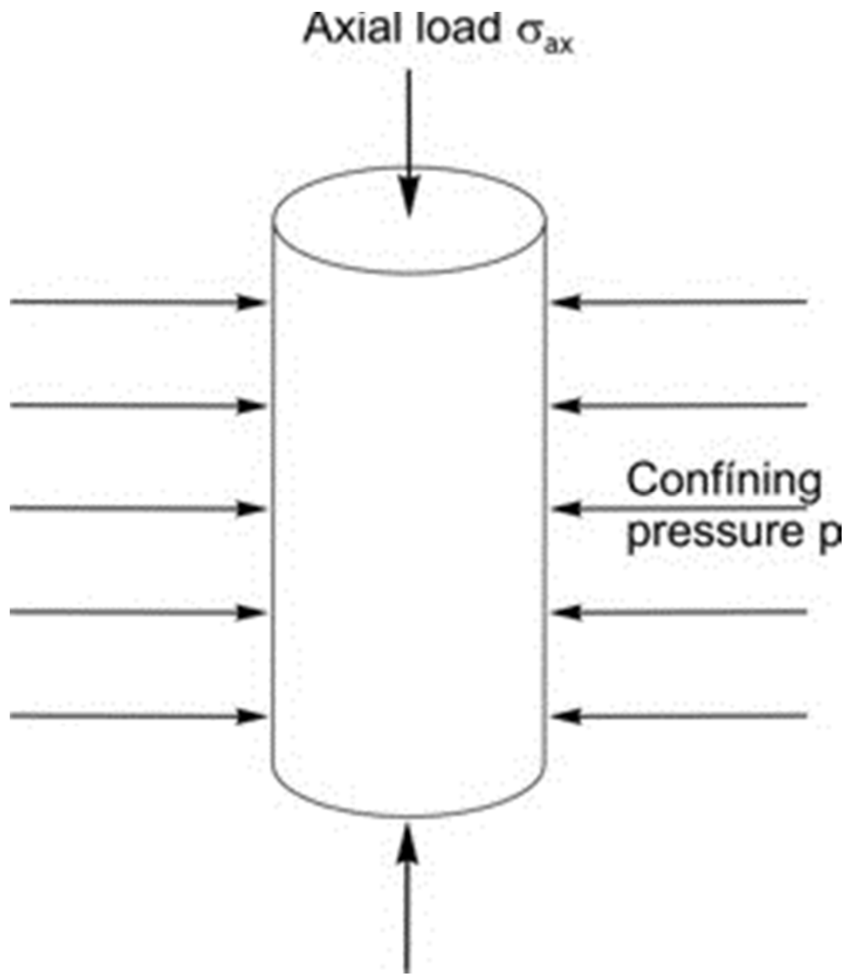


27. REMARKS		
28. TECHNICIAN *(Signature)*	29. COMPUTED BY *(Signature)*	30. CHECKED BY *(Signature)*

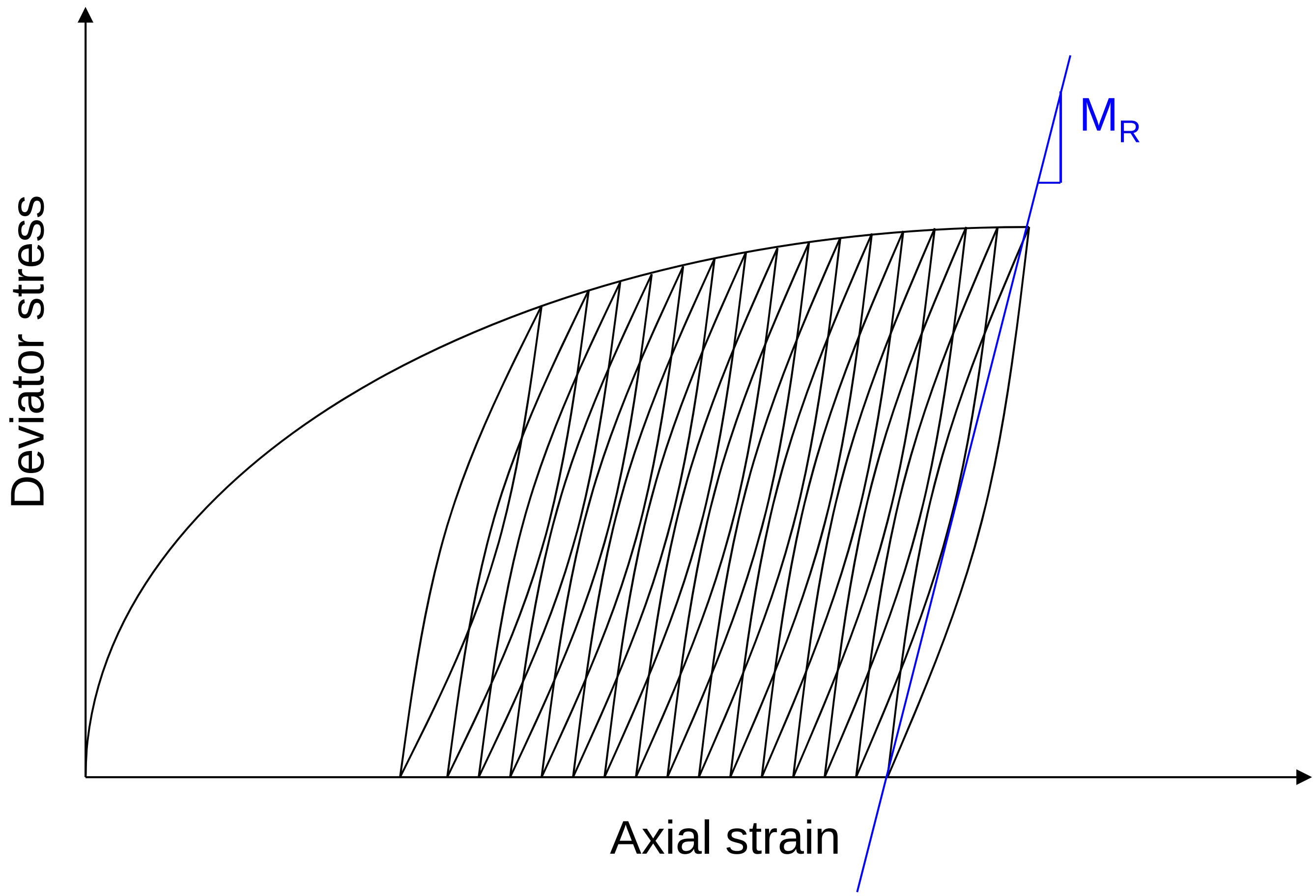
Reset

Resilient Modulus (M_R)

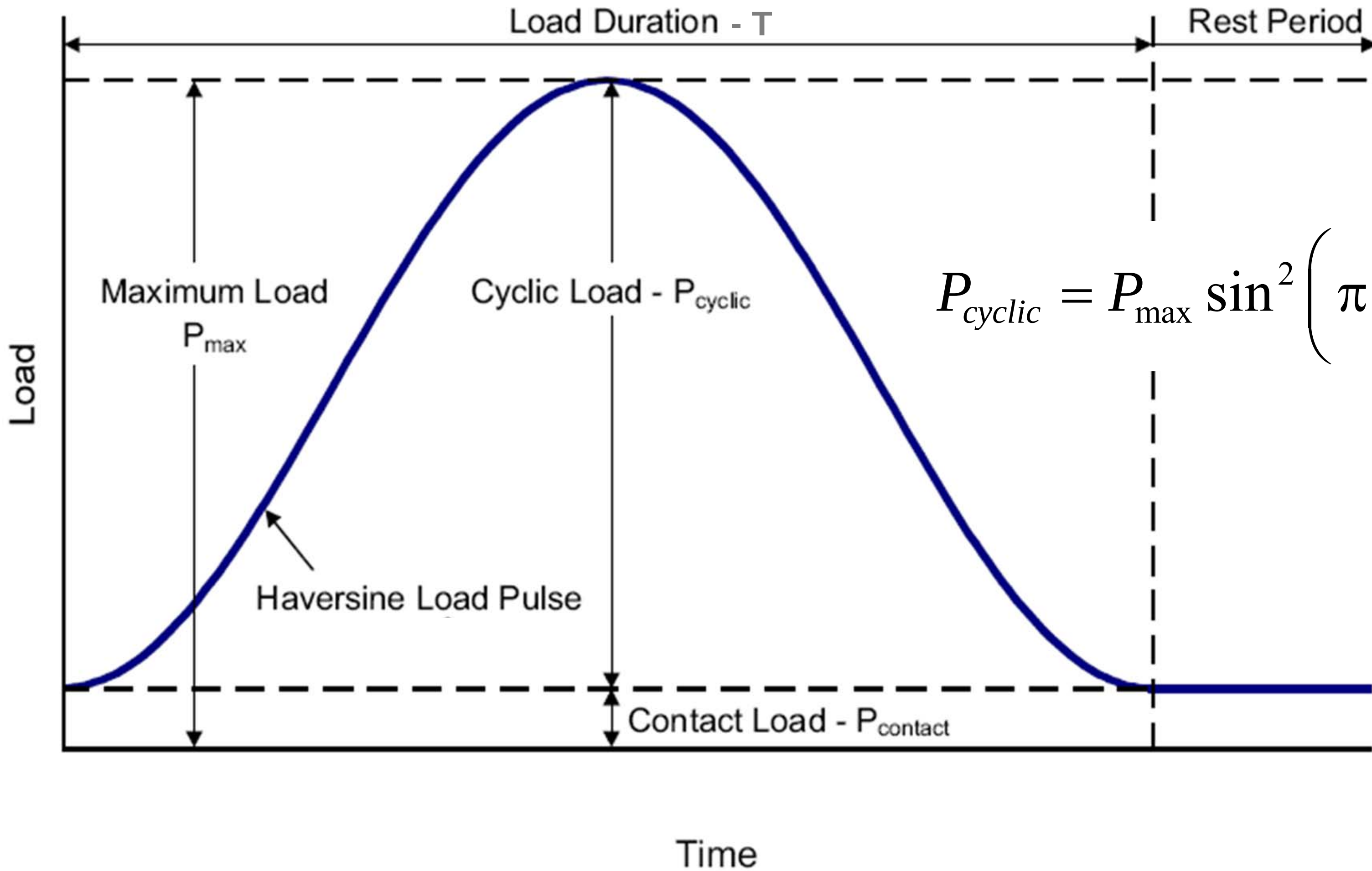
Resilient Modulus



Resilient Modulus

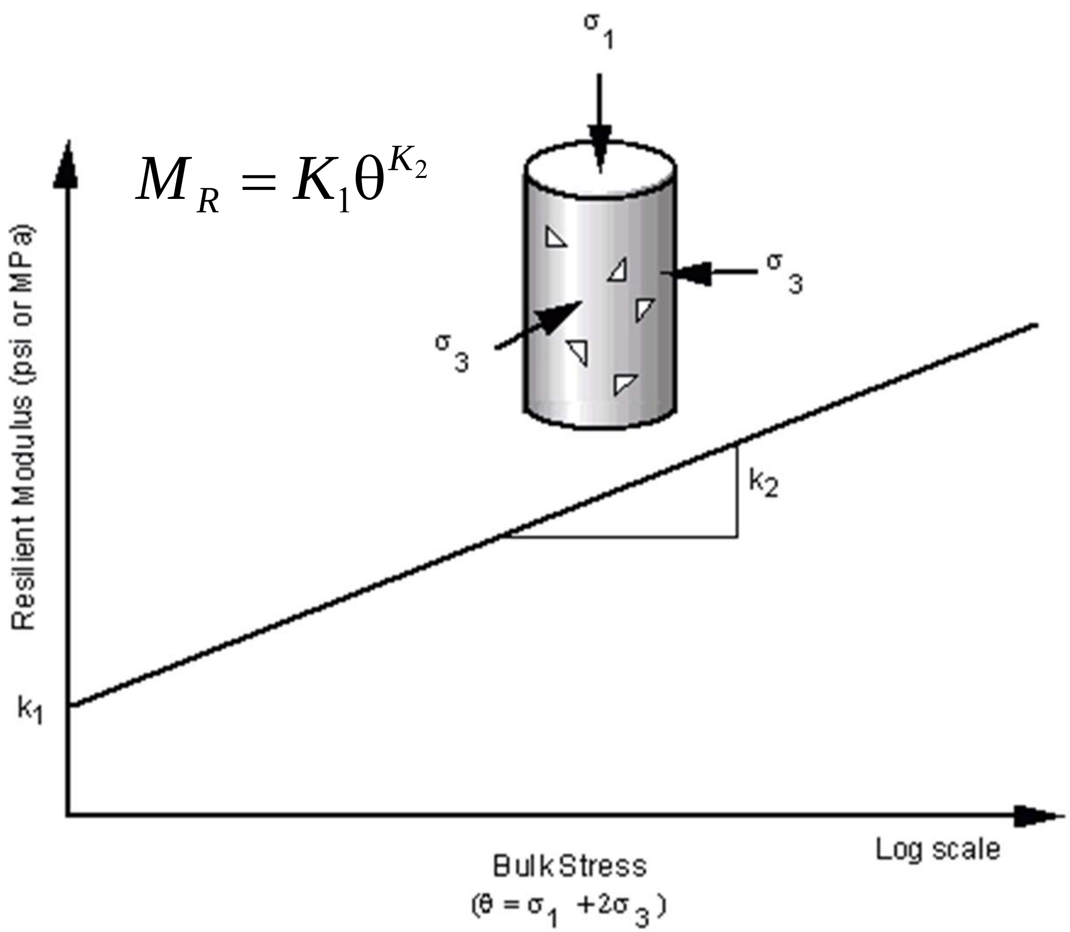


Haversine Load Pulse



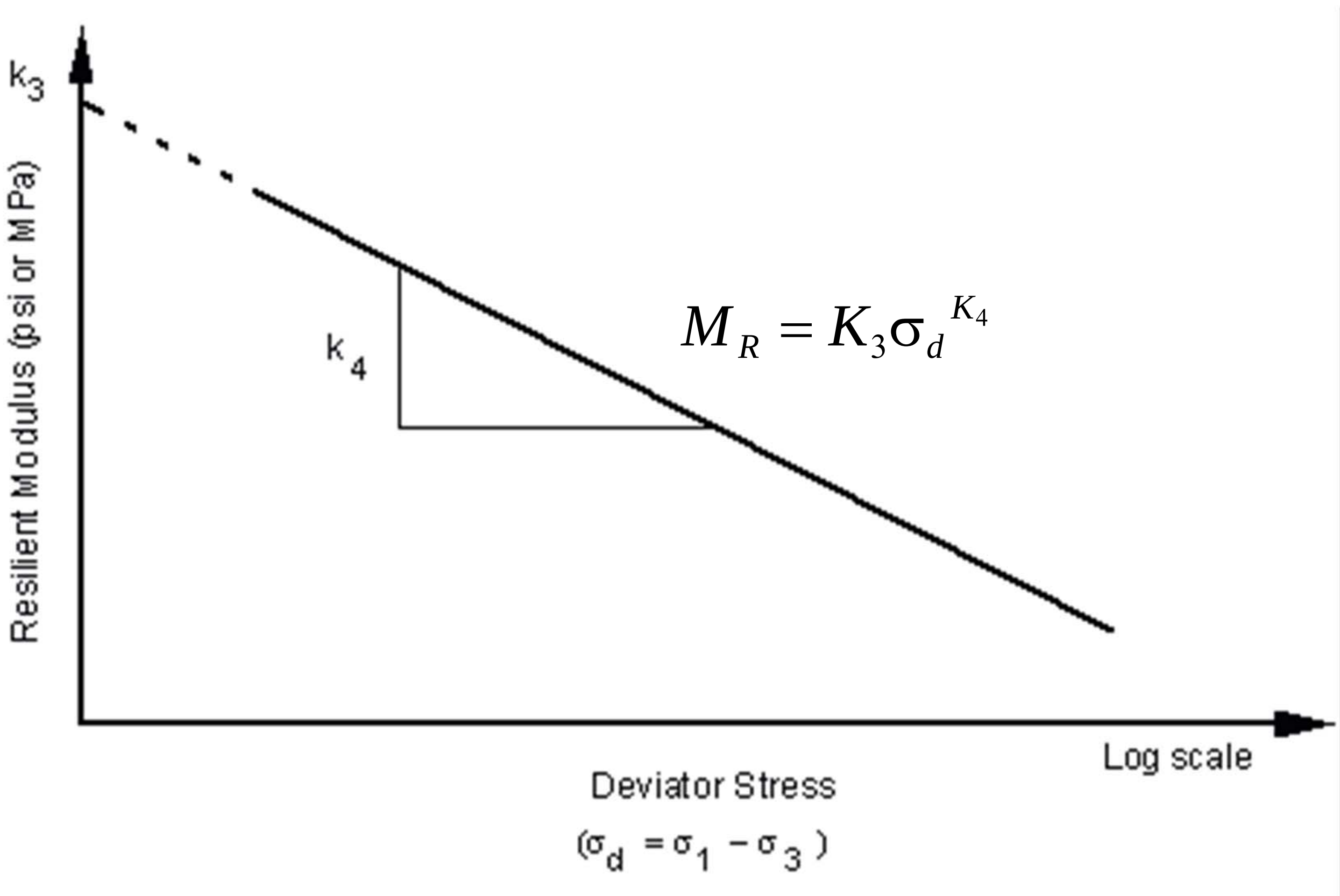
$$P_{cyclic} = P_{\max} \sin^2\left(\pi \frac{t}{T}\right)$$

Granular Soils



Source: WSDOT Pavement Guide Interactive CD-ROM

Cohesive Soils



Estimating Subgrade M_R

1993 AASHTO Guide

$$M_R = 1500 \times CBR$$

WARNING: Only for fine-grained soils with soaked CBR < 10.

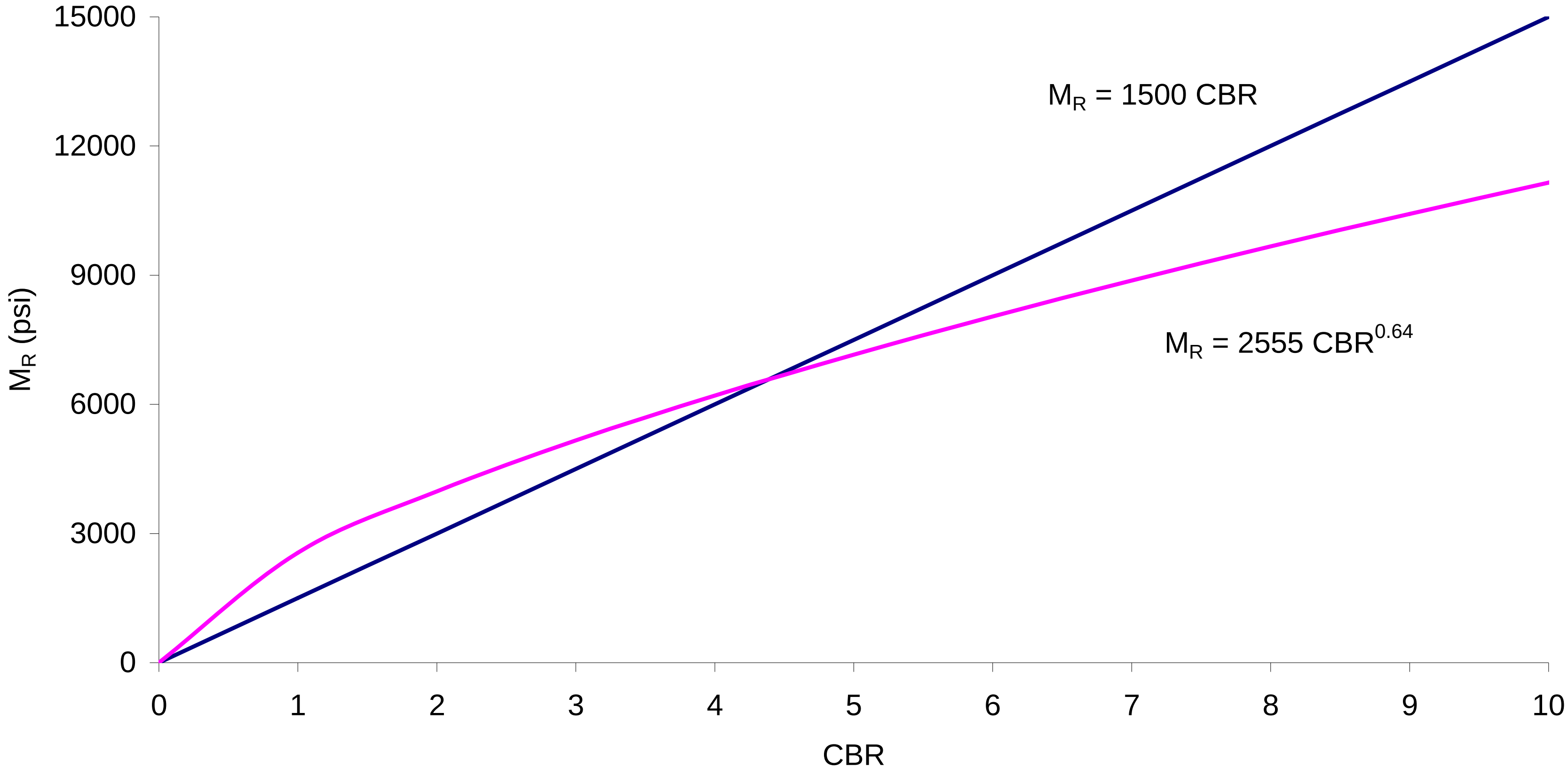
Estimating Subgrade M_R

AASHTO MEPDG

$$M_R = 2555 \times CBR^{0.64}$$

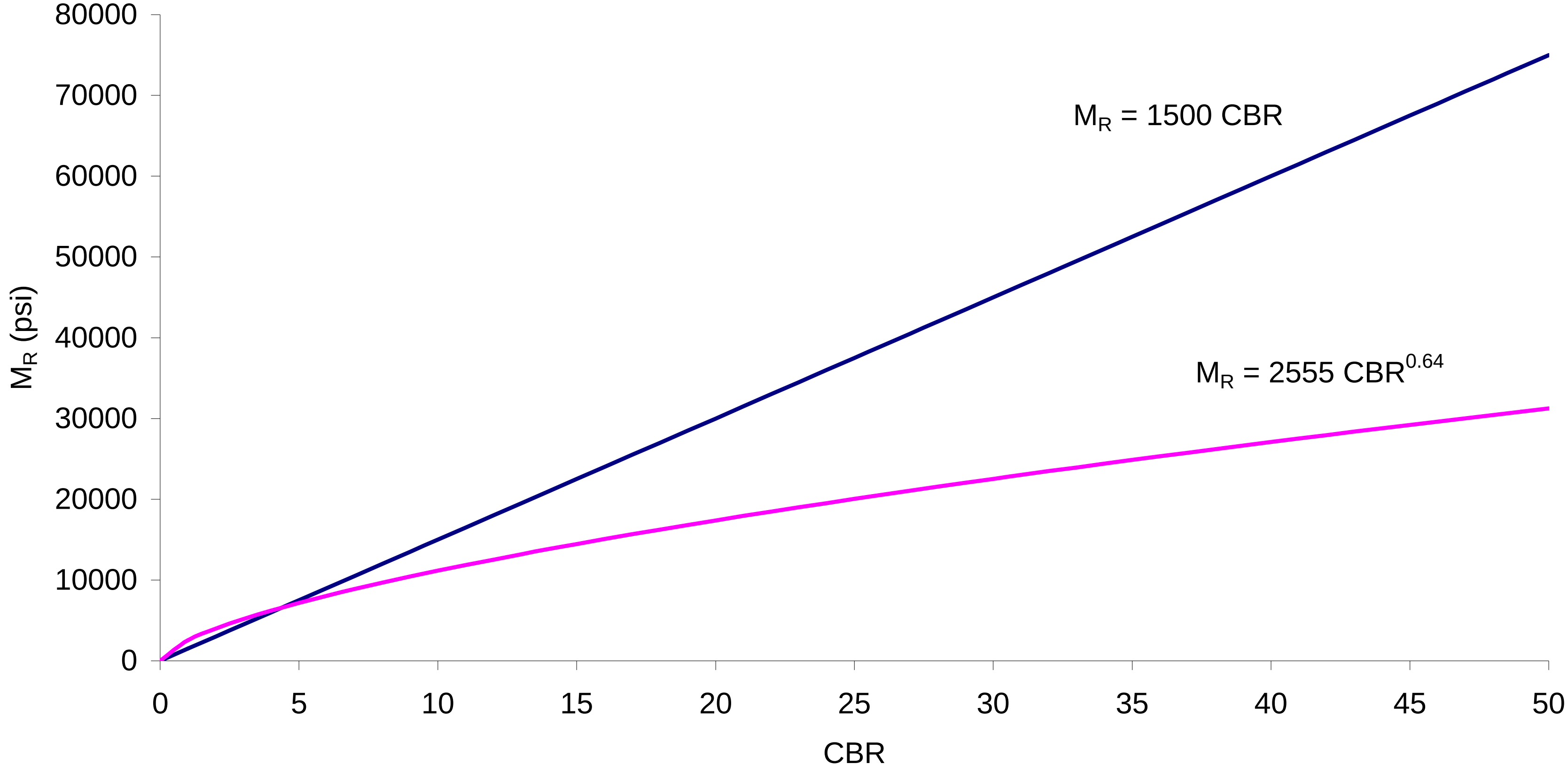
Good for a wide range of soil types

M_R vs. CBR



15000
12000
9000
6000
3000
0
MR (psi)
0
1
2
3
4
5
6
7
8
9
10
CBR
MR = 1500 CBR
MR = 2555 CBR0.64

M_R vs. CBR



80000
70000
60000
50000
40000
30000
20000
10000
0
MR (psi)
MR = 1500 CBR
MR = 2555 CBR0.64
0
5
10
15
20
25
30
35
40
45
50
CBR

Plate Load Test
(k)

Plate Load Test

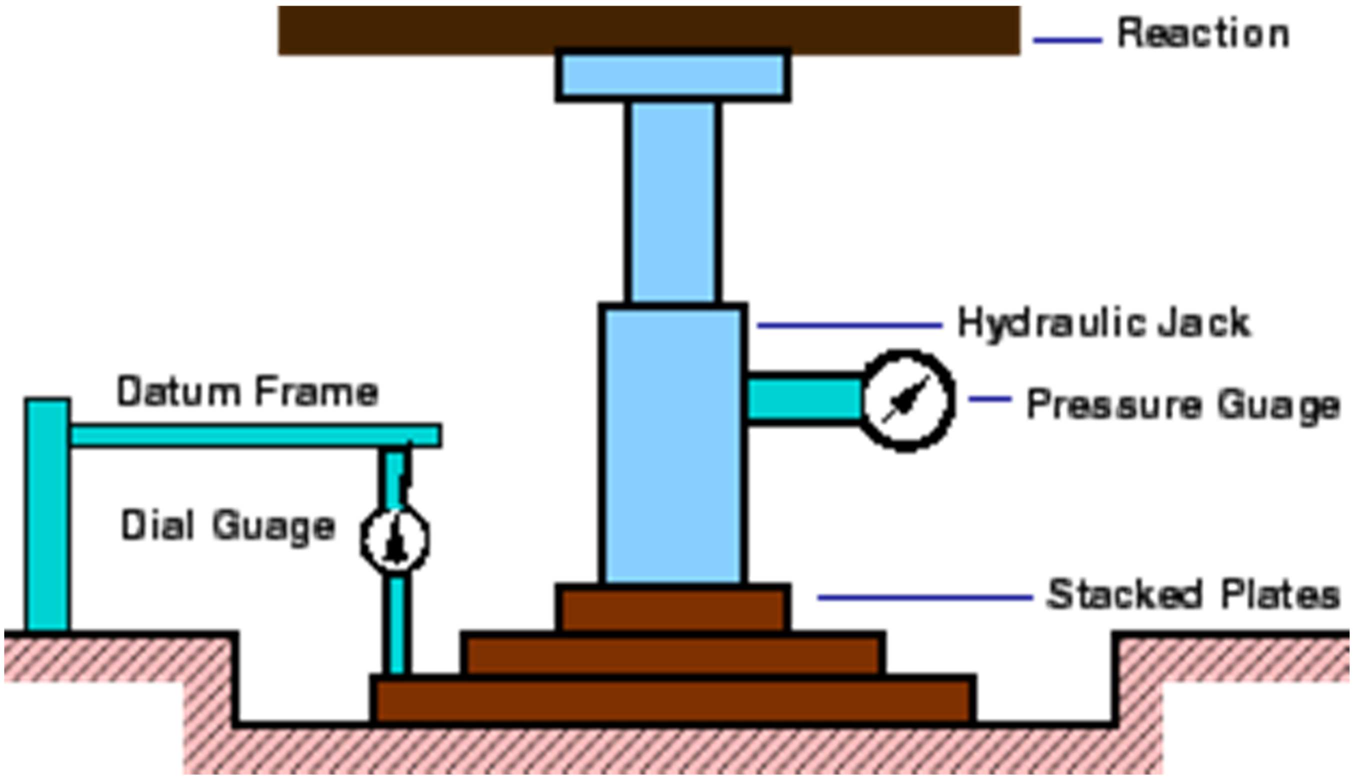


Plate Load Test

Plate Load Test

Plate Load Test

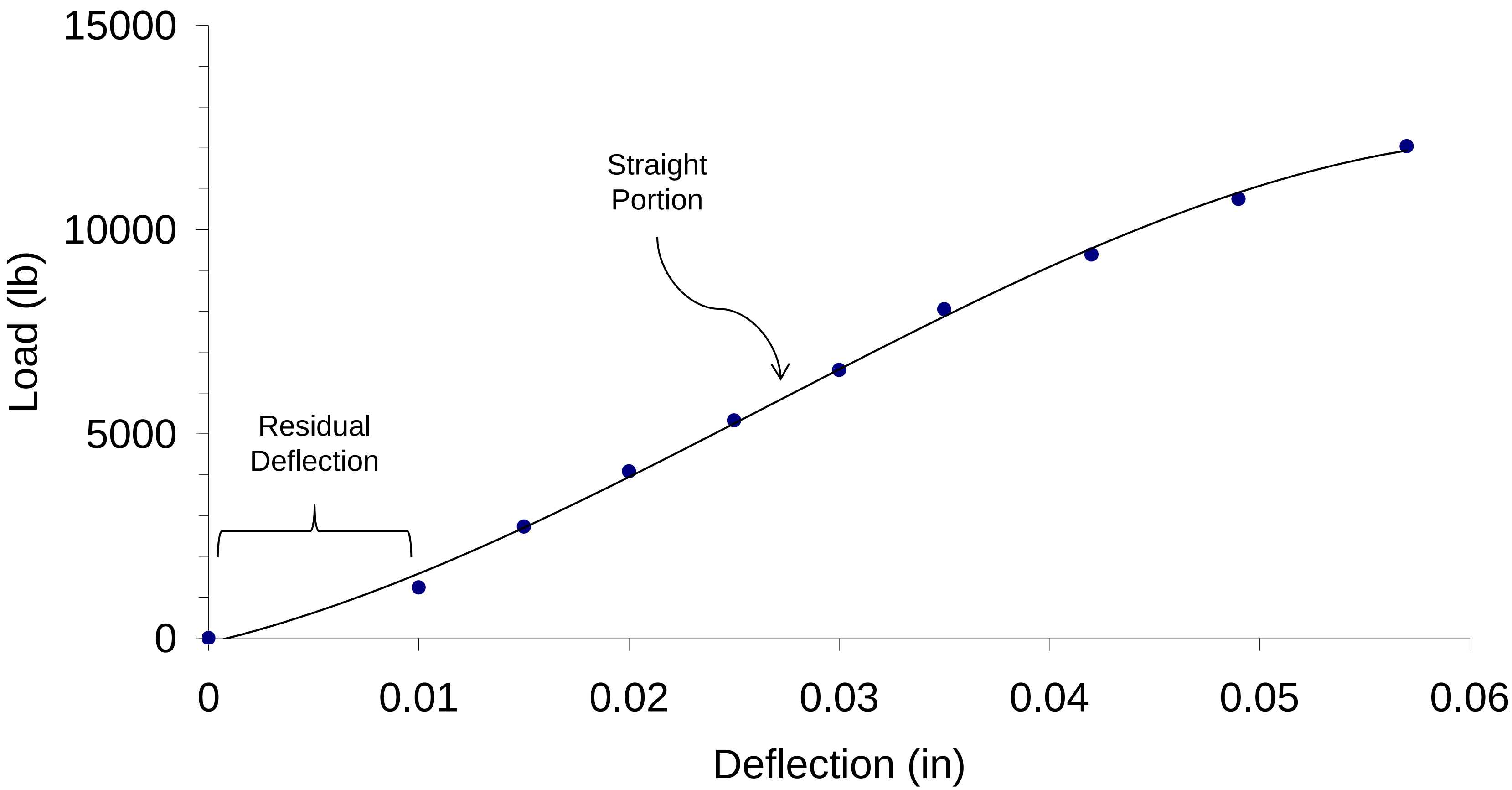
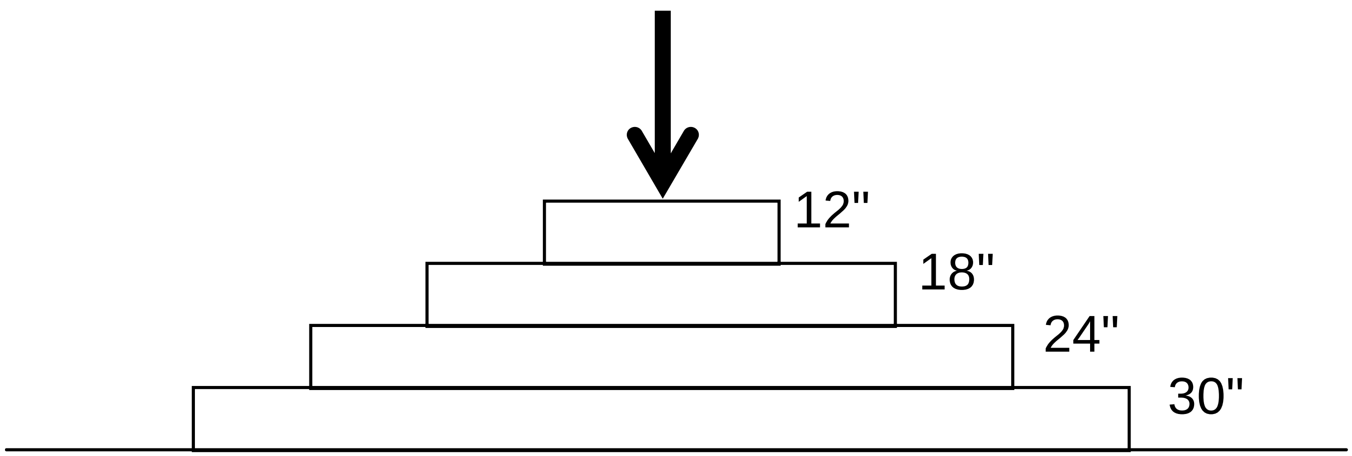
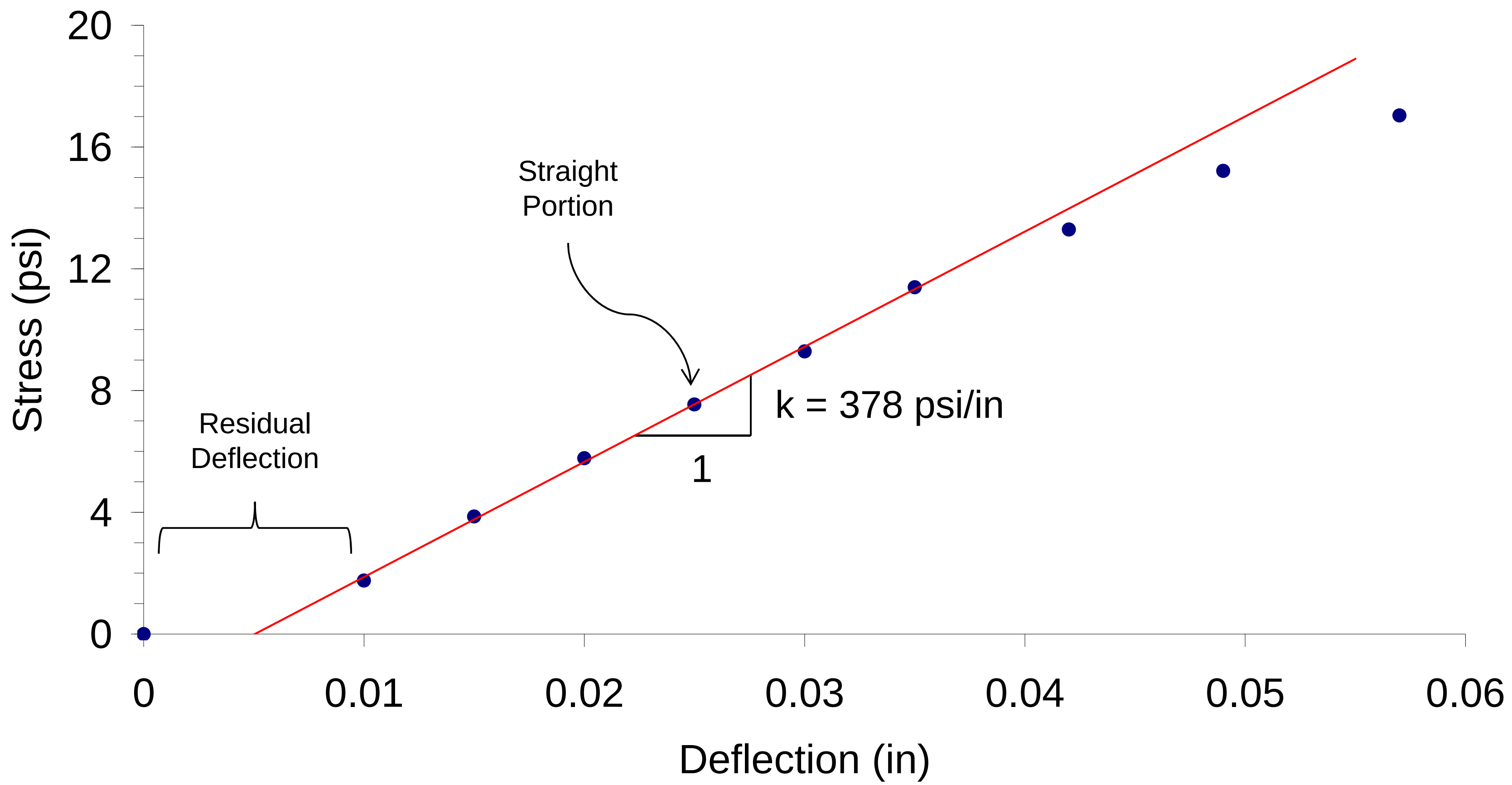


Plate Load Test

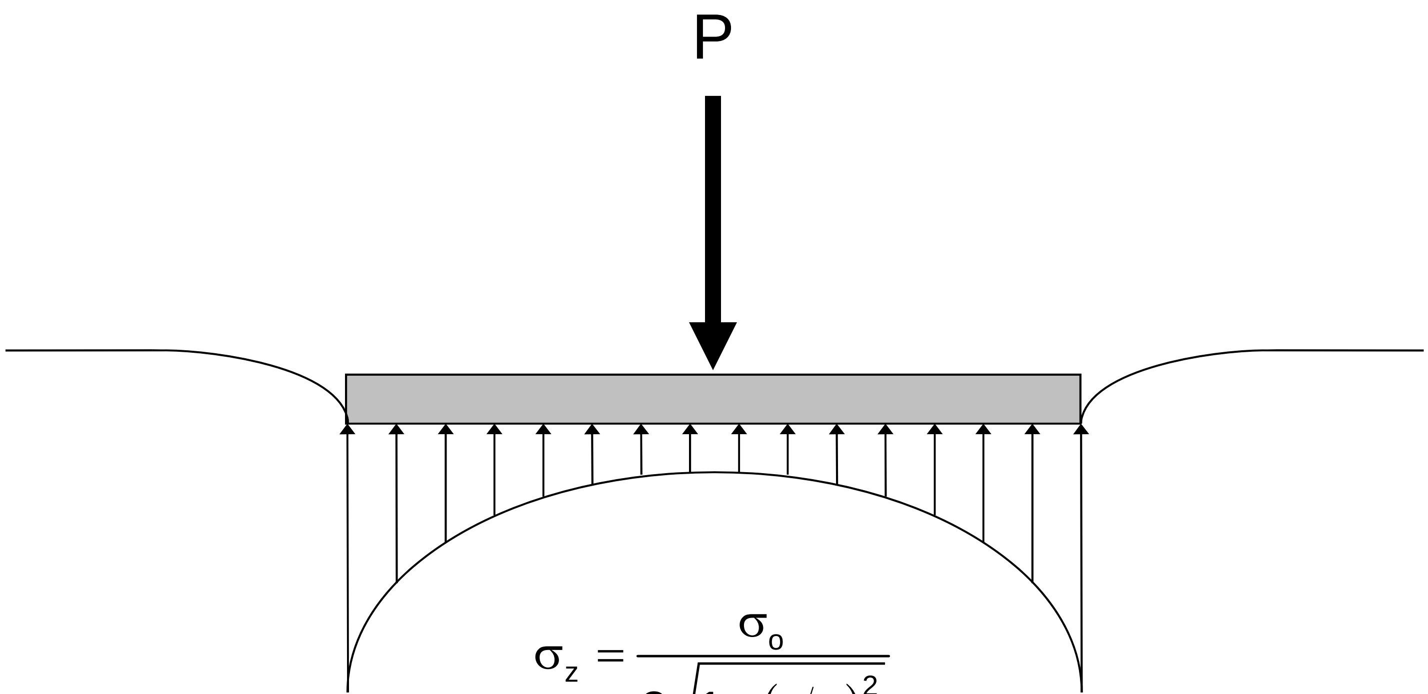


$$A = \pi r^2 = \pi(15\text{ in})^2 = 707\text{ in}^2$$

Plate Load Test



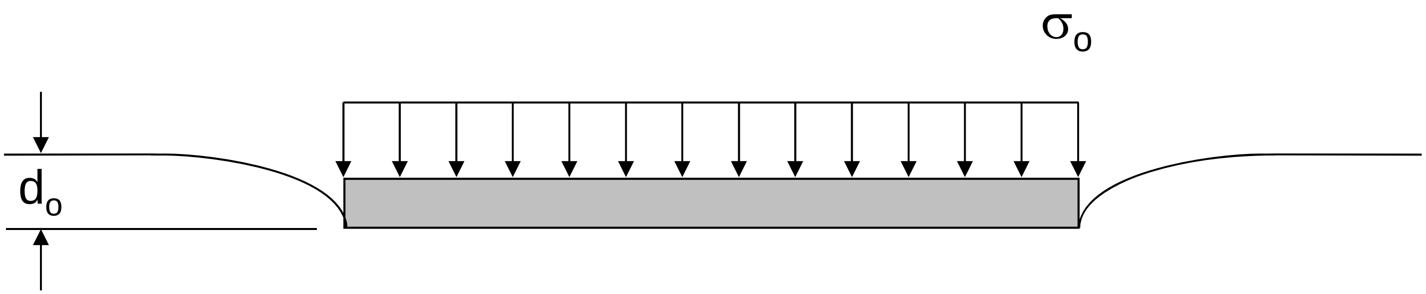
Rigid Loading



$$\sigma_z = \frac{\sigma_o}{2\sqrt{1-(r/a)^2}}$$

where $\sigma_o = \dfrac{P}{\pi a^2}$ is the average pressure on the plate

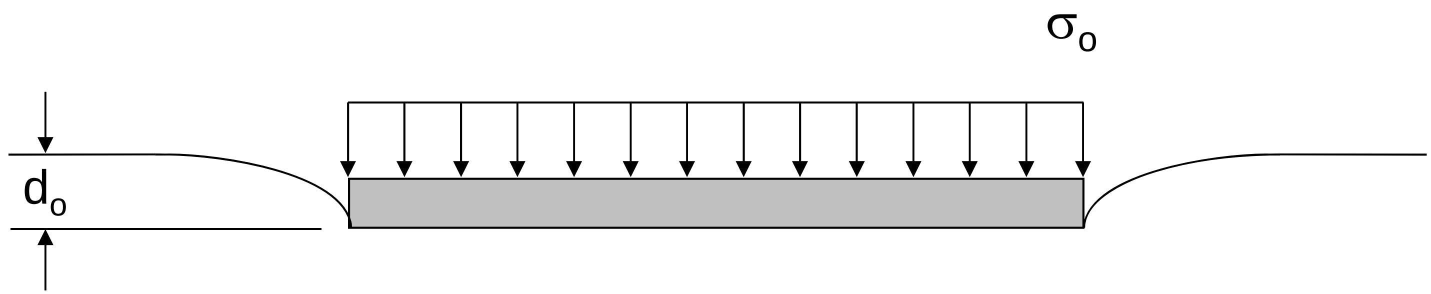
Rigid Loading



$$d_o = \frac{\pi \sigma_o a\left(1-\mu^2\right)}{2E} \quad \Rightarrow \quad E = \frac{\pi \sigma_o a\left(1-\mu^2\right)}{2d_o}$$

$$\frac{\sigma_o}{d_o} = k$$

Rigid Loading



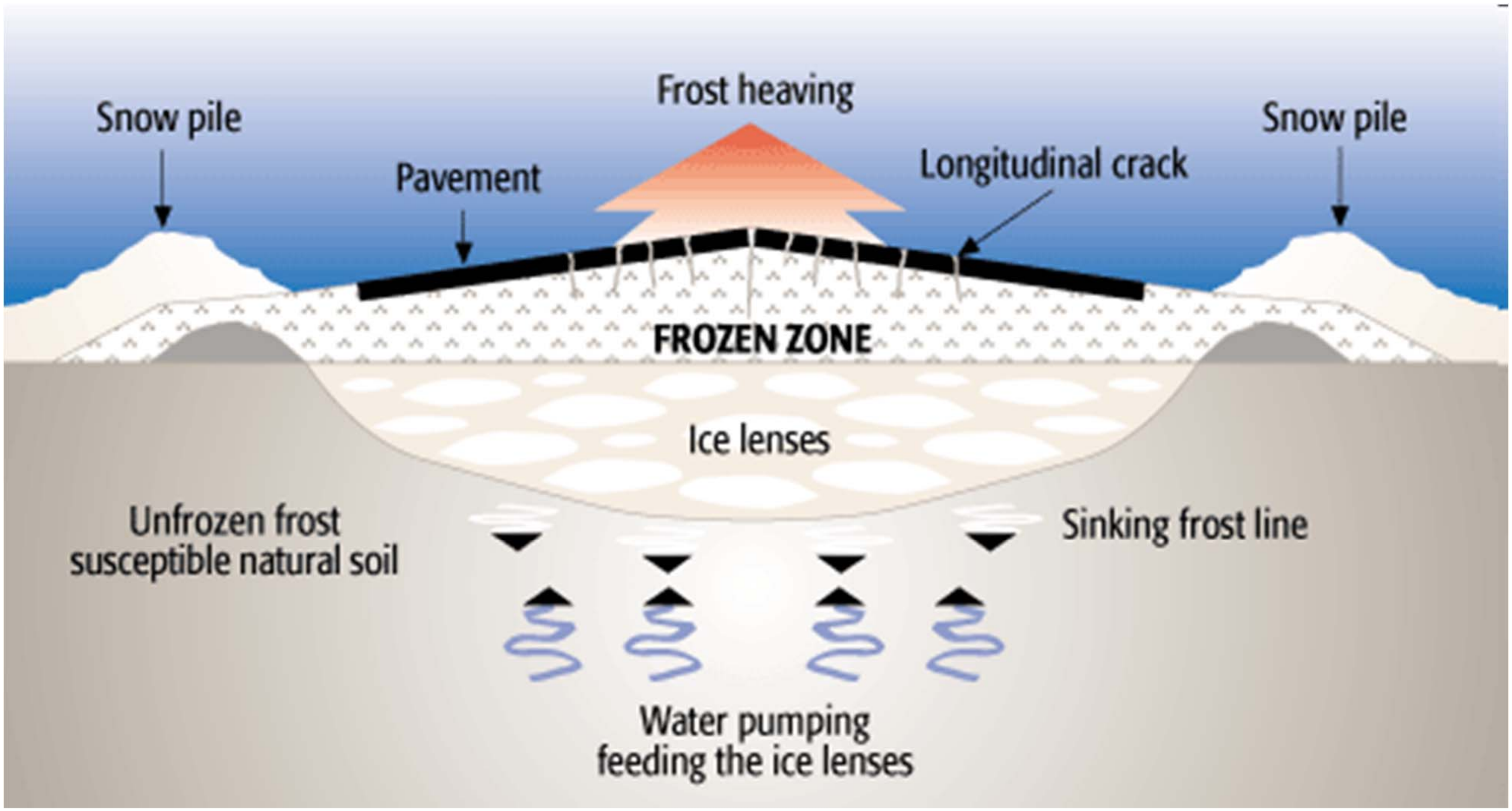
$$E = \frac{\pi k a\left(1-\mu^2\right)}{2}$$

Frost Penetration

Frost Heave

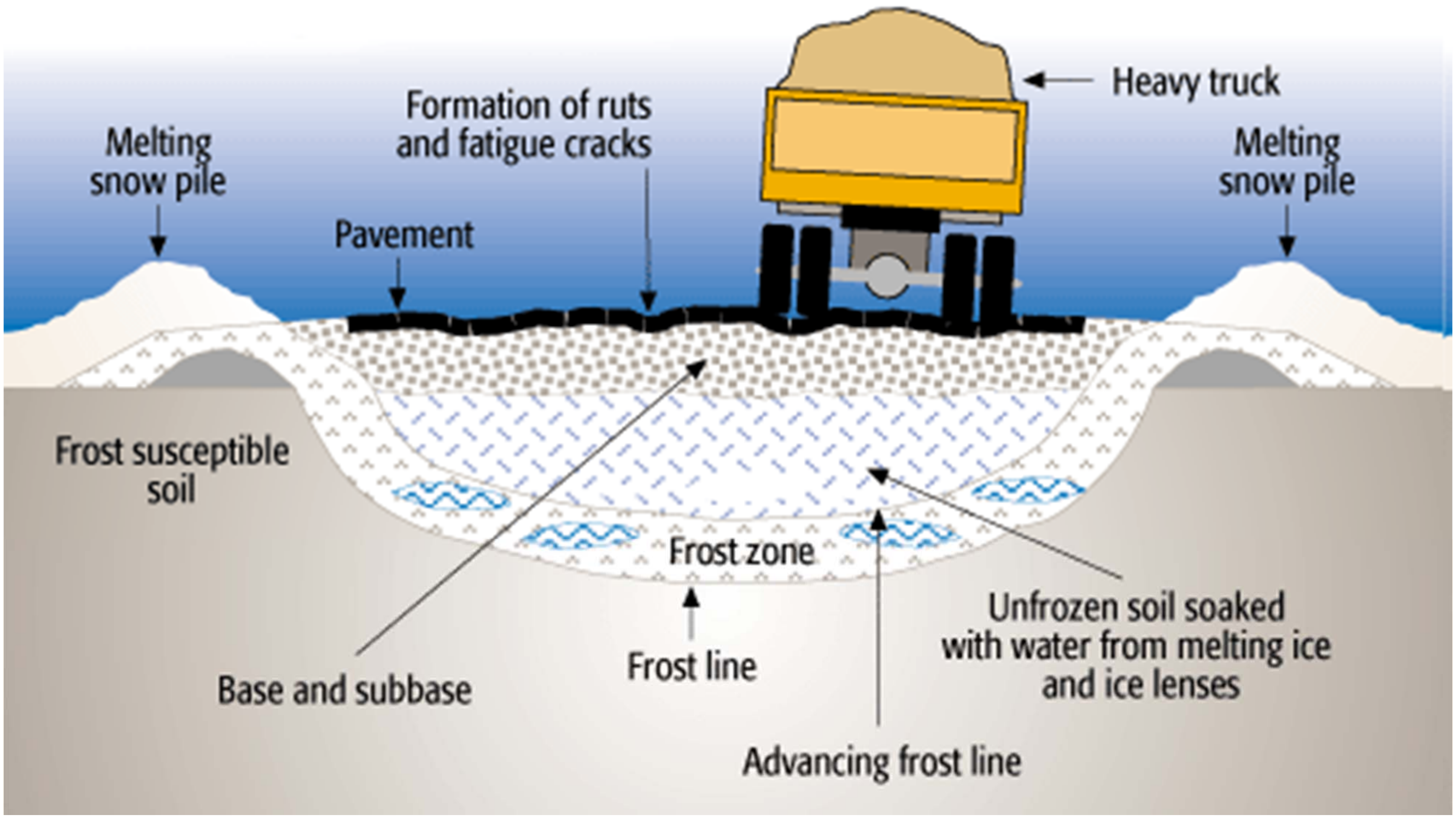
Source: http://www.mtq.gouv.qc.ca/portal/page/portal/entreprises_en/zone_fournisseurs/reseau_routier/chaussee/chaussees_climat_quebecois

Frost Heave



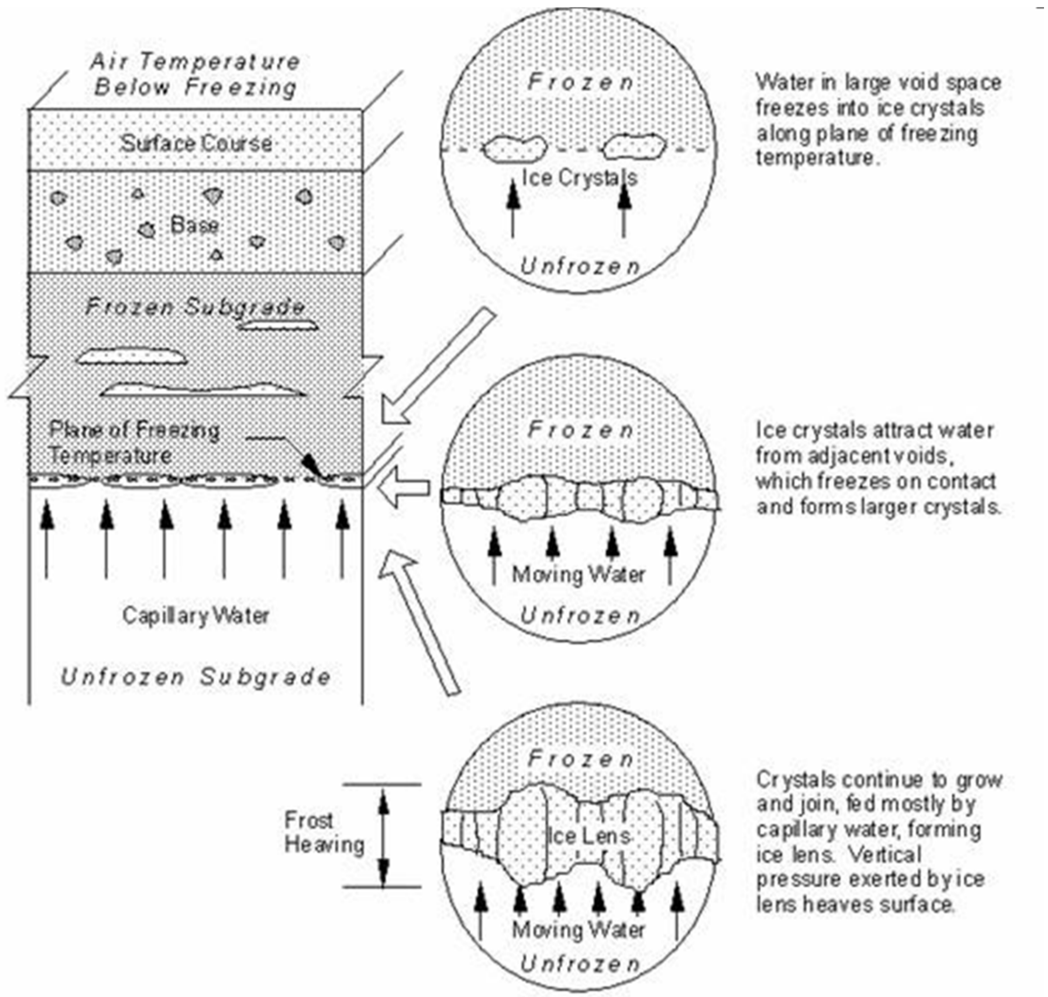
Source: http://www.mtq.gouv.qc.ca/portal/page/portal/entreprises_en/zone_fournisseurs/reseau_routier/chaussee/chaussees_climat_quebecois

Frost Heave



Source: http://www.mtq.gouv.qc.ca/portal/page/portal/entreprises_en/zone_fournisseurs/reseau_routier/chaussee/chaussees_climat_quebecois

Ice Lens Formation

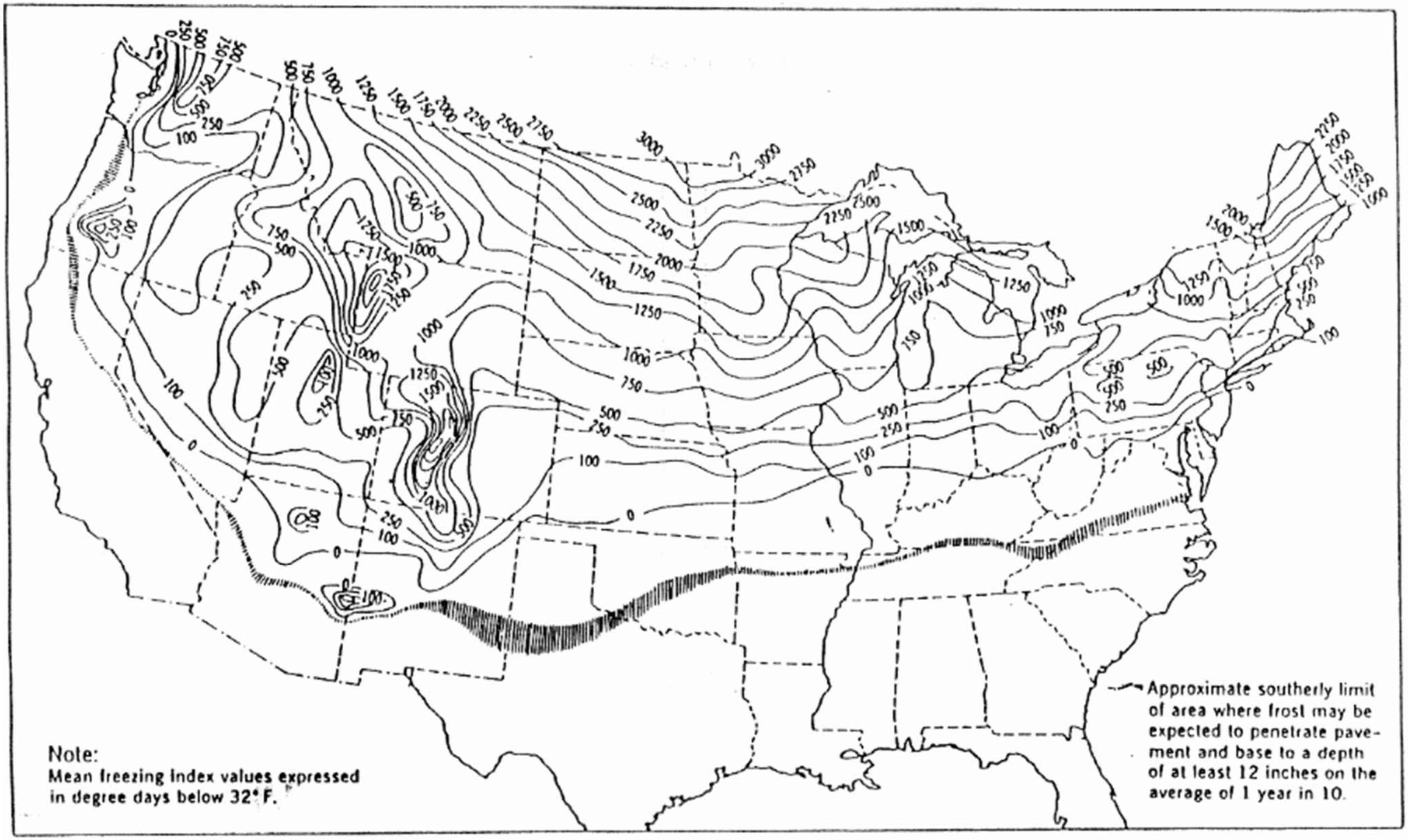


Source: WSDOT Pavement Guide Interactive CD-ROM

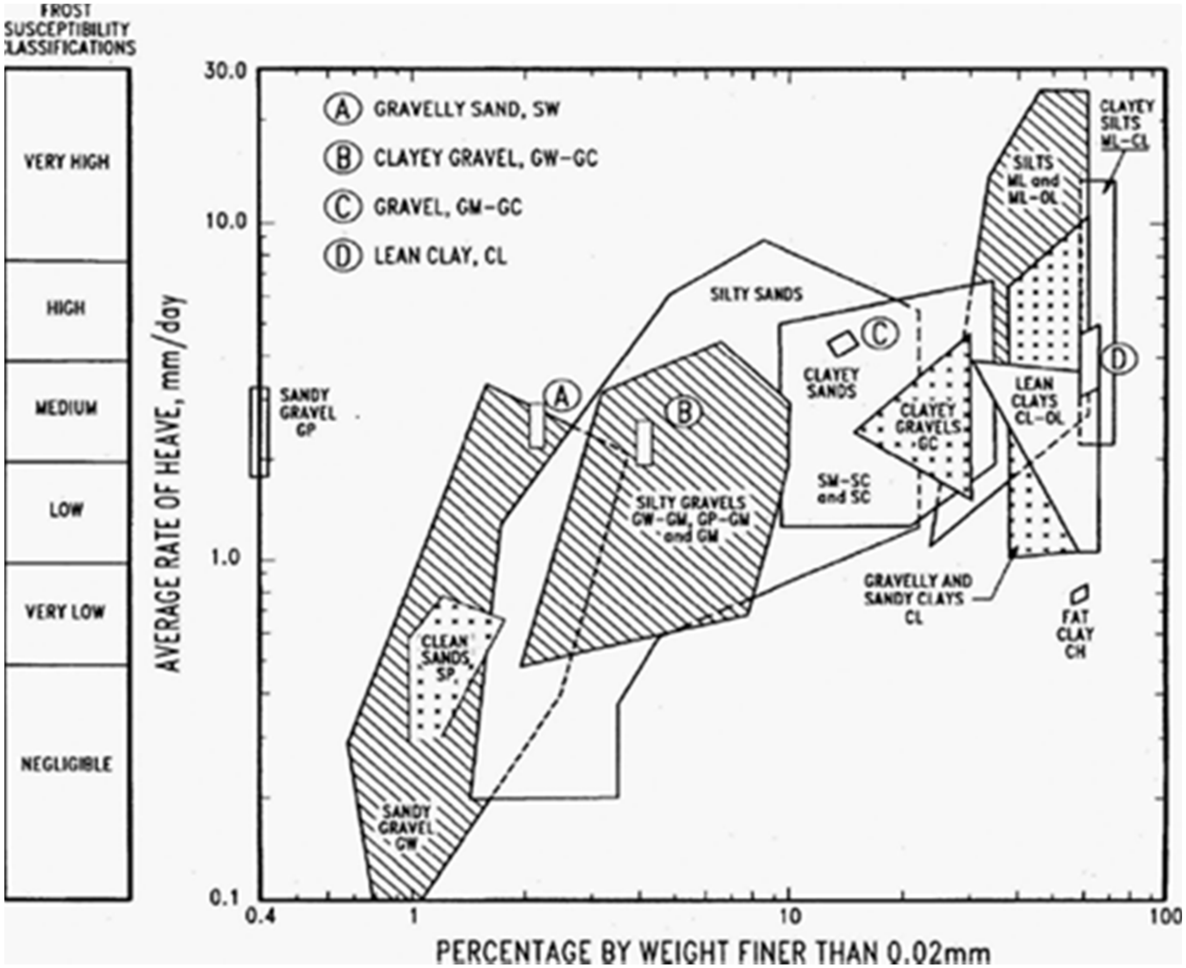
Requirements

- Frost susceptible soil
  - Granular soils can’t support capillarity
  - Clay soils aren’t permeable enough
  - Silts have capillarity and permeability
- Free moisture in the subgrade
  - Water table within capillary range of soil
- Freezing line penetrates into the subgrade
  - Sustained temperatures below freezing

Freezing Index



Frost Susceptibility



Source: http://www.fhwa.dot.gov/engineering/geotech/pubs/05037/07c.cfm

Frost Susceptibility

TABLE 7.5
Frost Codes and Soil Classification by the Federal Aviation Administration

Frost Group	Type of Soil	Percentage Finer than 0.02 mm by Weight	Soil Classification
FG-1	Gravelly soils	3 to 10	GW, GP, GW-GM, GP-GM
FG-2	Gravelly soils sands	10 to 3 to 15	GM, GW-GM, GP-GM, SW, SP, SM, SW-SM SP-SM
FG-3	Gravelly soils	Over 20	GM, GC
	Sands, except very fine silty sands	Over 15	SM, SC
	Clays, PI above 12		CL, CH
FG-4	Very fine silty sands	Over 15	SM
	All silts		ML, MH
	Clays, PI = 12 or less		CL, CL-ML
	Varied clays and other fine-grained banded sediments		CL, CH, ML, SM

Note: The higher the frost group number, the more susceptible the soil, i.e., soils in frost group 4 (FG-4) are more frost susceptible than soils in frost groups 1, 2, or 3.

Source: From FAA Advisory Circular No. 150/5320-6D (FAA, 1995).

Treatment for Frost Susceptible Soils

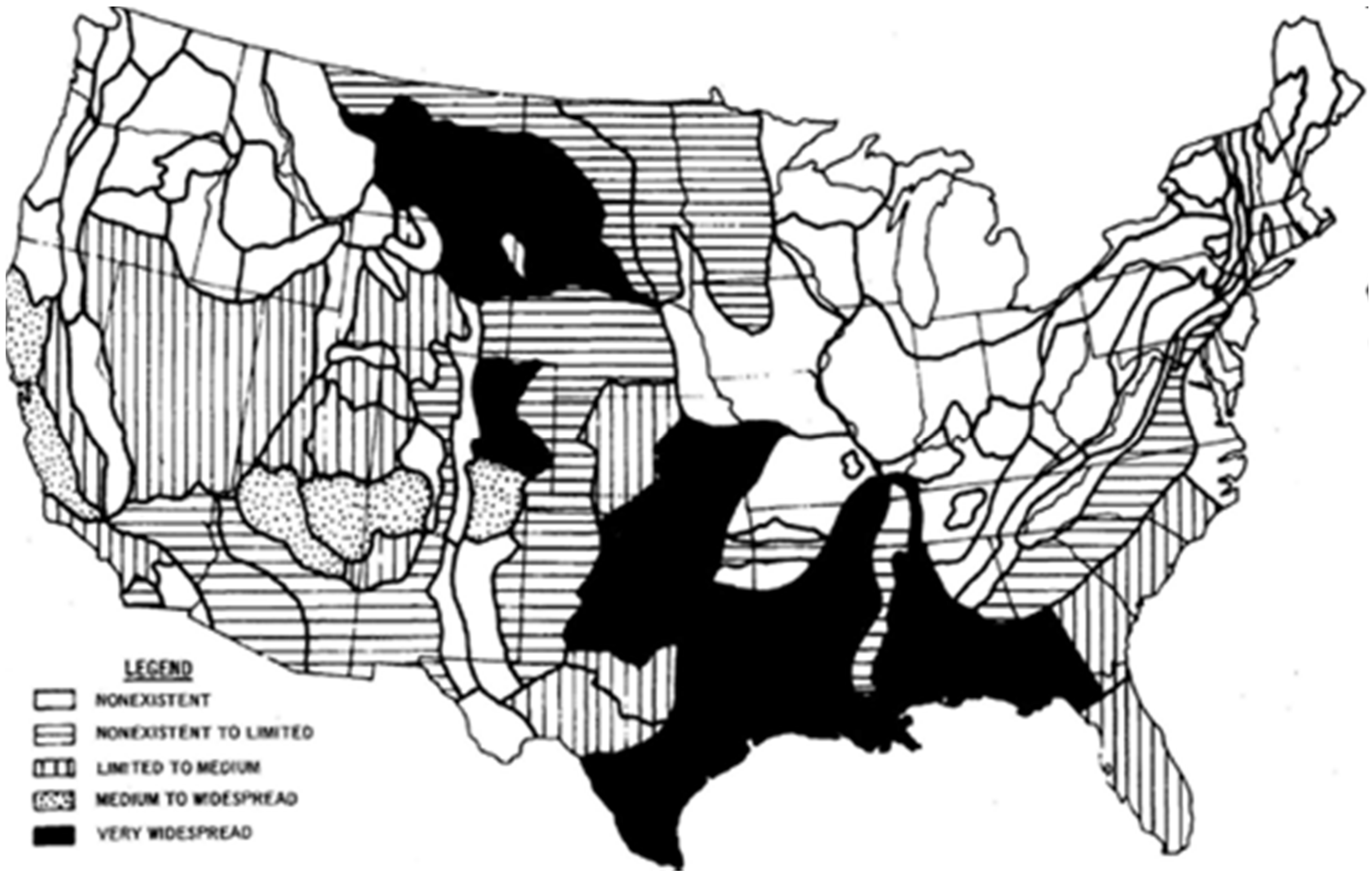
- Remove isolated pockets of frost-susceptible soils to eliminate abrupt changes in subgrade conditions.
- Increase the pavement structural layer thickness to account for strength reduction in the subgrade during the spring-thaw period (Groups F1, F2, and F3).
- Place and compact non-frost-susceptible borrow to a thickness sufficient to prevent subgrade freezing (Groups F2, F3, and F4).
- Remove the frost-susceptible soil and replace with select non-frost-susceptible borrow to the expected frost depth penetration. (Groups F3 and F4)

Treatment for Frost Susceptible Soils

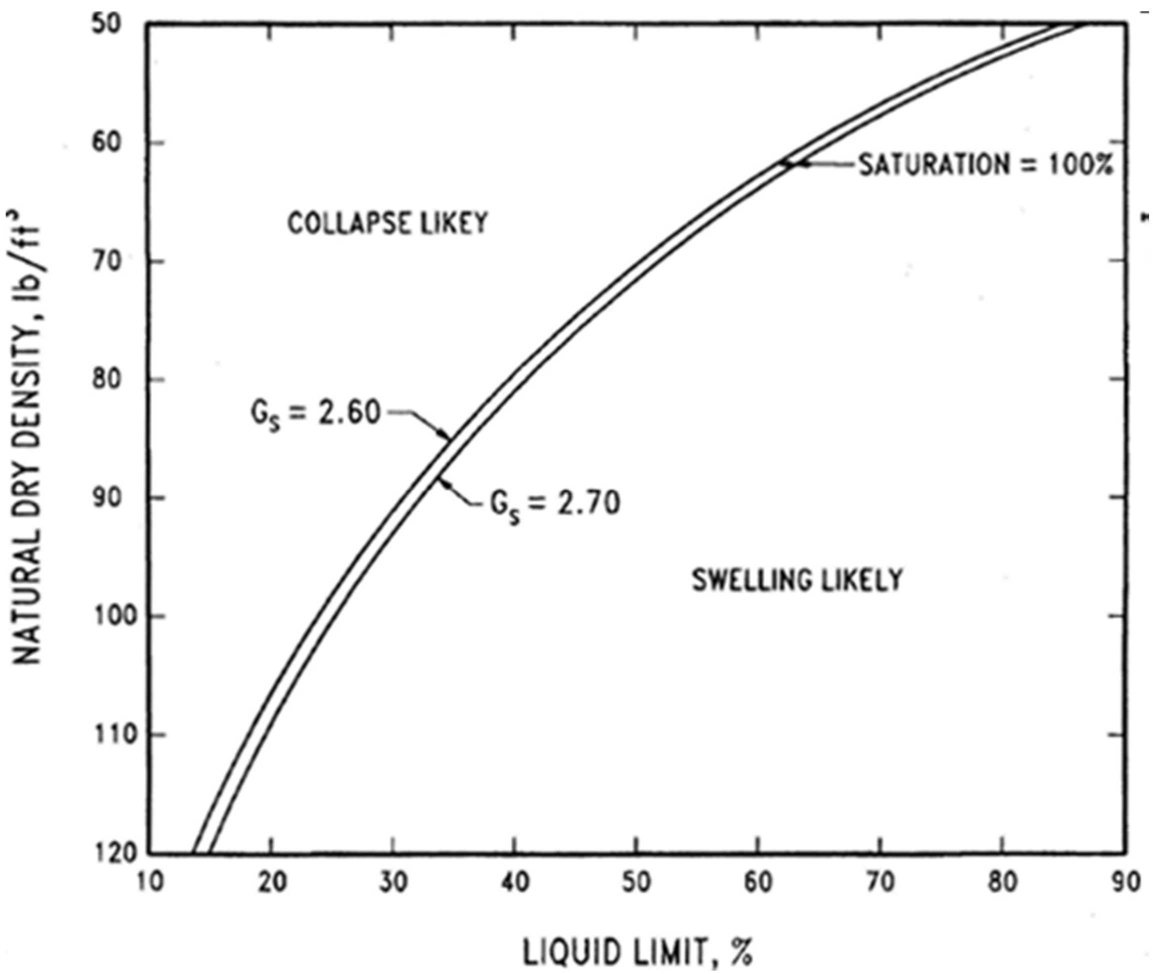
- Stabilize the frost-susceptible soil by mechanically removing or immobilizing fines through cementitious bonding. Cementation also partially removes capillary passages, thereby reducing the potential for moisture movement.
- Stabilize the frost-susceptible soil by installing a capillary barrier to prevent moisture from reaching the freezing zone. Capillary barriers can consist of either an open-graded gravel layer sandwiched between two geotextile layers, or a horizontal geocomposite drain.

Swelling Potential

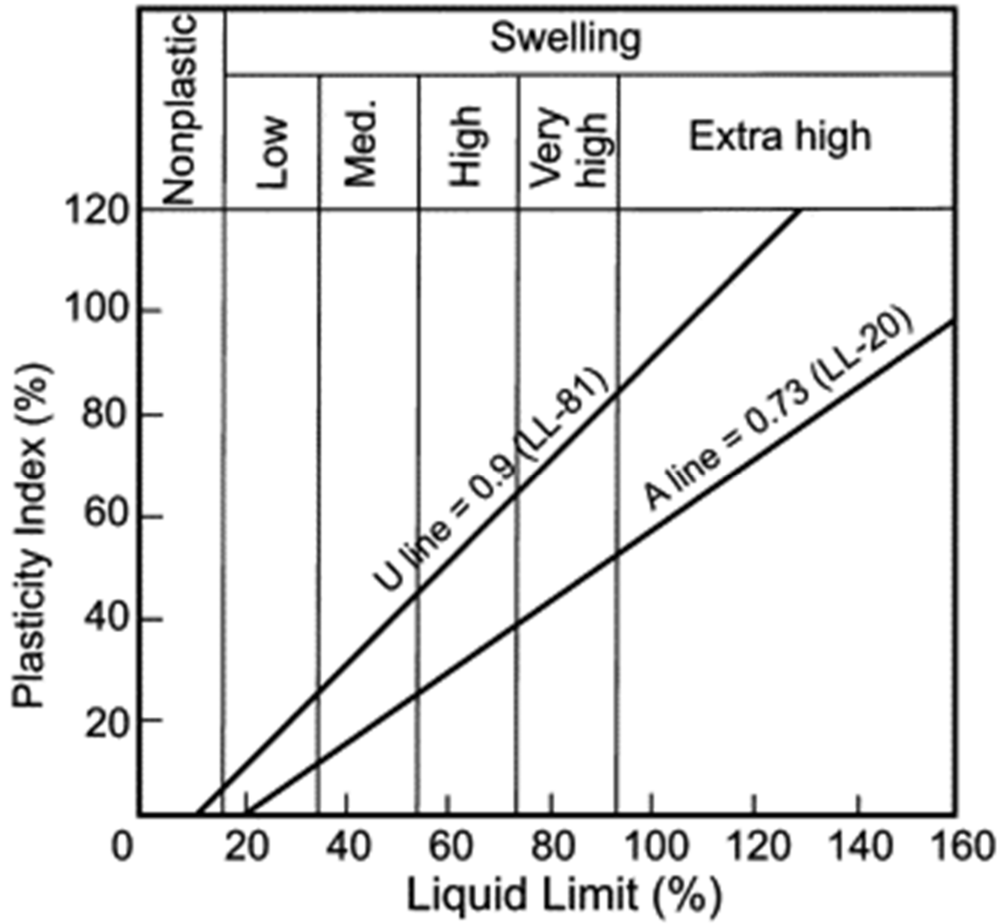
Swelling Soils



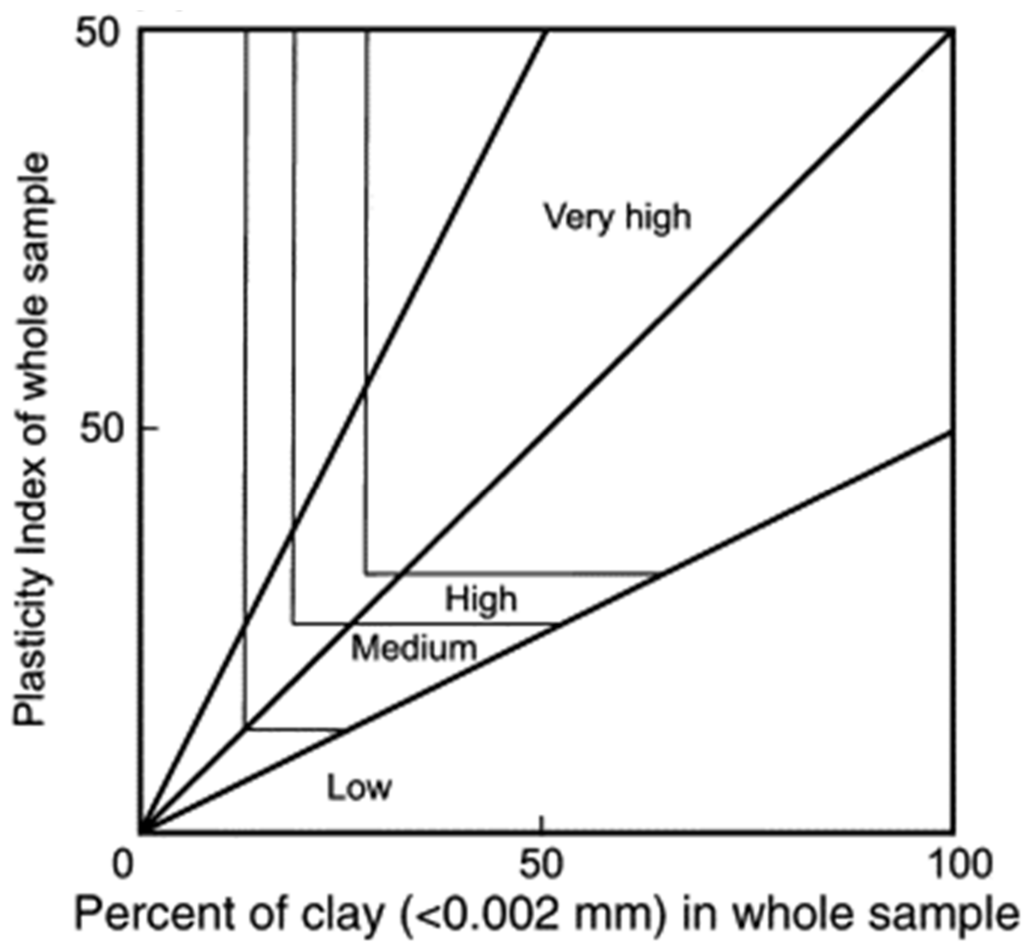
Swelling Potential



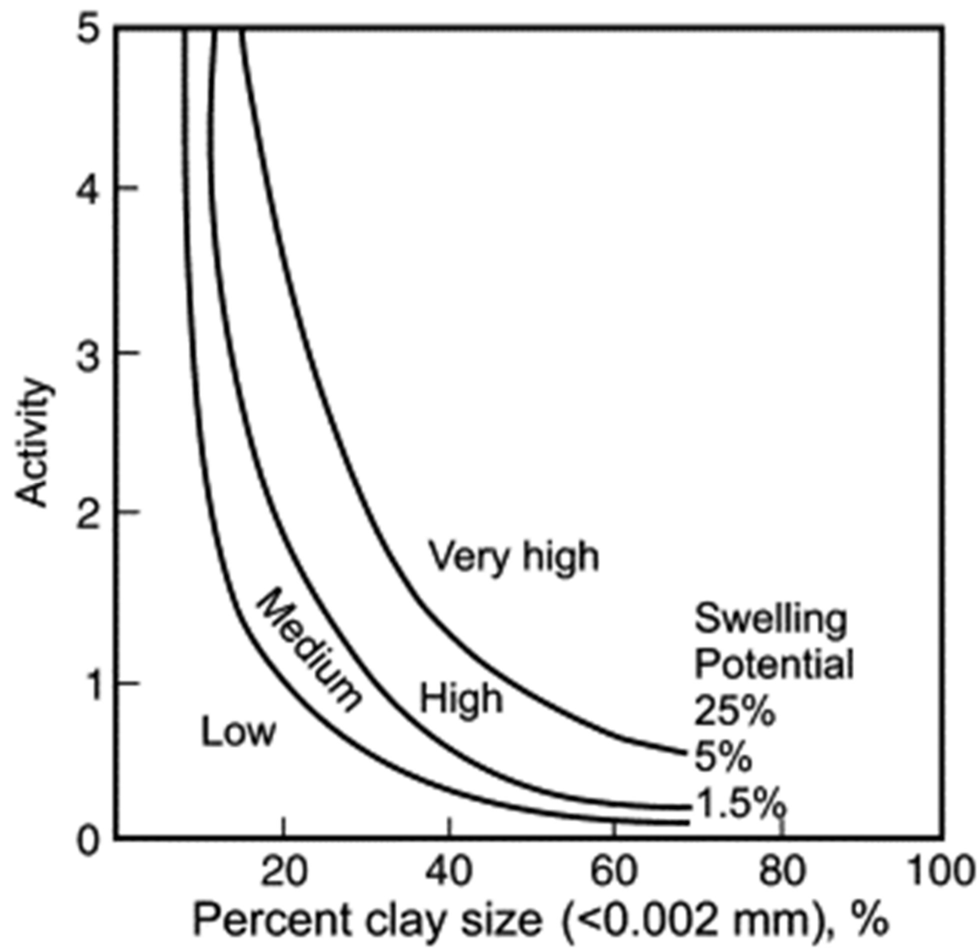
Swelling Potential



Swelling Potential



Swelling Potential



Swell Potential

$$S(\%) = a\left(\frac{PI}{C-5}\right)^{b} C^{3.44}$$

Activity ($\frac{PI}{C-5}$)

C: % finer than 0.002 mm

$$a, b = f\left(PI\right)$$

Treatment for Swelling Soils

TABLE 7.7
Federal Aviation Administration Recommendations for Treating Soils with Swelling Potential

Swell Potential (Based on Experience)	% Swell Measured (ASTM D-1883)	Potential for Moisture Fluctuation	Treatment
Low	3–5	Low	Compact soil on wet side of optimum (+2% to +3%) to not greater than 90% of appropriate maximum density.[a]
		High	Stabilize soil to a depth of at least 6 in.
Medium	6–10	Low	Stabilize soil to a depth of at least 12 in.
		High	Stabilize soil to a depth of at least 12 in.
High	Over 10	Low	Stabilize soil to a depth of at least 12 in.
		High	For uniform soils (i.e., redeposited clays), stabilize soil to a depth of at least 36 in. below pavement section, or remove and replace with nonswelling soil. For variable soil deposits, depth of treatment should be increased to 60 in.

[a] When control of swelling is attempted by compacting on the wet side of optimum and reduced density, the design subgrade strength should be based on the higher moisture content and reduced density.

Note: Potential for moisture fluctuation is a judgmental determination and should consider proximity of water table, likelihood of variations in water table, other sources of moisture, and thickness of the swelling soil layer.

Source: From FAA AC No. 150/5320-6D (FAA, 1995).

Treatment for Swelling Soils

- For relatively thin layers of expansive clays near the surface, remove and replace the expansive soil with select borrow materials.
- Extend the width of the subsurface pavement layers to reduce the change (*i.e.*, wetting or drying) in subgrade moisture along the pavement's edge, and increase the roadway crown to reduce infiltration moisture.
- Scarify, stabilize, and recompact the upper portion of the expansive clay subgrade. Lime or cement stabilization is an accepted method for controlling the swelling of soils.
- In areas with deep cuts in dense, over-consolidated expansive clays, complete the excavation of the subsurface soils to the proper elevation, and allow the subsurface soils to rebound prior to placing the pavement layers.