TEXAS A&M ENGINEERING

Edge Cracking in Pavements on Expansive Soils

Causes and Countermeasures

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Foundation Performance Association
Houston, Texas
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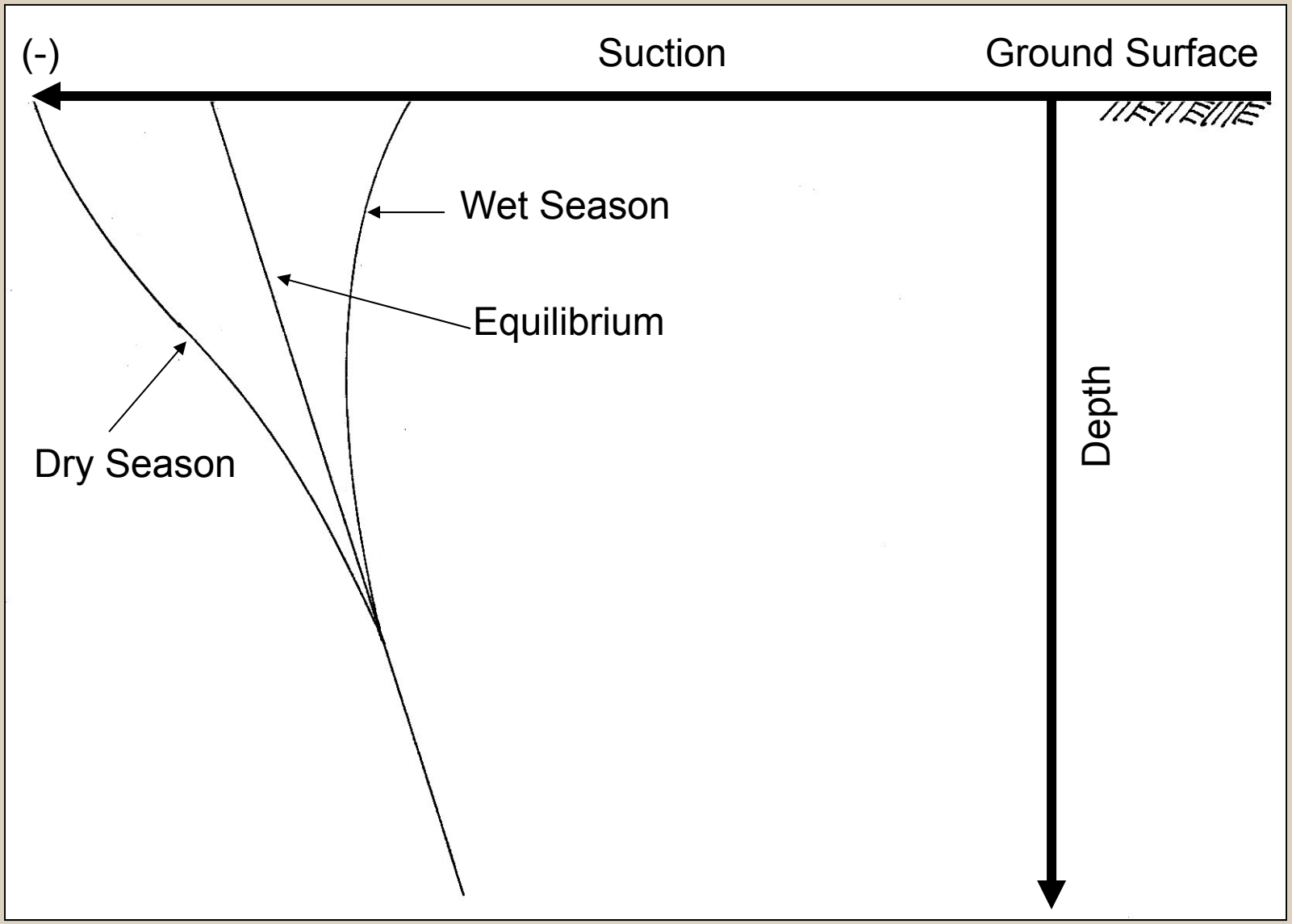
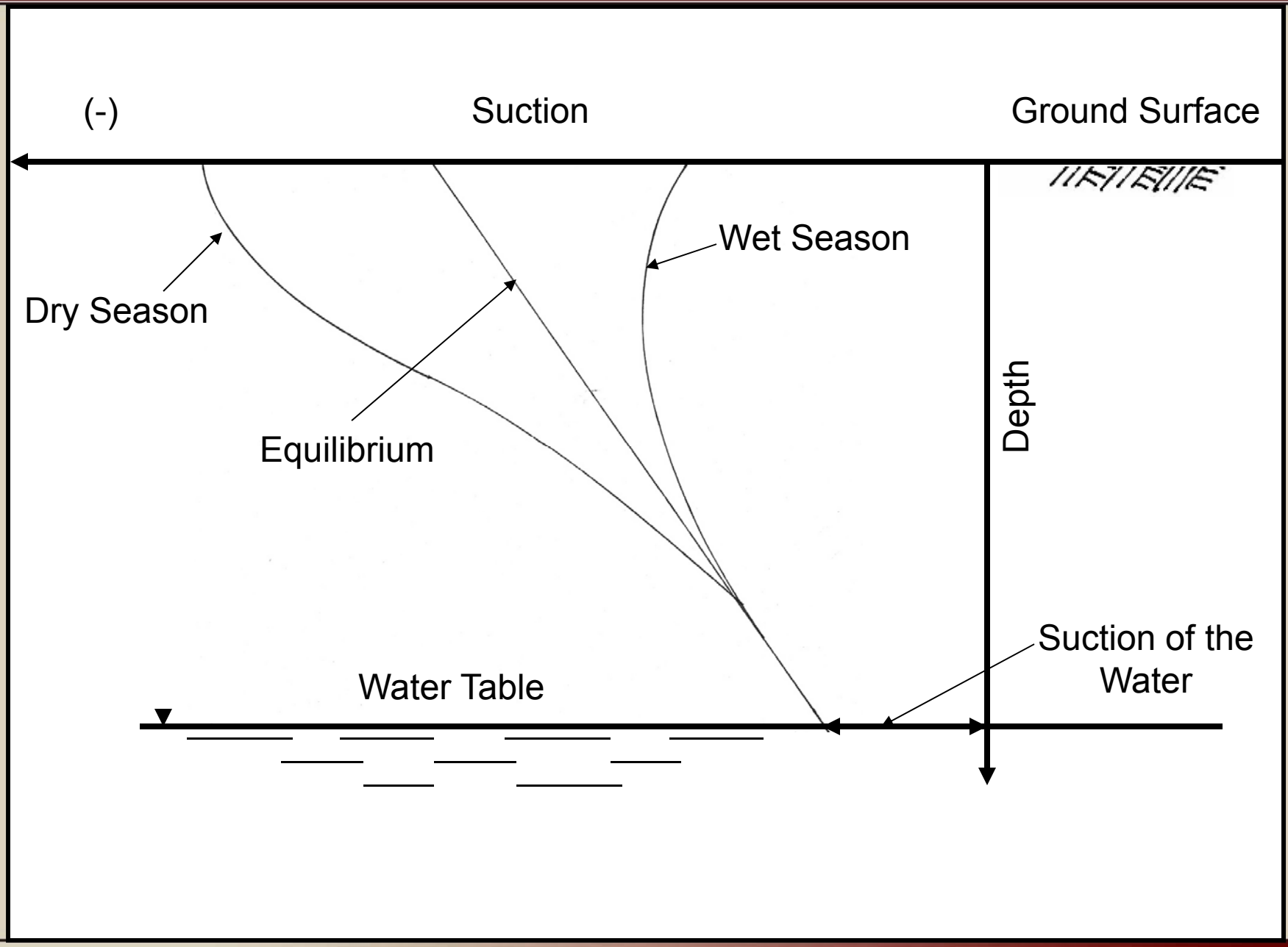
Edge cracking:

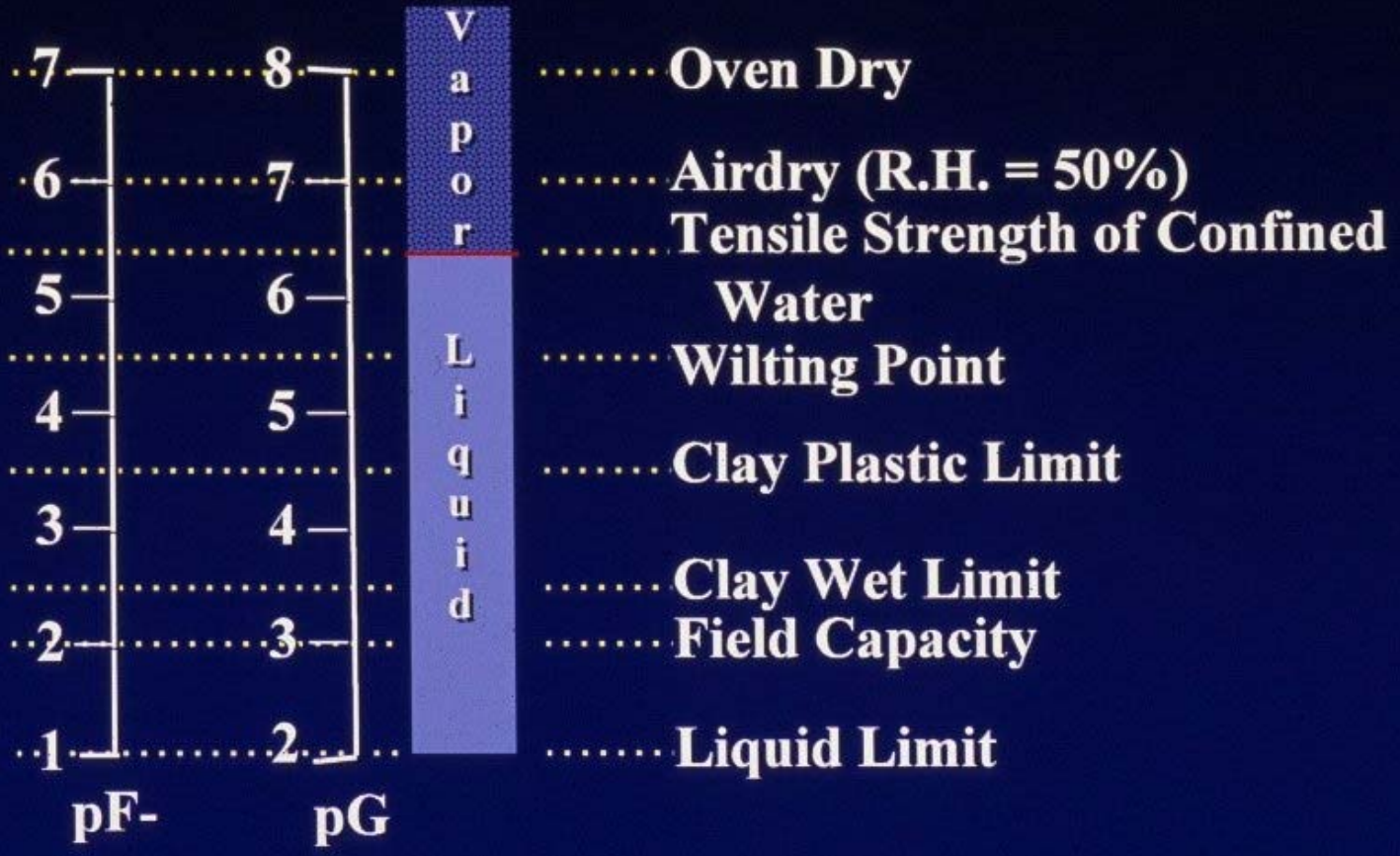
- Causes
- Countermeasures

Practice of Lime Treatment


(-)
Suction
Ground Surface
Wet Season
Equilibrium
Dry Season
Depth

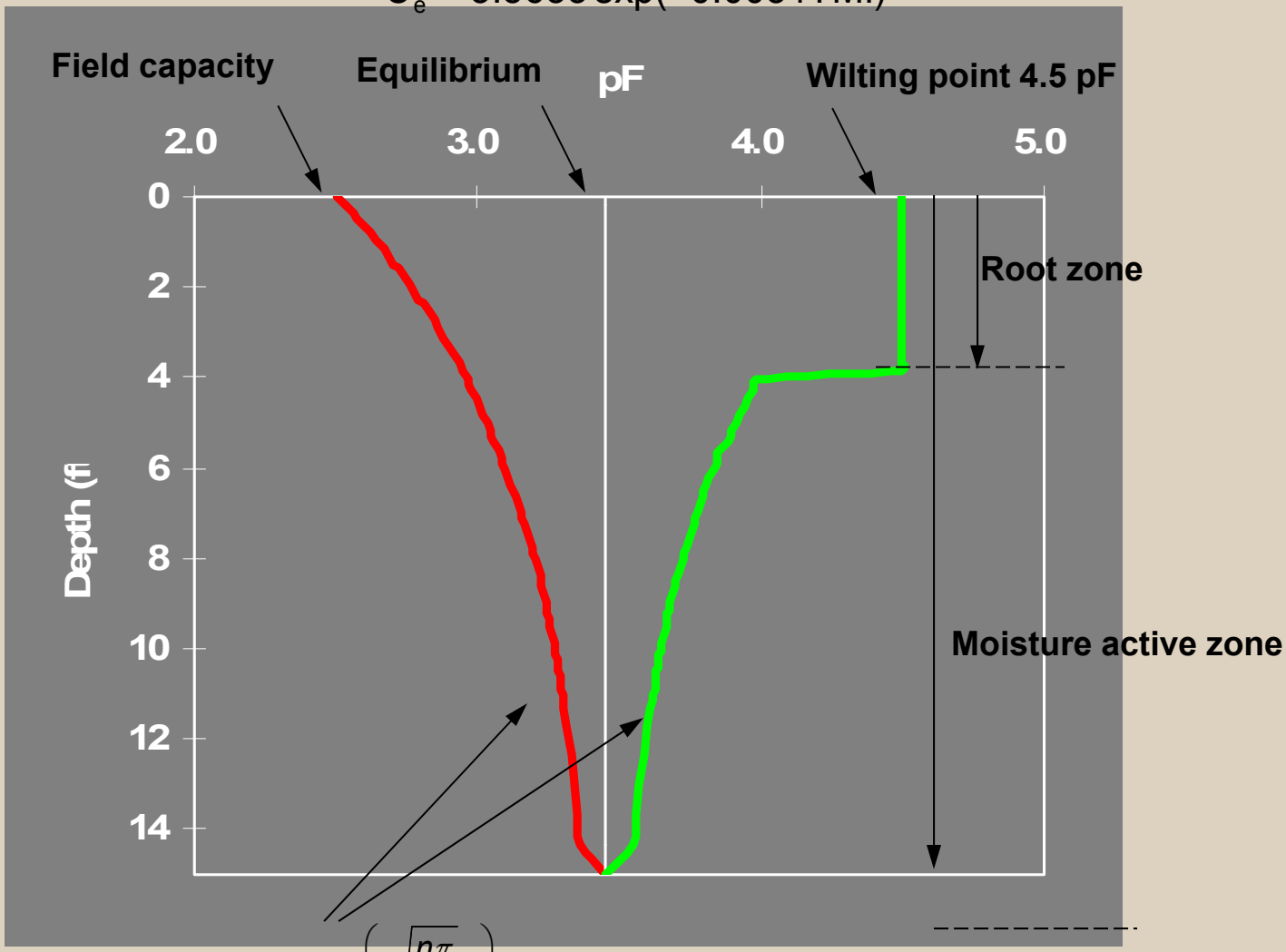

(-)
Suction
Ground Surface
Wet Season
Dry Season
Equilibrium
Depth
Suction of the Water
Water Table

Physical Meaning of Scales

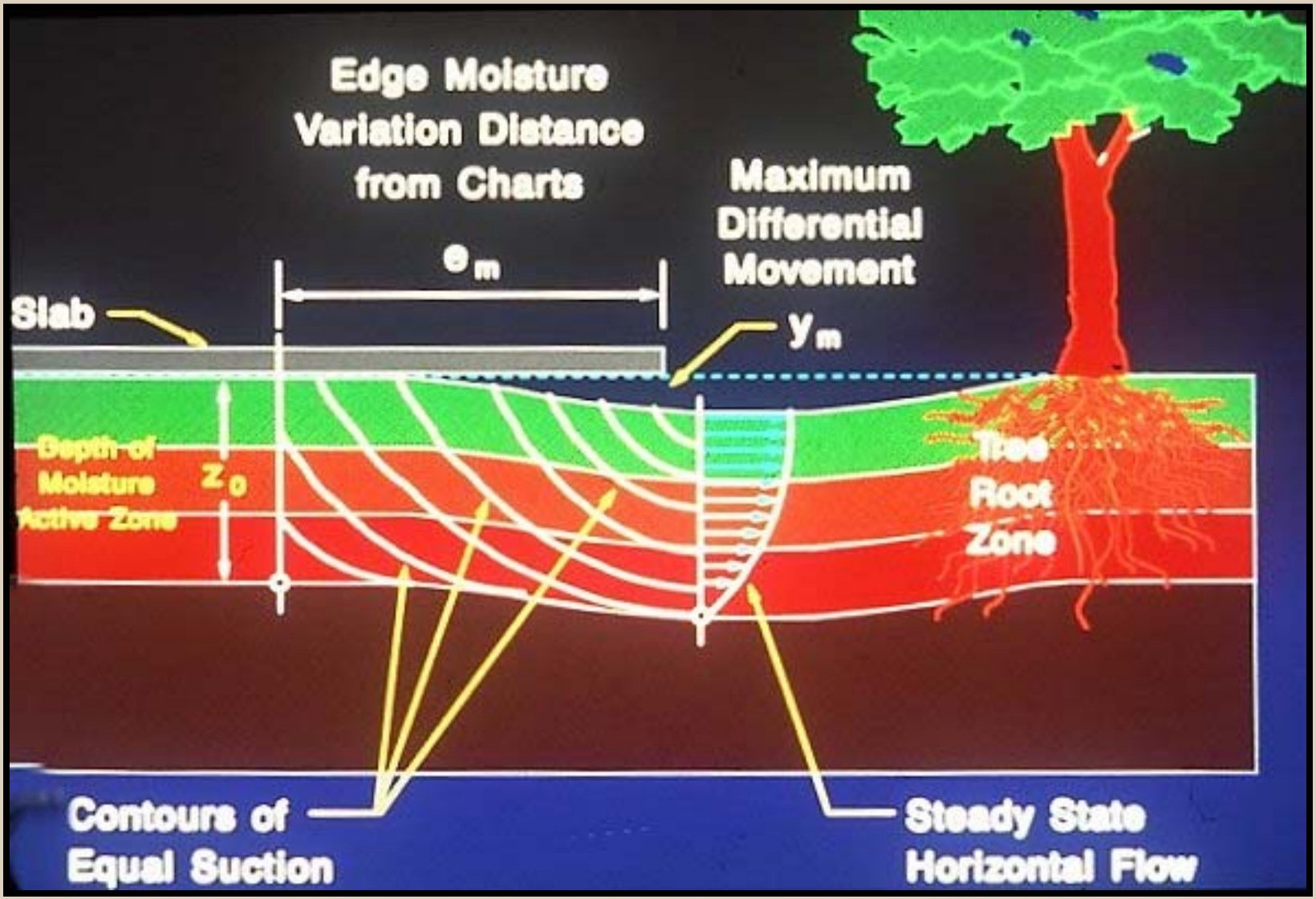


Field Conditions

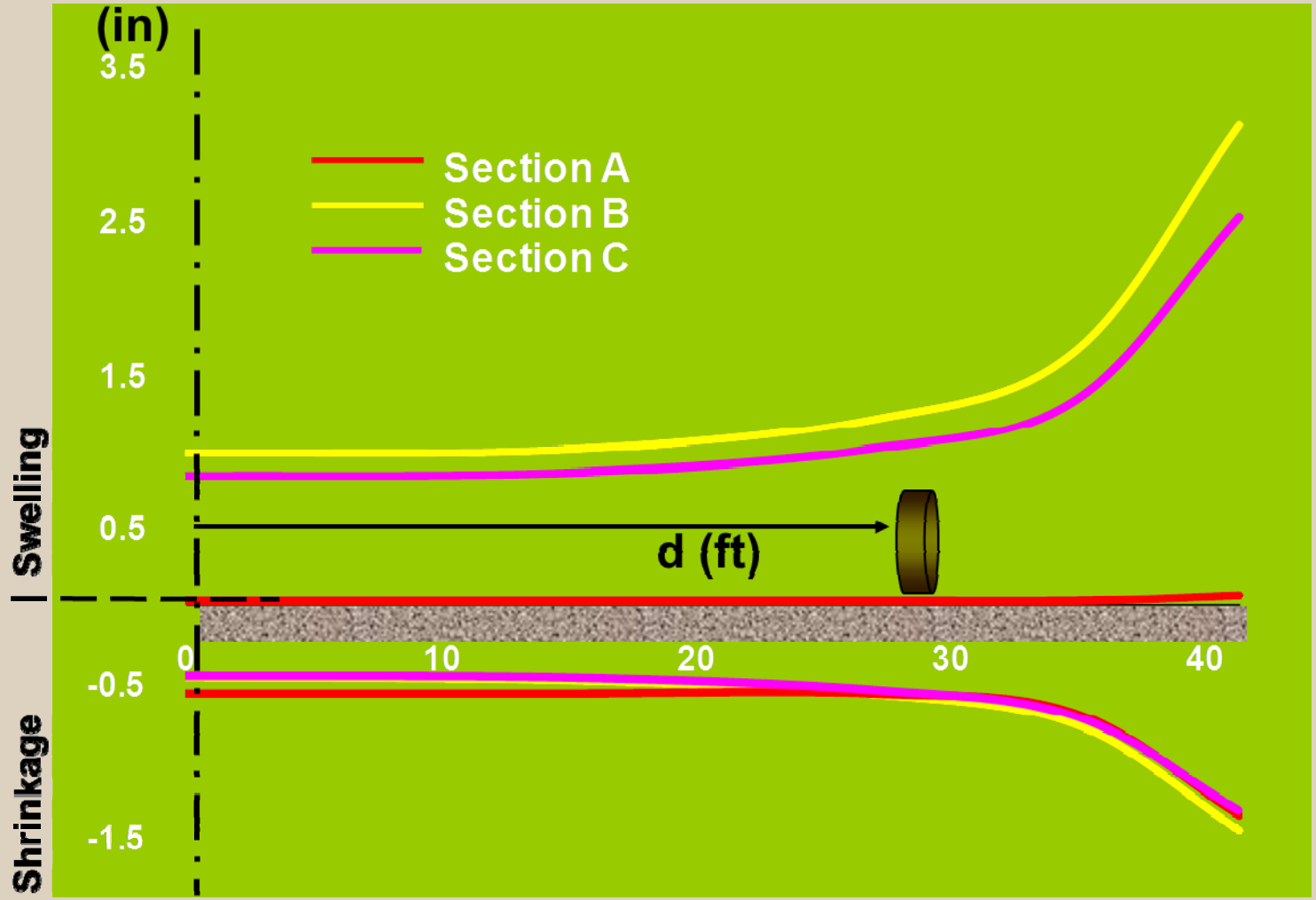
$$U_e = 3.5633 \exp(-0.0051 \mathrm{TMI})$$



$$U(Z) = U_e \pm U_0 \exp\left(-\sqrt{\frac{n\pi}{\alpha}} Z\right)$$

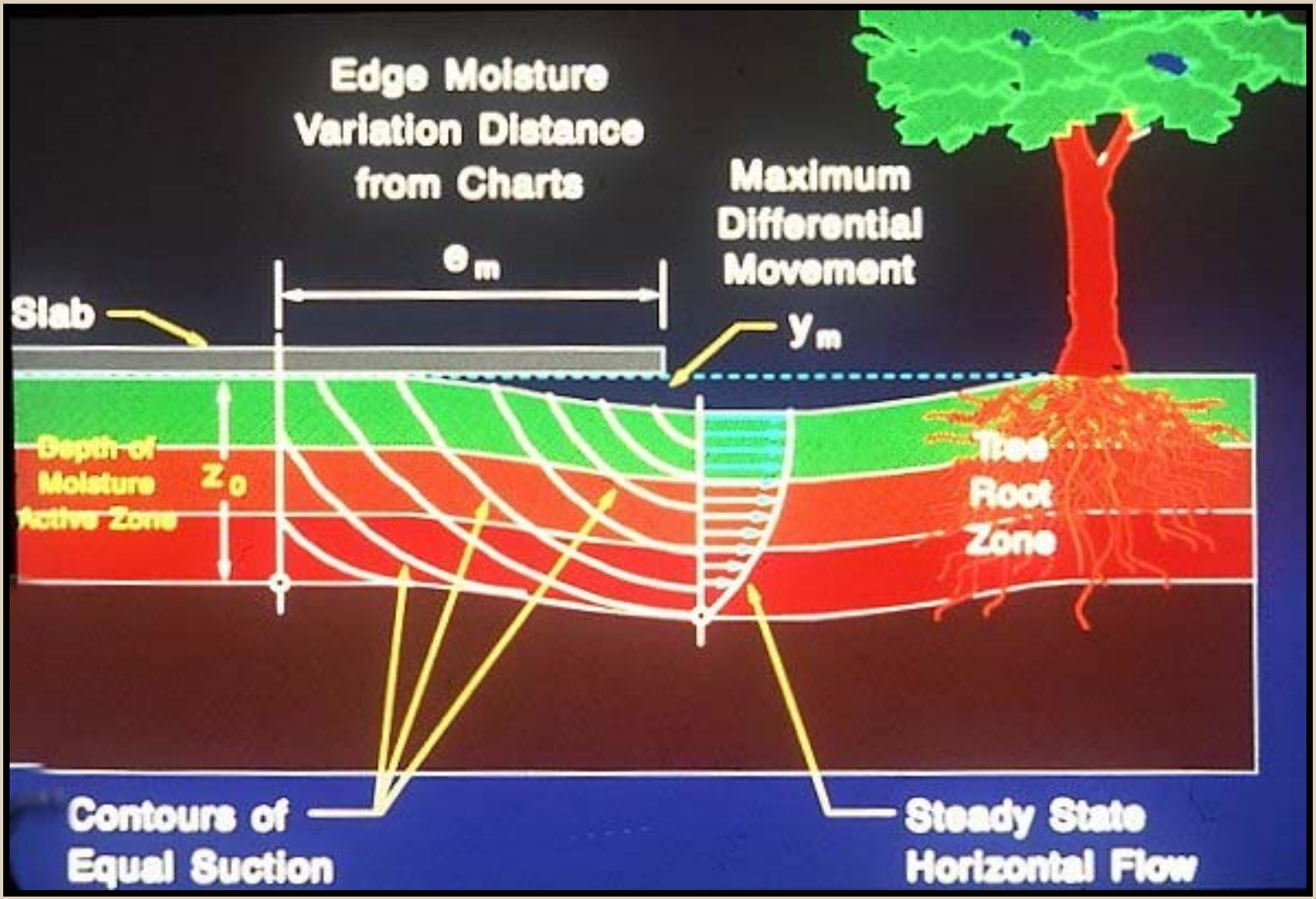

Edge Moisture
Variation Distance
from Charts
e_m
Maximum
Differential
Movement
y_m
Slab
Depth of
Moisture
Active Zone
z_0
Tree
Root
Zone
Contours of
Equal Suction
Steady State
Horizontal Flow

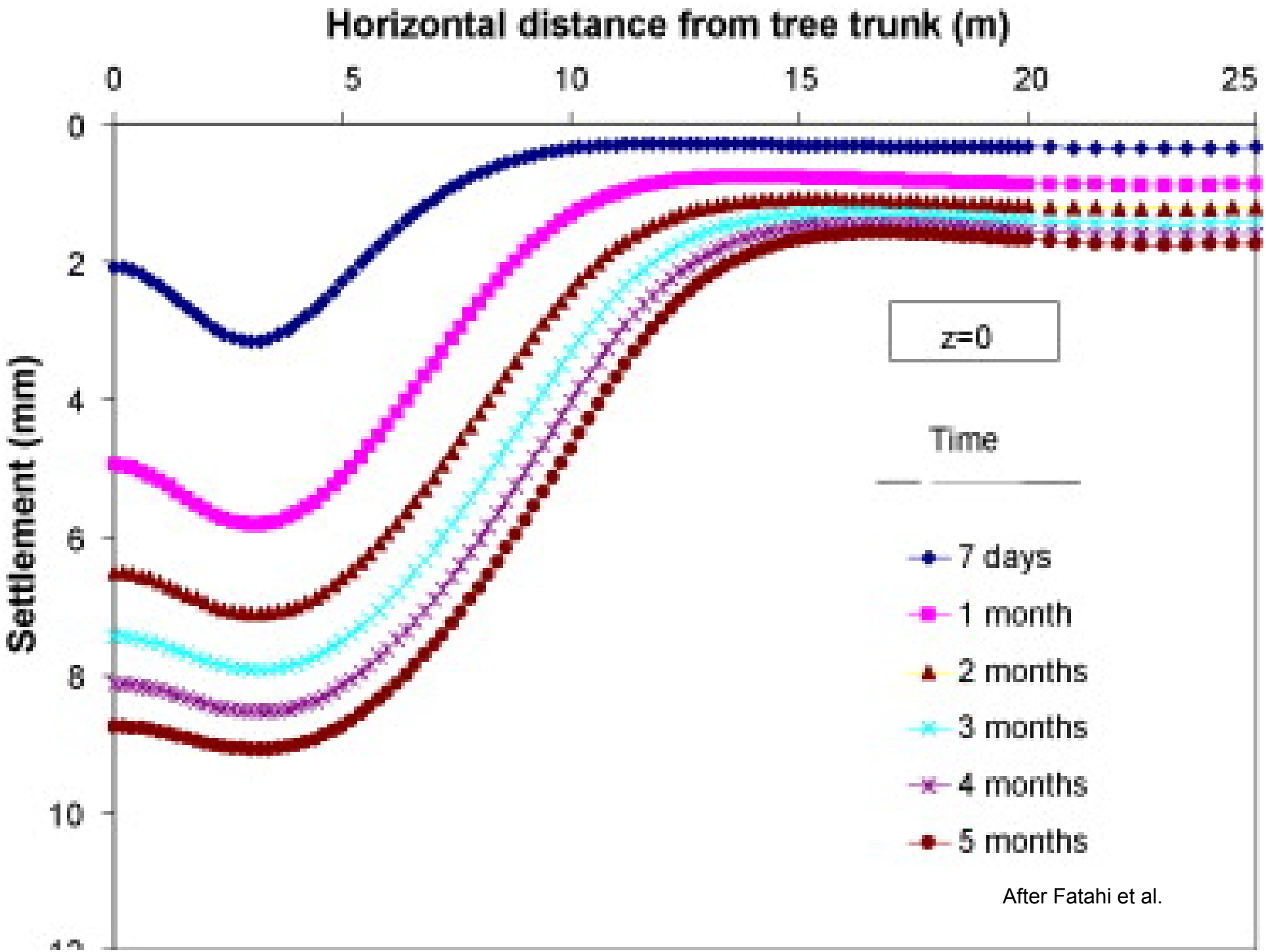
Transverse Distribution of Vertical Movements

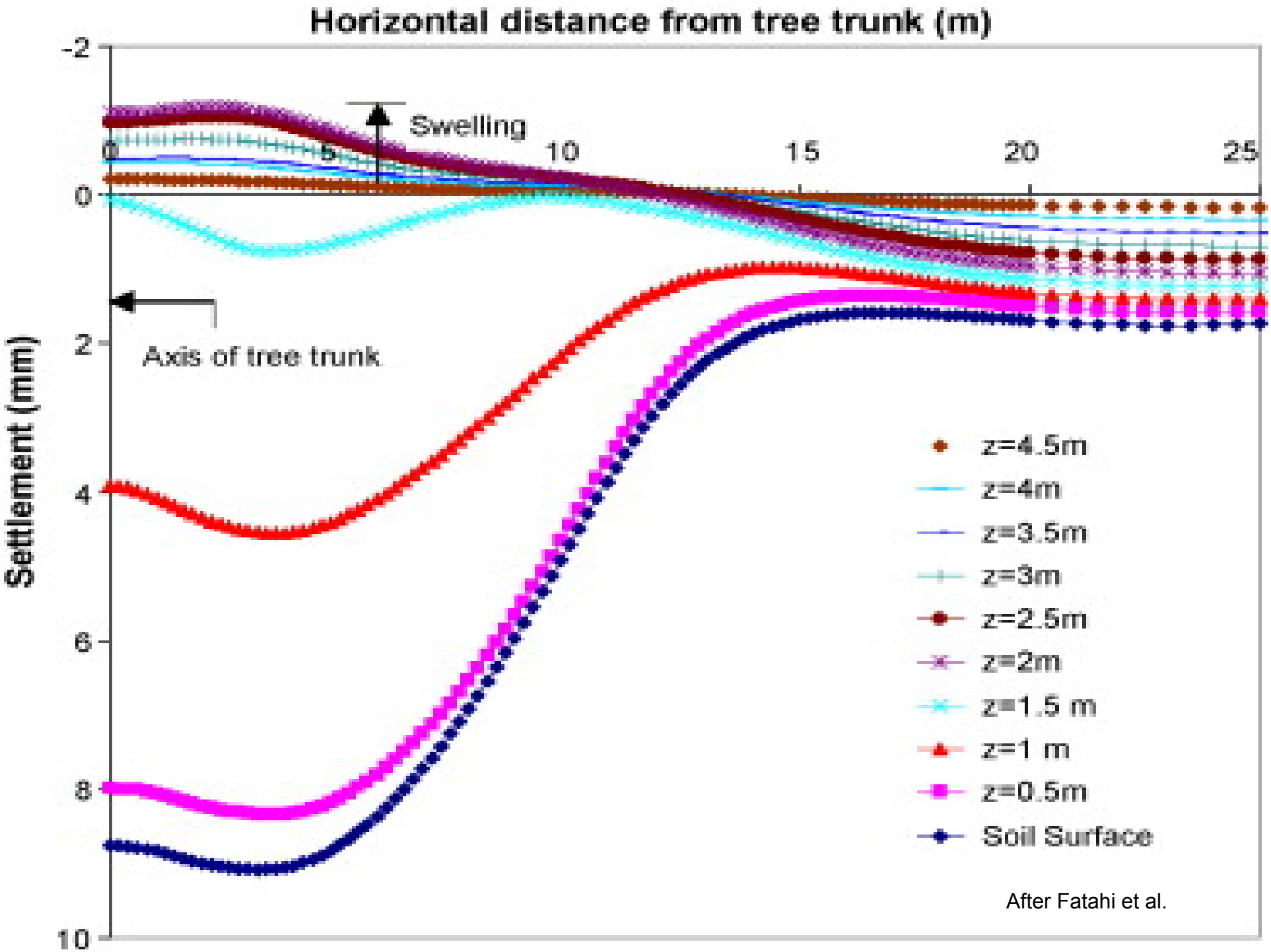


Longitudinal Cracking over Expansive Soils

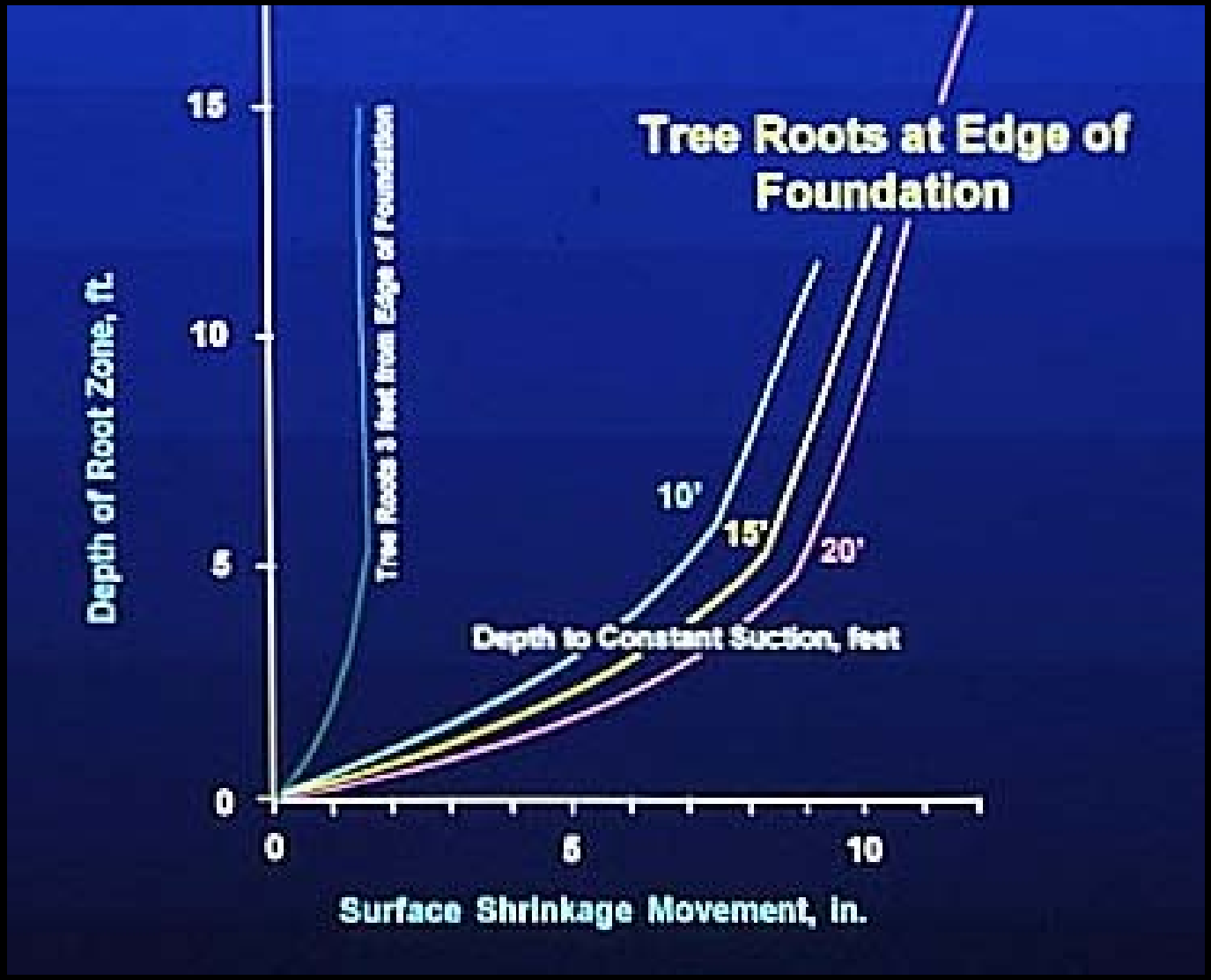
- Expansive Soil
  - Experience volumetric change when subjected to moisture variation
- Longitudinal Crack
  - Initiate in shrinking expansive subgrade
  - Propagate to pavement surface


Edge Moisture
Variation Distance
from Charts
e_m
Maximum
Differential
Movement
y_m
Slab
Depth of
Moisture
Active Zone
z_0
Tree
Root
Zone
Contours of
Equal Suction
Steady State
Horizontal Flow


Horizontal distance from tree trunk (m)
0
5
10
15
20
25
Settlement (mm)
0
2
4
6
8
10
z=0
Time
7 days
1 month
2 months
3 months
4 months
5 months
After Fatahi et al.


Horizontal distance from tree trunk (m)
-2
0
5
10
15
20
25
Swelling
Axis of tree trunk
Settlement (mm)
2
4
6
8
10
z=4.5m
z=4m
z=3.5m
z=3m
z=2.5m
z=2m
z=1.5 m
z=1 m
z=0.5m
Soil Surface
After Fatahi et al.

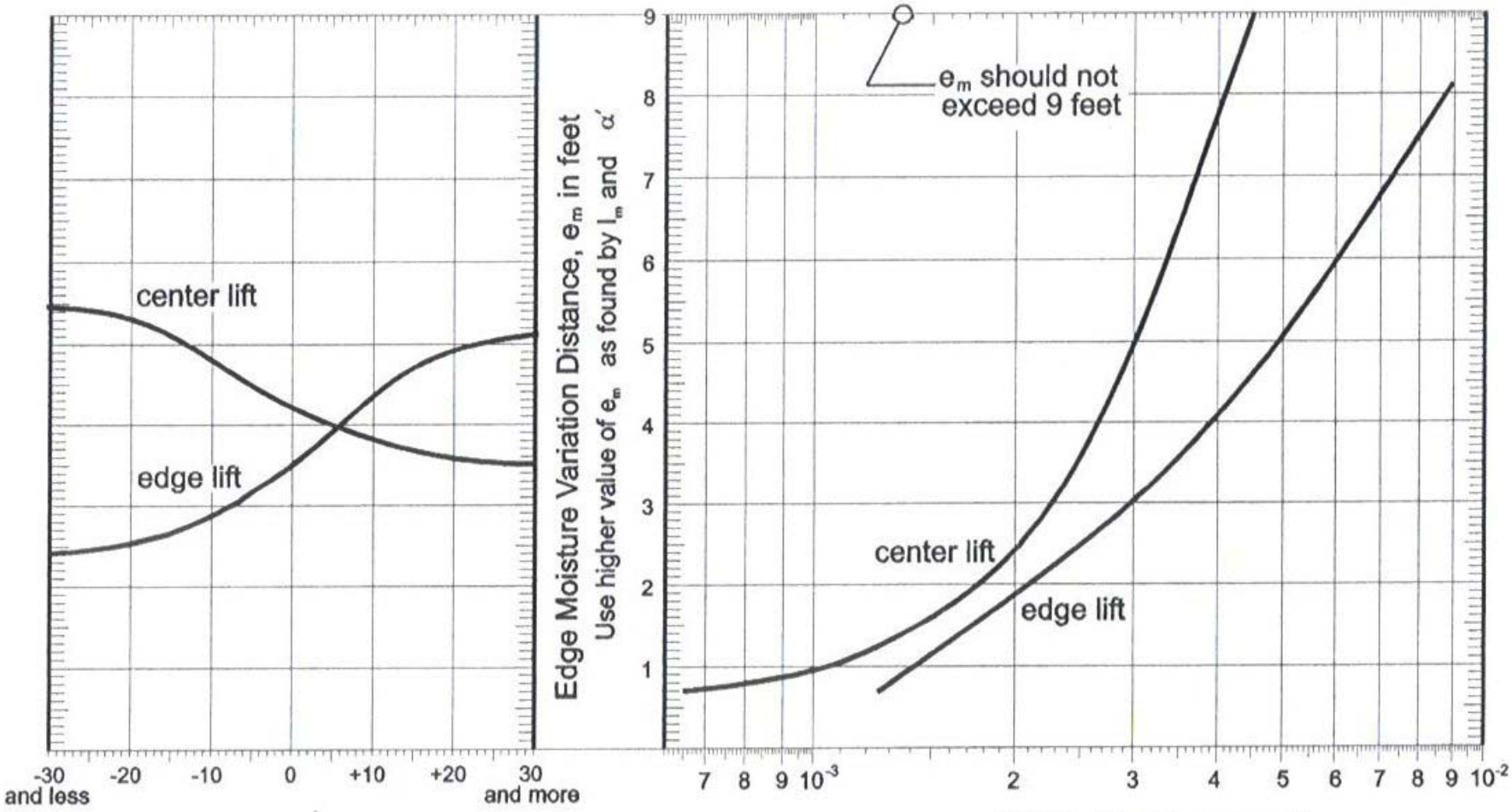
Effects of Trees

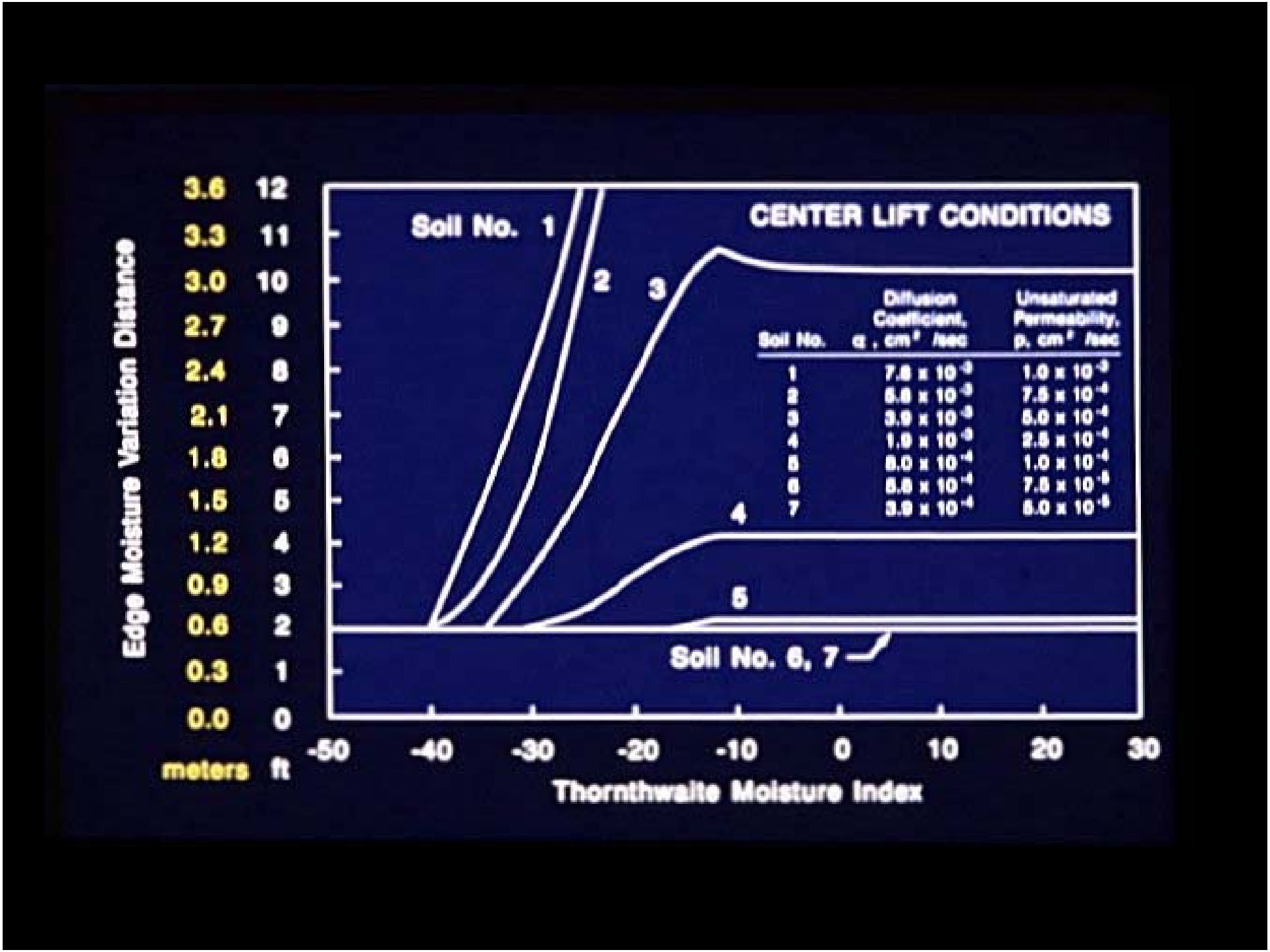


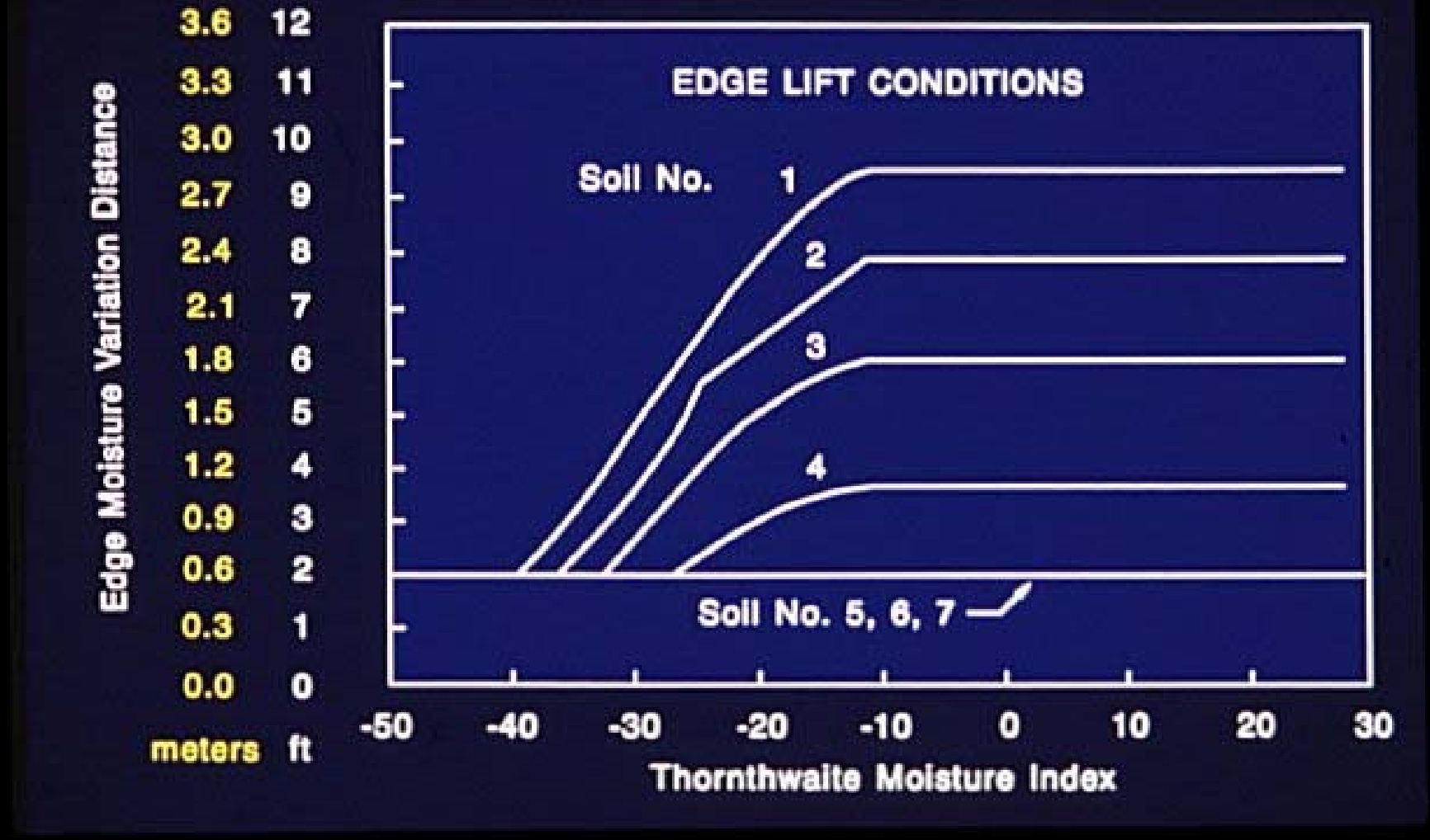
How do you find

- edge moisture variation distance, e_m
- depth of the moisture active zone, z_m?

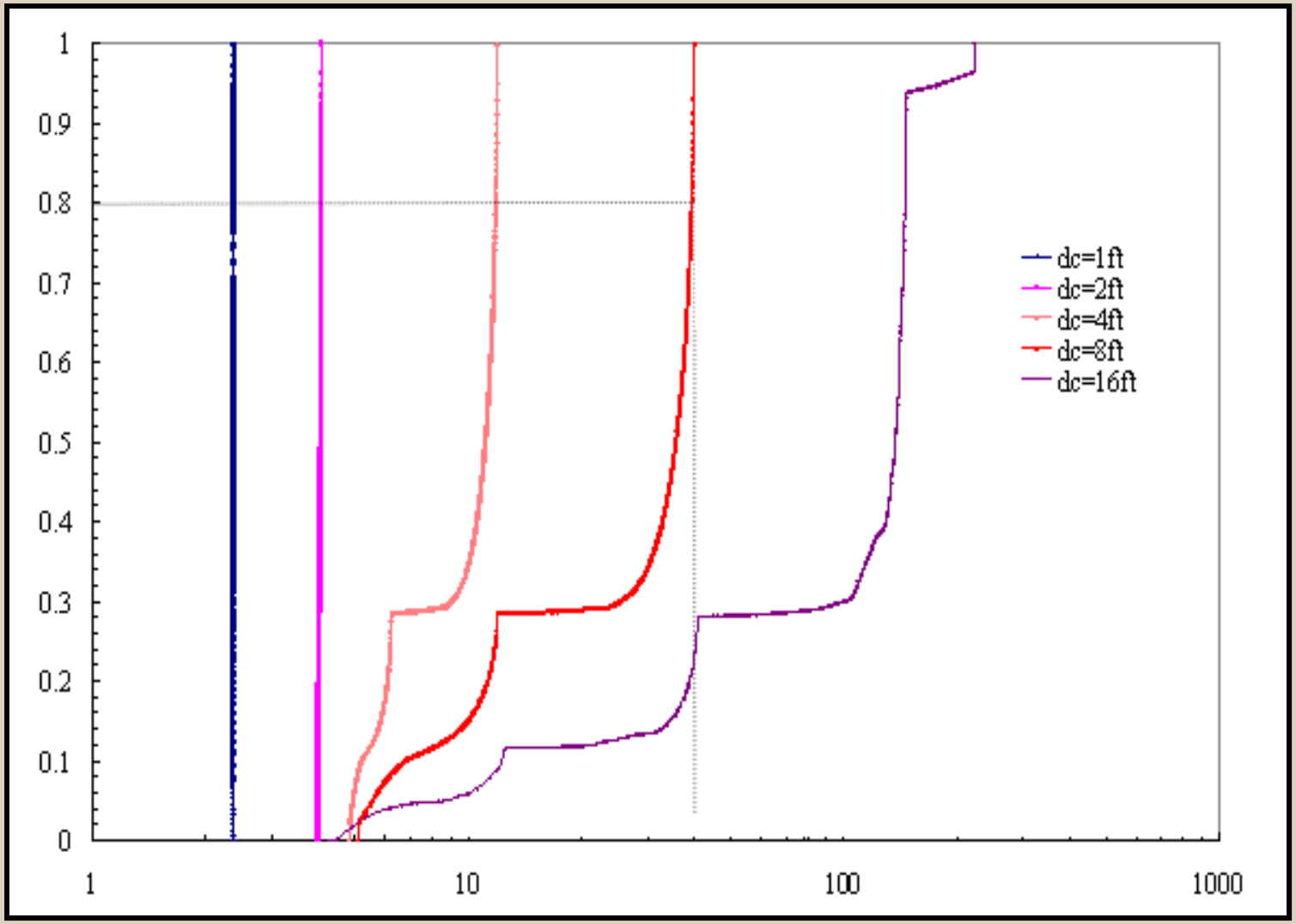
Figure 8 - e_m Selection Chart




CENTER LIFT CONDITIONS
Soil No. 1
2
3
4
5
Soil No. 6, 7
Edge Moisture Variation Distance
3.6 12
3.3 11
3.0 10
2.7 9
2.4 8
2.1 7
1.8 6
1.5 5
1.2 4
0.9 3
0.6 2
0.3 1
0.0 0
meters ft
-50 -40 -30 -20 -10 0 10 20 30
Thornthwaite Moisture Index
Soil No. | Diffusion Coefficient, α, cm²/sec | Unsaturated Permeability, p, cm²/sec
1 | 7.8 x 10⁻³ | 1.0 x 10⁻³
2 | 5.8 x 10⁻³ | 7.5 x 10⁻⁴
3 | 3.9 x 10⁻³ | 5.0 x 10⁻⁴
4 | 1.9 x 10⁻³ | 2.5 x 10⁻⁴
5 | 8.0 x 10⁻⁴ | 1.0 x 10⁻⁴
6 | 5.8 x 10⁻⁴ | 7.5 x 10⁻⁵
7 | 3.9 x 10⁻⁴ | 5.0 x 10⁻⁵


EDGE LIFT CONDITIONS
Soil No. 1
2
3
4
Soil No. 5, 6, 7
Edge Moisture Variation Distance
3.6 12
3.3 11
3.0 10
2.7 9
2.4 8
2.1 7
1.8 6
1.5 5
1.2 4
0.9 3
0.6 2
0.3 1
0.0 0
meters ft
-50 -40 -30 -20 -10 0 10 20 30
Thornthwaite Moisture Index

Field to Laboratory Diffusion Coefficient Ratio



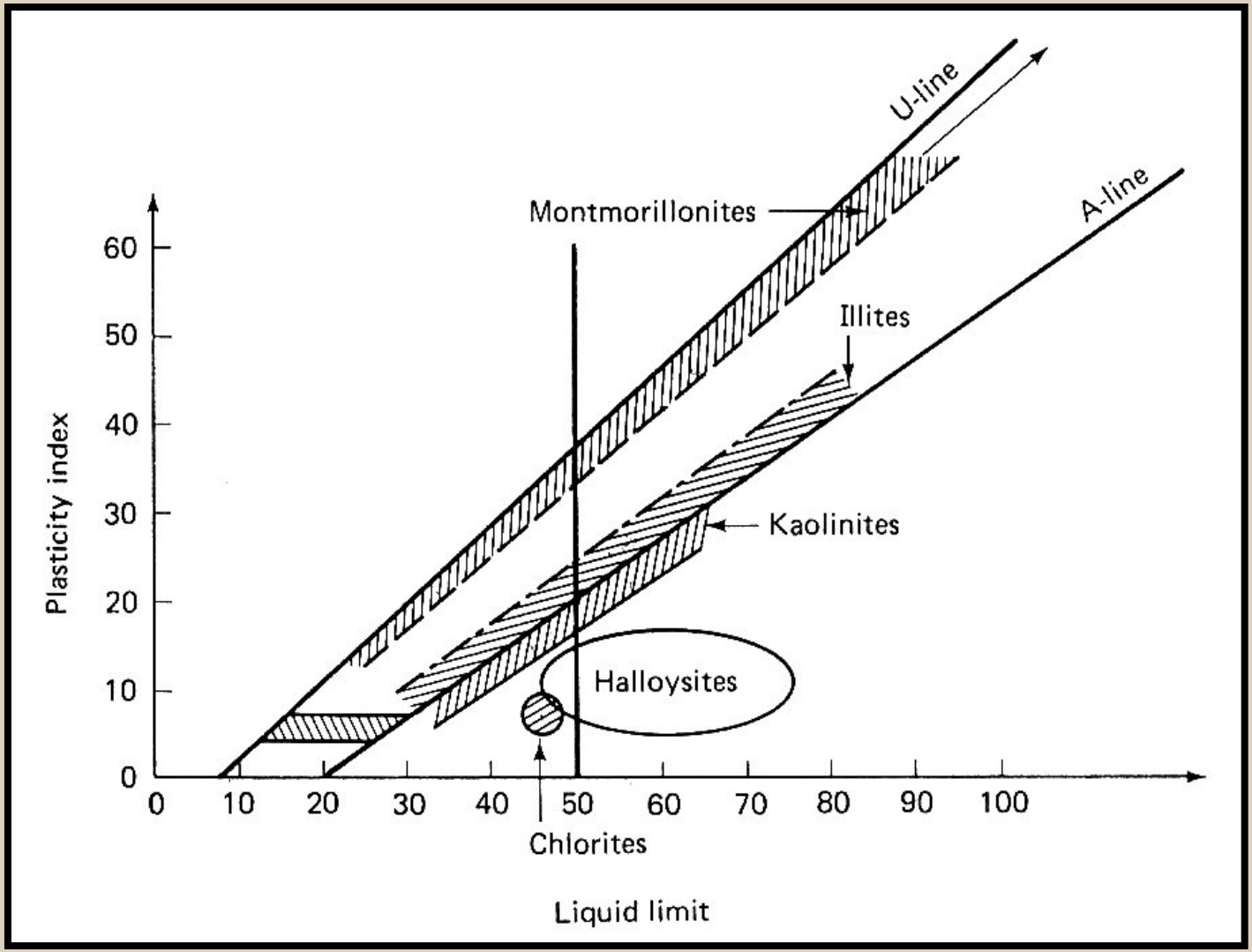
Field α/laboratory α_0

Alternative

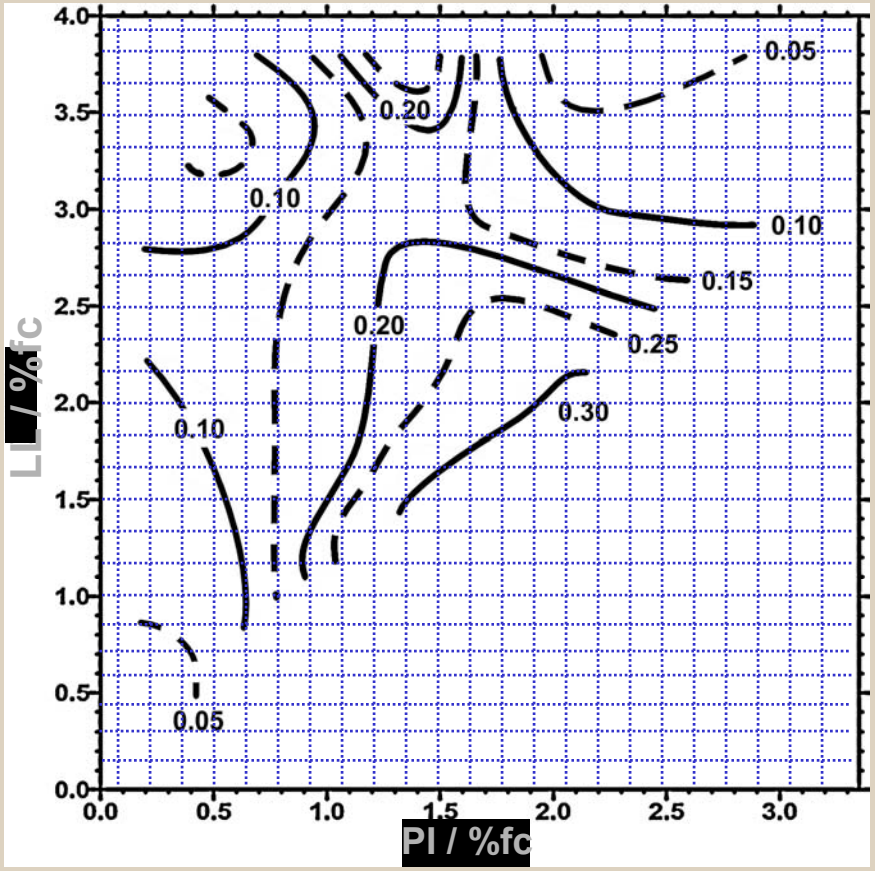
- Use built-in empirical expression:

$$\alpha = 0.0029 - 0.000162\, S - 0.0122\, \gamma_h$$

- where:
  - S = −20.3 – 0.155 (LL) – 0.117 (PI) + 0.068 (%−No. 200)
  - $\gamma_h = \gamma_0 \times \left[\dfrac{\%\text{-}2\,\mu m}{\%\text{-No.}200\ \text{sieve}} \right]$


U-line
A-line
Montmorillonites
Illites
Kaolinites
Halloysites
Chlorites
Plasticity index
Liquid limit
0
10
20
30
40
50
60
70
80
90
100

Volume Change



Zone III (Covar and Lytton, 2001)

$$\%fc = \frac{\% - 2\,\mu m}{\% - No.200\,sieve}$$

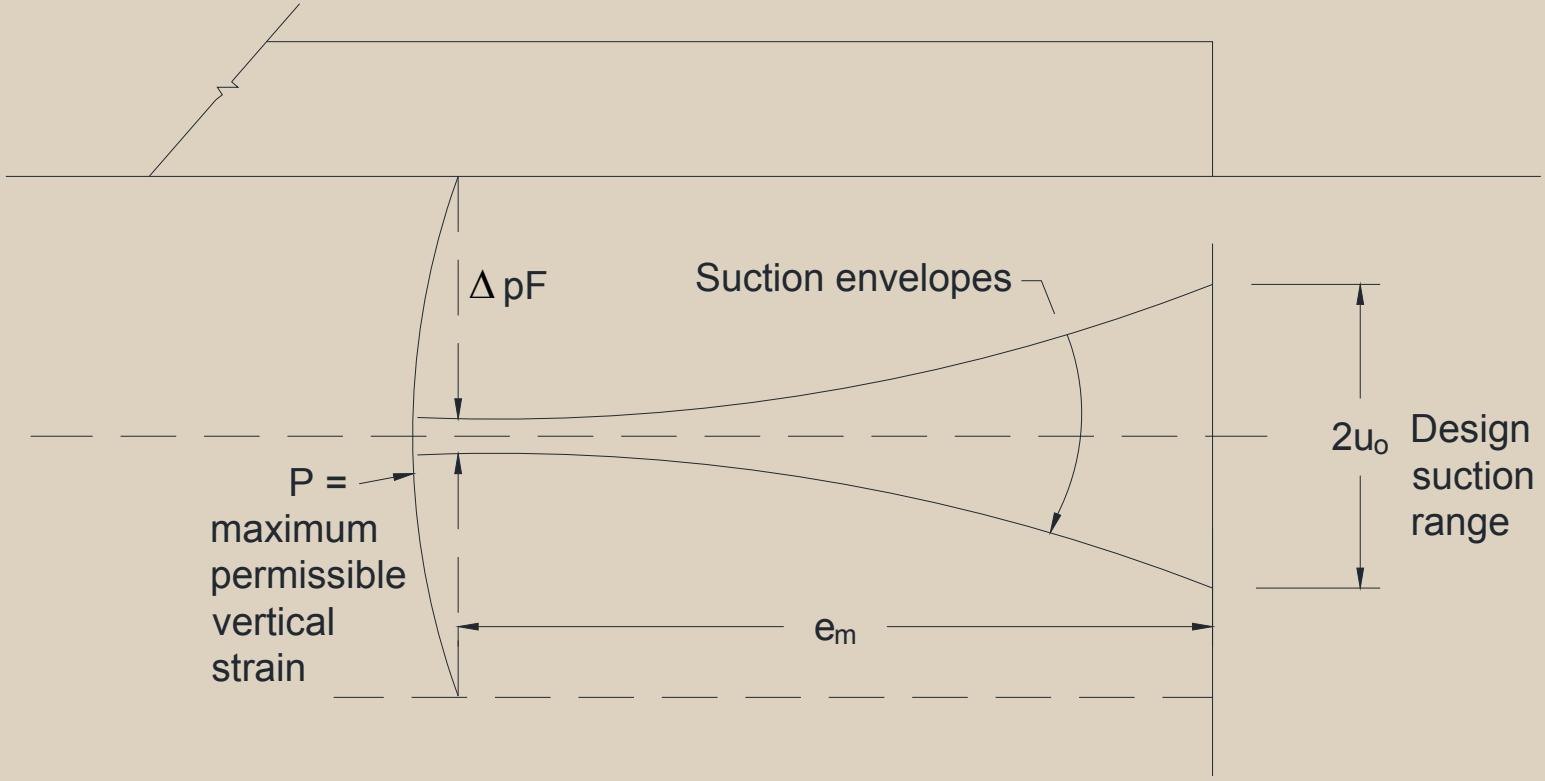
$$\gamma_h = \gamma_0 \times \left[\frac{\% - 2\,\mu m}{\% - No.200\,sieve} \right]$$

$$\gamma_\sigma = \gamma_h \frac{1}{1 + \frac{h}{\theta\left(\frac{\partial h}{\partial \theta}\right)}}$$

(Lytton, 1994)

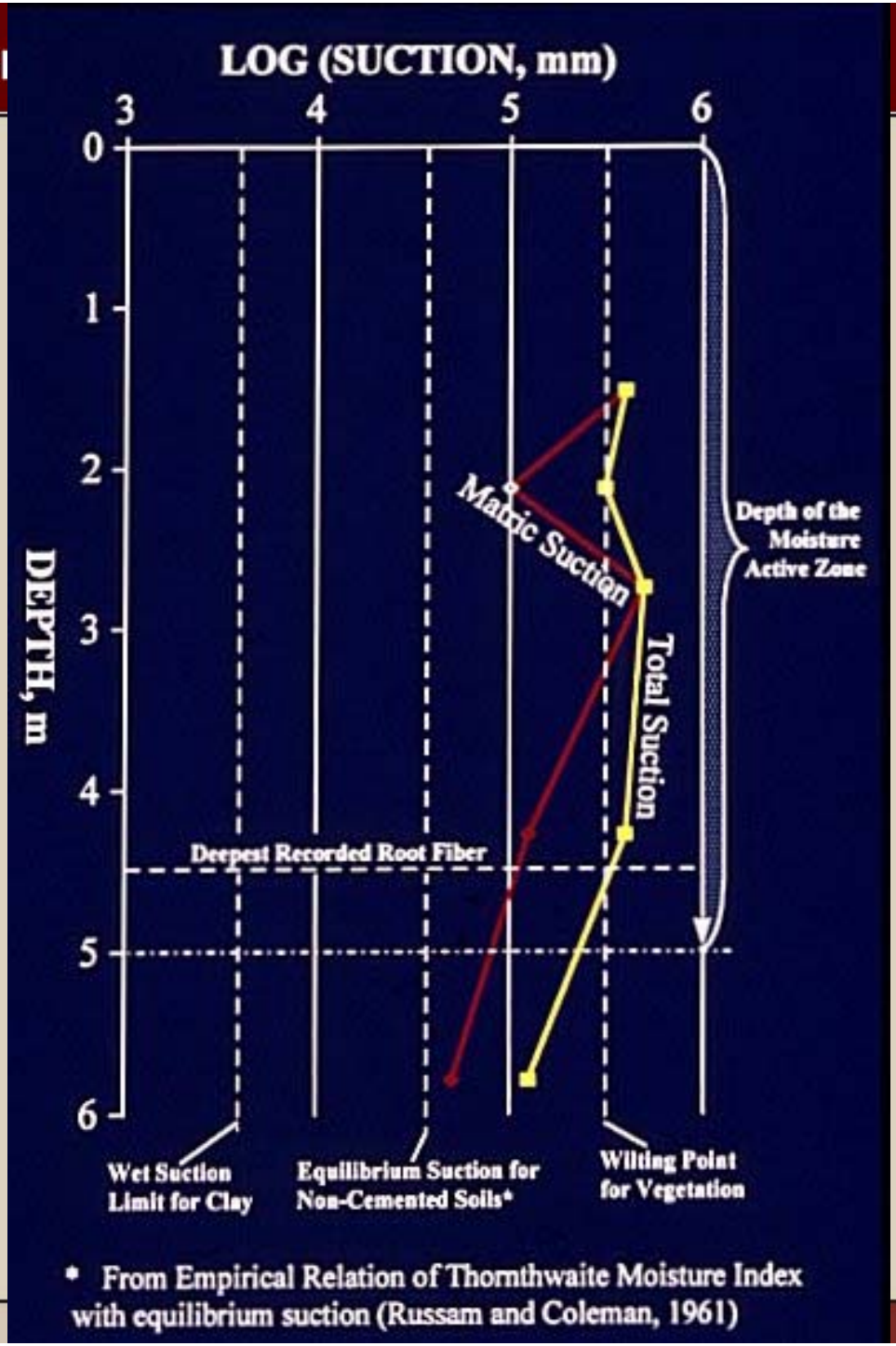
Excel spreadsheet for calculating α from field measurements

Edge Moisture Variation Distance, e_m

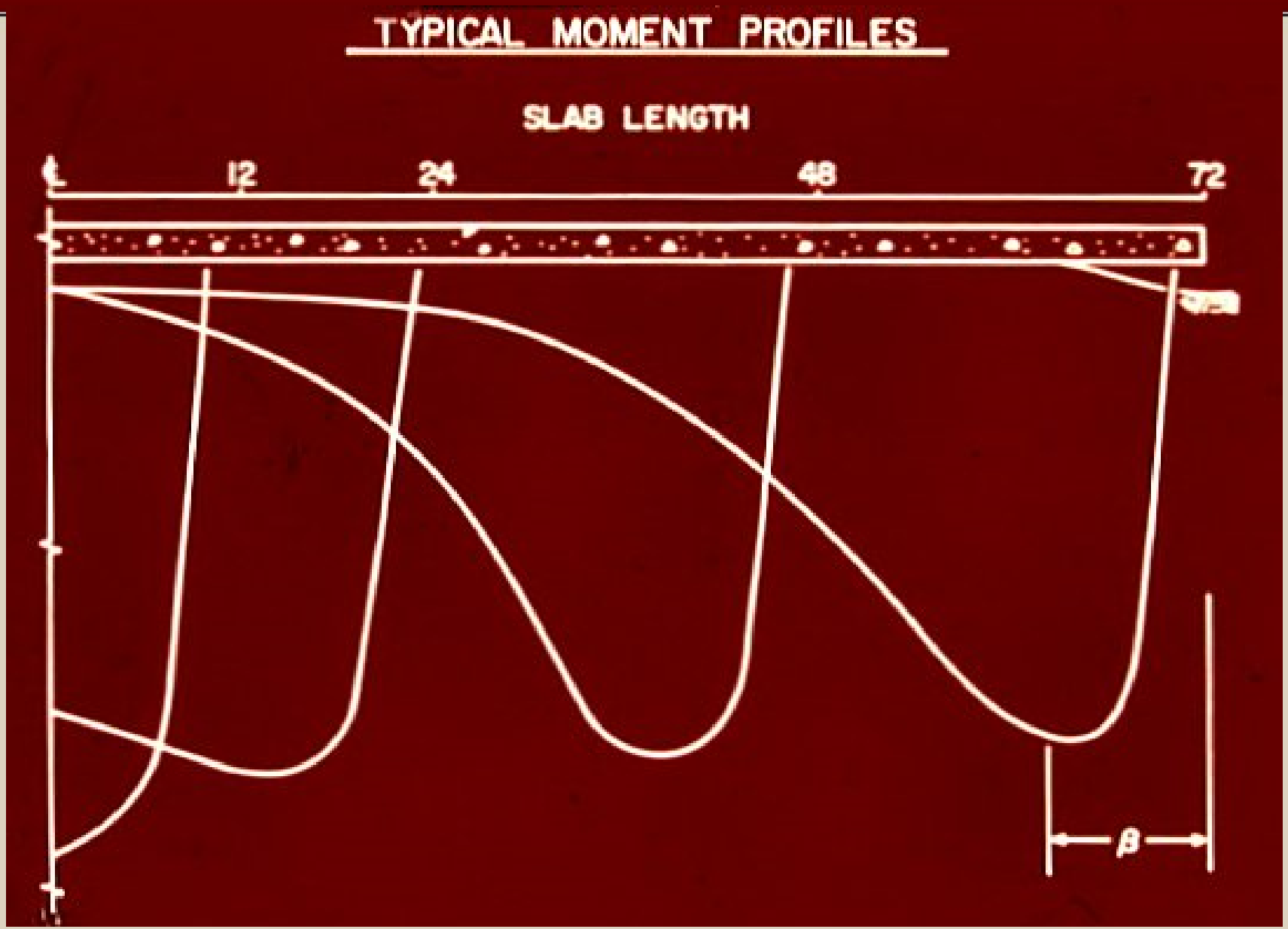


$$e_m = \sqrt{\frac{\alpha T}{\pi}} \ln\left(\frac{2u_0}{\Delta pF}\right) \qquad \Delta pF = 1 - \sqrt{1 + \frac{3p}{\gamma_h}}$$


MOISTURE ACTIVE ZONE
MOISTURE INACTIVE ZONE

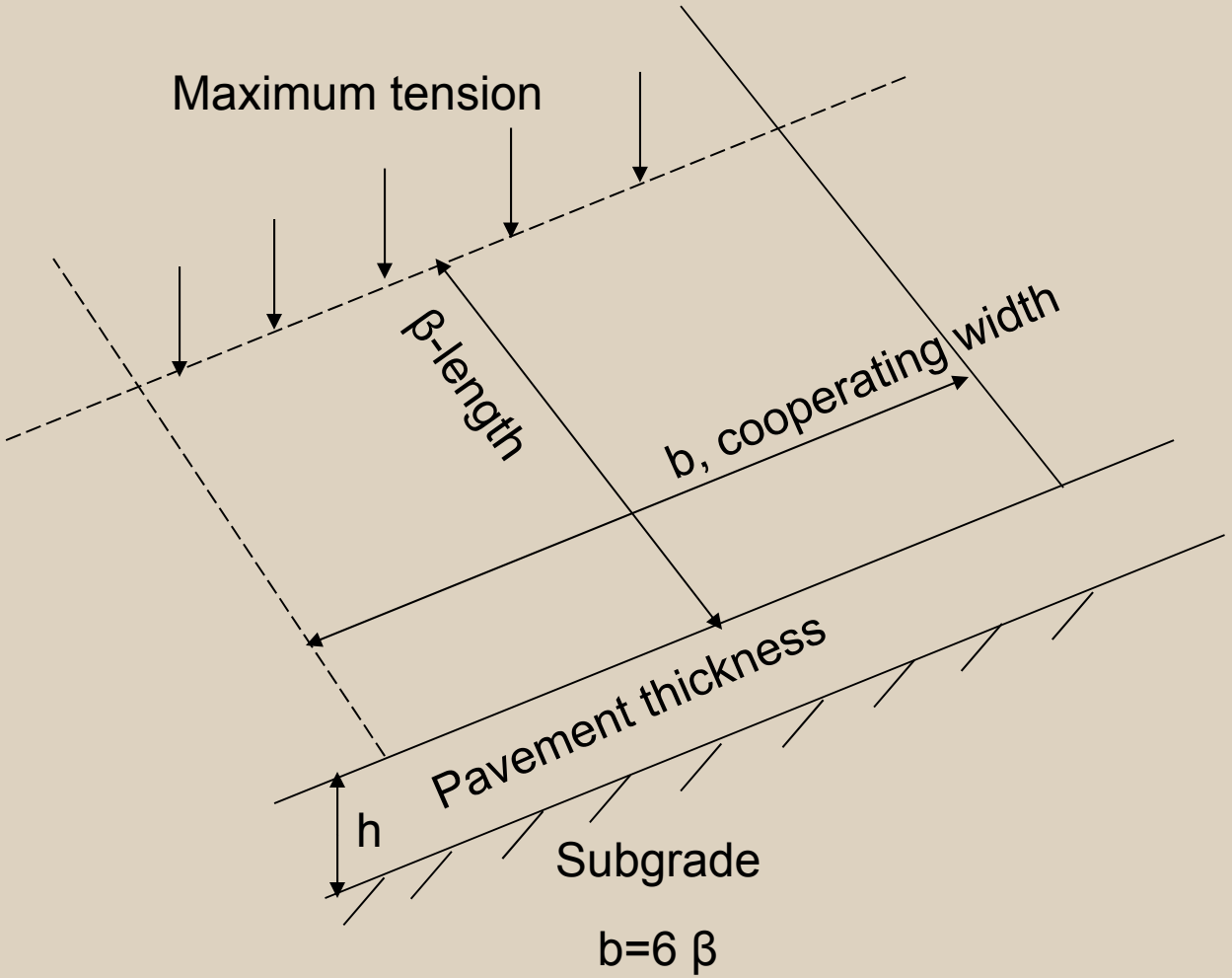

LOG (SUCTION, mm)
3
4
5
6
0
1
2
3
4
5
6
DEPTH, m
Matric Suction
Total Suction
Depth of the Moisture Active Zone
Deepest Recorded Root Fiber
Wet Suction Limit for Clay
Equilibrium Suction for Non-Cemented Soils*
Wilting Point for Vegetation
* From Empirical Relation of Thornthwaite Moisture Index with equilibrium suction (Russam and Coleman, 1961)

Where do the cracks occur?


TYPICAL MOMENT PROFILES
SLAB LENGTH
12
24
48
72
β

$$\beta(ft) = \frac{\pi}{48} \sqrt[4]{\frac{4E_p I}{E_{soil}}}$$

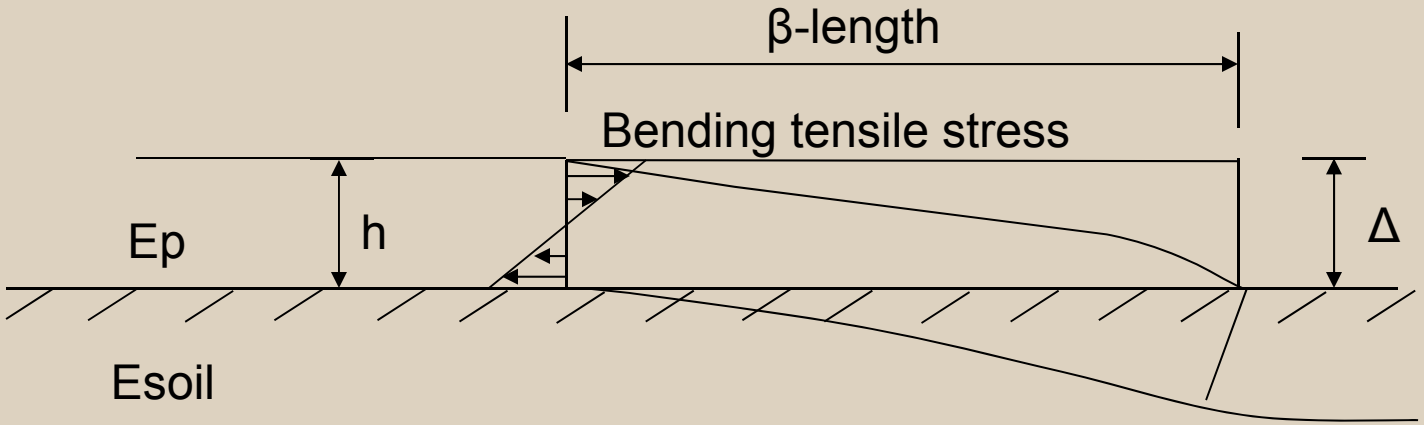
Ep = modulus of pavement
Esoil = modulus of soil
I = moment of inertia of pavement
$I = bh^3/12$
b = cooperating width
h = thickness of pavement layer, inches


Maximum tension
β-length
b, cooperating width
Pavement thickness
h
Subgrade
b=6 β

$$\beta(ft) = \frac{h}{12}\sqrt[3]{\frac{E_p}{E_{soil}}}$$

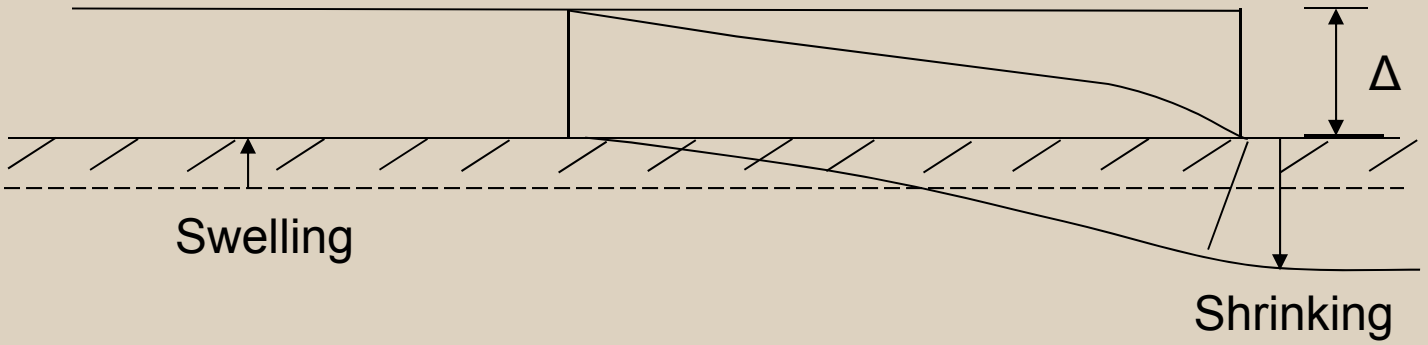
β – lengths, ft

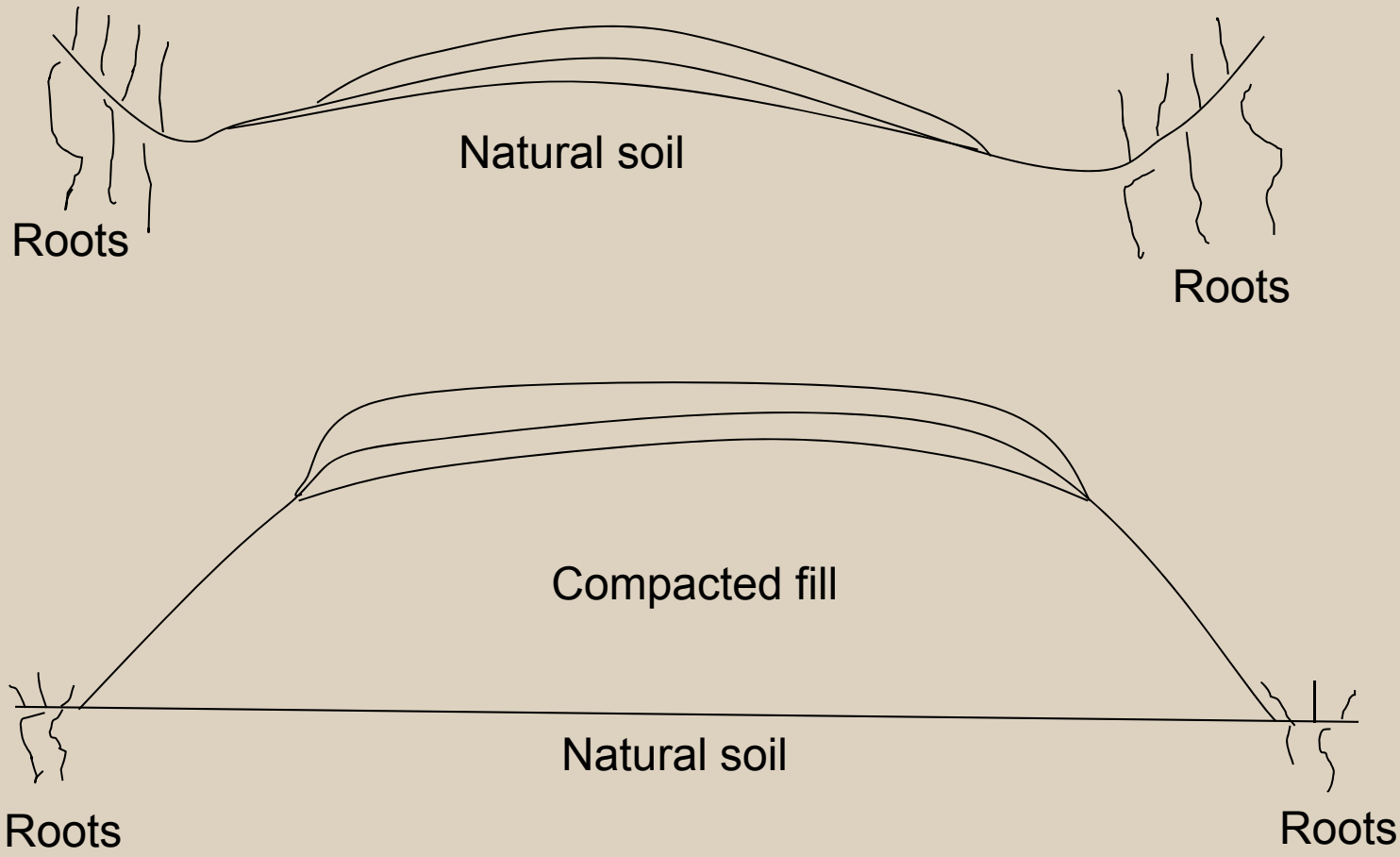
Pavement thickness, inches	Modulus ratios Ep/Esoil			
	5	10	15	20
6	0.9	1.1	1.2	1.4
12	1.7	2.2	2.5	2.7
18	2.6	3.2	3.7	4.1
24	3.4	4.3	4.9	5.4
30	4.3	5.4	6.2	6.8

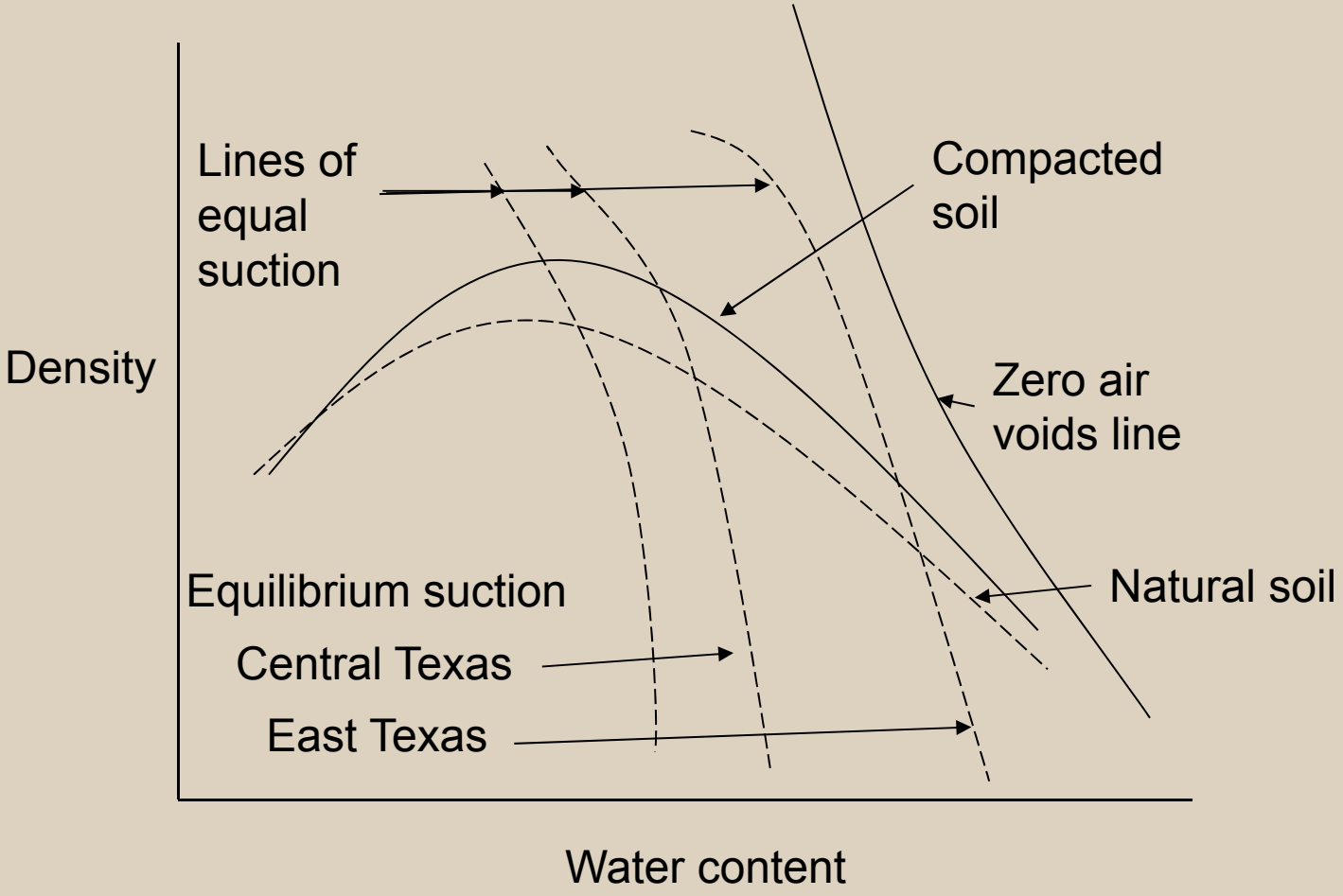


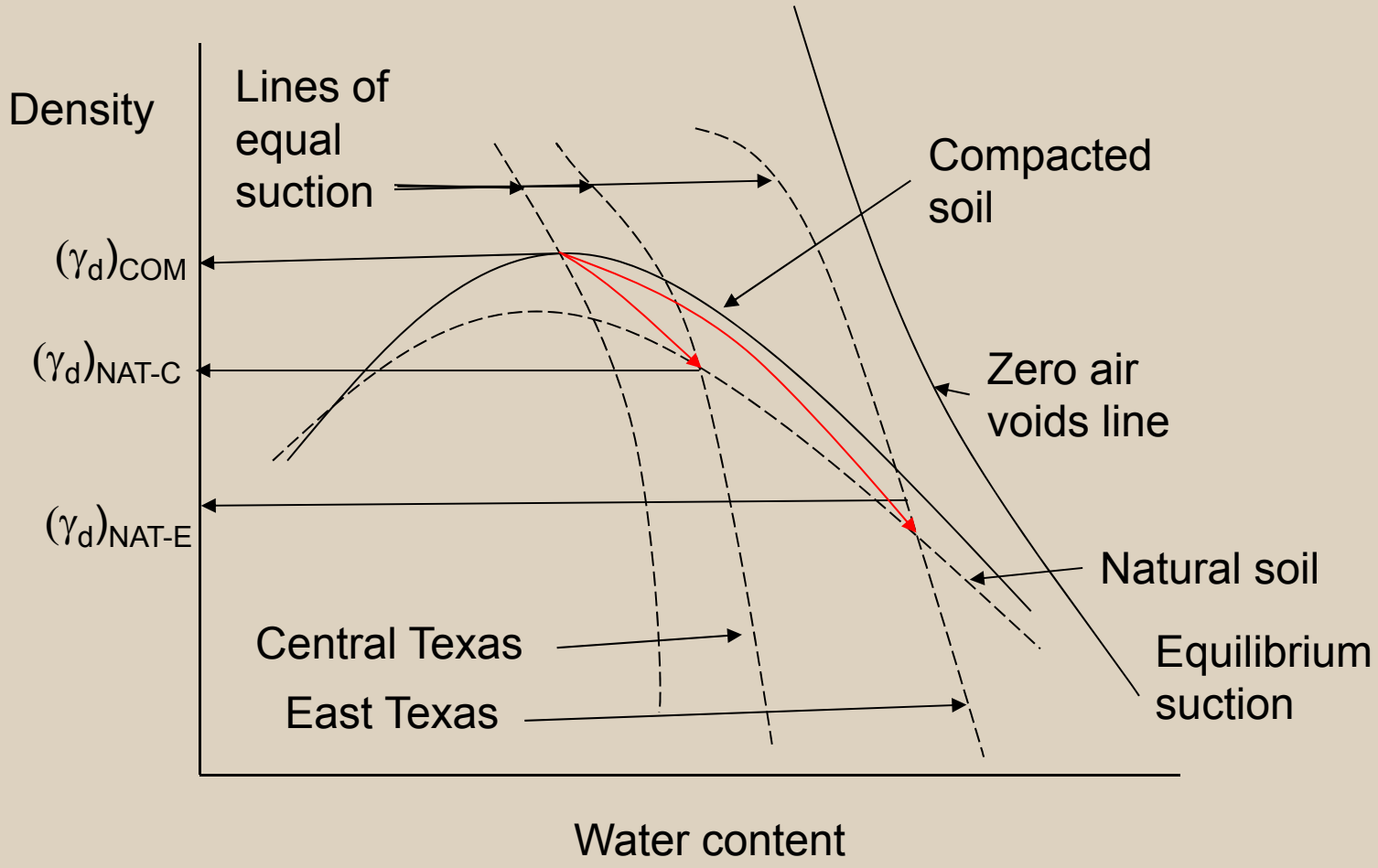
$$\text{Bending stress} = \frac{Ep\Delta}{72h\left(\frac{Ep}{Esoil}\right)^{\frac{2}{3}}}$$

How can this shape occur?




Natural soil
Roots
Roots
Compacted fill
Natural soil
Roots
Roots


Lines of equal suction
Compacted soil
Density
Zero air voids line
Natural soil
Equilibrium suction
Central Texas
East Texas
Water content


Density
Lines of equal suction
Compacted soil
$(\gamma_d)_{COM}$
$(\gamma_d)_{NAT-C}$
Zero air voids line
$(\gamma_d)_{NAT-E}$
Natural soil
Central Texas
East Texas
Equilibrium suction
Water content

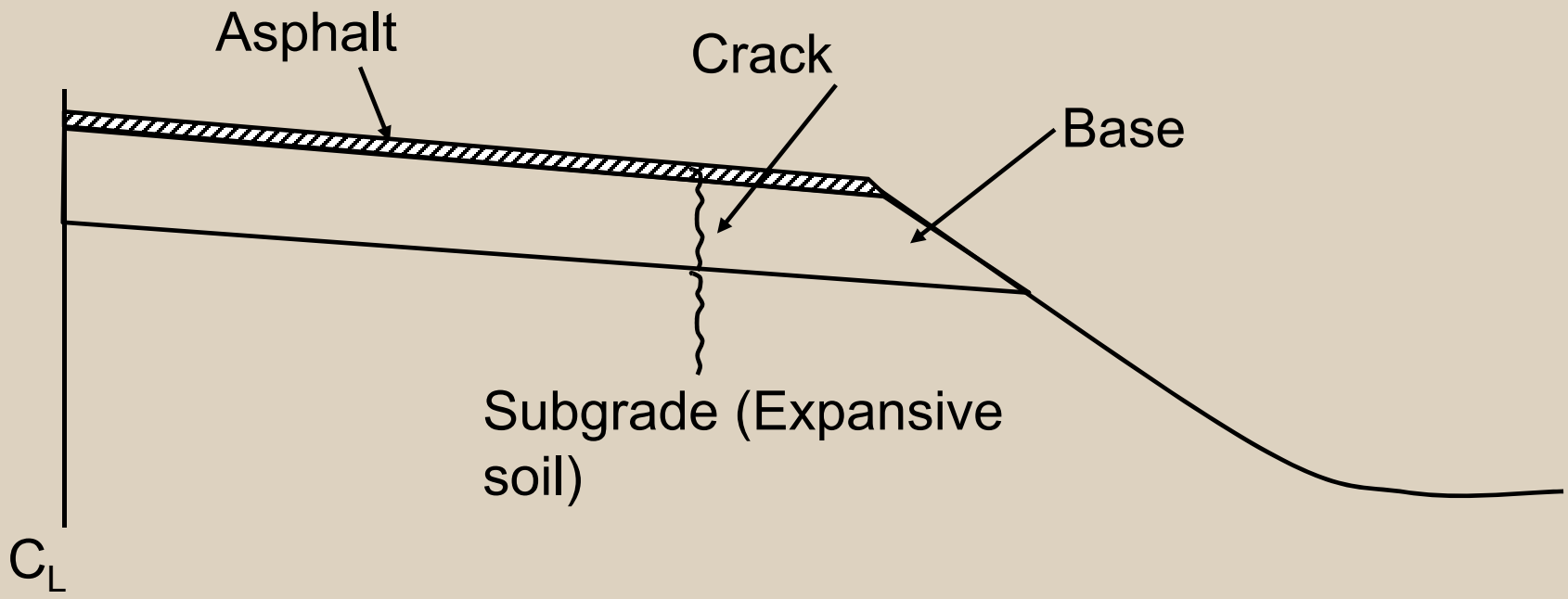
How much will it swell?

$$\frac{\Delta V}{V} = \frac{\frac{1}{(\gamma_d)_{NAT}} - \frac{1}{(\gamma_d)_{COM}}}{\frac{1}{(\gamma_d)_{COM}}}$$

Counter measures

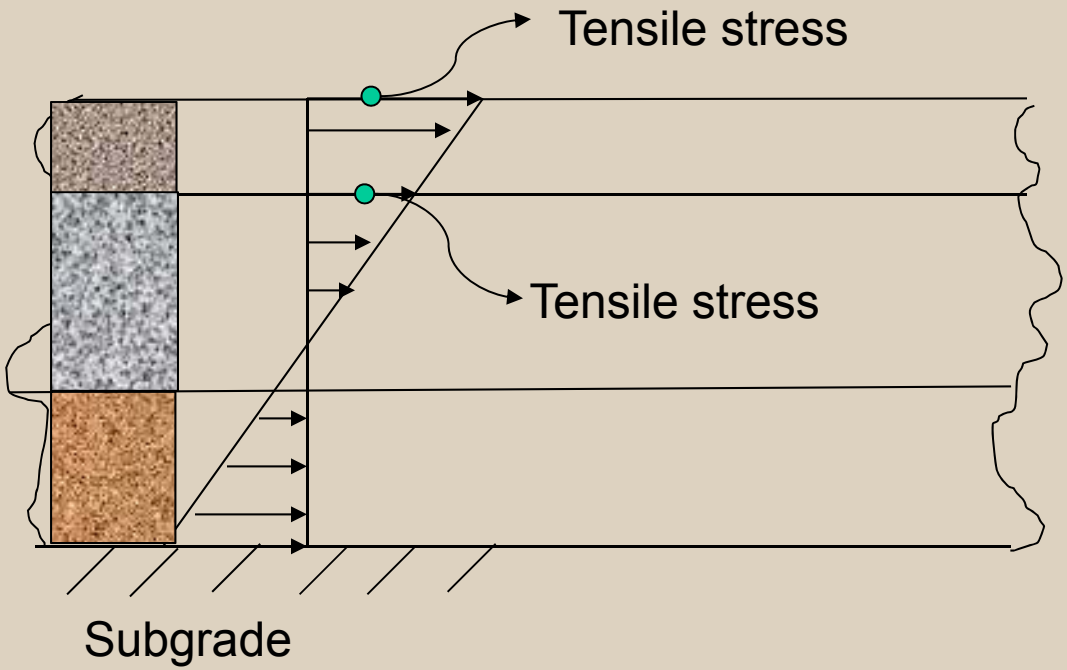
- Tensile strength in pavement layers
- Geosynthetics
- Wide shoulders
- Vertical moisture barriers

Without Geogrid Reinforcement…



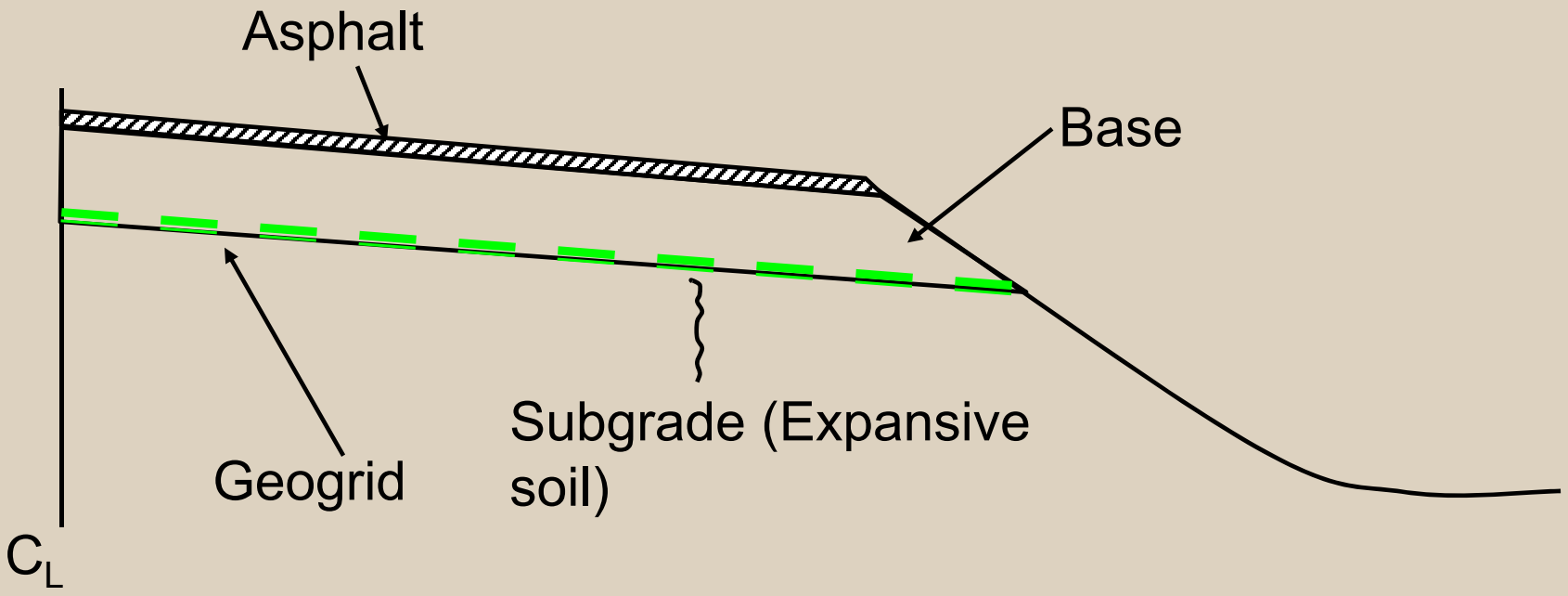
*** Rong Luo, Texas A&M University**

Multi-layer pavements

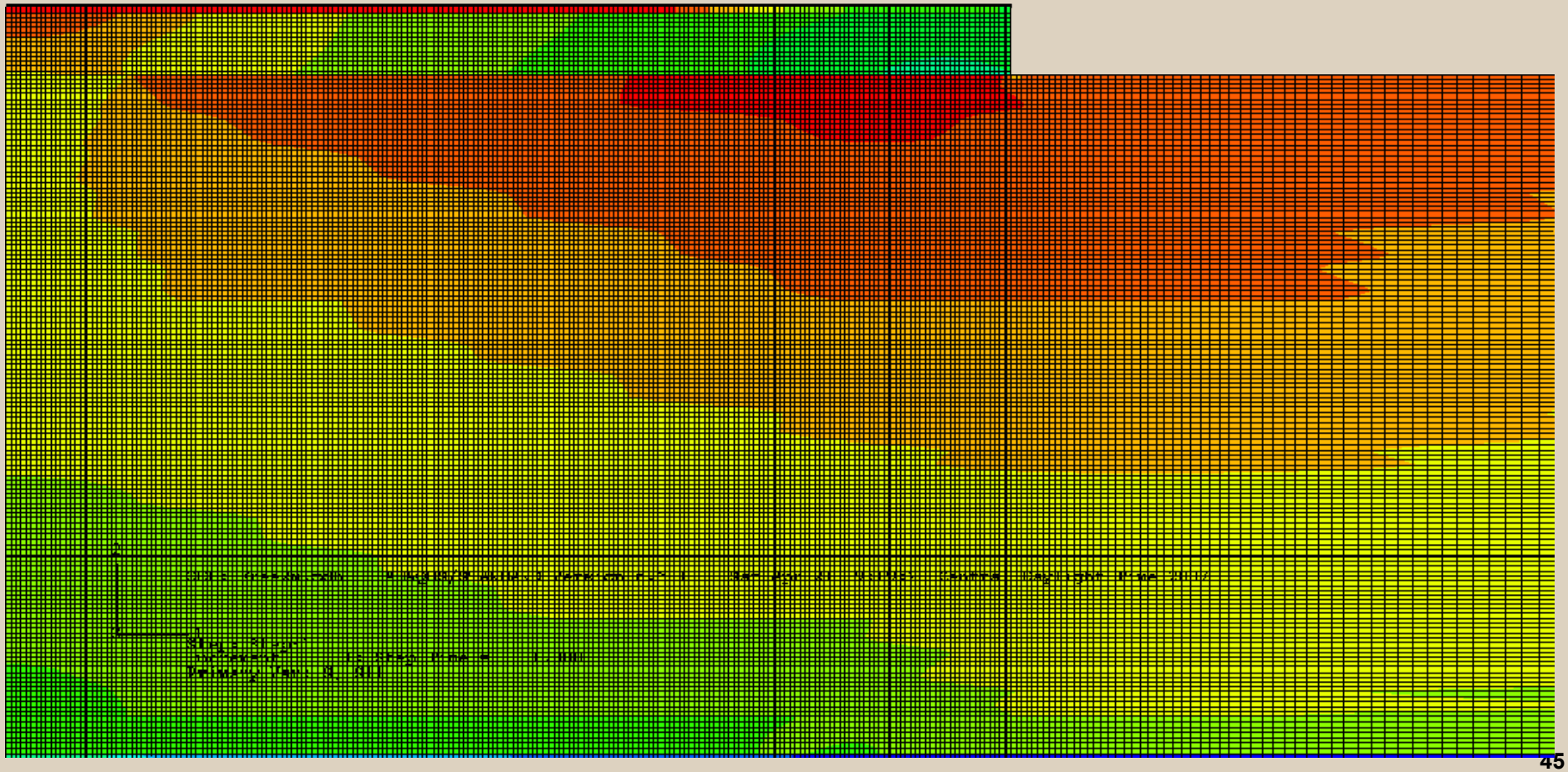


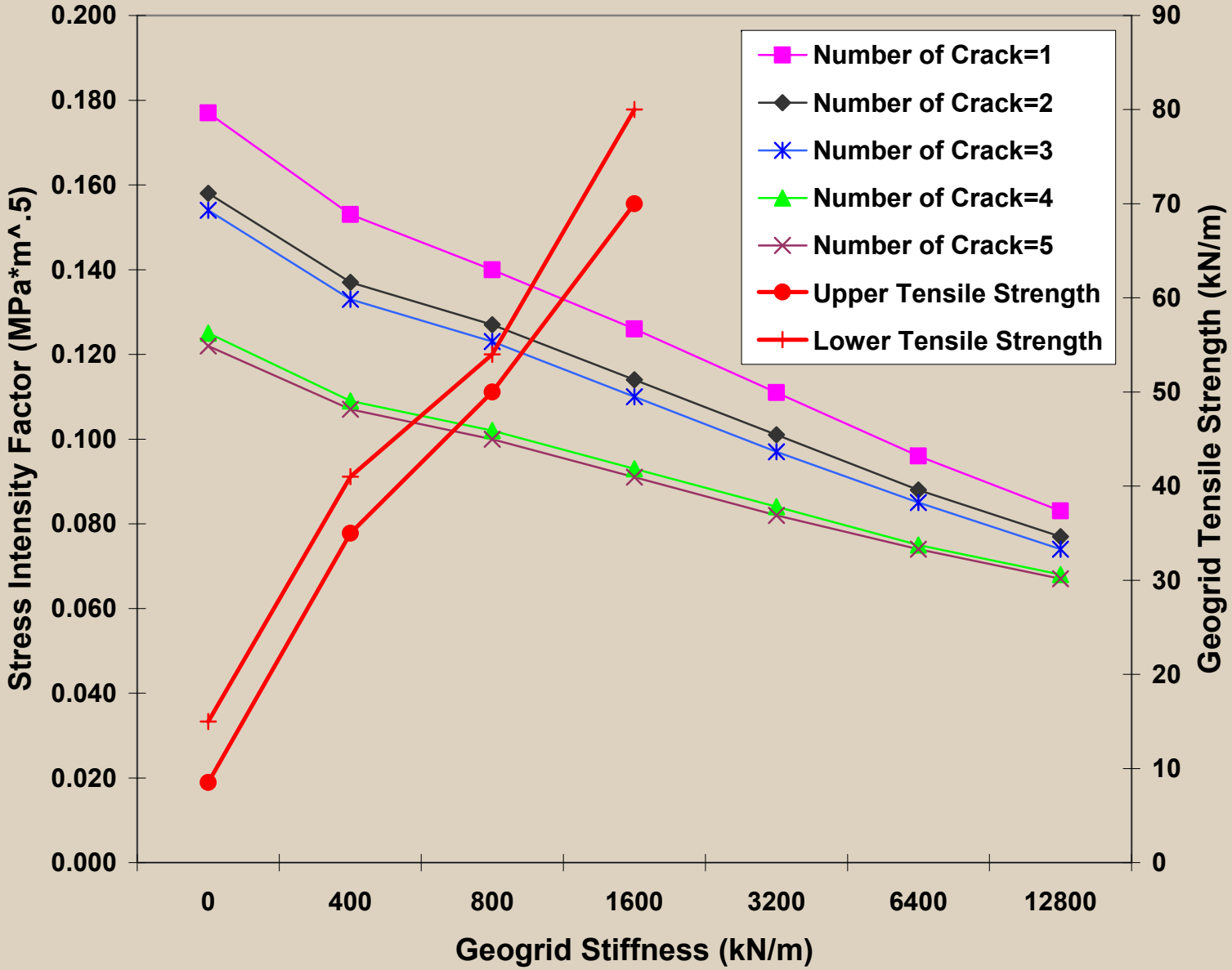
Check tensile stress < tensile strength

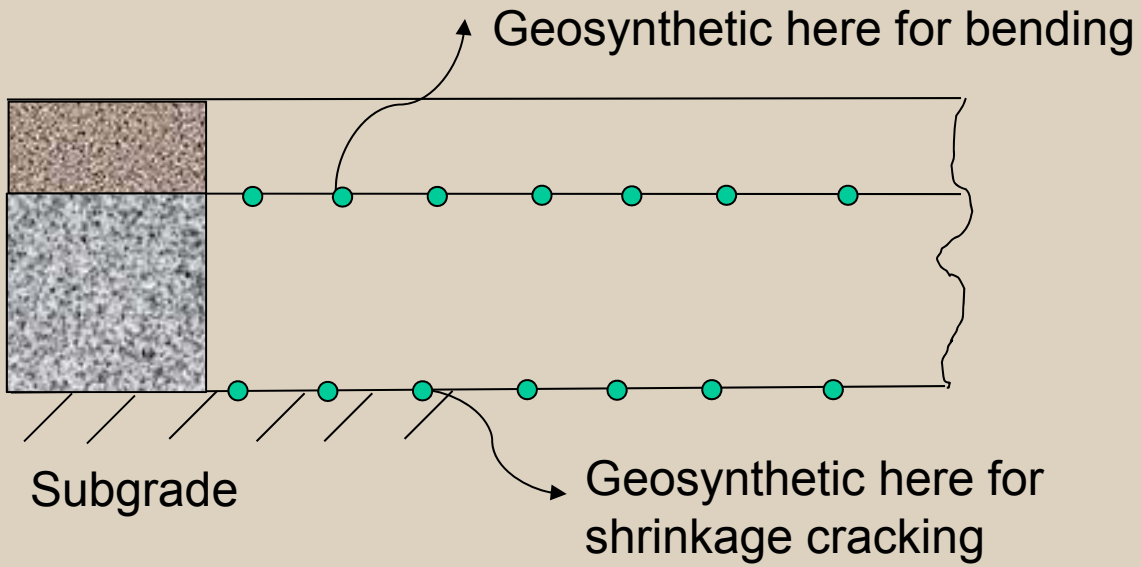
With Geogrid Reinforcement…



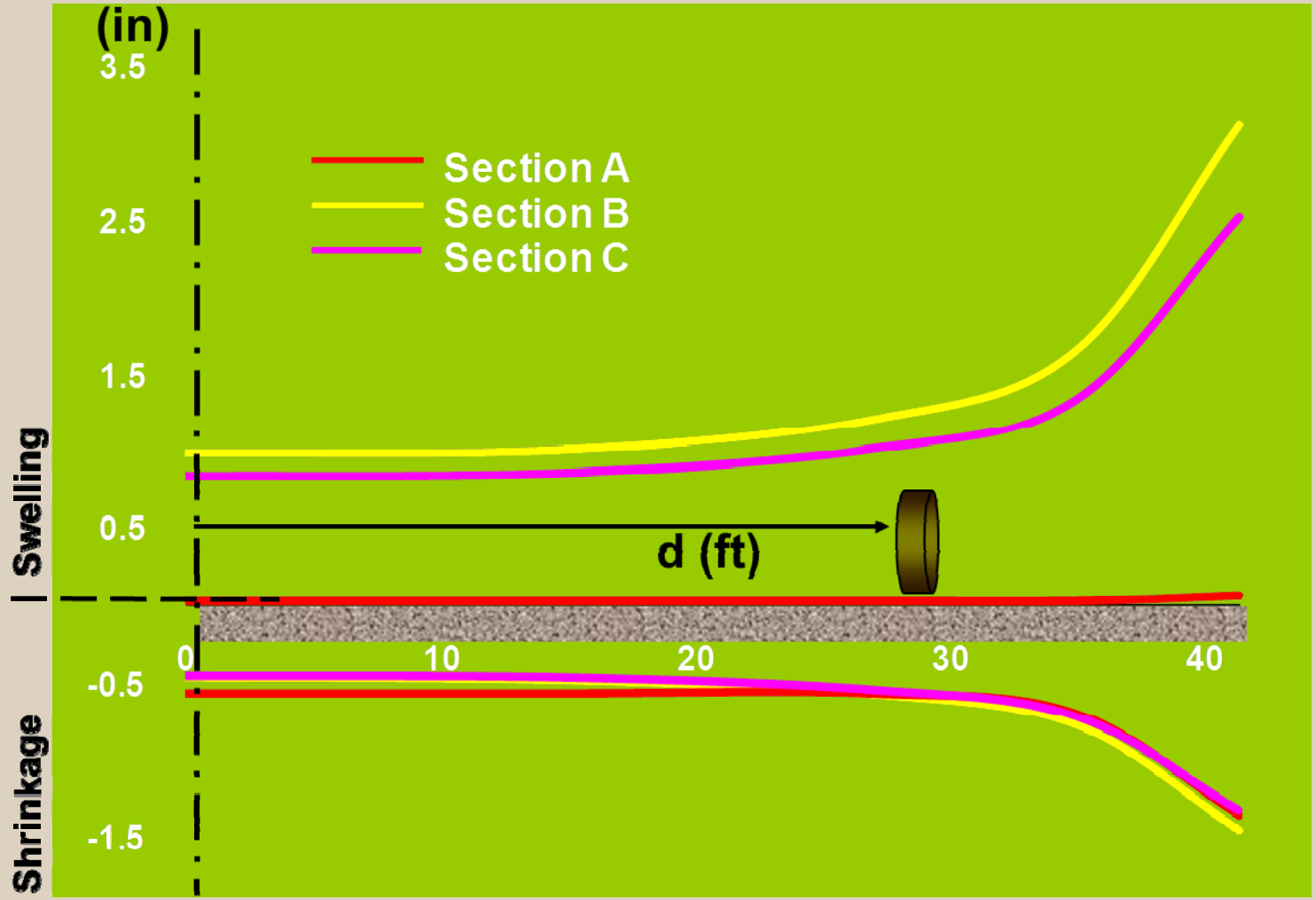
Transverse Stress Distribution in Pavement (Crack at Edge of Shoulder)



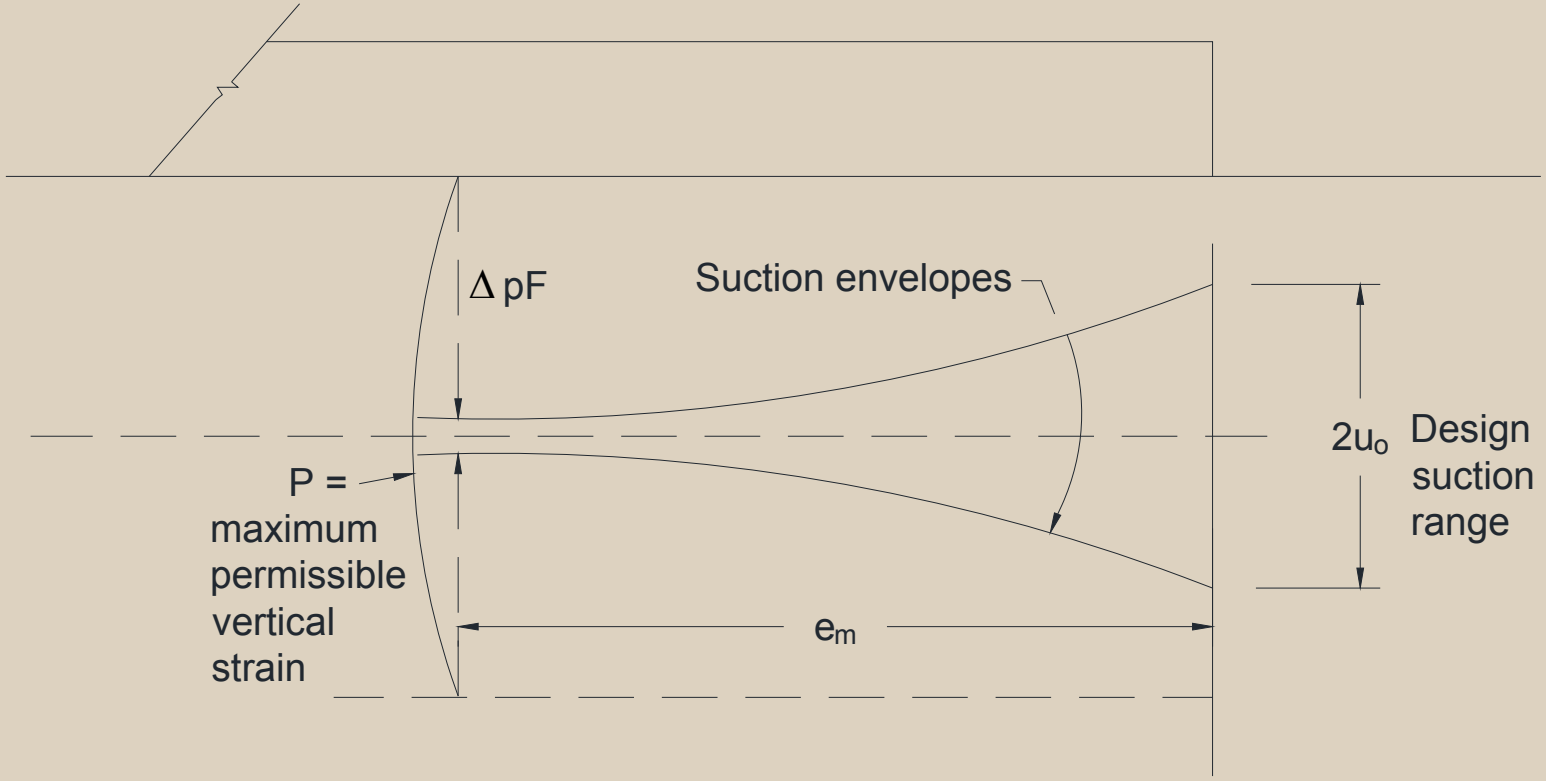

0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Stress Intensity Factor (MPa*m^.5)
90
80
70
60
50
40
30
20
10
0
Geogrid Tensile Strength (kN/m)
0
400
800
1600
3200
6400
12800
Geogrid Stiffness (kN/m)
Number of Crack=1
Number of Crack=2
Number of Crack=3
Number of Crack=4
Number of Crack=5
Upper Tensile Strength
Lower Tensile Strength


Geosynthetic here for bending
Subgrade
Geosynthetic here for
shrinkage cracking

Transverse Distribution of Vertical Movements

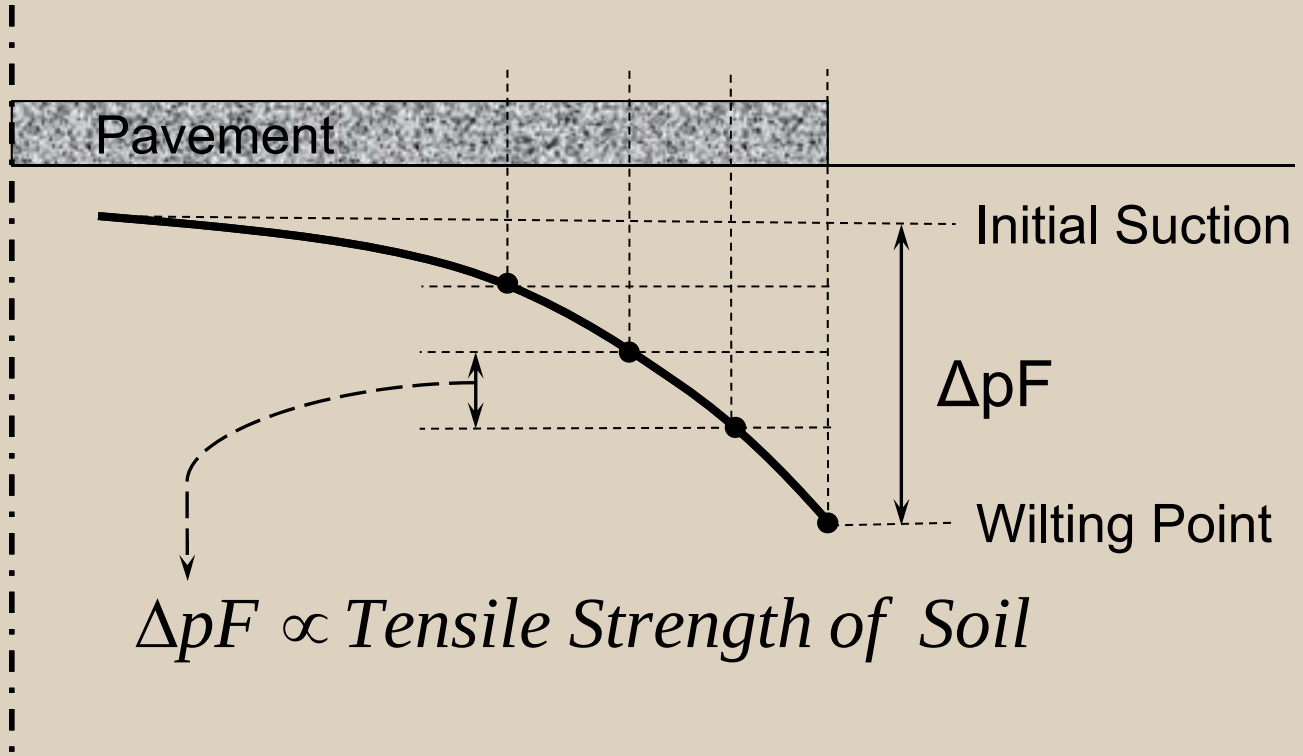


Edge Moisture Variation Distance, e_m



$$e_m = \sqrt{\frac{\alpha T}{\pi}} \ln\left(\frac{2u_0}{\Delta pF}\right) \qquad \Delta pF = 1 - \sqrt{1 + \frac{3p}{\gamma_h}}$$

Longitudinal Crack Spacing

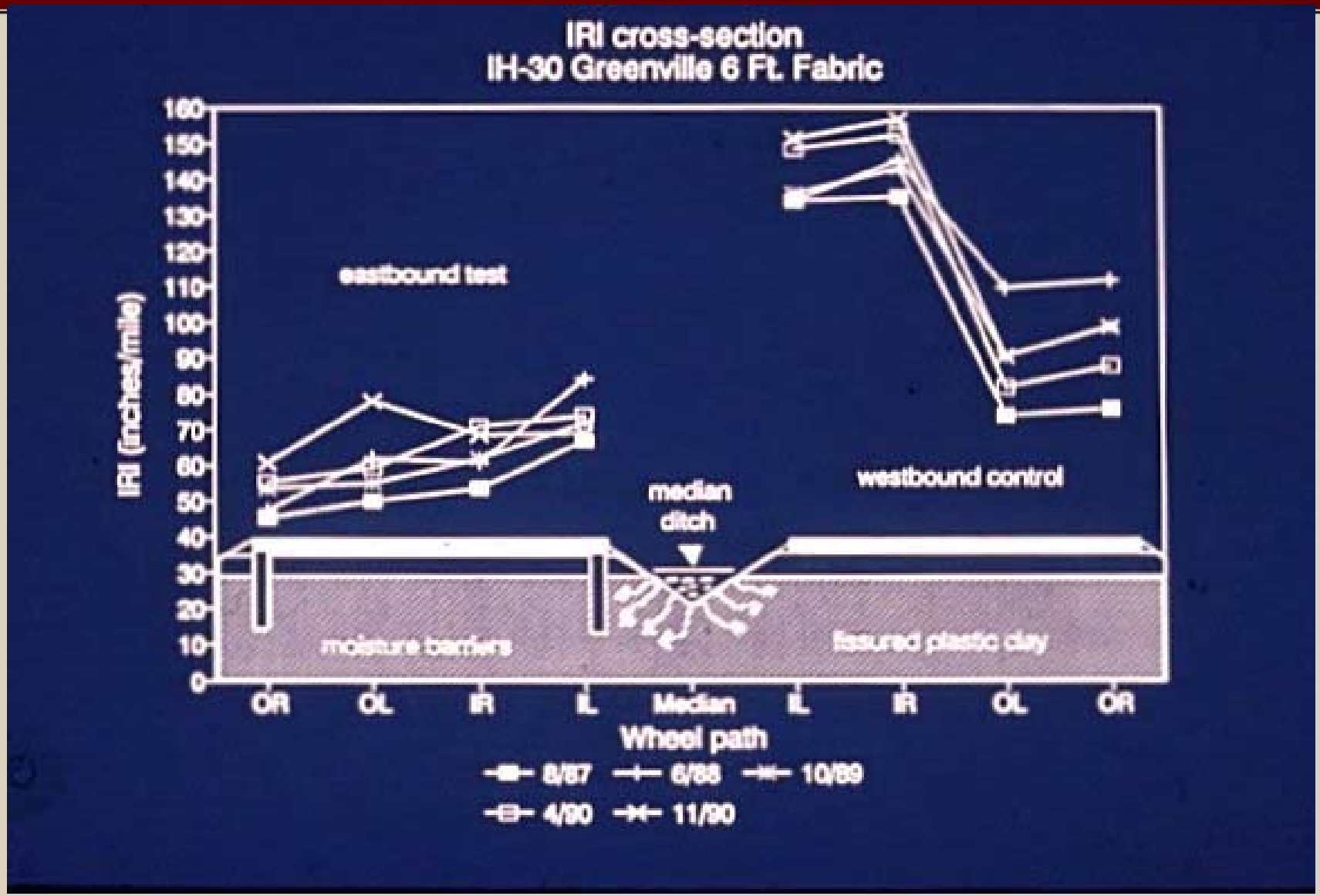


Distance to First Shrinkage Crack

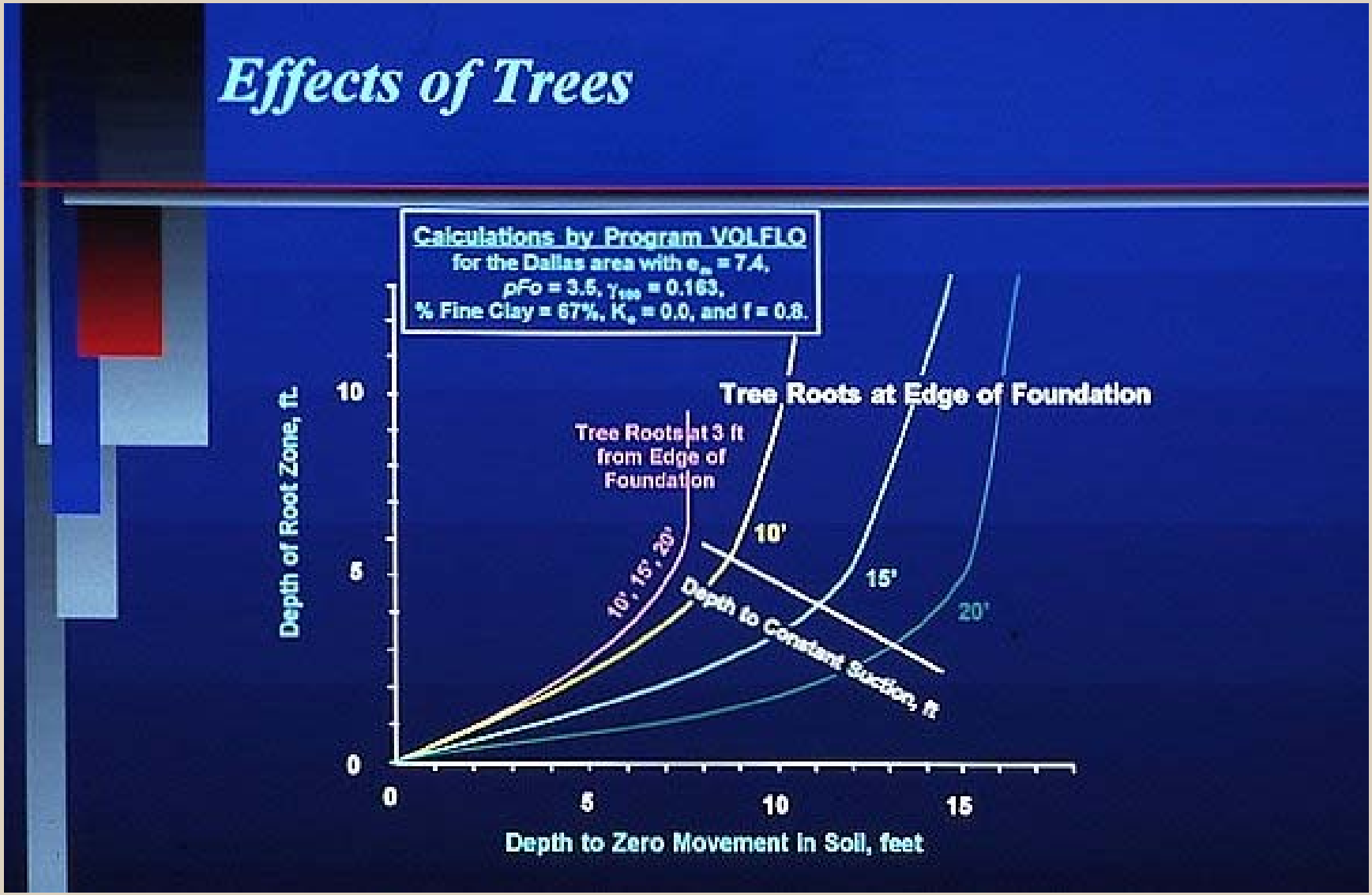
$$x_1 = \sqrt{\frac{\alpha T}{\pi}} \ln\left(\frac{2u_0}{2u_0 - \Delta pF}\right)$$

Distance to All Shrinkage Cracks

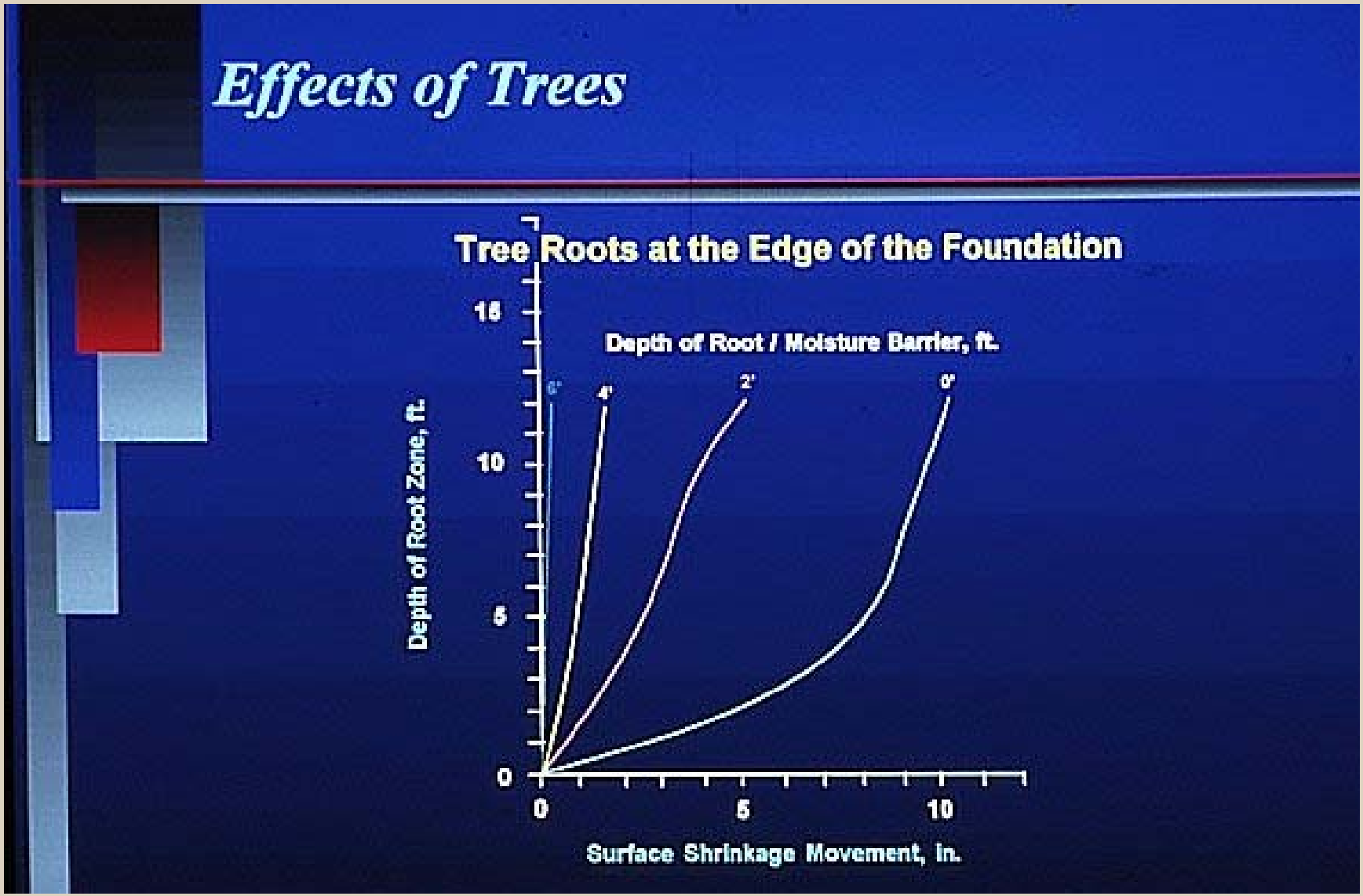
$$x_k = \sqrt{\frac{\alpha T}{\pi}} \ln \left[\frac{2u_0}{2u_0 - \sum_{i=1}^{k} (\Delta pF)_i} \right]$$


IRI cross-section
IH-30 Greenville 6 Ft. Fabric
IRI (inches/mile)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
eastbound test
westbound control
median
ditch
moisture barriers
fissured plastic clay
OR
OL
IR
IL
Median
IL
IR
OL
OR
Wheel path
8/87
6/88
10/89
4/90
11/90

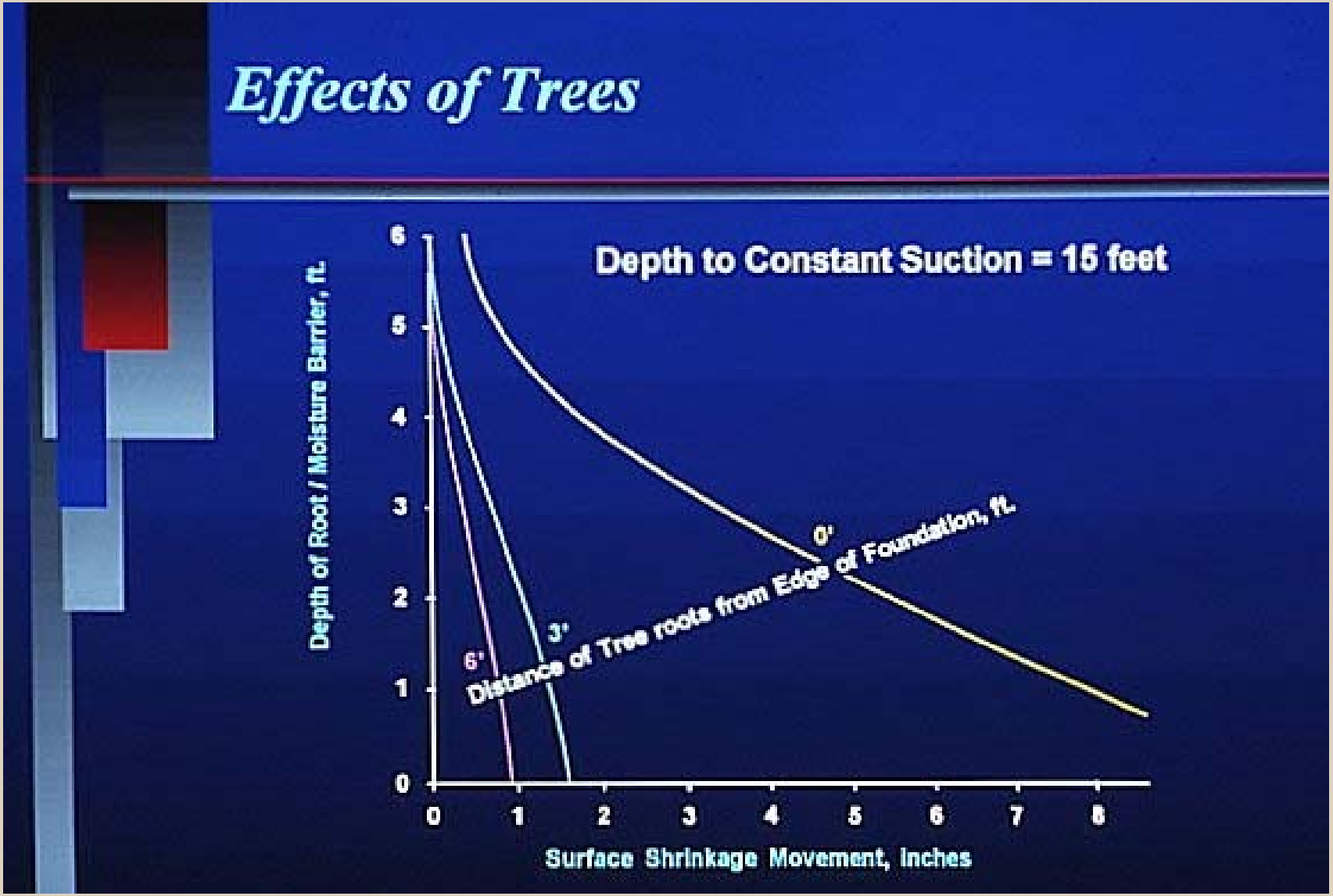
Effects of Trees

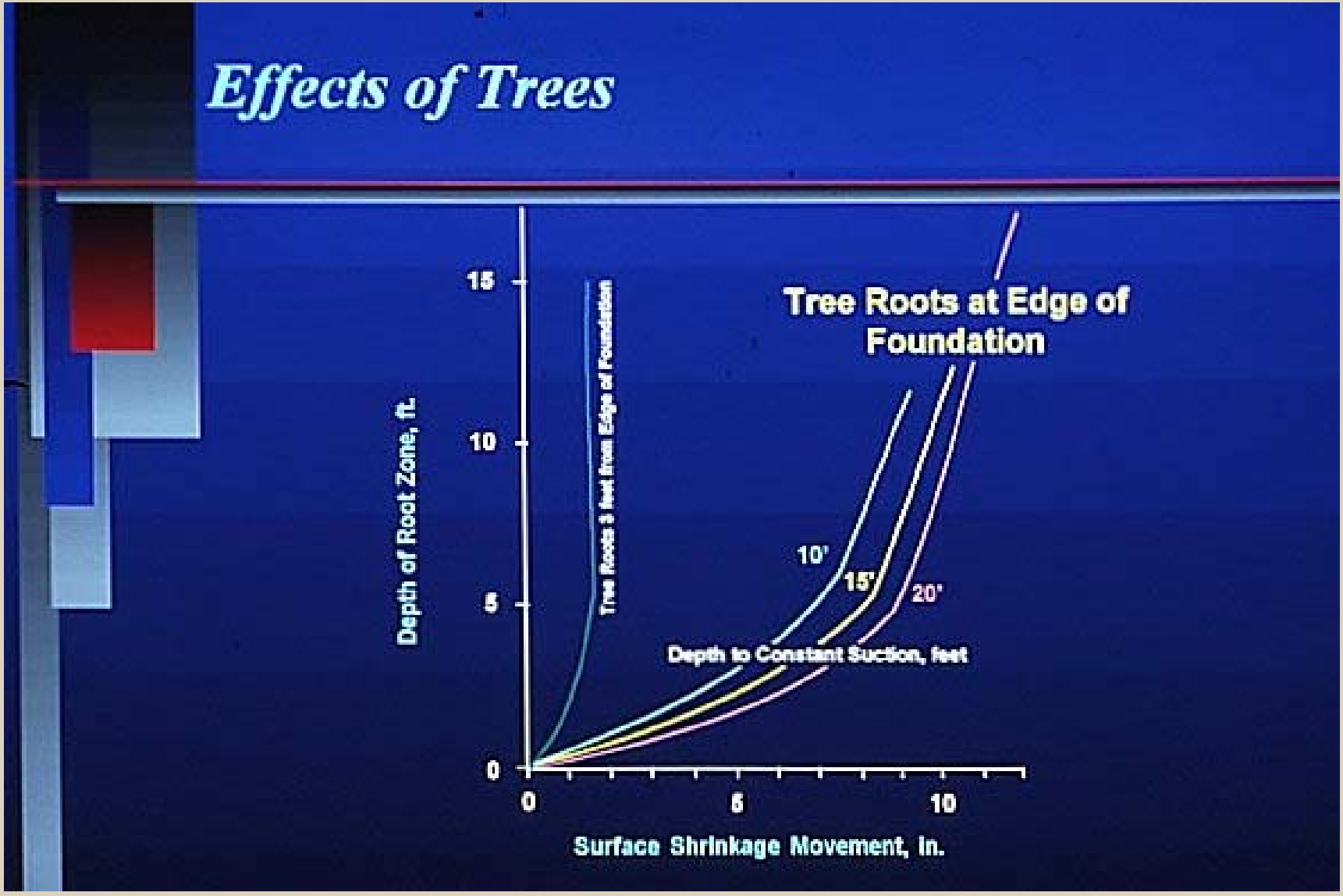


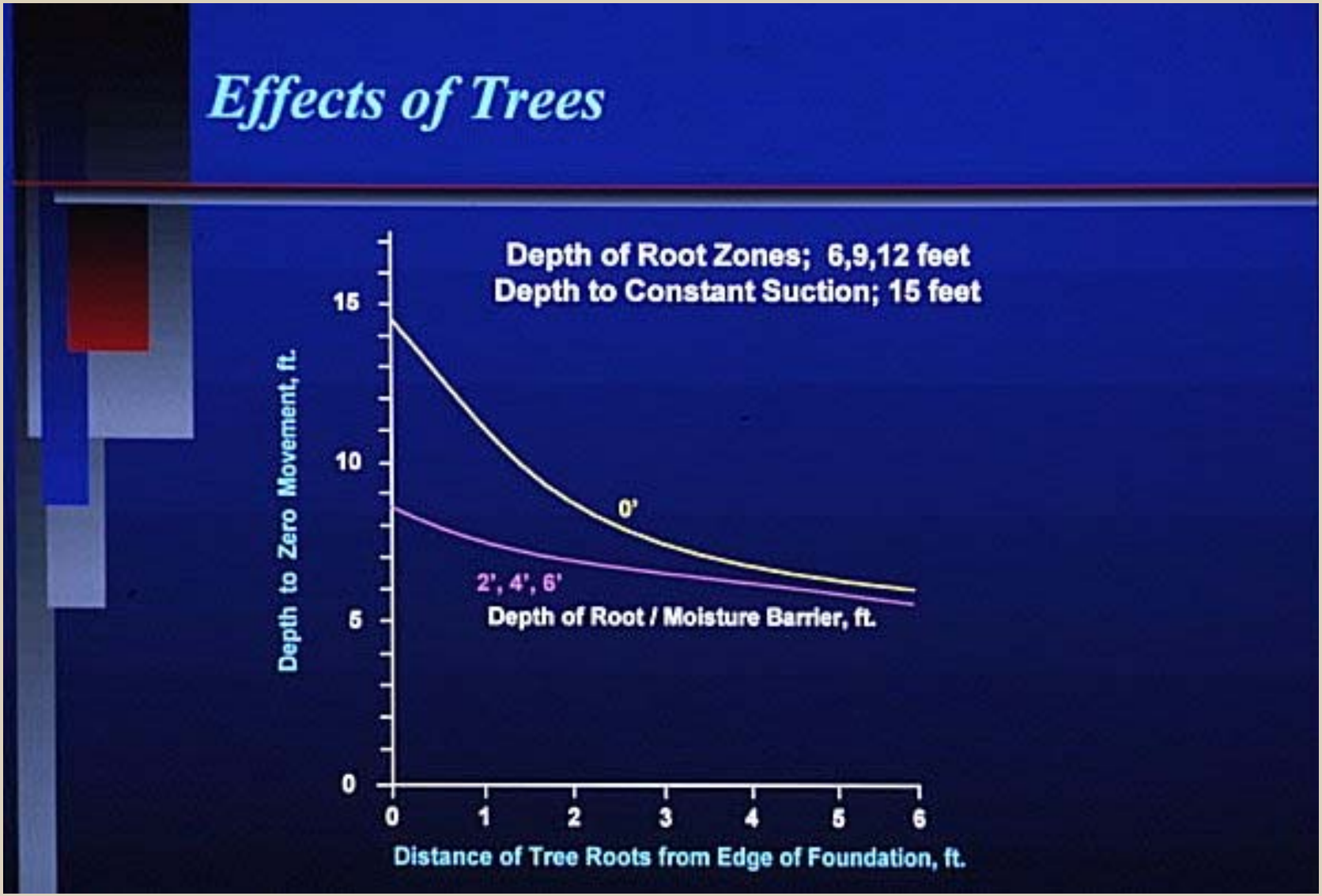
Effects of Trees

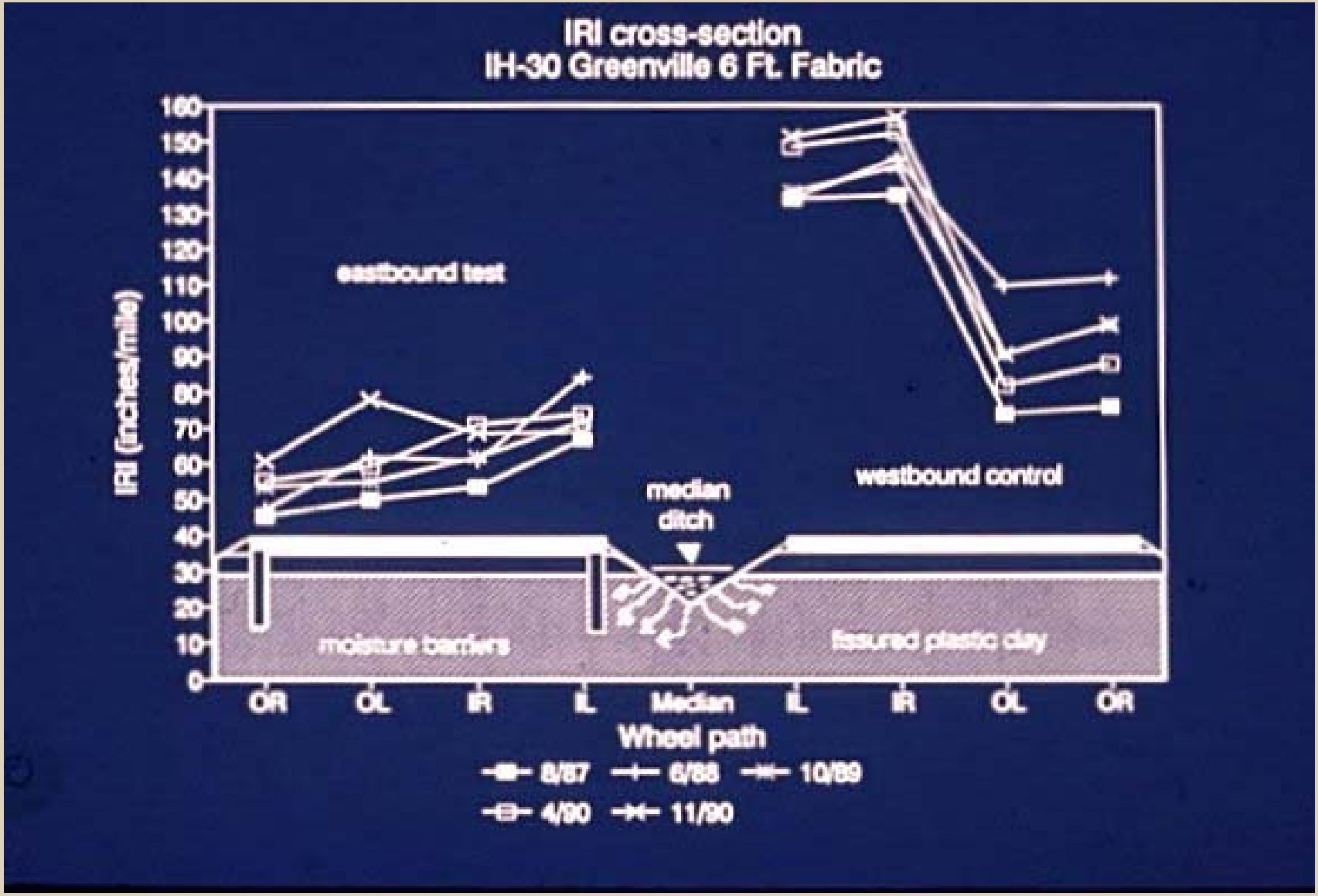


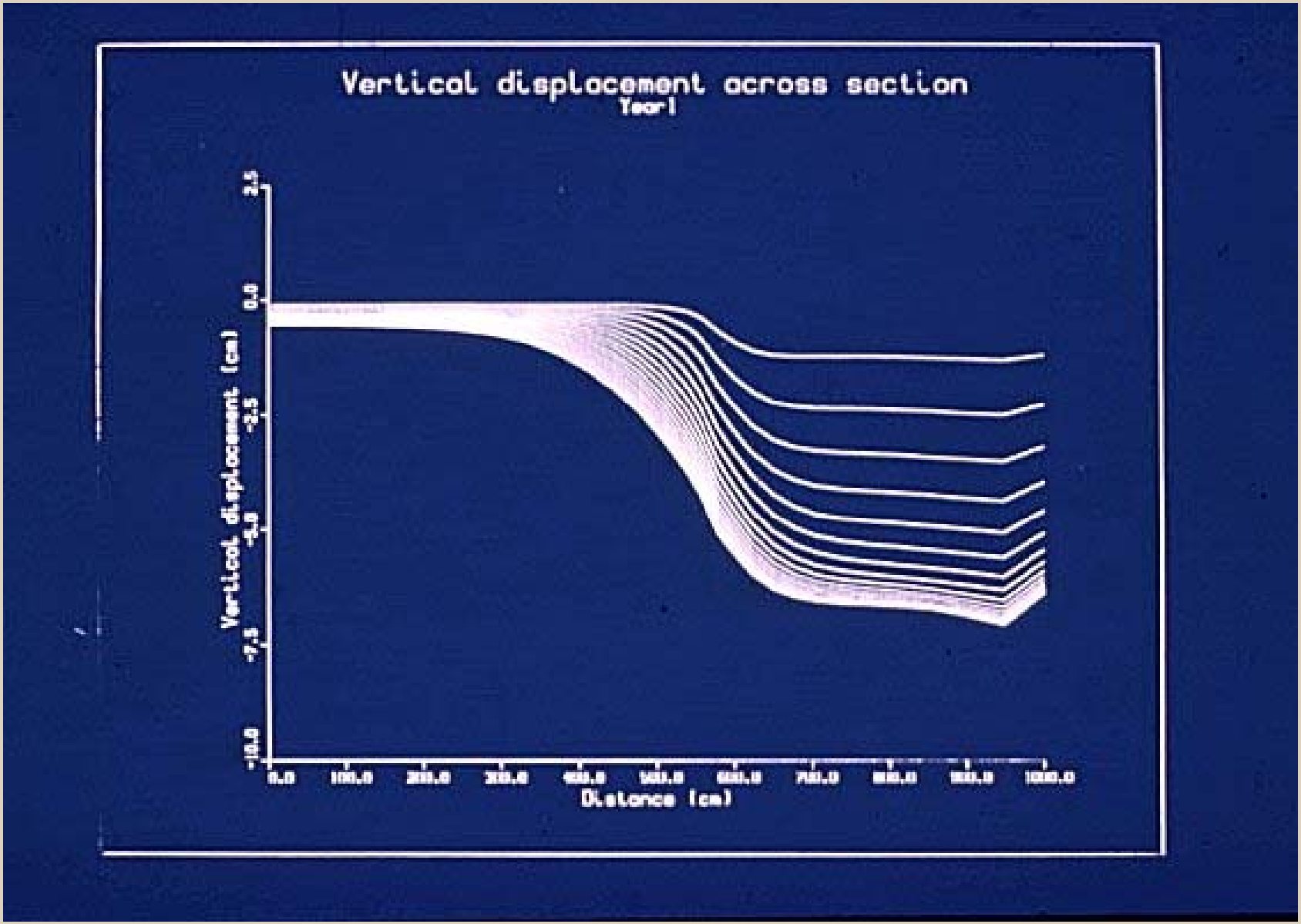
Effects of Trees

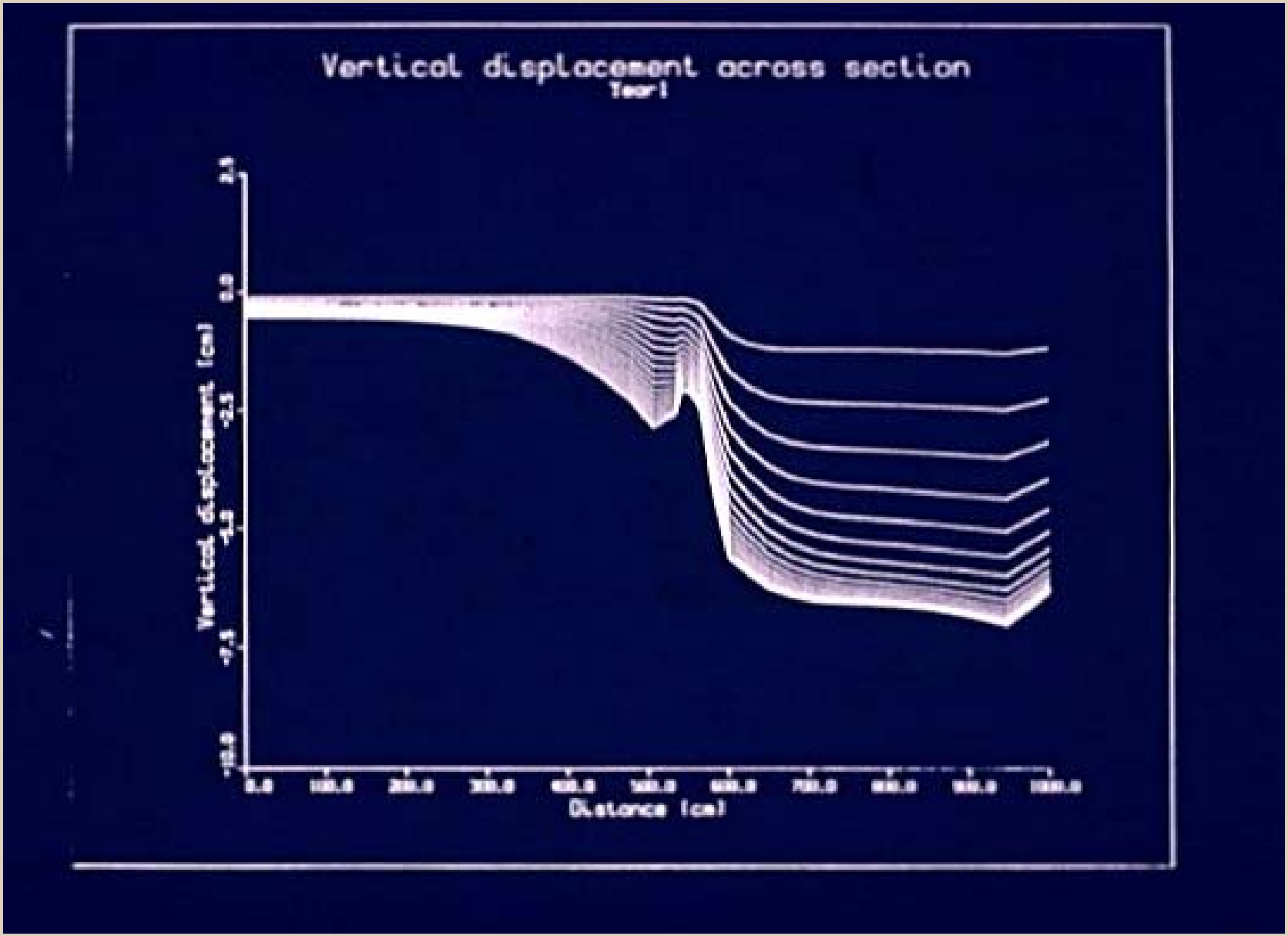


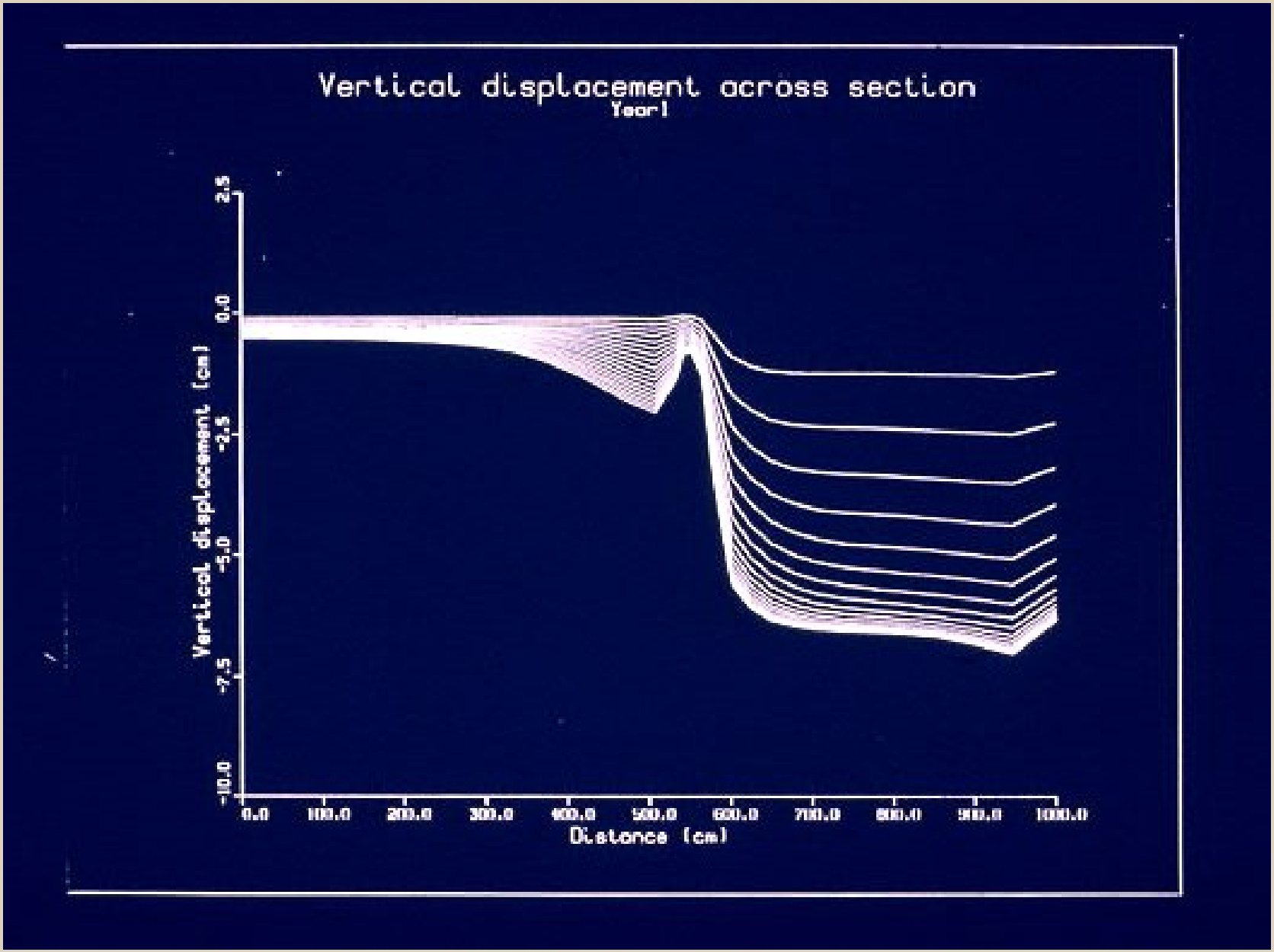

Effects of Trees
Tree Roots at Edge of Foundation
Depth of Root Zone, ft.
15
10
5
0
Tree Roots 3 feet from Edge of Foundation
10'
15'
20'
Depth to Constant Suction, feet
0
5
10
Surface Shrinkage Movement, in.

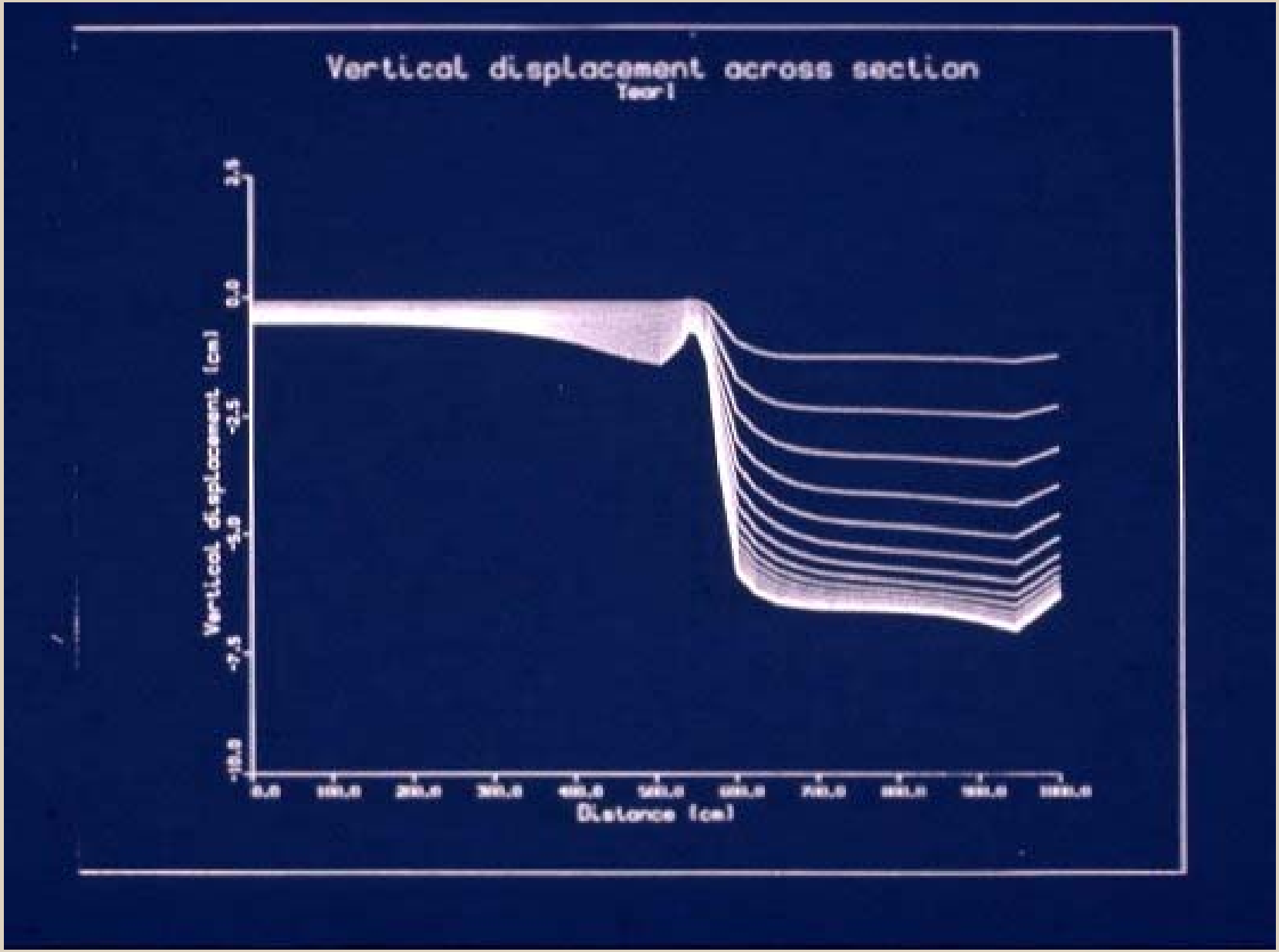

Effects of Trees
Depth of Root Zones; 6,9,12 feet
Depth to Constant Suction; 15 feet
Depth to Zero Movement, ft.
15
10
5
0
0'
2', 4', 6'
Depth of Root / Moisture Barrier, ft.
0
1
2
3
4
5
6
Distance of Tree Roots from Edge of Foundation, ft.

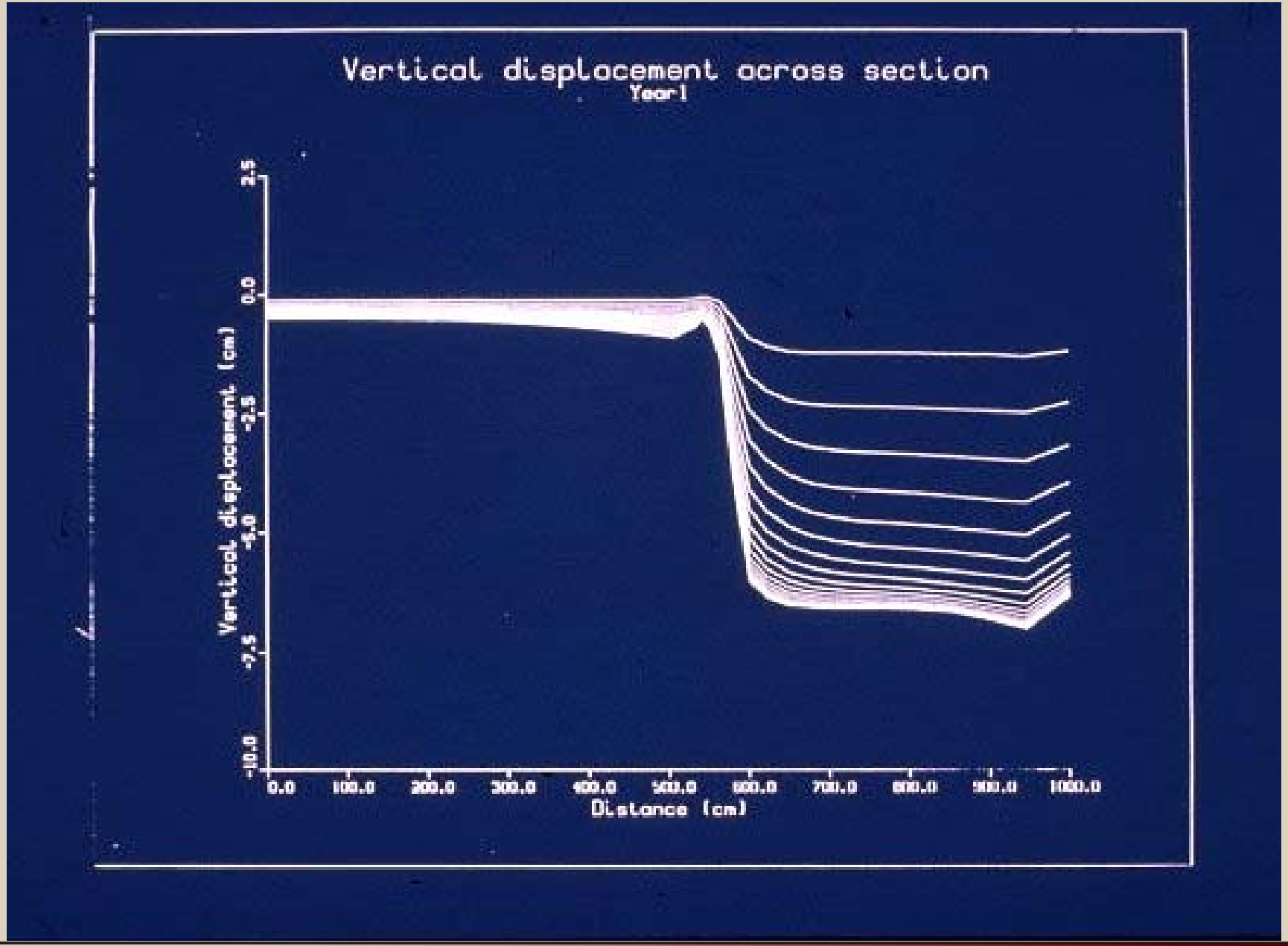

IRI cross-section
IH-30 Greenville 6 Ft. Fabric
IRI (inches/mile)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
eastbound test
westbound control
median
ditch
moisture barriers
fissured plastic clay
OR
OL
IR
IL
Median
IL
IR
OL
OR
Wheel path
8/87
6/88
10/89
4/90
11/90


Vertical displacement across section
Year1
Vertical displacement (cm)
2.5
0.0
-2.5
-5.0
-7.5
-10.0
0.0
Distance (cm)


Vertical displacement across section
Vertical displacement (cm)
Distance (cm)

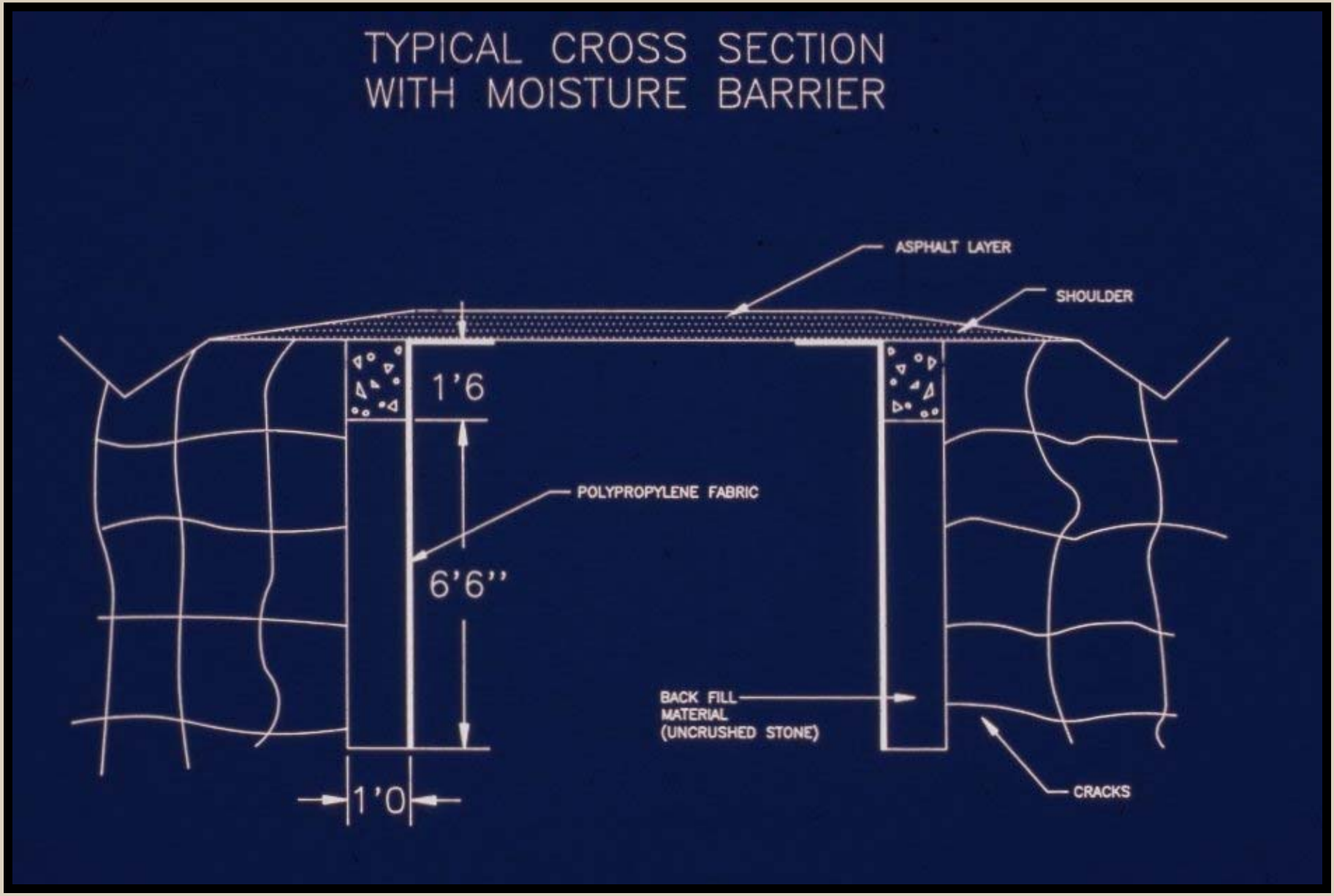

Vertical displacement across section
Year1
Vertical displacement (cm)
2.5
0.0
-2.5
-5.0
-7.5
-10.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
Distance (cm)

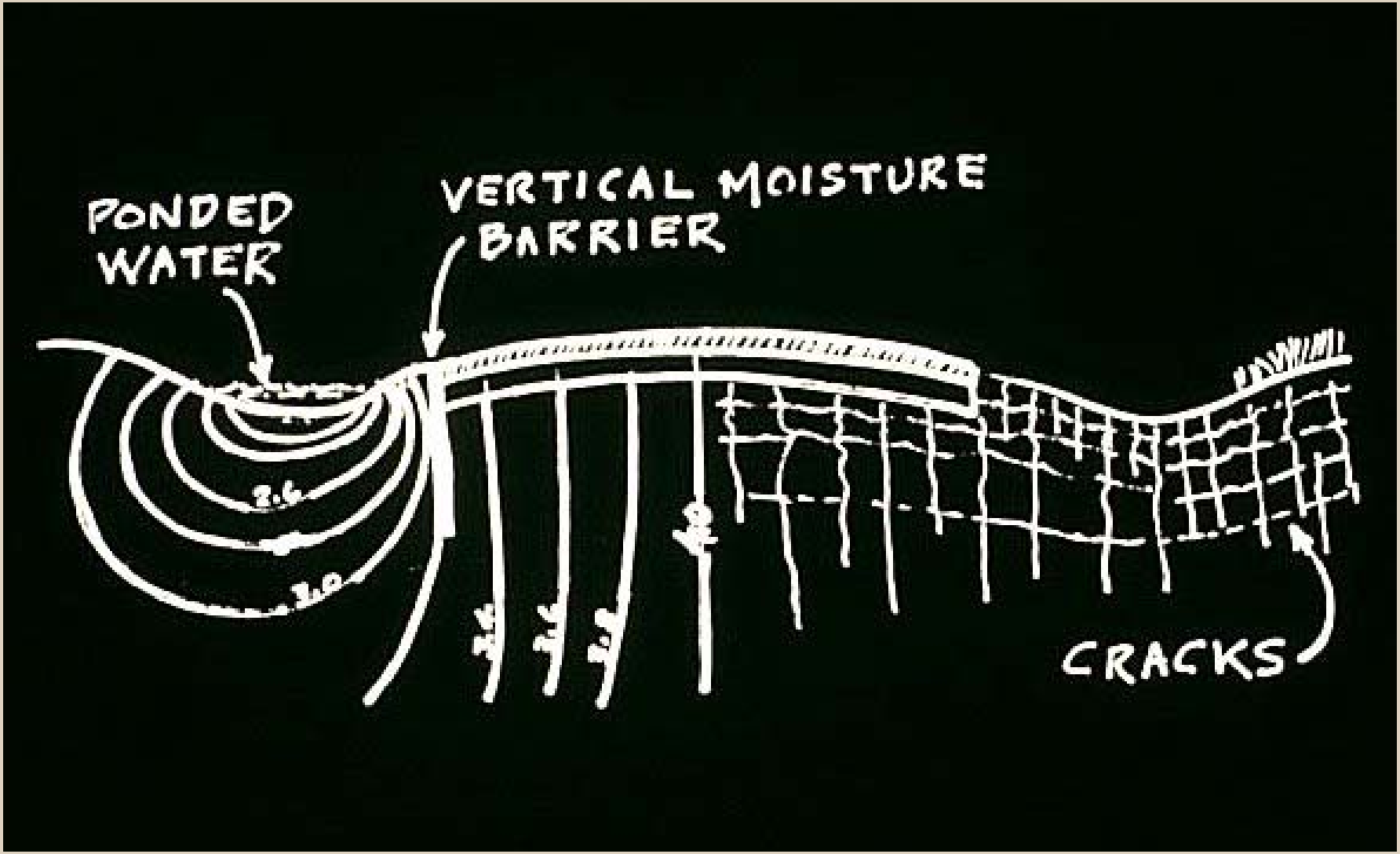

Vertical displacement across section
Year 1
Vertical displacement (cm)
Distance (cm)

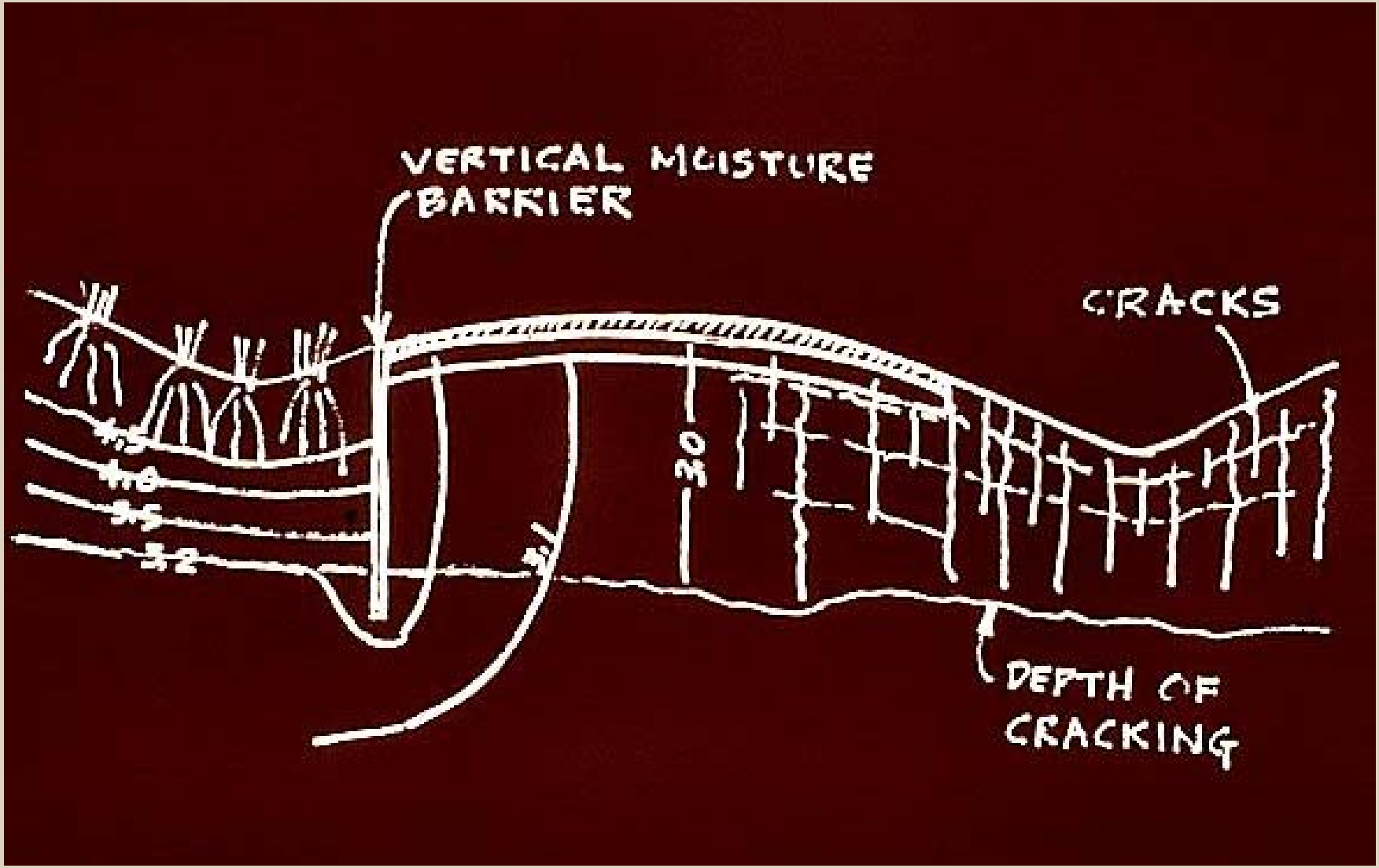

Vertical displacement across section
Year1
Vertical displacement (cm)
2.5
0.0
-2.5
-5.0
-7.5
-10.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
Distance (cm)

Guardrail between pavement lanes
on expansive clay subgrade
IH37, San Antonio, Texas (c. 1974)


CEM. STAB. BACKFILL
GRAVEL BACKFILL
VERTICAL MOISTURE SEAL
PROPOSED
TYPICAL MAINLANE PAVEMENT
SECTION


TYPICAL CROSS SECTION
WITH MOISTURE BARRIER
ASPHALT LAYER
SHOULDER
1'6
POLYPROPYLENE FABRIC
6'6''
BACK FILL
MATERIAL
(UNCRUSHED STONE)
1'0
CRACKS


PONDED WATER
VERTICAL MOISTURE BARRIER
CRACKS


VERTICAL MOISTURE
BARRIER
CRACKS
DEPTH OF
CRACKING

Edge cracking:

- Causes
- Countermeasures

TEXAS A&M ENGINEERING

Edge Cracking in Pavements on Expansive Soils

Causes and Countermeasures

Robert L. Lytton

Professor, Fred J. Benson Endowed Chair
Zachry Department of Civil Engineering
Texas A&M University

Foundation Performance Association
Houston, Texas
December 9, 2015