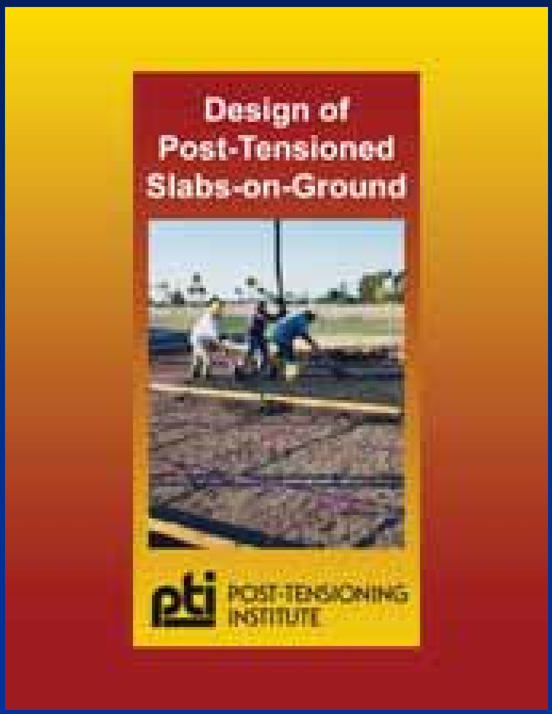
Application of Expansive Soil Geotechnical Procedures

FPA PRESENTATION
John T. Bryant, Ph.D., P.G., P.E with Robert L. Lytton, Ph.D., PE. And Mr. Dean Read
HOUSTON, TEXAS

WEDNESDAY DECEMBER 10, 2008

PTI 3rd Edition Manual



The "Design of Post-Tensioned Slabs-On-Ground", 3rd Edition manual was published by the Post-Tensioning Institute in December 2004.

Addendum #1–May 2007
Addendum #2–May/June 2008 ?

Issue: Complexity of the Procedure

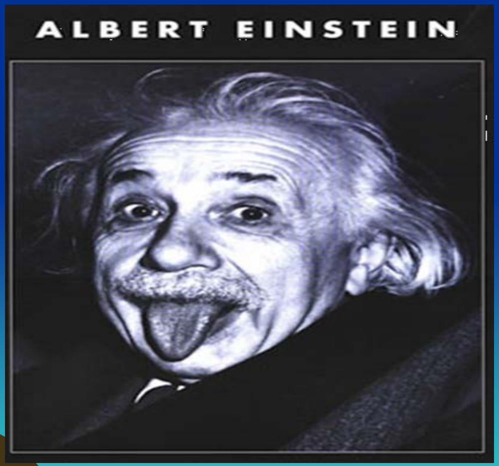
URBAN MYTH 1: To use and understand the PTIGDPE you must either:

a. Be Albert Einstein?

b. Be a Protégé of Albert Einstein?

c. Know who Albert Einstein is?

d. None of the above?



Fact: Answer is d, none of the above!

- The procedure is not difficult and is based simply on the relationship between stress and strain in material, which in this case is soil.
- Chart 1 helps to explain the relationships between the various known and unknown variables in the procedure.

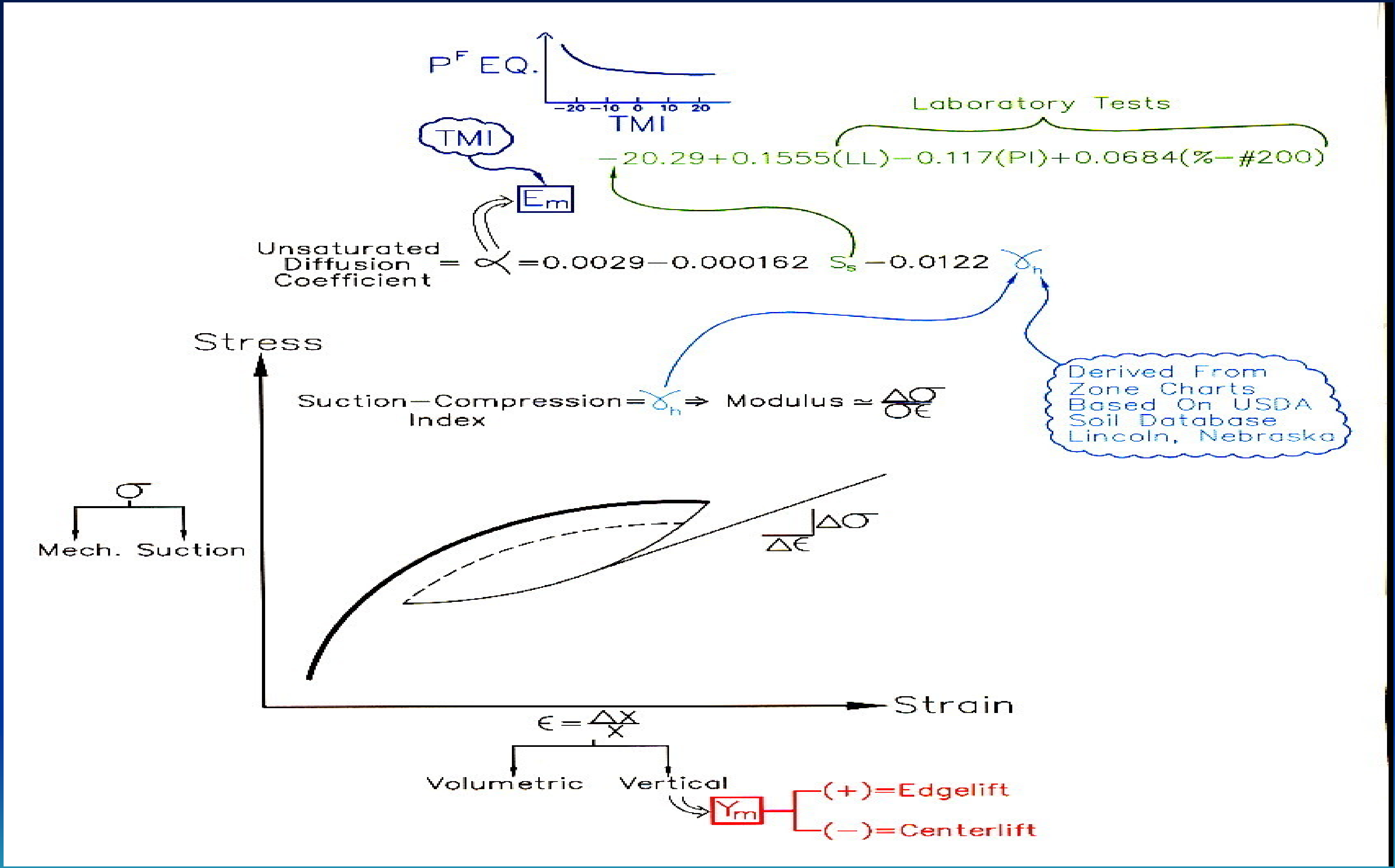


Chart 1. Relationship between PTI soil parameters and stress/strain curve

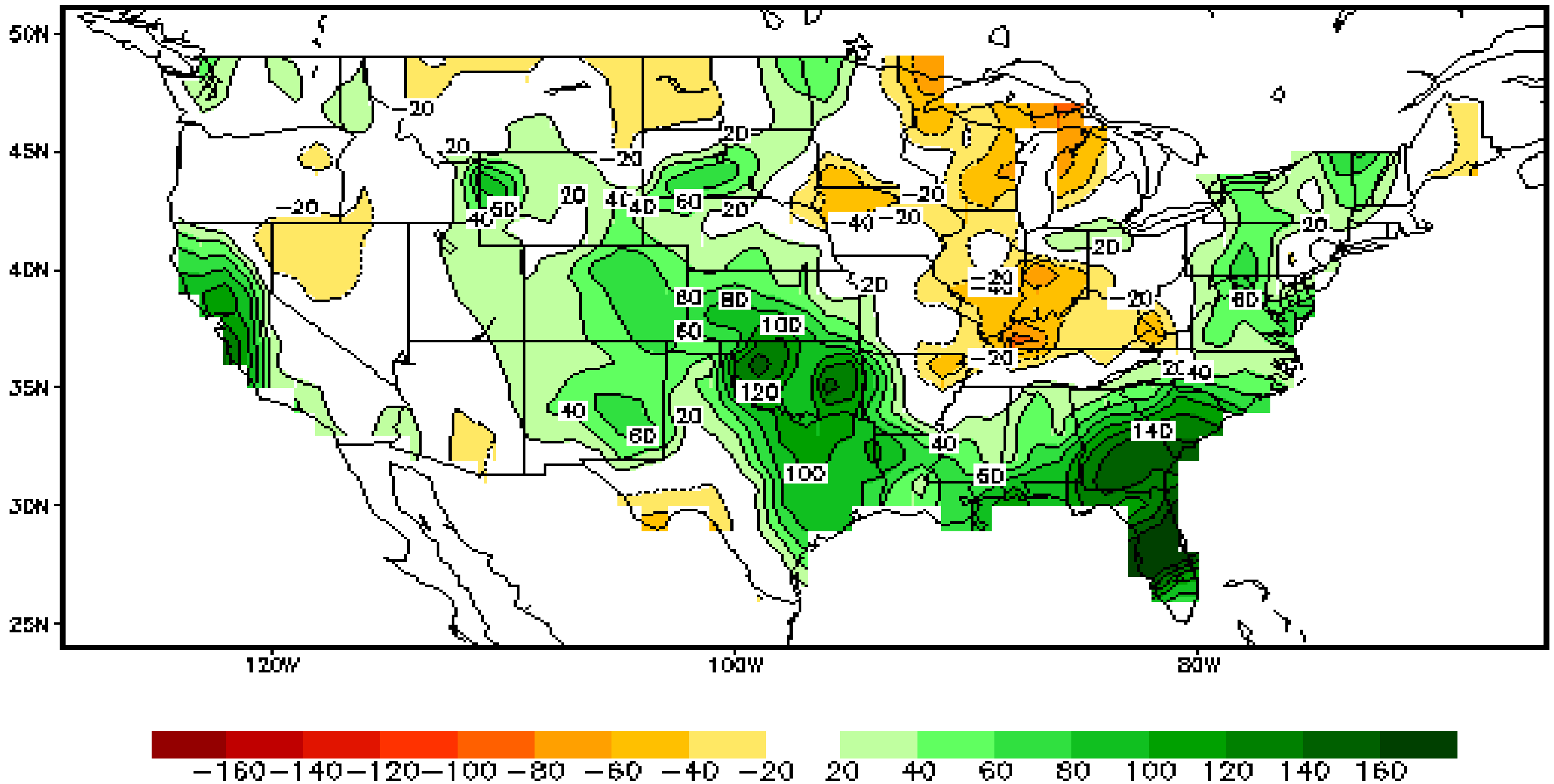
Expansive Soil?

PTI 3.2.1 - Expansive Soil Design is applicable if:

- All three of the following are true
  - Weighted PI of soil profile >= 15
  - Weighted Passing #200 Sieve > 10%
  - Weighted Finer than 5 micron > 10%
- Or EI > 20

Modified definition of an expansive site included in Addendum #1

Calculated Soil Moisture Anomaly (mm)
JAN, 1998



Issue—Where did the Zone Chart Curves come from for ?

Myth: The zone chart curves found in the PTI manual, Figures 3.8 to 3.13 (pp. 17 to 19 3rd Edition Manual) were developed by extra-terrestrial intelligence and actually model the topography of some mountains on Mars?

Figure 3.12 - Zone V Chart for Determining γ_o

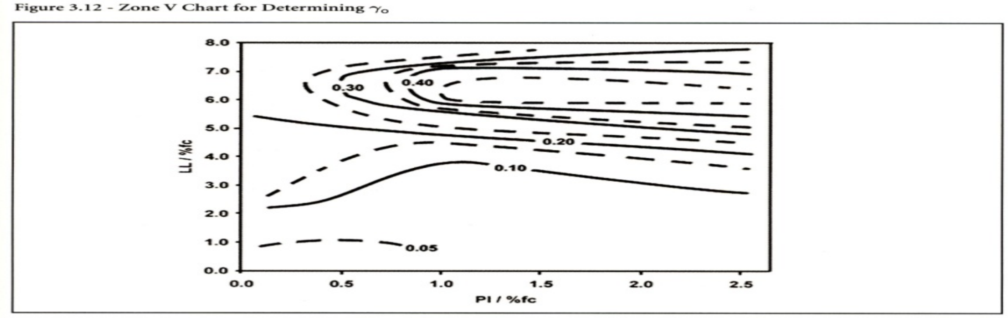
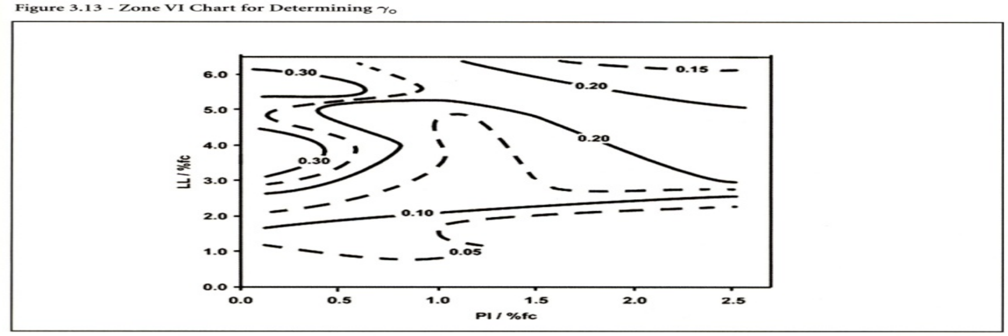


Figure 3.13 - Zone VI Chart for Determining γ_o



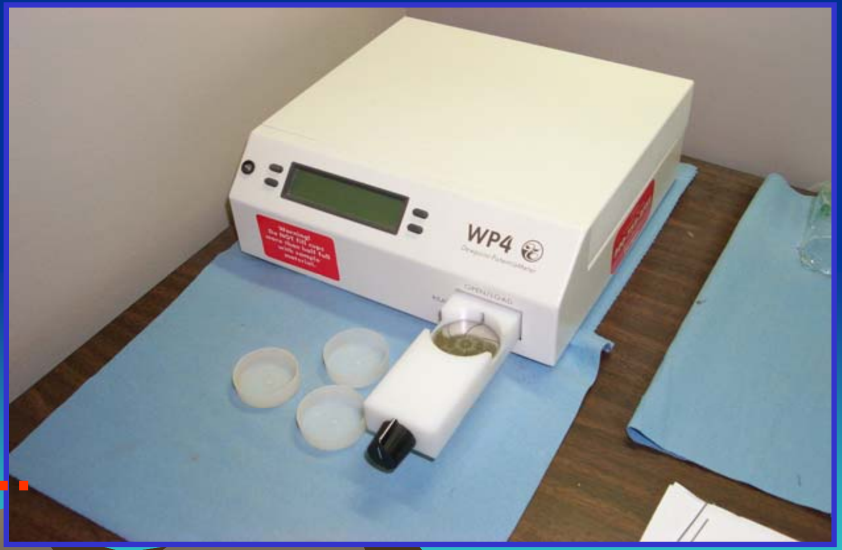
Newest Fact:

We are currently reviewing the gamma values for application across all soil types

Issue--New Equipment?

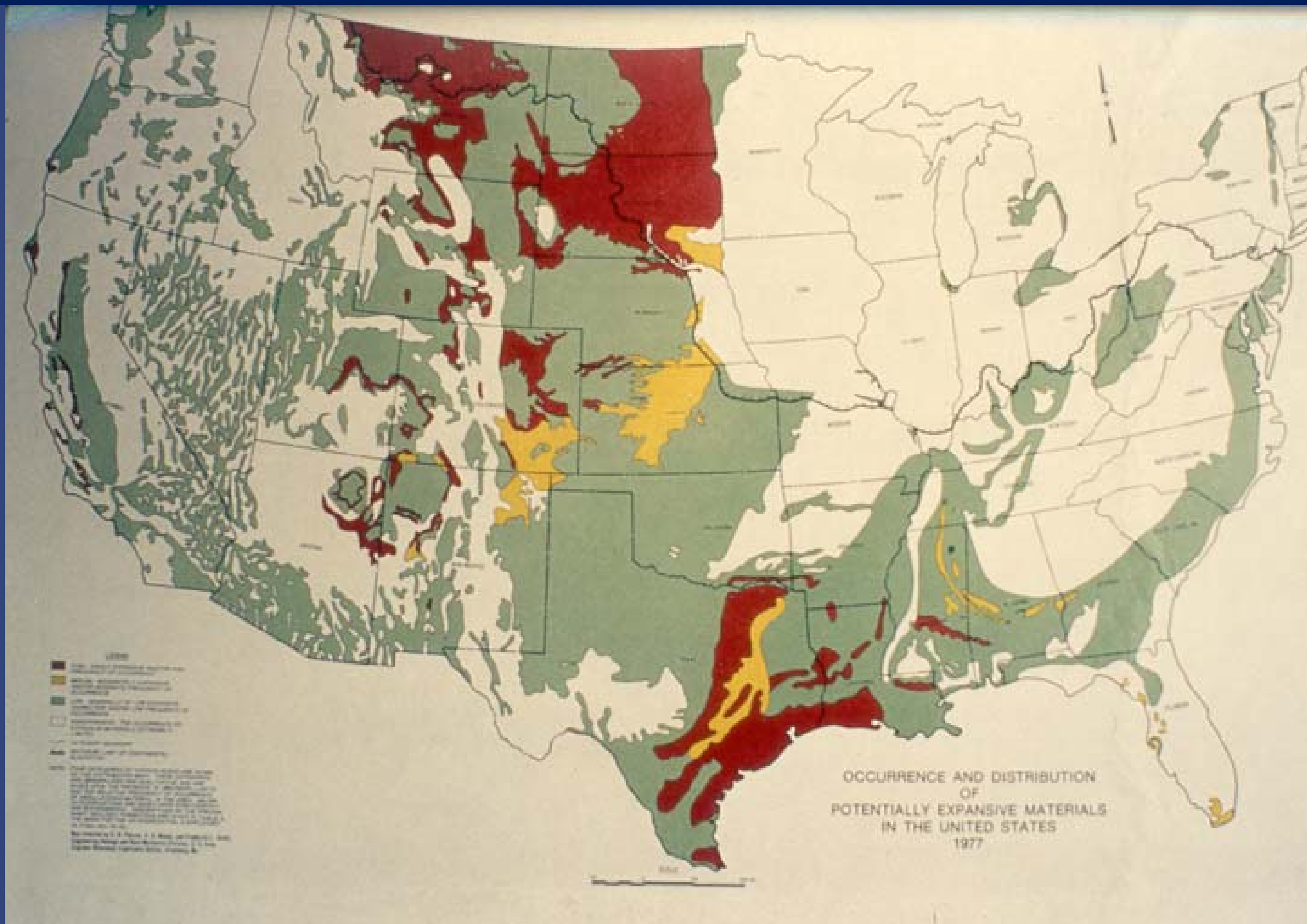
Urban Myth: **In order to use the PTI 3.1/3.2 , we must buy expensive laboratory equipment and we must do more testing AND WE MUST DO SOIL SUCTION TESTING!**

Fact: **Not true. In fact the same test data that were required for the 1st and 2nd edition procedures are all that is required for the 3rd edition. No additional tests are required and suction testing is not even required.**

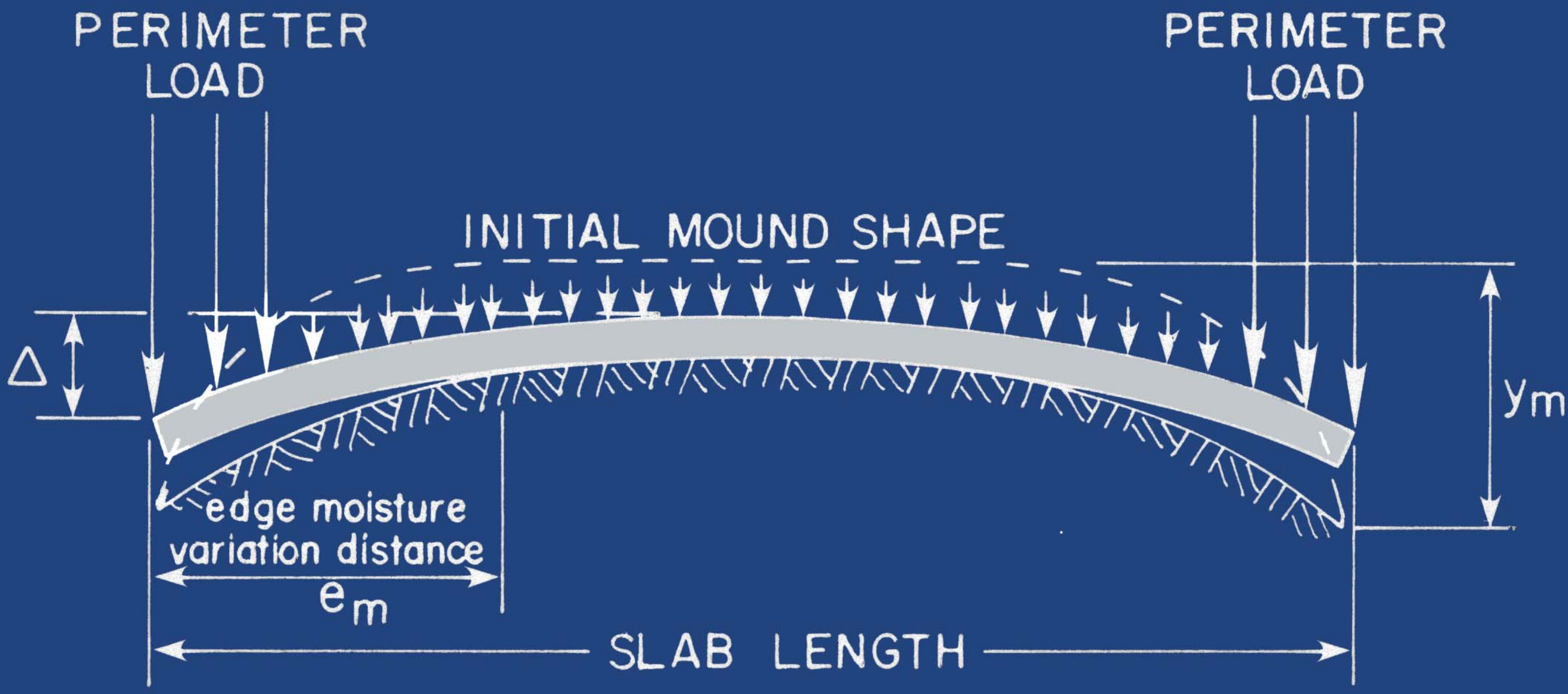


BUT………

Distribution of Expansive Soils

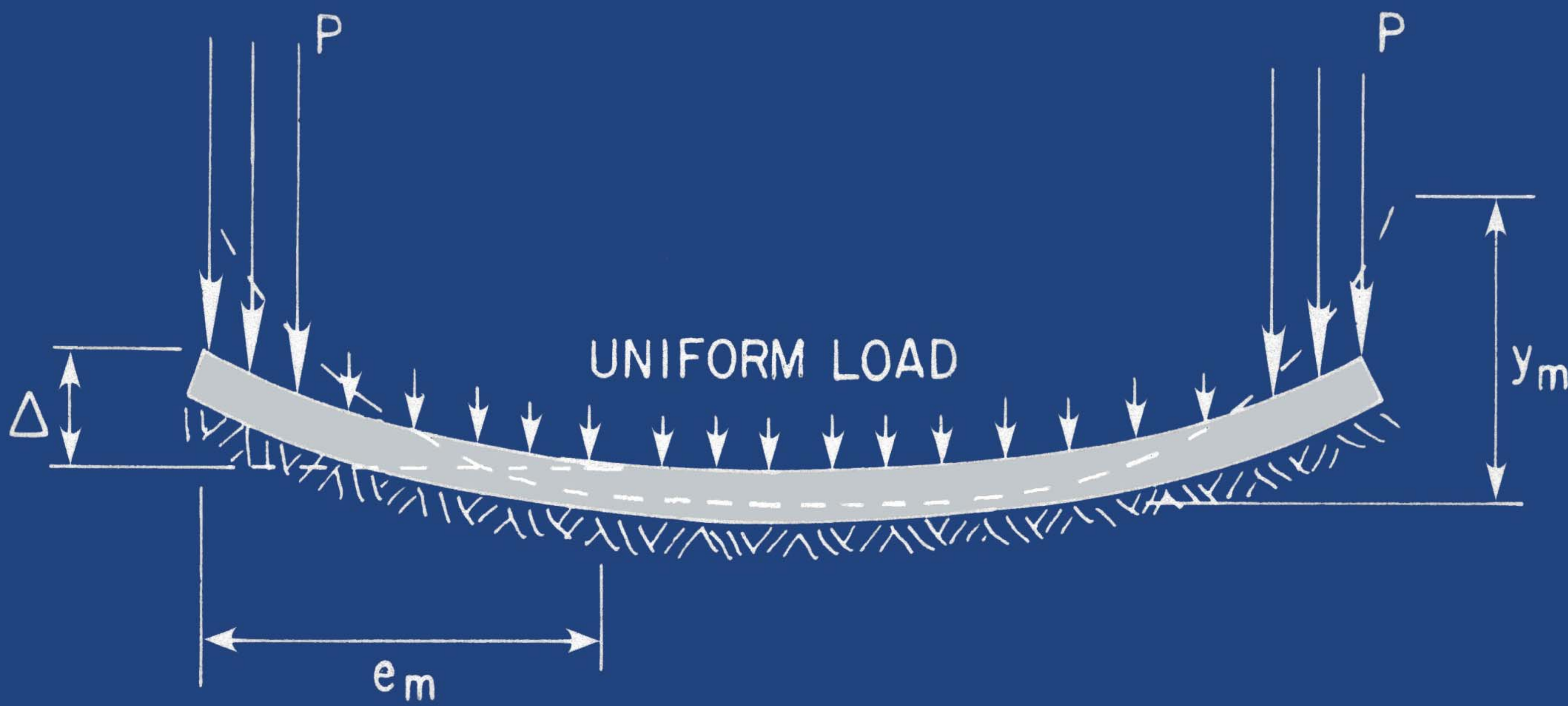


Soil Structure Interaction – Center Lift



CENTER LIFT (Also commonly referred to as Edge Drop)

Soil Structure Interaction – Edge Lift



EDGE LIFT

Differential Soil Movement, y_m

- Differential Soil Movement - y_m represents the change in soil surface elevation at two locations separated by a distance e_m.

- y_m can be determined using the Stress Change Factor (SCF) method or computer methods.

Differential Soil Movement, y_m

- y_m is NOT the expected differential deflection of the foundation. y_m should always be greater than the actual differential deflection of the foundation due to foundation stiffness.
- y_m would only equal the differential deflection for a "perfectly flexible" foundation with no externally applied loads.
- y_m is NOT the same as Potential Vertical Rise (PVR). PVR is a commonly used swell predictor used in Texas.

Edge Moisture Variation Distance, e_m

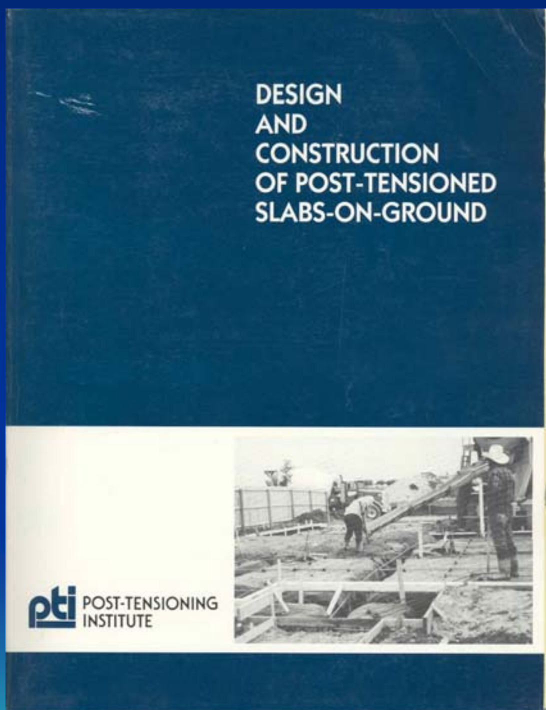
- Edge Moisture Variation Distance

  - e_m represents the distance measured inwards from the edge of a shallow foundation within which moisture will change due to wetting or drying influences around the perimeter of the foundation.

- e_m is a function of both climatic and soil properties.

  (2nd Edition only included the effect of climate on e_m)

PTI 2nd Edition Manual



The "Design and Construction of Post-Tensioned Slabs-On-Ground", 2nd Edition manual was published by the Post-Tensioning Institute in October 1996.

PTI 2nd Edition Manual

REQUIRED Inputs for determining e_m and y_m

- Liquid Limit (LL) – 55
- Plastic Limit (PL) – 28
- % Passing #200 Sieve – 79
- % Finer than 2 micron – 26
- Geographic Location – near Sacramento, CA
- Depth to Constant Suction – 9 feet

PTI 2nd Edition Manual

Determine y_m

Determine clay type from L, PL, %-200 and #-2μ

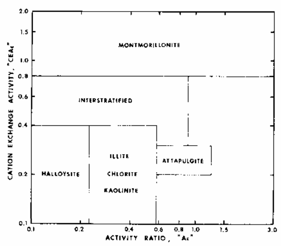


Fig. A.3.5 Clay type classification to cation exchange and clay activity ratio after Pearring (65) and Holt (34)

Determine % fine clay from #-200 and %-2_m

Percent Clay (%)	Depth to Constant Suction (FT)	Constant Suction (pF)	Velocity of Moisture Flow (inches/ month)	DIFFERENTIAL SWELL (IN) EDGE DISTANCE PENETRATION (FT) 1FT	2FT	3FT	4FT	5FT	6FT	7FT	8FT
60	3	3.2	0.5	0.015	0.031	0.048	0.065	0.082	0.101	0.120	0.140
			0.7	0.022	0.044	0.068	0.092	0.119	0.147	0.176	0.209
		3.4	0.5	0.031	0.065	0.102	0.143	0.189	0.240	0.300	0.372
			0.7	0.044	0.093	0.147	0.211	0.286	0.380	0.503	0.683
		3.6	0.5	0.073	0.161	0.272	0.420	0.645	1.056	2.037	4.865
			0.7	0.101	0.229	0.407	0.689	1.246	2.689	6.912	—
	5	3.2	0.5	0.037	0.074	0.113	0.153	0.194	0.237	0.282	0.392
			0.7	0.050	0.103	0.158	0.217	0.278	0.343	0.412	0.487
		3.4	0.5	0.073	0.152	0.237	0.331	0.435	0.551	0.686	0.846
			0.7	0.102	0.214	0.341	0.485	0.655	0.865	1.140	1.541
		3.6	0.5	0.169	0.370	0.618	0.945	1.425	2.280	4.284	9.923
			0.7	0.234	0.526	0.922	1.528	2.686	5.574	—	—
	7	3.2	0.5	0.068	0.137	0.209	0.283	0.360	0.441	0.524	0.612
			0.7	0.093	0.191	0.294	0.402	0.516	0.637	0.767	0.907
		3.4	0.5	0.135	0.280	0.438	0.609	0.799	1.013	1.260	1.553
			0.7	0.188	0.395	0.627	0.892	1.204	1.587	2.092	2.840
		3.58	0.5	0.256	0.549	0.895	1.320	1.879	2.702	4.182	8.216
			0.7	0.354	0.779	1.317	2.059	3.247	5.677	—	—

Table A.3.14 Differential Swell Occuring at the Perimeter of a Slab for a Center Lift Swelling Condition in Predominantly Montmorillonite Clay Soil (60 Precent Clay).

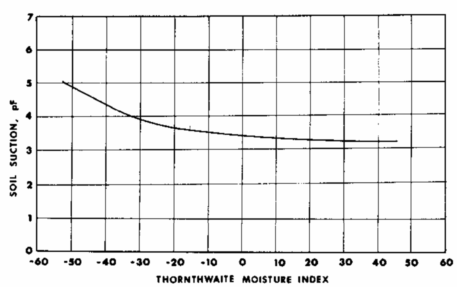


Fig. A.3.6 Variation of constant soil suction with Thornthwaite Index (76)

Determine equilibrium suction from TMI

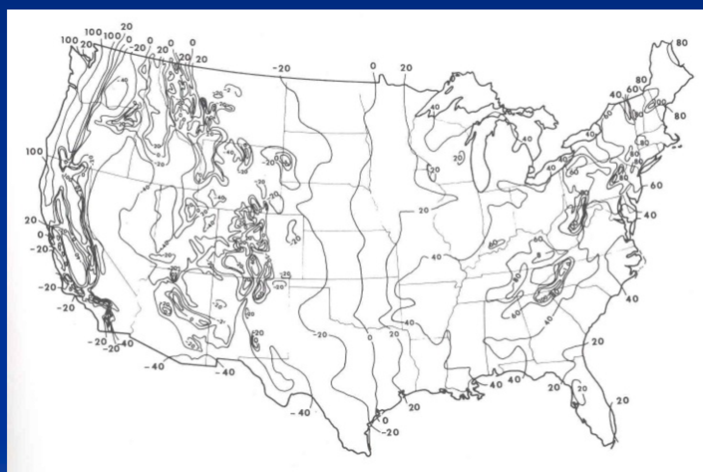
Depth to constant suction

Estimate velocity from TMI

PTI 2nd Edition Manual

Determine e_m

Determine TMI from geographic location



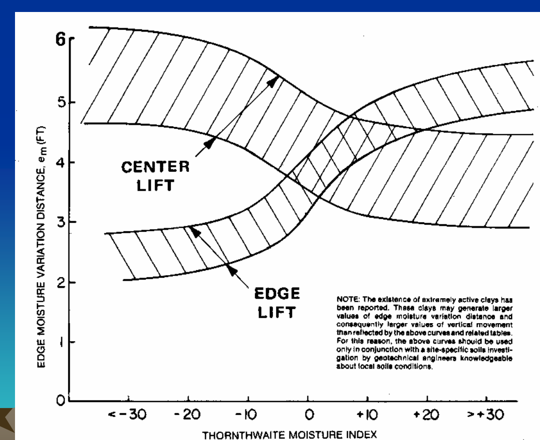
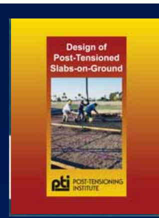


Fig. A.3.4. Approximate relationship between Thornthwaite Index and moisture variation distance (108)

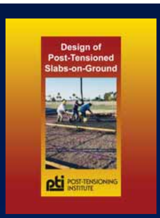


PTI 3rd Edition Manual

REQUIRED Inputs for determining e_m and y_m

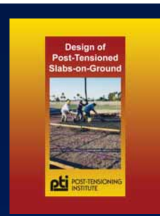
- Liquid Limit (LL) – 55
- Plastic Limit (PL) – 28
- % Passing #200 Sieve – 79
- % Finer than 2 micron – 26
- Geographic Location – near Sacramento, CA
- Depth to Constant Suction – 9 feet
- Fabric Factor (Ff) – 1.2

Note: With the exception of the Fabric Factor, the inputs were all required in the 2nd Edition procedure.



Depth to Constant Suction

- The Depth to Constant Suction can be estimated by several different methods:
  - Published analytical procedures
  - The depth at which the suction changes less than 0.027 pF (difficult to measure to this accuracy)
  - 2 feet deeper than the deepest root
  - Depth of “moisture active zone” (difficult to determine, can vary on different sites)
- While the Depth to Constant Suction is commonly assumed to be 9 feet it can be significantly deeper.



Optional Variables

Additional Optional Variables for determining e_m and y_m

- **% Passing #10 Sieve**
- **Dry Unit Weight** (at natural water content)
- **Wet Total Unit Weight** (at approx. 2.5 pF)

Note: Variables only required for Coarse Grained Soil Correction.

Example of y_m Calculation

y_m

- y_m, in simple terms, is a function of a change in suction AND how much the soil changes volume for a given suction change.
  - The change in suction is modeled using Design Suction Envelopes.
  - The Suction Compression Index is the change in soil volume for a change in suction.

Steps to determine y_m

- Step 1 – Calculate Plasticity Index (PI)
- Step 2 – Calculate Percent fine clay (%fc)
- Step 3 – Determine Zone from Mineral Classification chart
- Step 4 – Calculate Activity Ratio (PI/%fc)
- Step 5 – Calculate LL / %fc

Steps to determine y_m

- Step 6 – Determine suction compression index
  - 6a – Determine (γ_o) from gamma charts
  - 6b – Correct for Percent Fine Clay (γ_h)
  - 6c – Correct for Coarse Grained Component ($\gamma_{h\ corr}$)
  - 6d – Modify for shrinking and swelling ($\gamma_{h\ shrinking}$ and $\gamma_{h\ swelling}$)
  - 6e – Calculate weighted suction compression index

Steps to determine y_m

- Step 7 – Determine Thornthwaite Moisture Index (I_m)
- Step 8 – Develop Suction Envelopes
- Step 9 – Determine Stress Change Factors
- Step 10 – Calculate y_m

y_m Steps 1 & 2 – Calculate PI and %fc

- **Step 1 – Calculate Plasticity Index (PI)**

  PI = LL – PL

  PI = 55 – 28 = 27

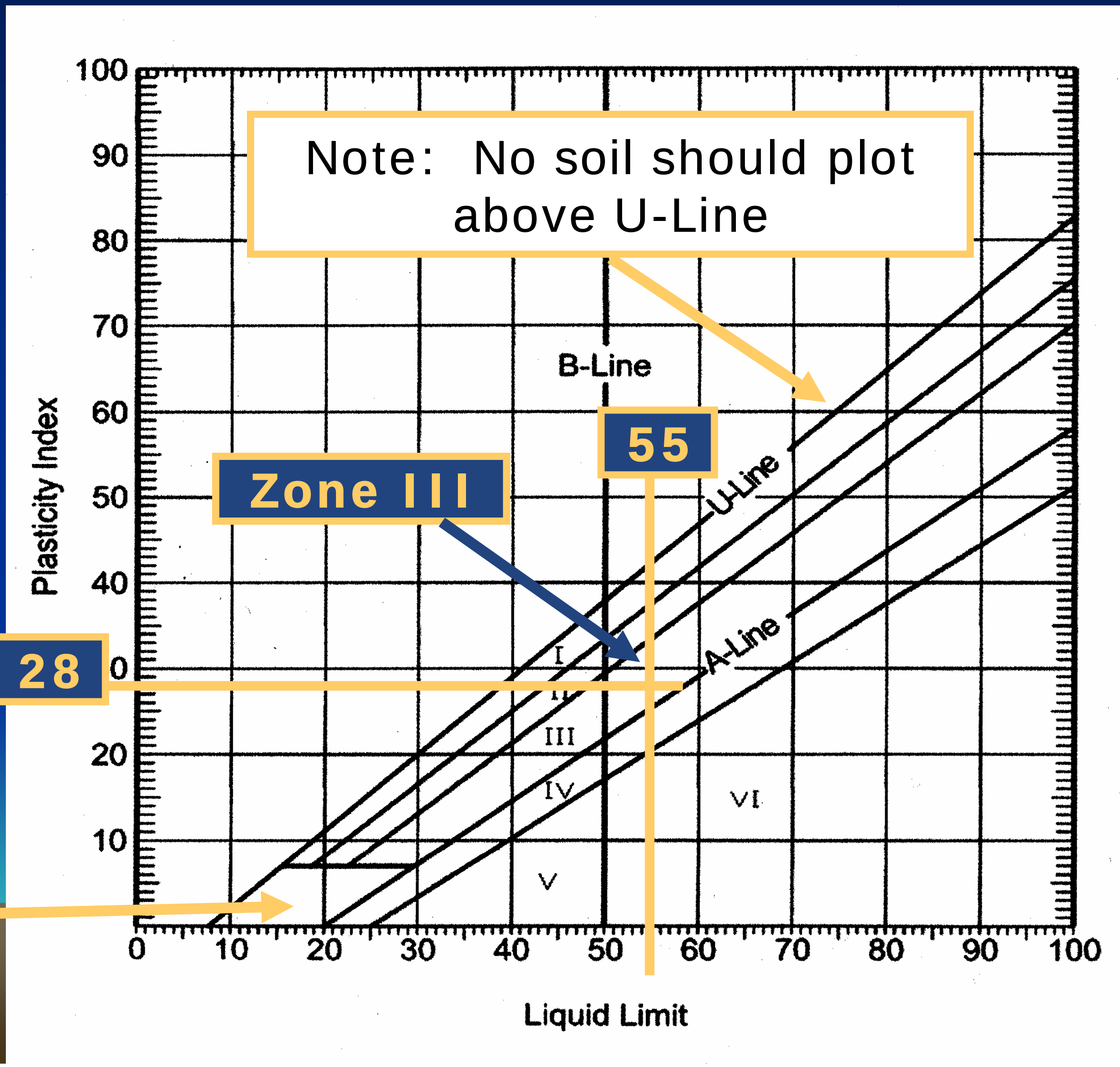
- **Step 2 – Calculate Percent Fine Clay (%fc)**

  $$\%fc = \frac{\%\ \text{finer than 2 micron}}{\%\ \text{passing \#200 sieve}}$$

  %fc = (26 / 79) * 100 = 33%

Note: Percent Fine Clay is not the same as Percent Clay as published in other sources.

y_m Step 3 –
Determine Zone from Mineral Classification Chart



There is no Zone Chart for this area. PTI 3.6.2 says to use γ_o = 0.01

y_m Steps 4 & 5 – Calculate Activity Ratio and LL / %fc

- **Step 4 – Calculate Activity Ratio**

  (PI / %fc)

  PI / %fc

  PI / %fc = 27 / 33 = 0.82

- **Step 5 – Calculate LL / %fc**

  LL / %fc

  LL / %fc = 55 / 33 = 1.67

y_m Step 6 –
Determine Suction Compression Index

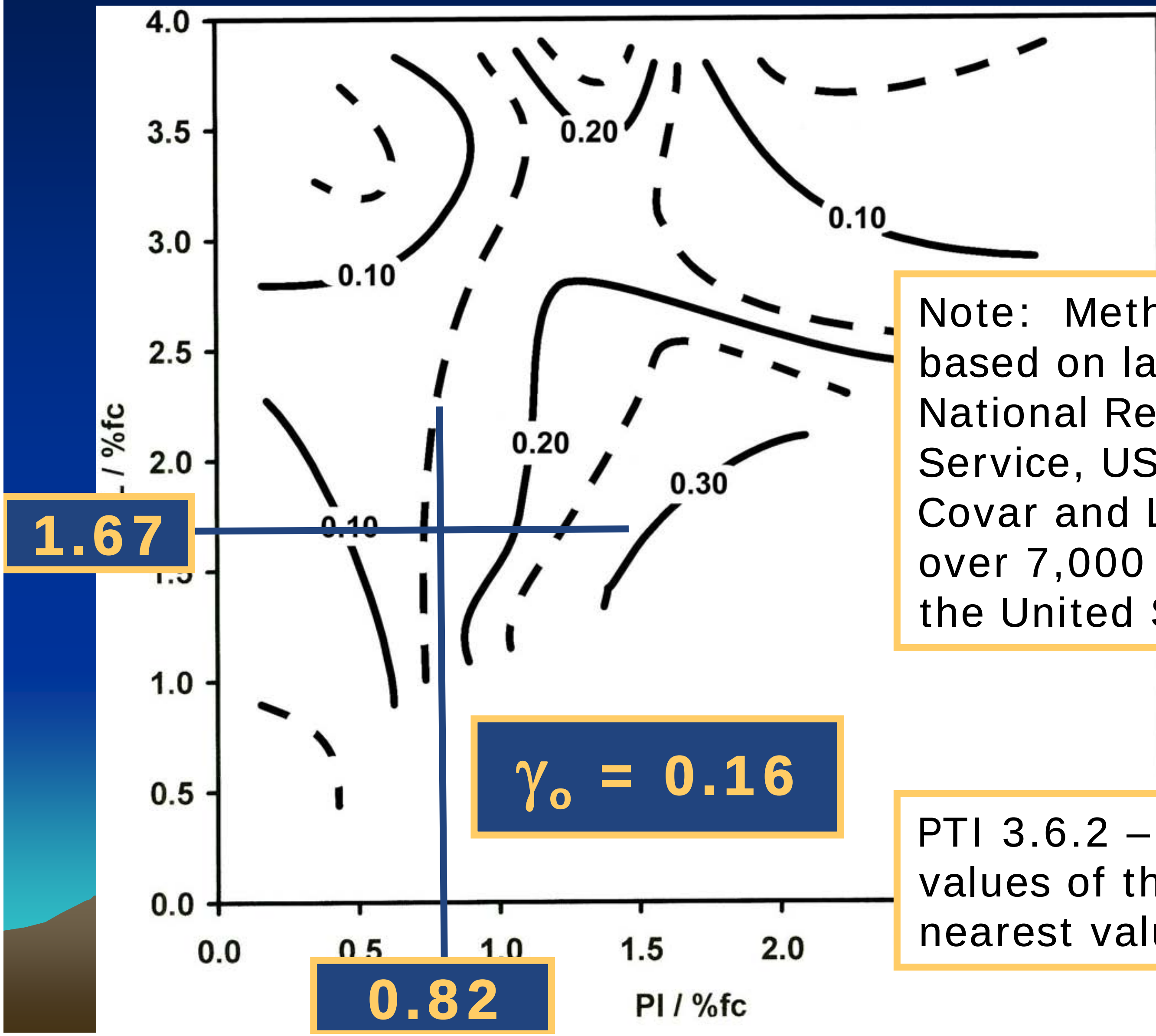
The Suction Compression Index is the change of soil volume for a change in suction.

y_m Step 6 –
Determine Suction Compression Index

- γ_o is the suction compression index for a soil with 100% fine clay (all particles smaller than 2 micron).
- γ_h is the suction compression index corrected for the actual percentage of fine clay
- $\gamma_{h\ corr}$ is the suction compression index corrected for the coarse grained component of the soil.

y_m Step 6a –
Determine Suction Compression Index (γ_o)

Zone III



Note: Method for determining γ_o based on laboratory data from the National Resources Conservation Service, USDA with analysis by Covar and Lytton. Data included over 7,000 samples from across the United States.

PTI 3.6.2 – Beyond extreme values of the contours, use the nearest values for γ_o.

y_m Step 6b –
Correct for Percent Fine Clay (γ_h)

- γ_o is the suction compression index for a soil with 100 % fine clay (all particles smaller than 2 micron).
- γ_h is the suction compression index adjusted for the actual percentage of fine clay and coarse grained soils.

$$\gamma_h = \gamma_o (\%fc)/100$$

$$\gamma_h = 0.16(33)/100 = 0.053$$

γ_m Step 6c –

Correct for Coarse Grained Component ($\gamma_{h\ corr}$)

Coarse Grained Soil Correction

$$F = \frac{100}{1 + \left(\frac{J}{100 - J}\right)\left(\frac{(\gamma_t - wet)}{\gamma_w (G_s)_{coarse}}\right)}$$

$$(\gamma_h)_{corr} = \gamma_h \left[\frac{100}{F\left(\frac{\gamma_t - wet}{\gamma_d - dry}\right) + (100 - F)}\right]$$

Note: Should only be used in cases where the percentage retained on the #10 sieve is 10% or more. Clarification regarding use provided in Addendum #1.

Error exists in Equation 3-11 in 1st Printing of 3rd Edition.

y_m Step 6d – Modify for Shrinking and Swelling

- γ_o and γ_h determined with zone charts represent mean values.
- γ_h needs to be modified for shrinking and swelling.

$$\gamma_{h\ shrinking} = \gamma_h e^{-\gamma_h}$$

$$\gamma_{h\ shrinking} = 0.053e^{-0.053} = 0.050$$

$$\gamma_{h\ swelling} = \gamma_h e^{\gamma_h}$$

$$\gamma_{h\ swelling} = 0.053e^{0.053} = 0.056$$

Note: Correction is different than in Technical Note #12. Incorrect modification performed in Example problems.

Alternate Procedures for Determining $\gamma_{h\ Swelling}$

- Expansion Index Procedure - use ASTM D 4829 to determine EI:

$$\gamma_{h\ swell} = EI/1700$$

$$EI = \frac{1000x\left(final\ thickness - initial\ thickness\right)}{initial\ thickness}$$

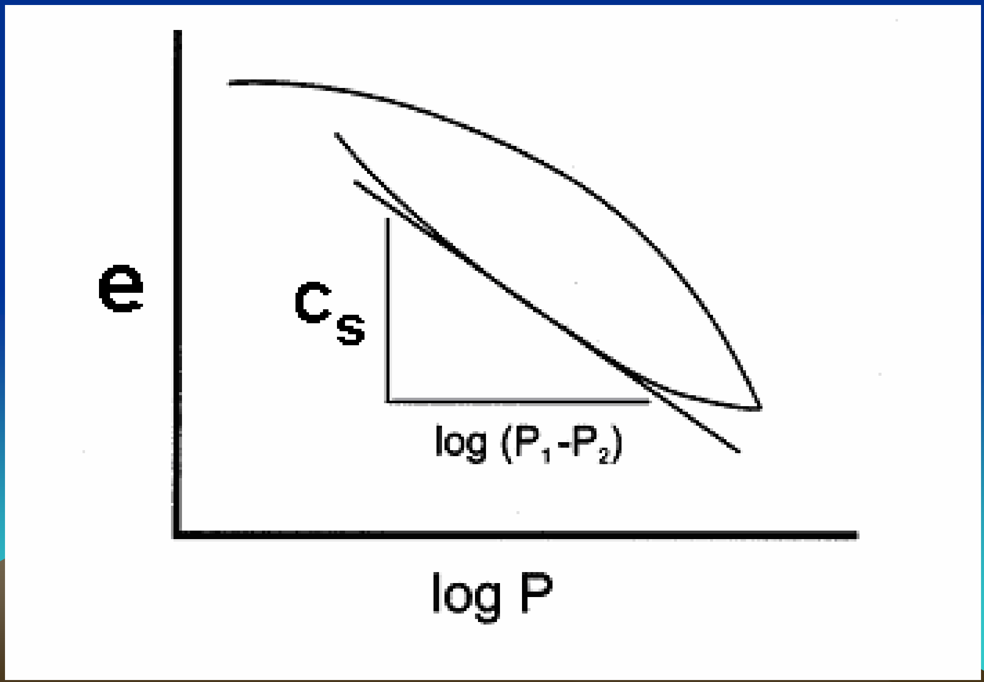
For comparison purposes:

$\gamma_{h\ swelling}$ = 101/1700 = 0.059

Alternate Procedures for Determining $\gamma_{h\ Swelling}$

- Consolidation - Swell Pressure Test Procedure: use ASTM D4546 Method C

$$\gamma_{h\ swell} = \frac{(0.7)(C_s)}{(1+e_2)}$$



Alternate Procedures for Determining $\gamma_{h\ Swelling}$

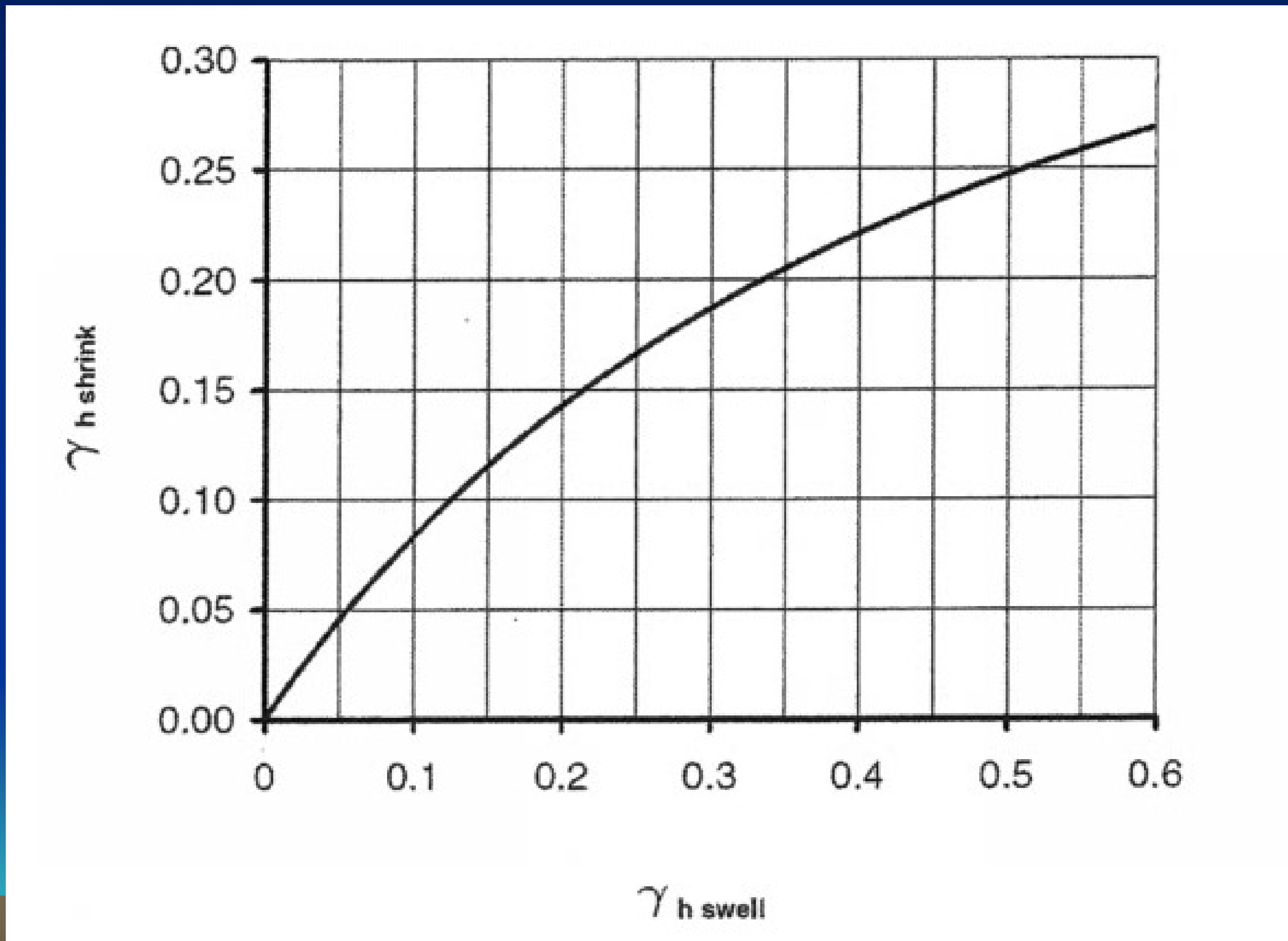
- Overburden Pressure Swell Test

$$\gamma_{h\ swell} = \frac{\frac{\Delta H}{H}}{1.7 - Log_{10} P}$$

$\frac{\Delta H}{H}$ is decimal change of specimen height divided by the initial height

P Overburden Pressure

Alternate Procedures for Determining $\gamma_{h\ Swelling}$

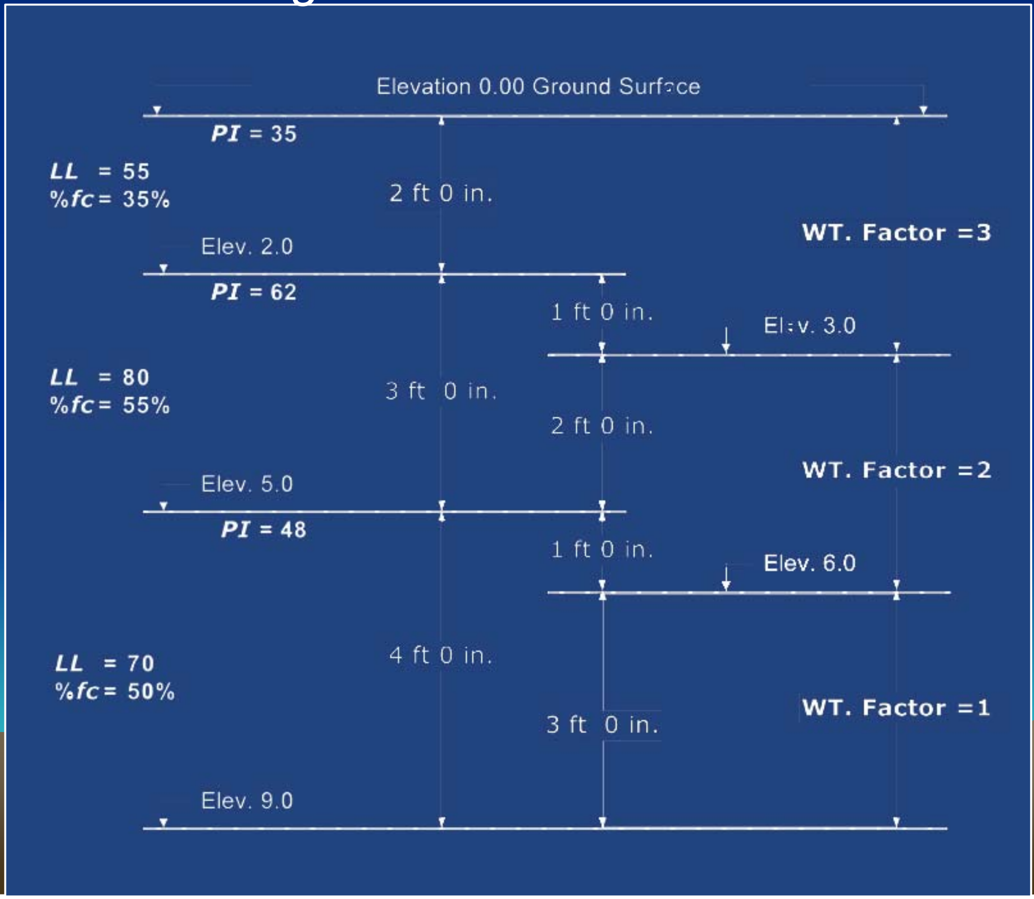


y_m Step 6e –

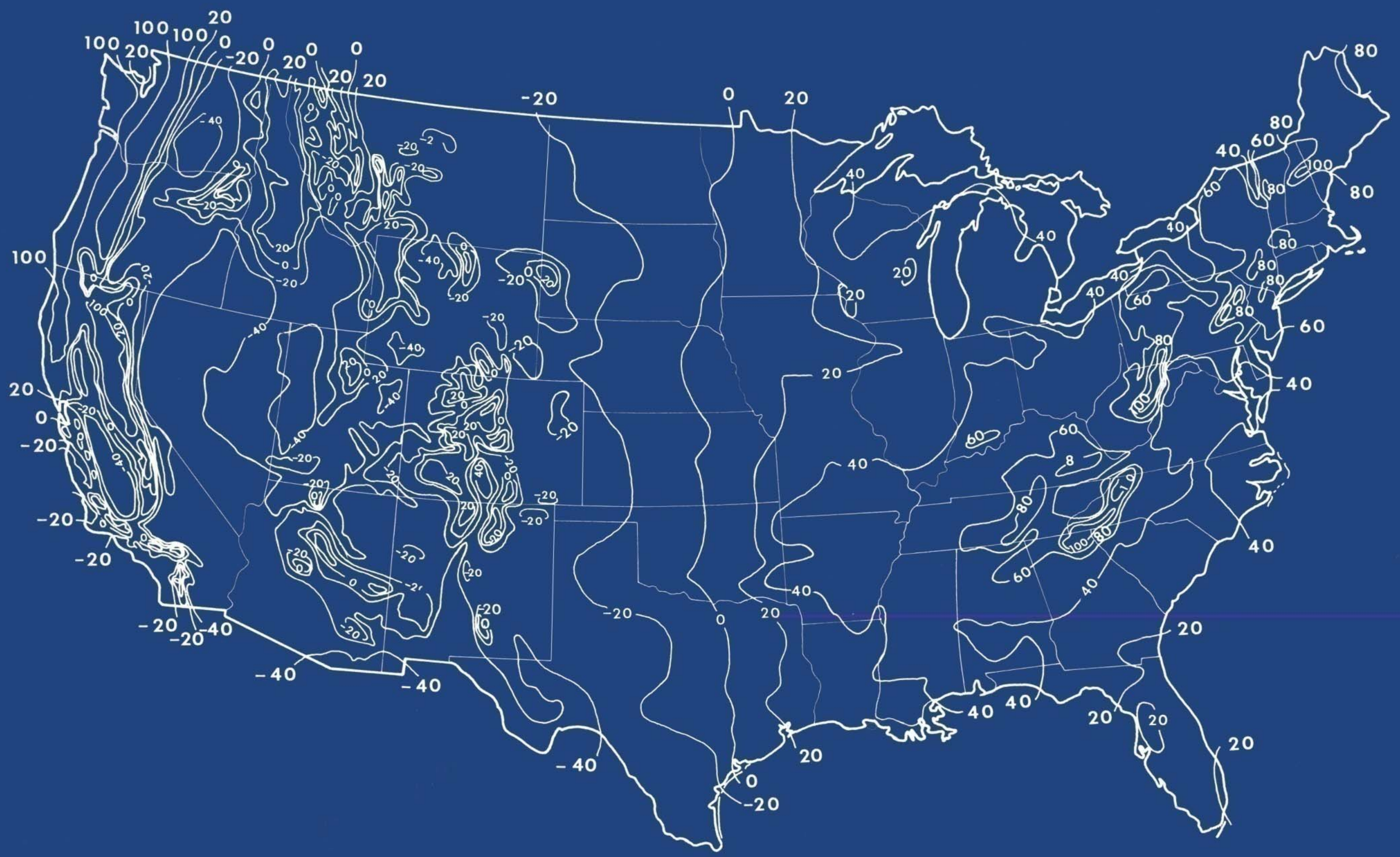
Calculate Weighted Suction Compression Index

For layered soil profiles - $(\gamma_h)_{weighted}$ to be calculated per the following equation:

$$(\gamma_h)_{weighted} = (\Sigma F_i \times D_i \times \gamma_{hi}) / (\Sigma F_i \times D_i)$$



y_m Step 7 –
Determine Thornthwaite Moisture Index (I_m)

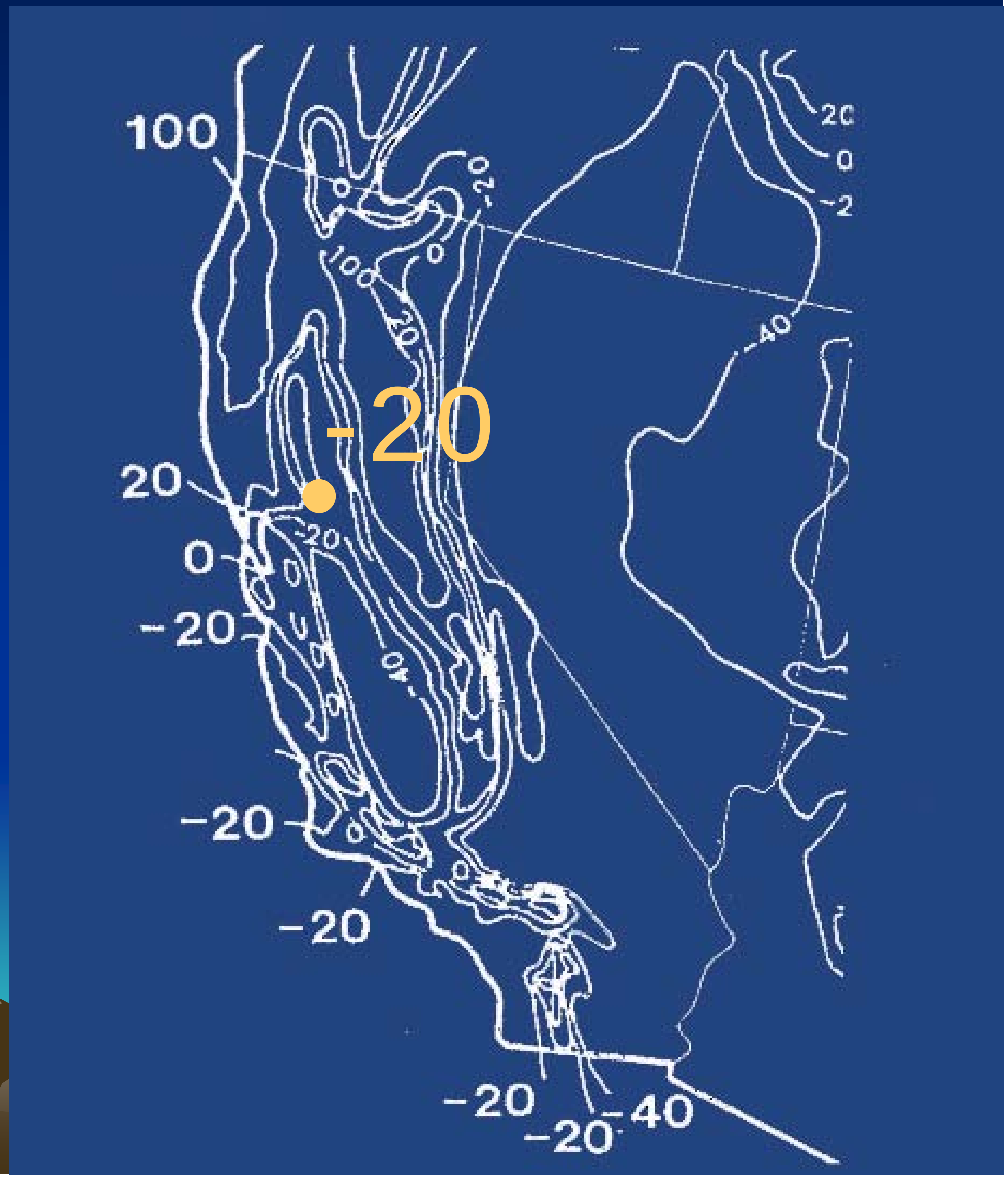


y_m Step 7 –

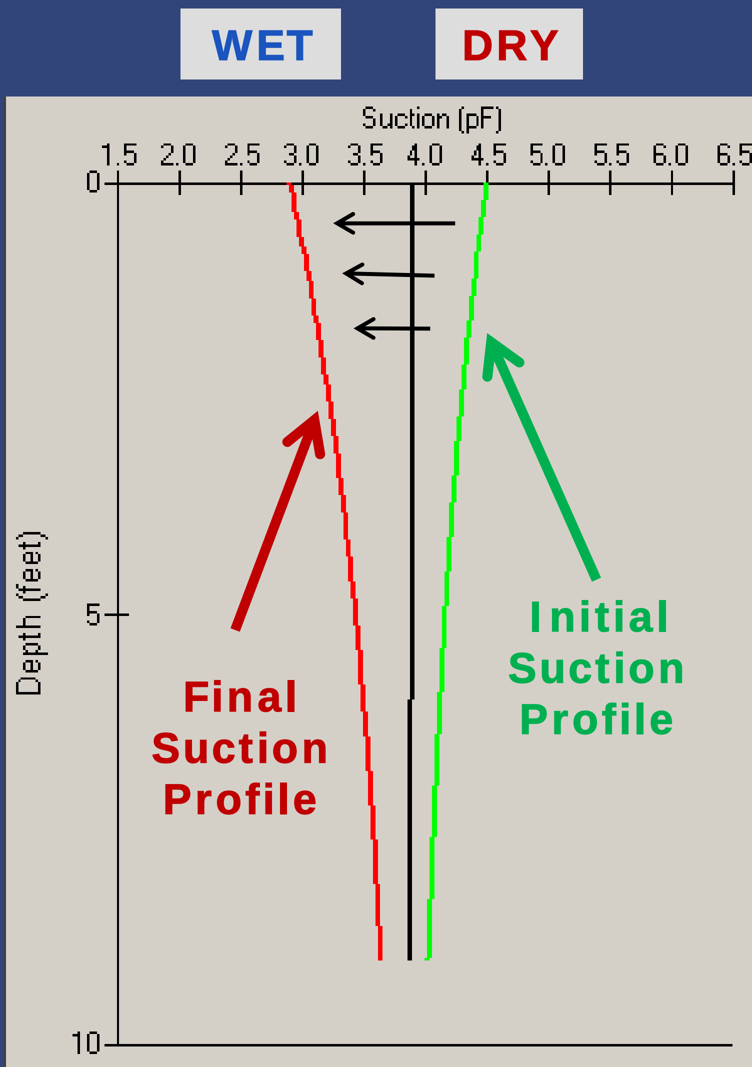
Determine Thornthwaite Moisture Index (I_m)

Sacramento, California

I_m = -20



y_m Step 8 – Develop Suction Envelopes



- A Suction Envelope consists of an Initial Suction Profile and a Final Suction Profile between which the actual field suction is expected to change.
- The suction profiles do not represent the actual field suction but the boundary condition which the suction is not expected to go beyond.
- A suction change from dry (higher suction) to wet (lower suction) results in swell ($y_{m\ edge}$).
- A suction change from wet (lower suction) to dry (higher suction) results in shrink ($y_{m\ center}$).

y_m Step 8 –
Develop Suction Envelopes

The Suction Profiles (initial or final) can model:

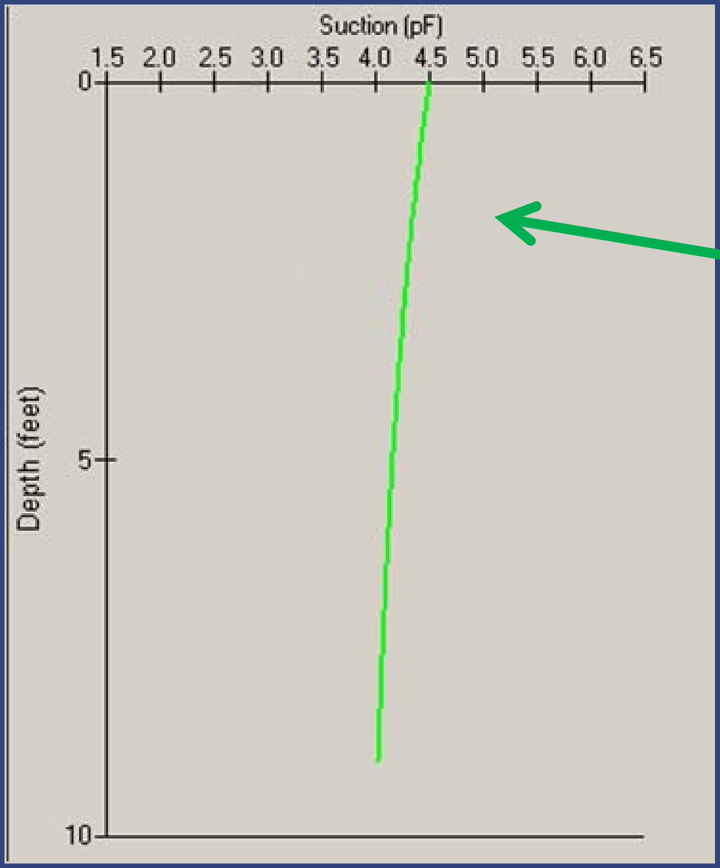
- Sites controlled by climate (precipitation, evaporation, etc.) – (typical profiles for design)
- Equilibrium condition (typical profile for design)
- Site modifications such as:
  - Moisture controlled fill pads
  - Moisture injection
- Vertical moisture barriers
- Vegetation
  - Trees
  - Flower Beds
- Poor Drainage

A Suction Envelope can consist of a combination of profiles (one for the initial profile and one for the final profile).

y_m Step 8 - Develop Suction Envelopes

The suction profile for a site controlled by climate takes the form of a "trumpet" shape based on Mitchell's suction distribution.

Typically used for design cases.

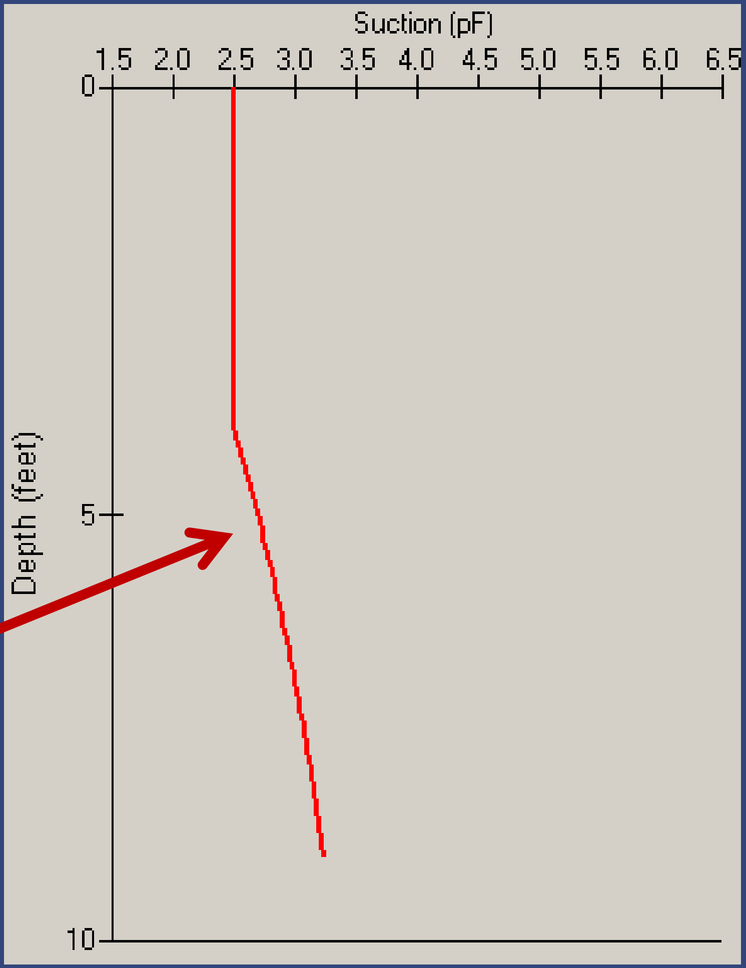


Initial Suction Profile for a site controlled by climate only

y_m Step 8 - Develop Suction Envelopes

Suction profile for “Bad Drainage”.

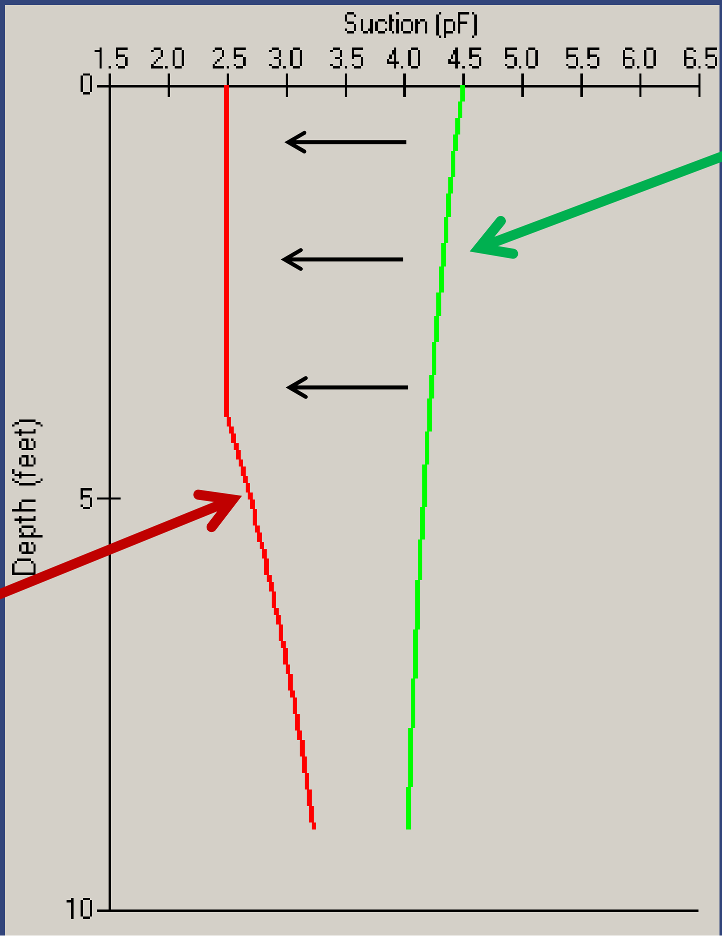
Final Suction Profile for a site controlled by “Extremely Bad Drainage“



Not typically used for design cases. Used more for analysis cases.

y_m Step 8 -
Develop Suction Envelopes

Combining the Initial Suction Profile and the Final Suction Profile results in the Suction Envelope.



Initial Suction Profile for a site controlled by climate

Final Suction Profile for a site controlled by “Extremely Bad Drainage“

Note: Not a typical Suction Envelope used for design cases.

y_m Step 8 - Develop Suction Envelopes

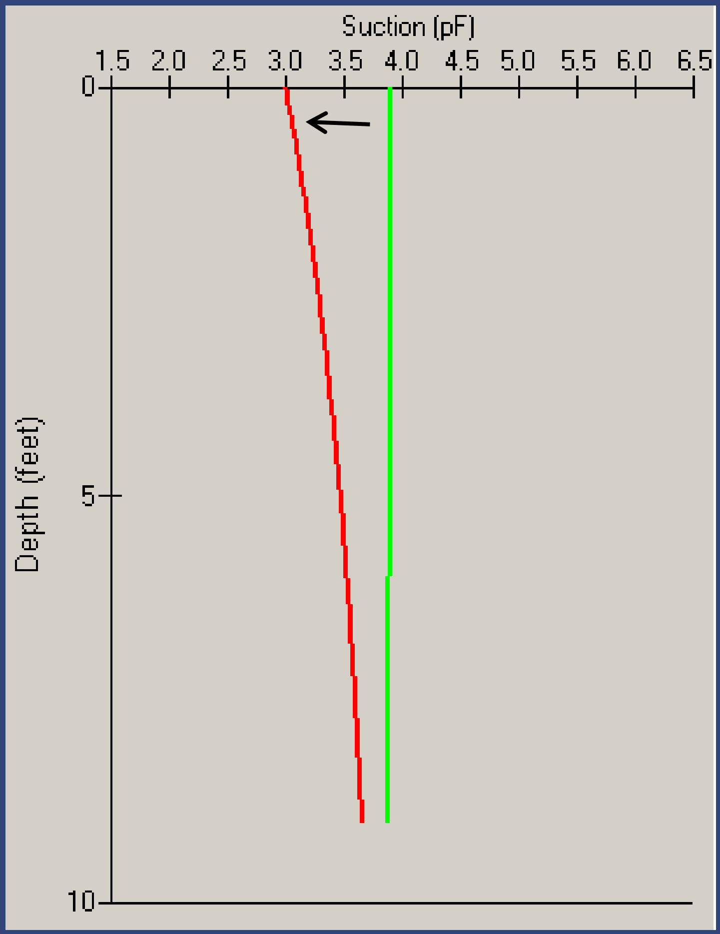
Typical Suctions Envelopes used for design

Post-Equilibrium Suction Envelopes start with an equilibrium initial suction profile and changes to either a wet or dry climate controlled final suction profile.

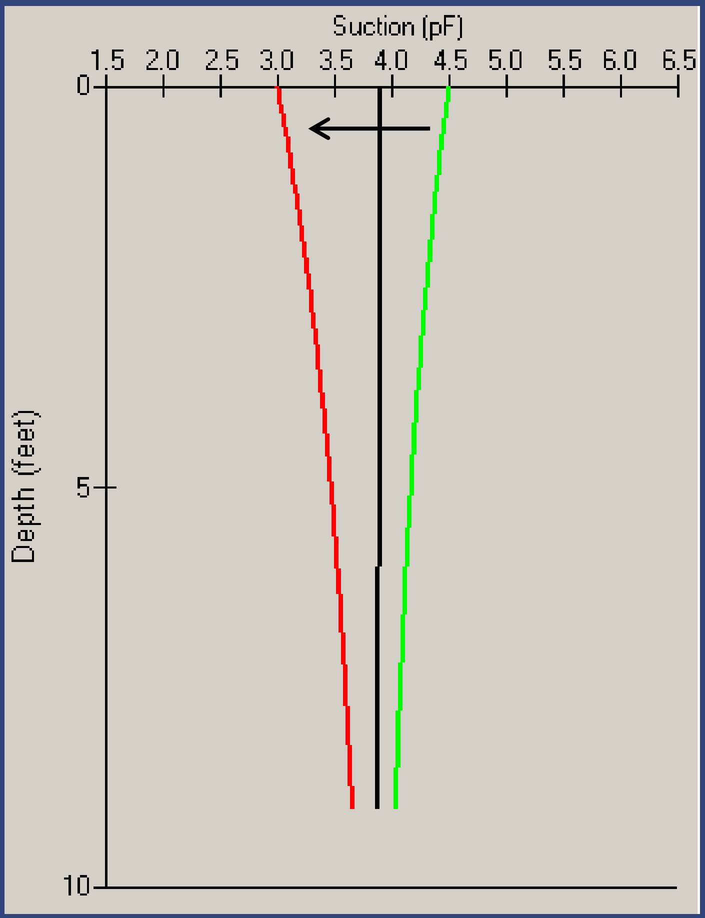
Post-Construction Suction Envelopes start with either a wet or dry climate controlled initial suction profile and changes to the opposite climate controlled suction profile.

y_m Step 8 -
Develop Suction Envelopes

Swell Case – Both envelopes start dry and end wet.



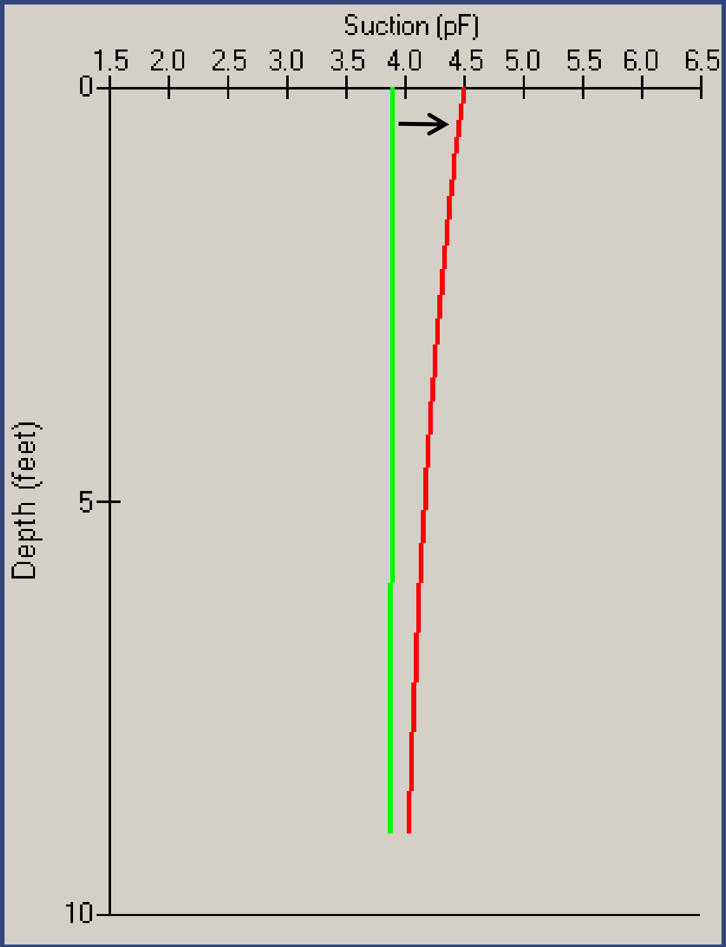
Post–Equilibrium



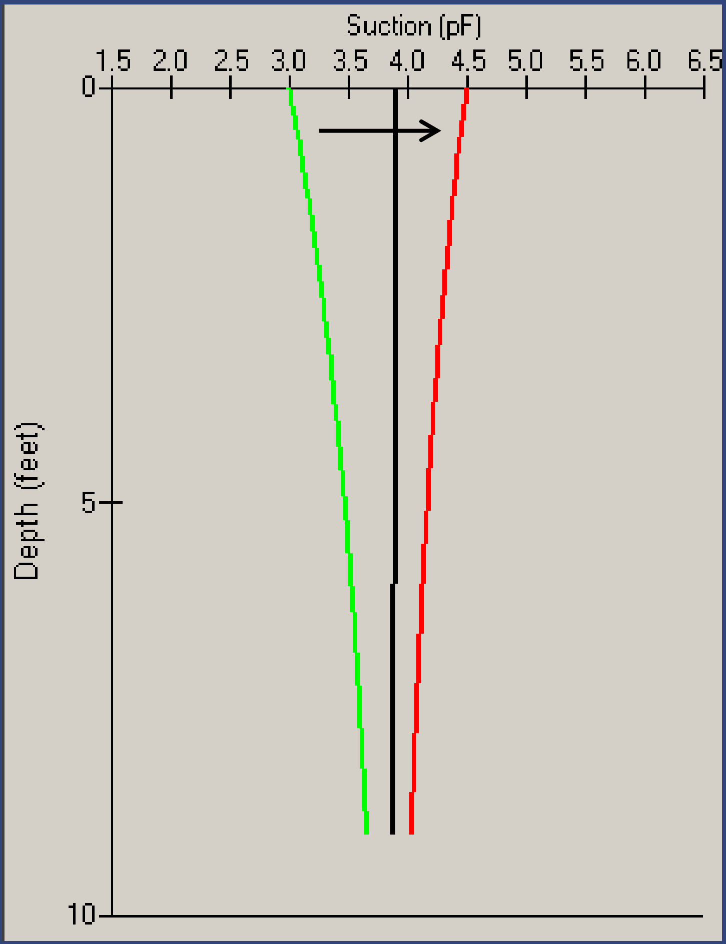
Post–Construction

y_m Step 8 - Develop Suction Envelopes

Shrink Case – Both envelopes start wet and end dry.



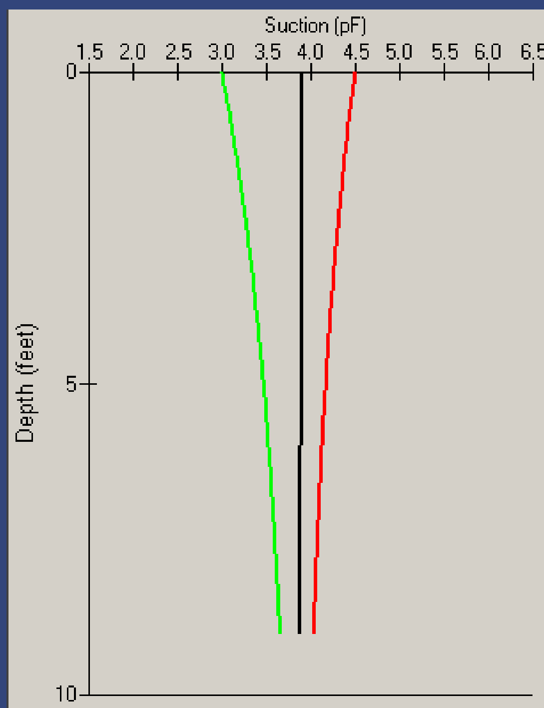
Post–Equilibrium



Post–Construction

y_m Step 8 -
Develop Suction Envelopes

The magnitude of shrink and swell is a function of the area between the two profiles.

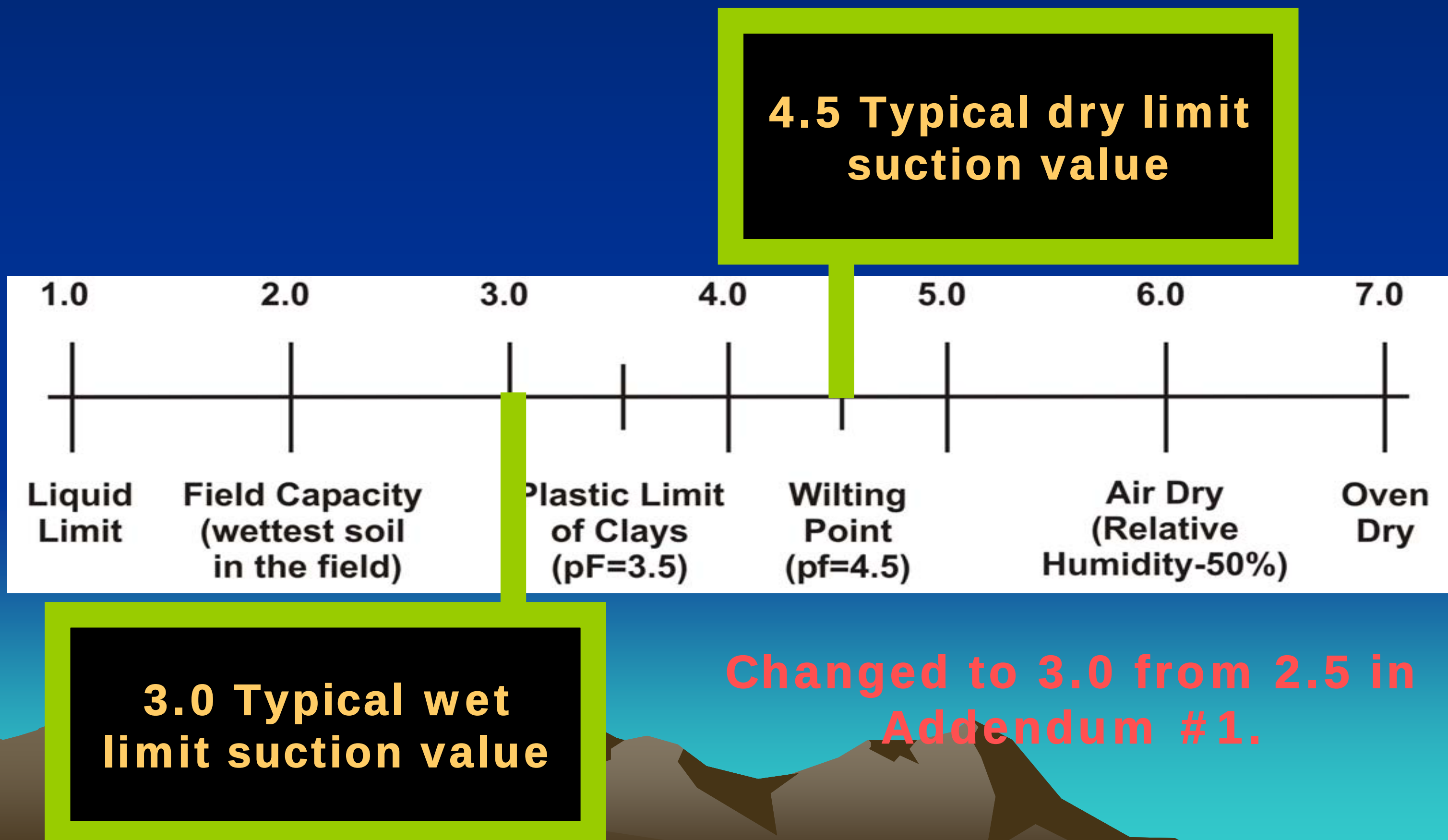


For the same soil the envelope on the right will produce significantly more shrink.

Note the right envelope is for illustration purposes only and is NOT representative of an envelope that should be used for design purposes.

y_m Step 8 –
Develop Suction Envelopes

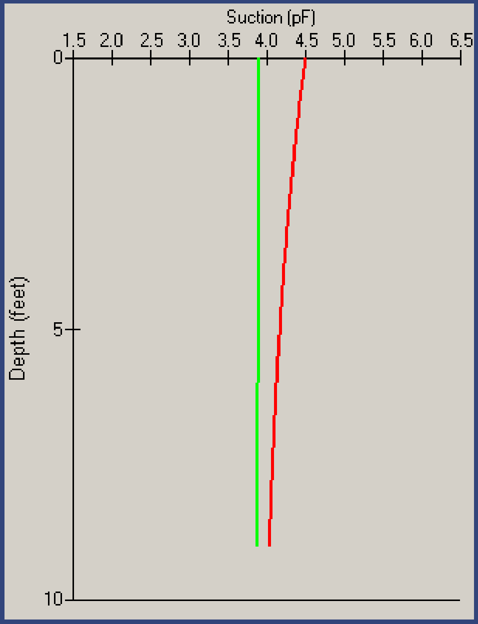
What values of the surface suction should be used for “typical” design?



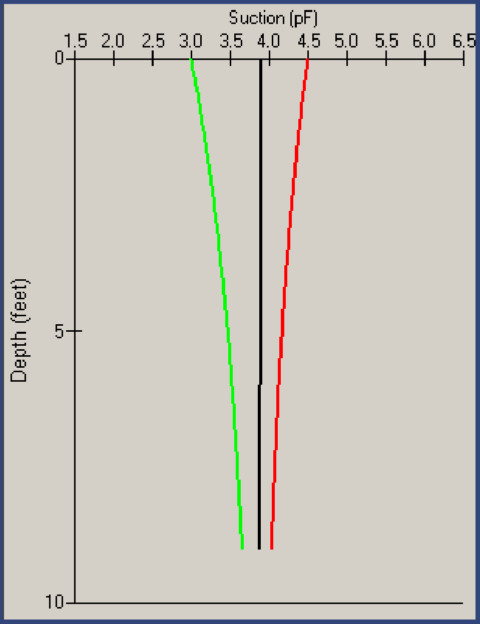
Changed to 3.0 from 2.5 in Addendum #1.

y_m Step 8 -
Develop Suction Envelopes

The magnitude of shrink and swell is a function of the area between the two profiles.



Post-Equilibrium

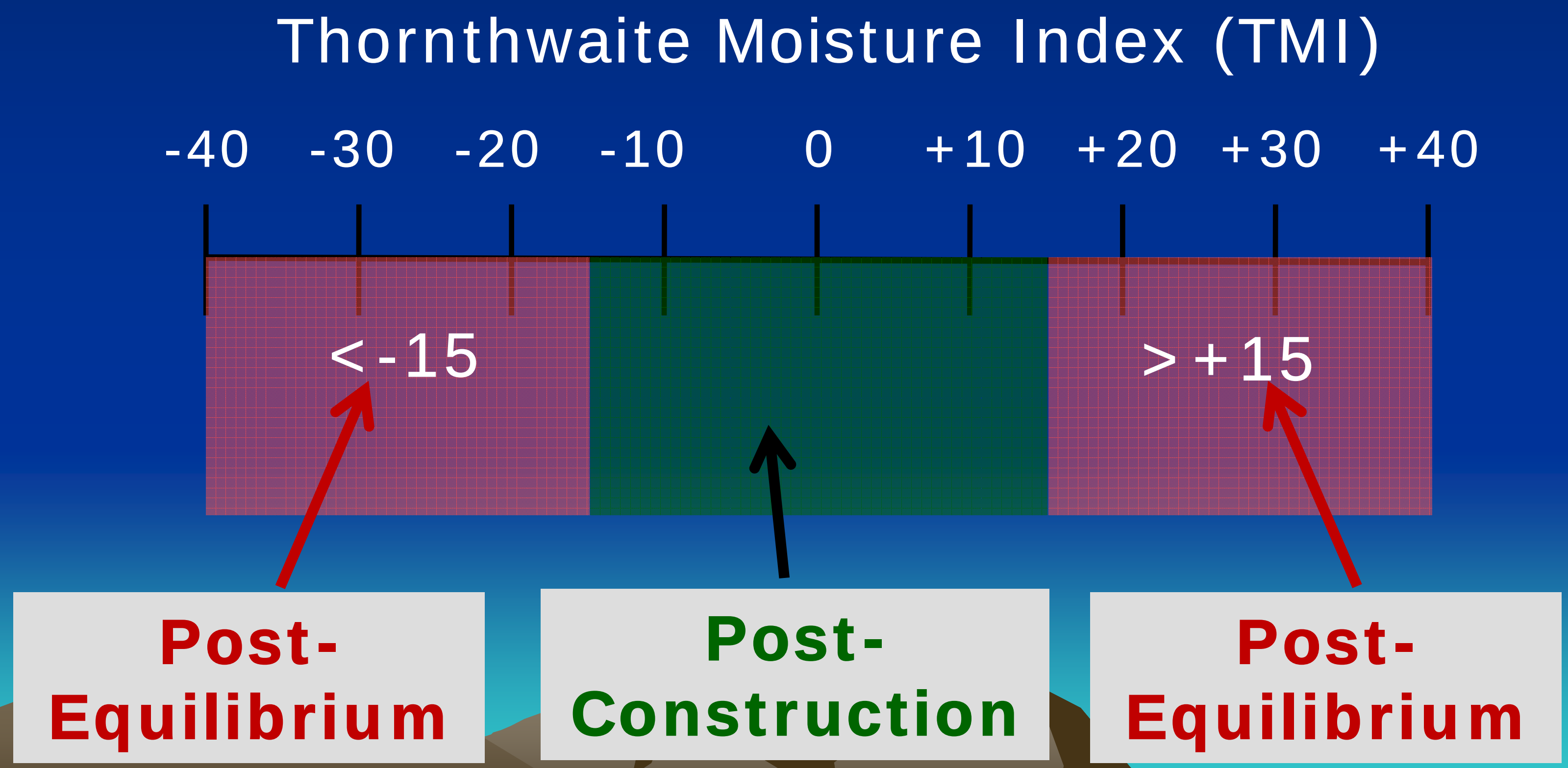


Post-Construction

For the same soil, the Post-Construction Envelope (on the right) will produce significantly more shrink than the Post-Equilibrium Envelope on the left.

y_m Step 8 – Develop Suction Envelopes

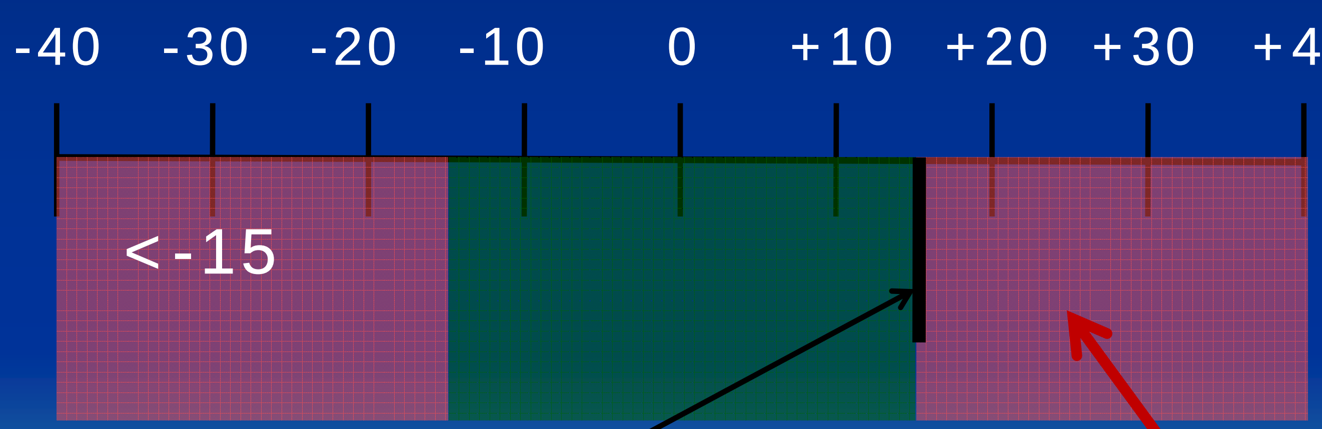
When to use Post-Equilibrium Envelopes versus Post-Construction Envelopes? (Addendum #1)



y_m Step 8 –
Develop Suction Envelopes

When to use Post-Equilibrium Model versus Post-Construction Model?
(Addendum #1)

Thornthwaite Moisture Index (TMI)



Houston, Texas (I_m = +15)

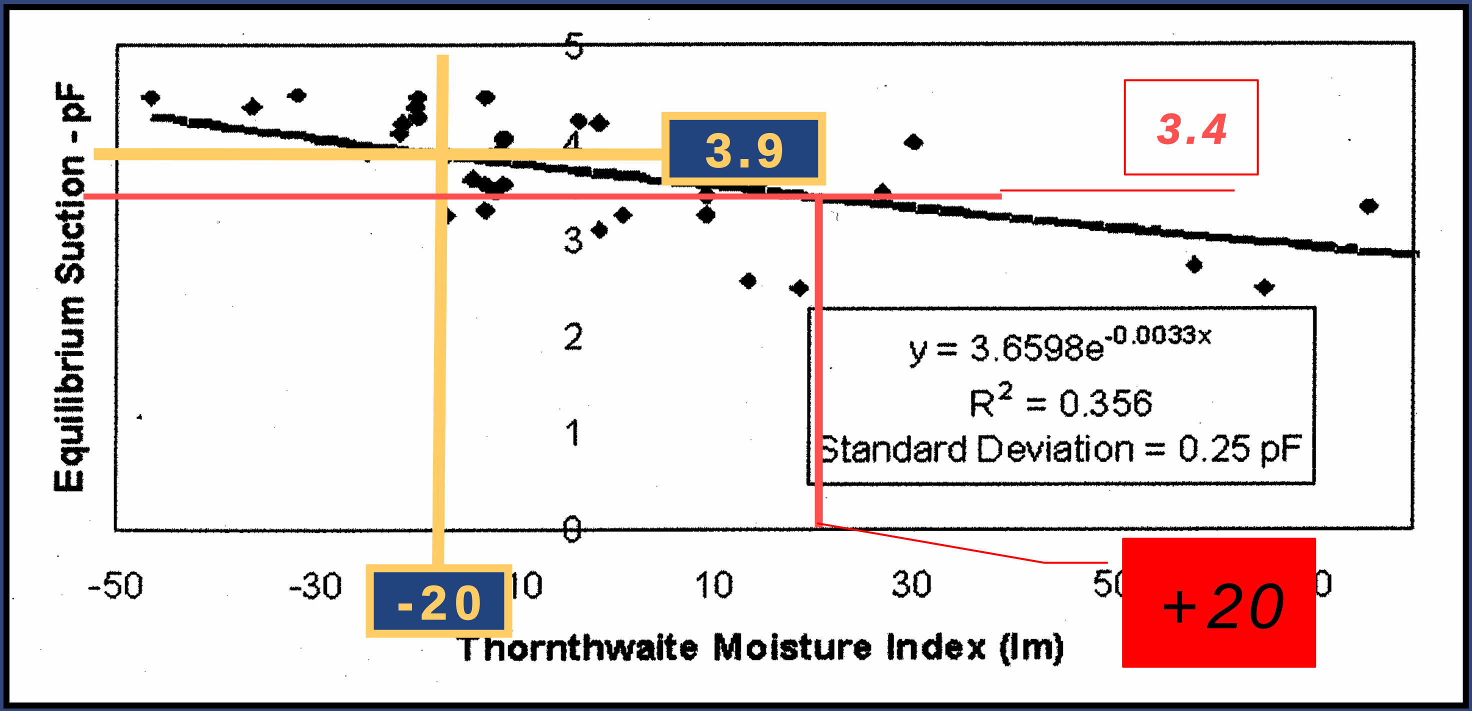
USE POST-EQUILIBRIUM MODEL

Post-Equilibrium

y_m Step 8 -
Develop Suction Envelopes

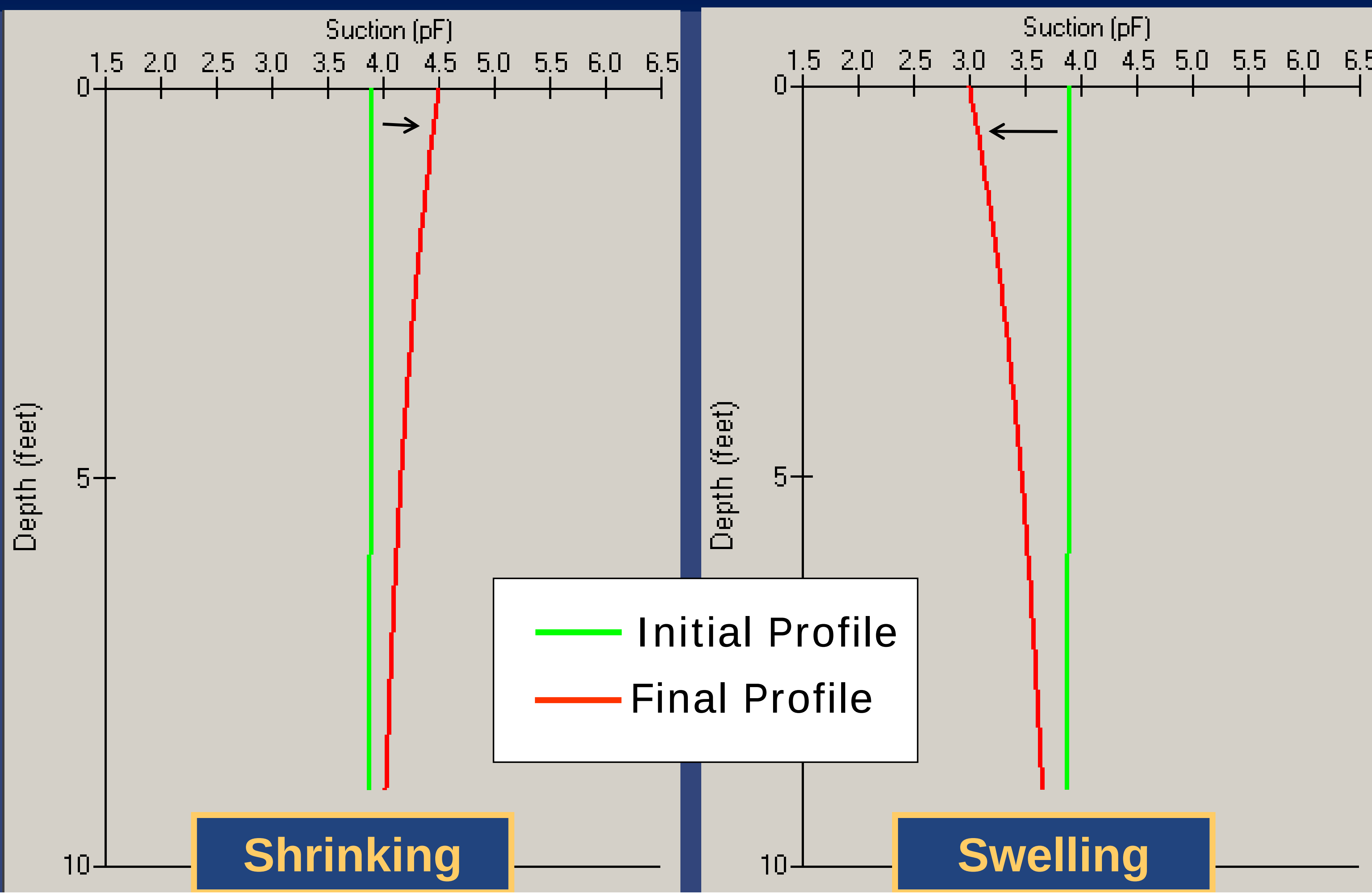
What value do I use for the Equilibrium Suction?

Equilibrium Suction may be estimated from the correlation below in the absence of local observations:



Note: Also referred to as constant suction or measured suction at depth. This figure has changed from 2nd Edition.

γ_m Step 8 – Develop Suction Envelopes



y_m Step 9 - Determine Stress Change Factors

- For Post-Equilibrium or Post-Construction envelopes use Stress Change Factor (SCF) procedure included in 3rd Edition manual. **(Post-Construction SCF table added in Addendum #1).**
- The PTI Manual includes SCF tables to use other profiles (tree, moisture barrier, flowerbed) with the equilibrium as the initial suction profile.
- Other envelopes (including those above) can be modeled using VOLFLO or other computer methods.

Post-Equilibrium Envelope
Stress Change Factor Method

- Assumes initial suction is at equilibrium.
- Assumes final suction profile is climate controlled and typical “trumpet shape”.
- Assumes Depth to Constant Suction is 9ft.
- Possibly Over- or Under- conservative for soil profiles with multiple layers where γ_h varies significantly (See PTI 3.6.3).

Post-Construction Envelope Stress Change Factor Method

- **Added in Addendum #1.**

- Assumes initial and final suction profiles are climate controlled and typical “trumpet shape”.

- Assumes Depth to Constant Suction is 9ft.

- Possibly Over- or Under- conservative for soil profiles with multiple layers where γ_h varies significantly (See PTI 3.6.3).

y_m Step 9 - Determine Stress Change Factors

Table 3.2a Stress Change Factor (*SCF*) for Use in Determining y_m - Post-Equilibrium Case

Measured Suction (*pF*) at Depth z_m	Final Controlling Suction At Surface, *pF*						
	2.5	2.7	3.0	3.5	4.0	4.2	4.5
2.7	+3.2	0	-4.1	-13.6	-25.7	-31.3	-40.0
3.0	+9.6	+5.1	0	-7.5	-18.2	-23.1	-31.3
3.3	+17.7	+12.1	+5.1	-2.6	-11.5	-15.8	-23.1
3.6	+27.1	+20.7	+12.1	+1.6	-5.7	-9.4	-15.8
3.9	+38.1	+30.8	+20.7	+7.3	-1.3	-4.1	-9.4
4.2	+50.4	+42.1	+30.8	+14.8	+3.2	0	-4.1
4.5	+63.6	+54.7	+42.1	+23.9	+9.6	+5.1	0

$SCF_{shrinking} = -9.4$

$SCF_{swelling} = +20.7$

y_m Step 10 – Calculate y_m

- $y_{m\ Center} = \gamma_{h\ shrinking} \times SCF_{shrinking}$
- $y_{m\ Center} = 0.050 \times 9.4$
- $y_{m\ Center}$ = 0.47 inches (Use 0.5 inches)

- $y_{m\ Edge} = \gamma_{h\ swelling} \times SCF_{swelling}$
- $y_{m\ Edge} = 0.056 \times 20.7$
- $y_{m\ Edge}$ = 1.16 inches (Use 1.2 inches)

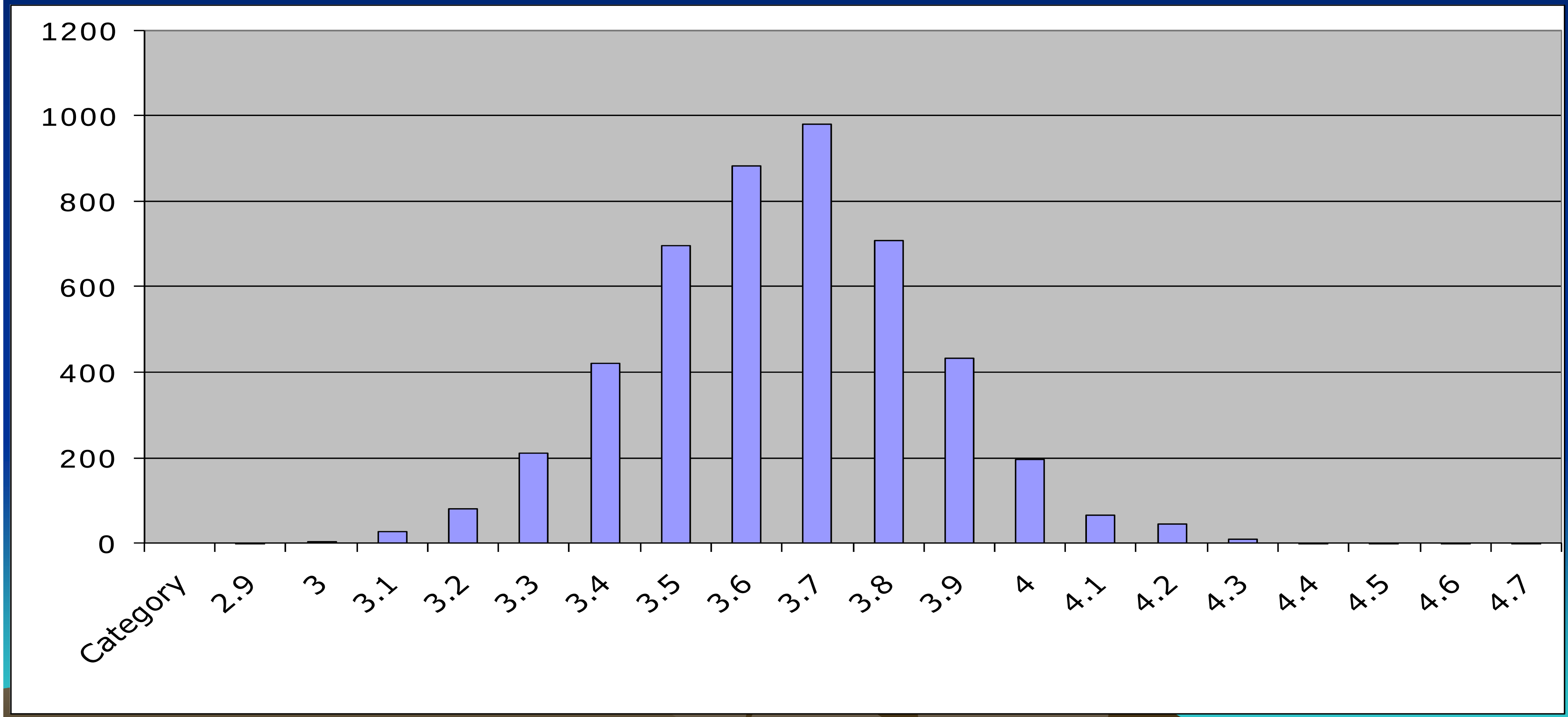
Recommended Suction Change Range for Design

- Addendum 1 Section 3.6.3, typical range is 1.5 pF for most conditions
- Typical versus Extreme Values

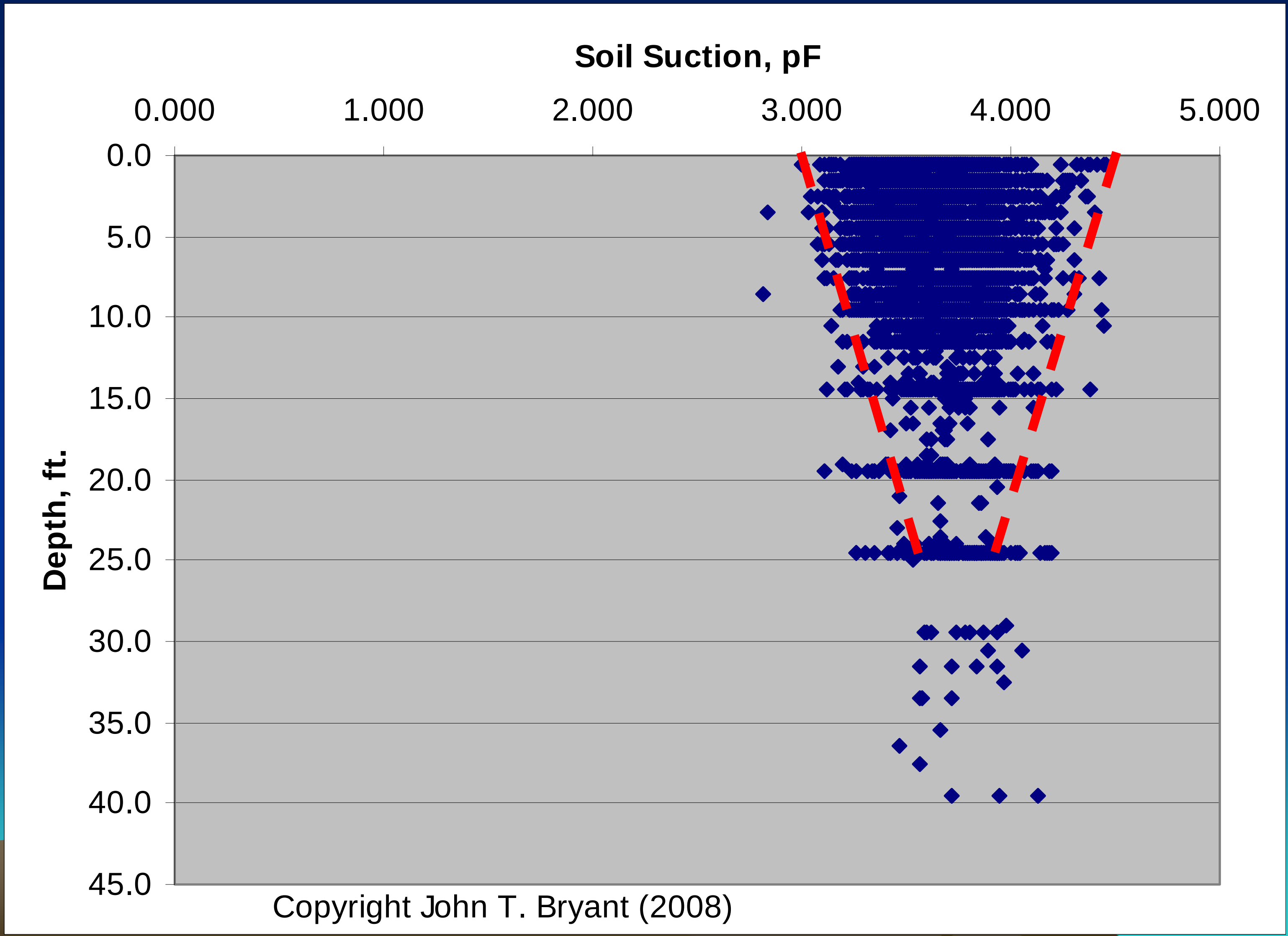
Suction in pF units	Wet	Dry
Typical (well drained)	3.0	4.5
Extreme	2.5	6.0

Reasonable Suction Change Range

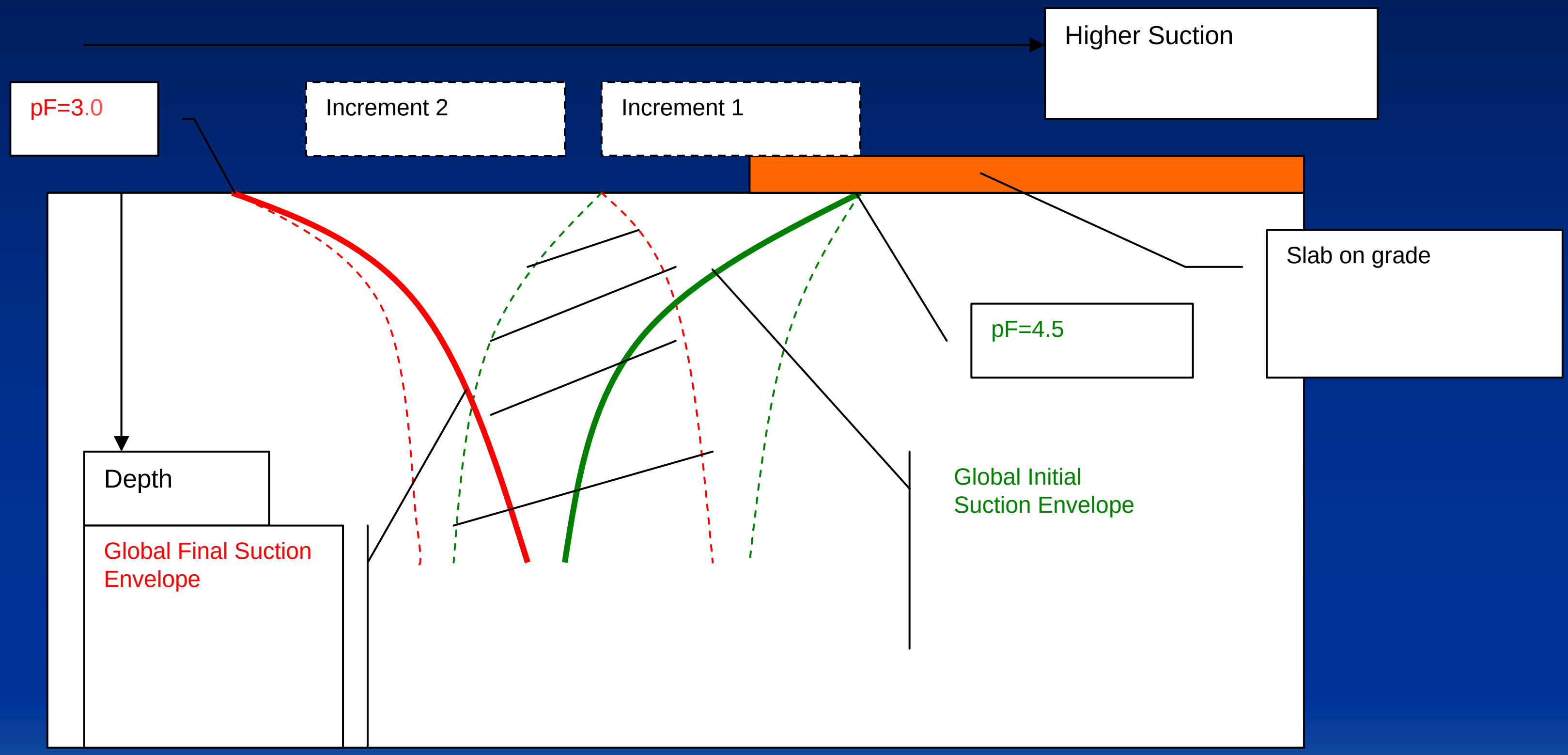
- 2003 TOTAL SOIL SUCTION DATA (4776 OBSERVATIONS)



Empirically Measured Suctions BCI 2002 to 2008 = 26,000+ Data Points

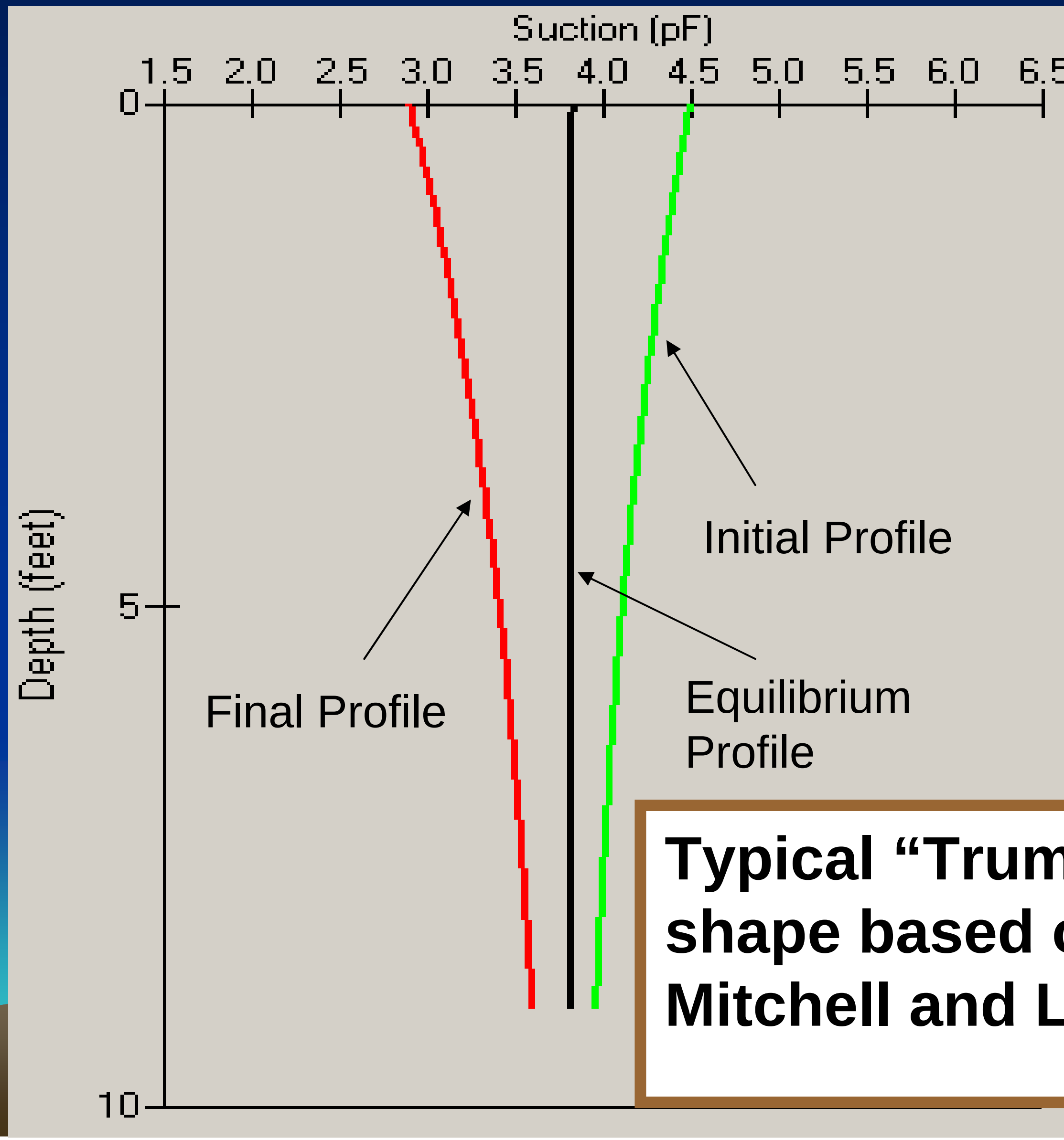


Global vs. Incremental Suction Change ym Analysis



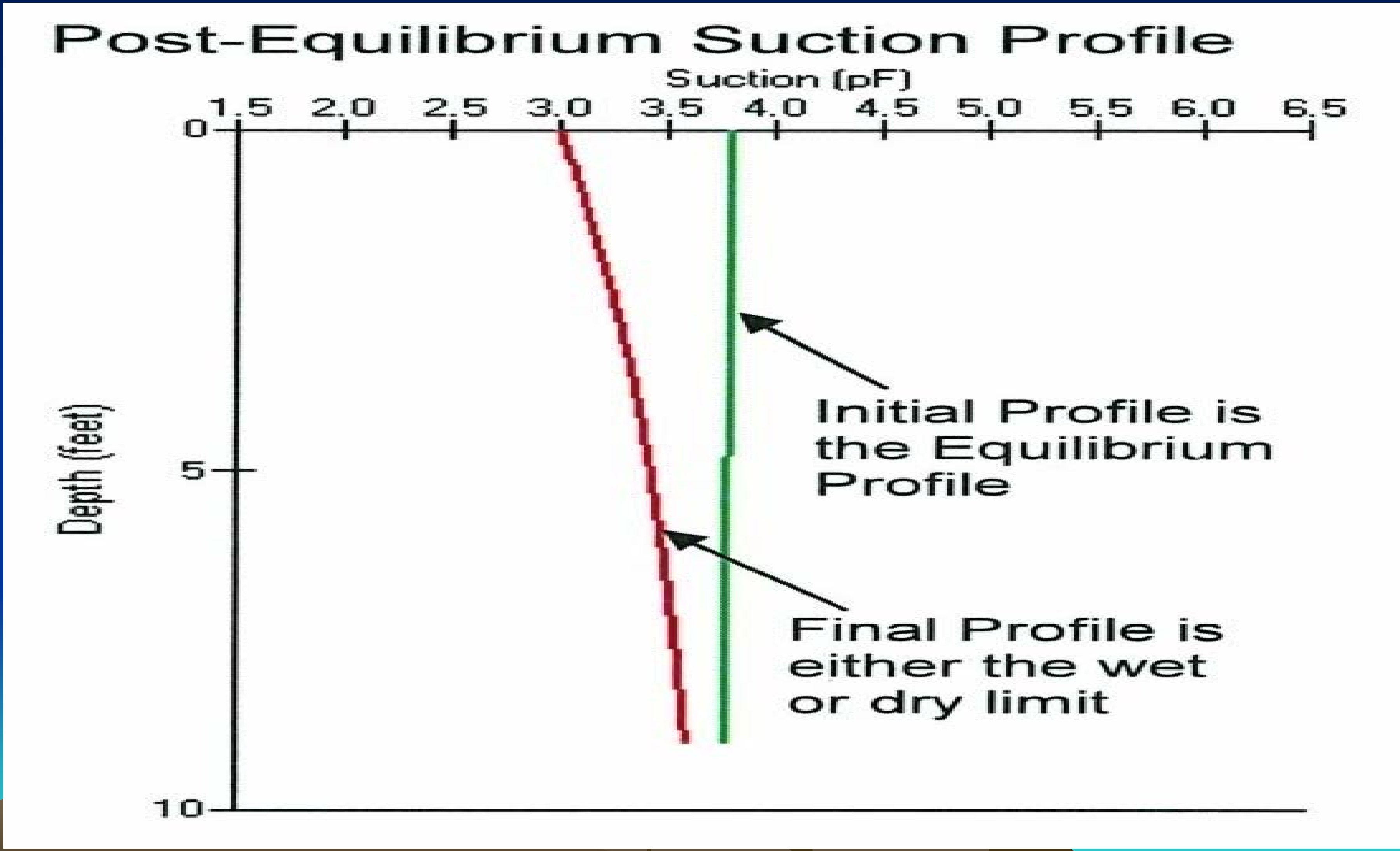
Unsaturated Soil Mechanics

Typical Suction Envelope

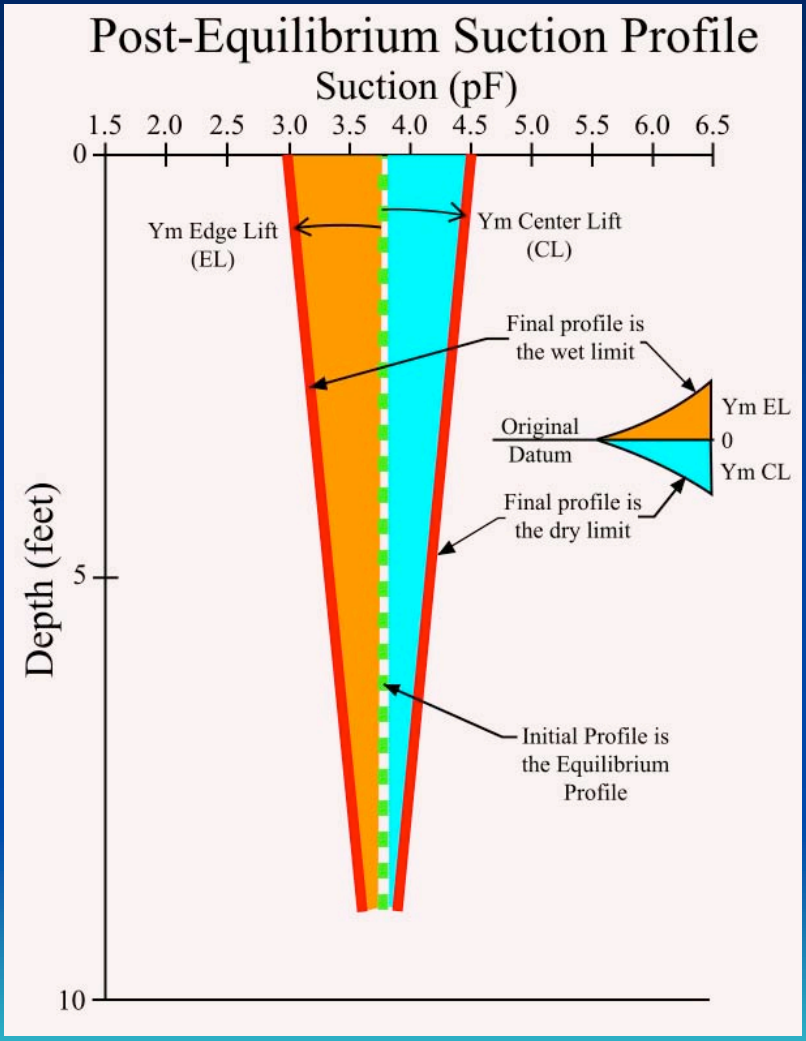


Typical "Trumpet" shape based on Mitchell and Lytton.

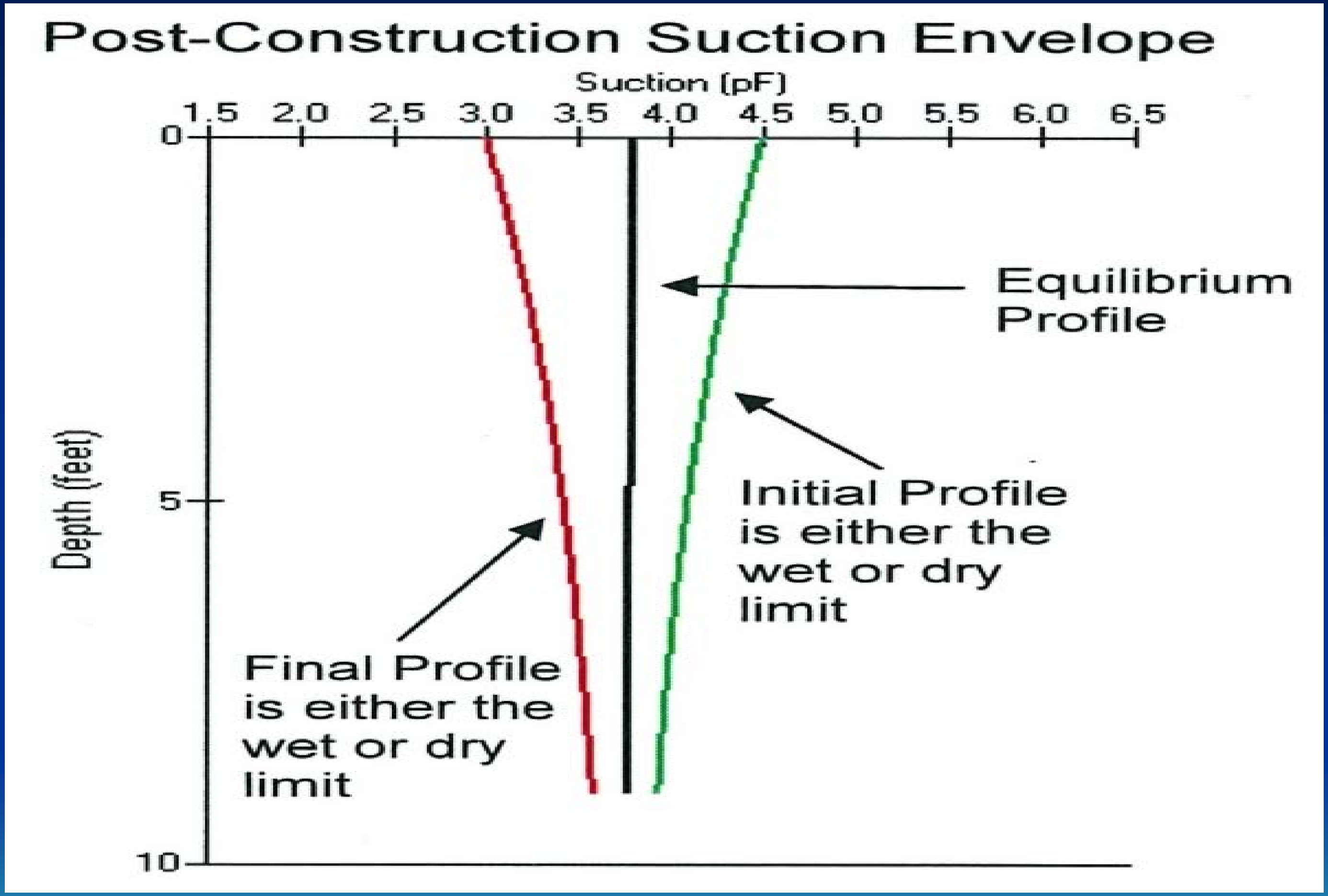
Post Equilibrium



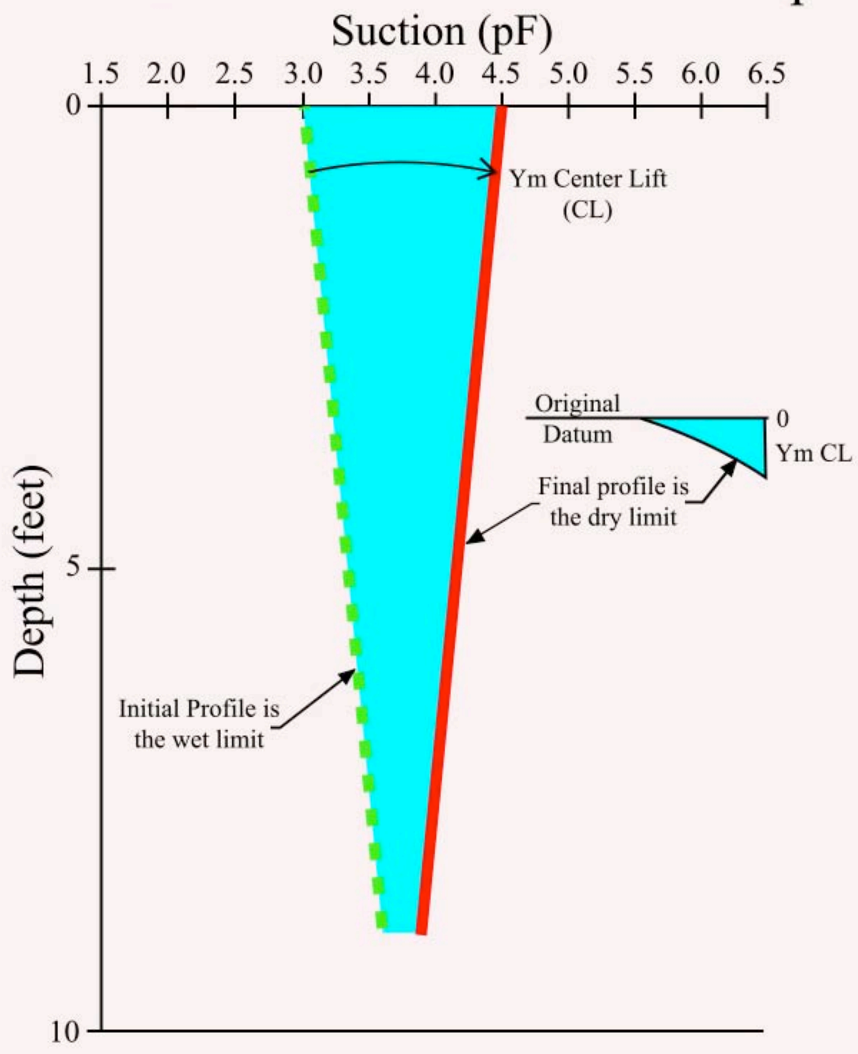
Post Equilibrium



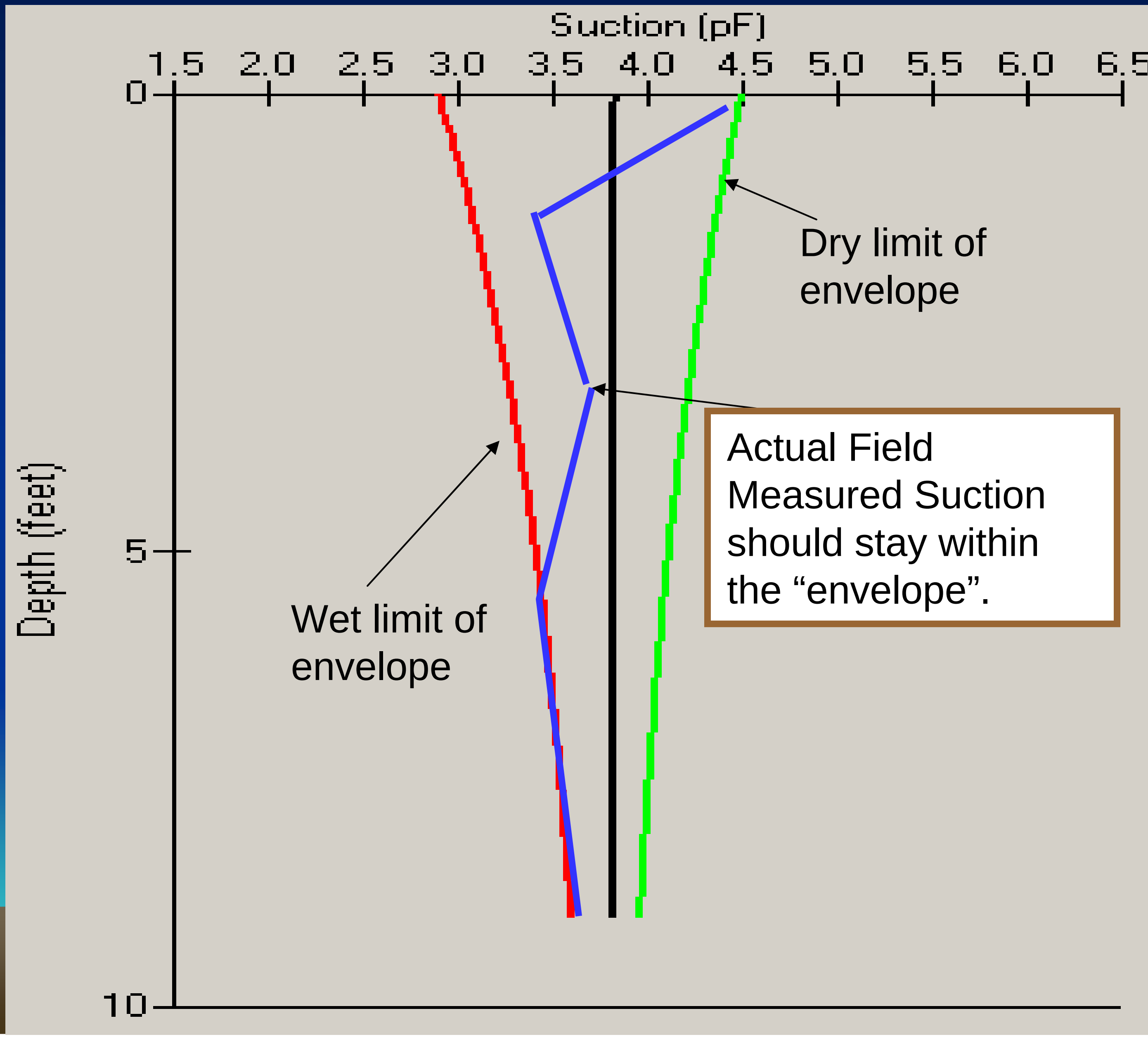
Post Construction



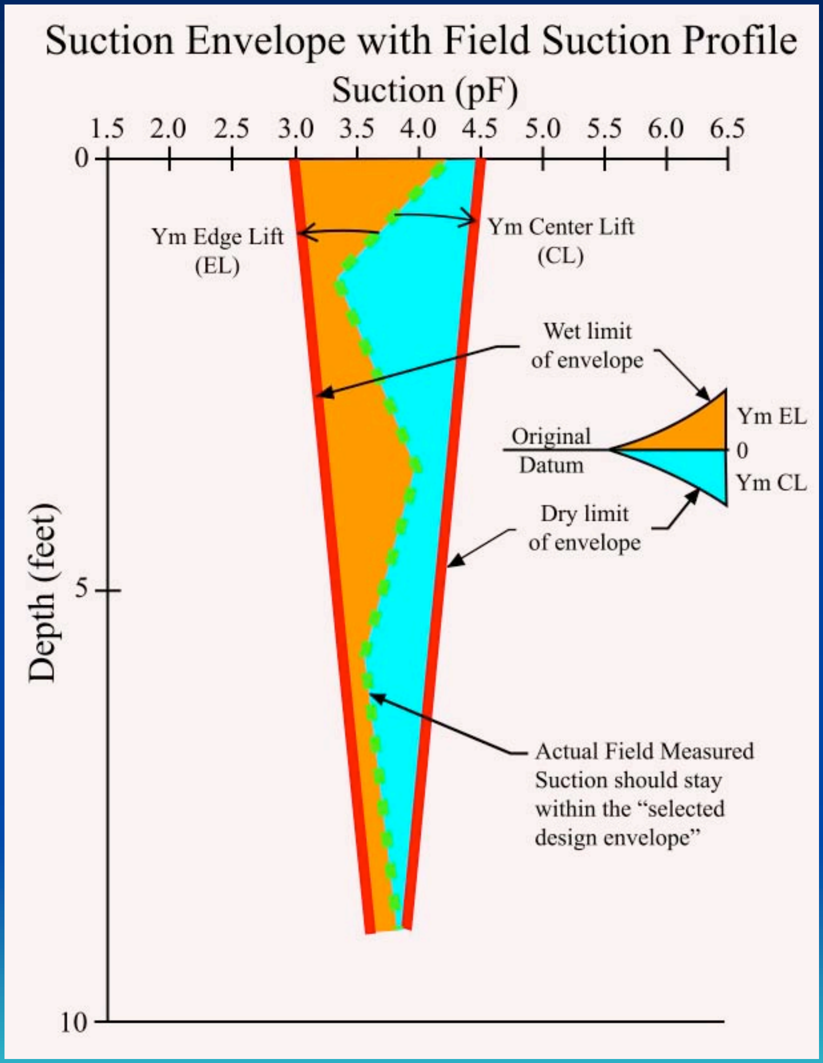
Post-Construction Suction Envelope



Suction Envelope



Field Suction Envelopes



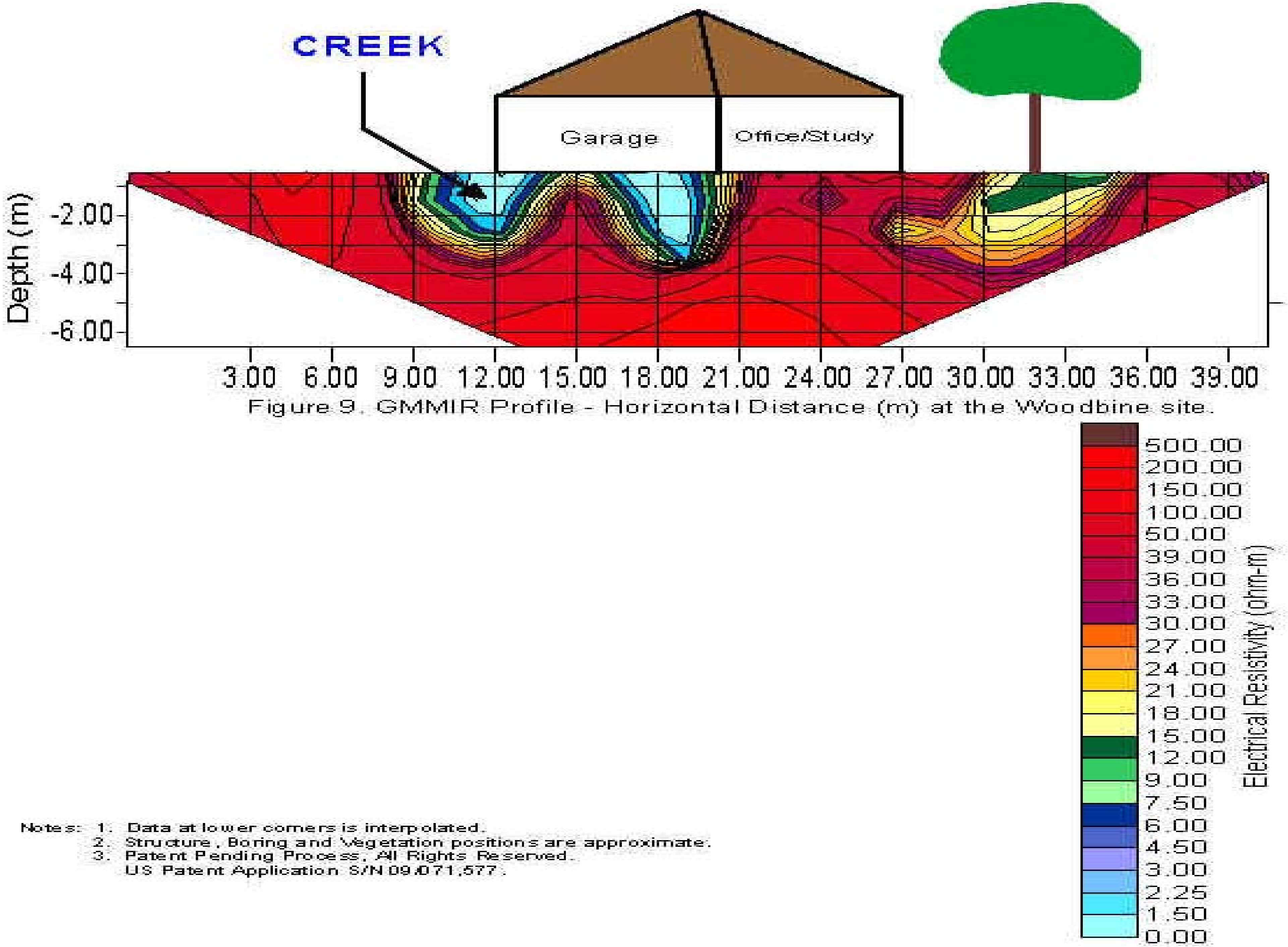
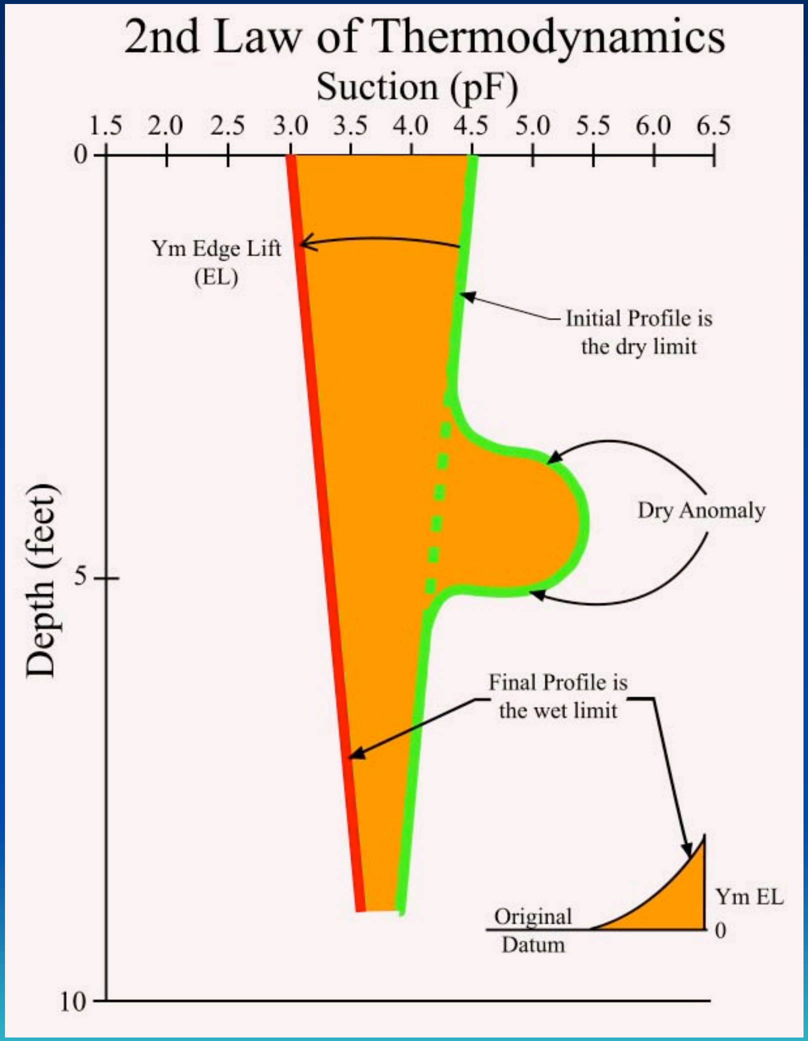


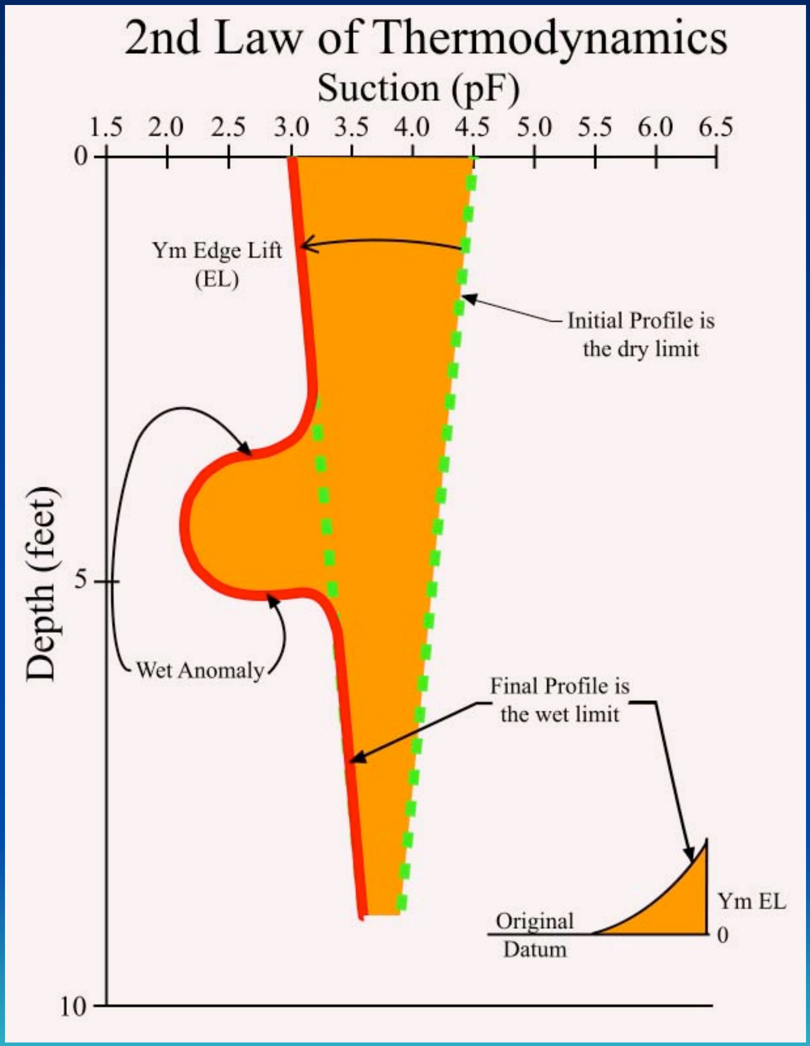
Figure 9. GMMIR Profile - Horizontal Distance (m) at the Woodbine site.

Notes: 1. Data at lower corners is interpolated.
2. Structure, Boring and Vegetation positions are approximate.
3. Patent Pending Process, All Rights Reserved.
US Patent Application S/N 09/071,577.

Anomalous Suction Envelopes

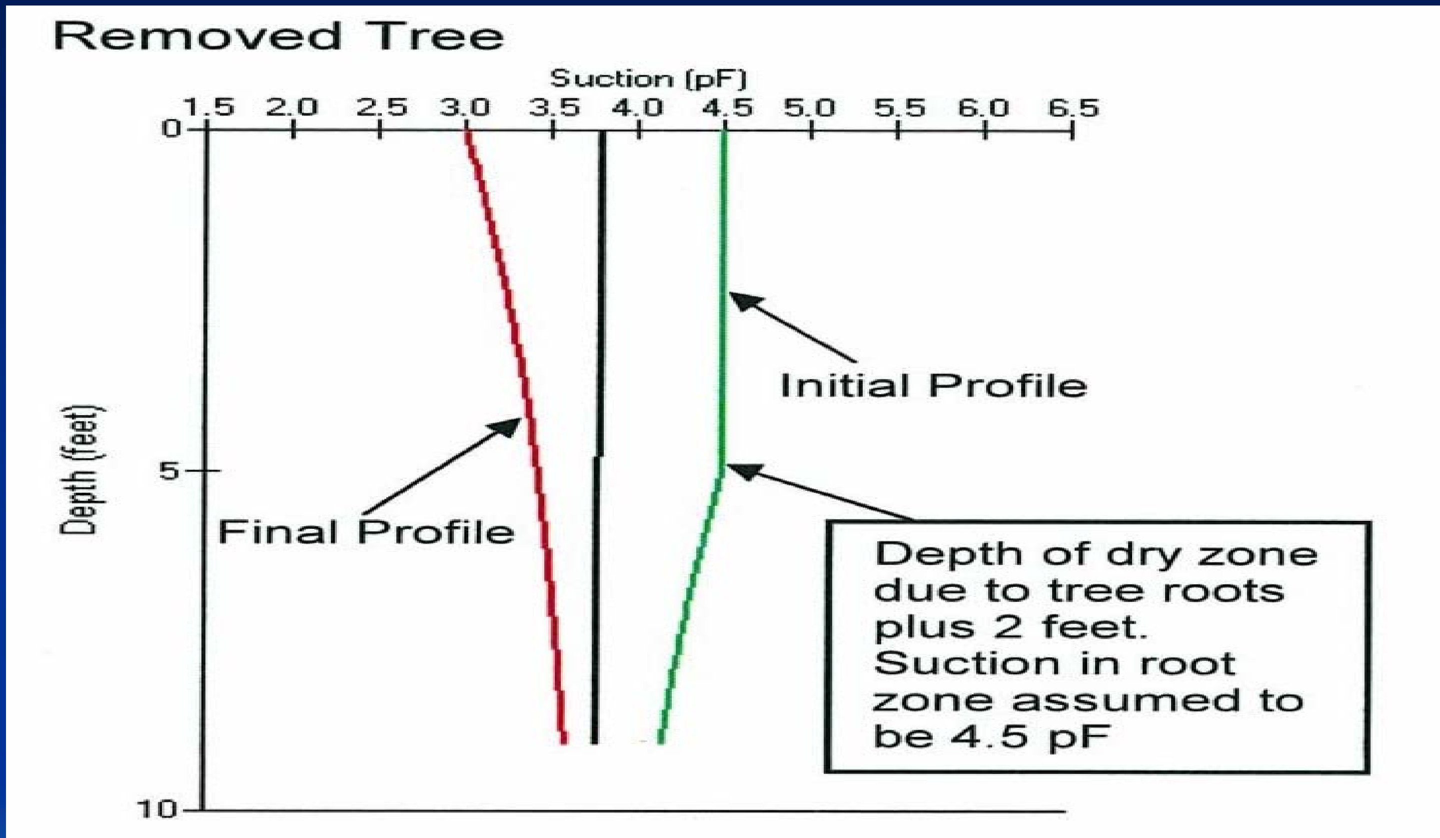


Anomalous Suction Envelopes

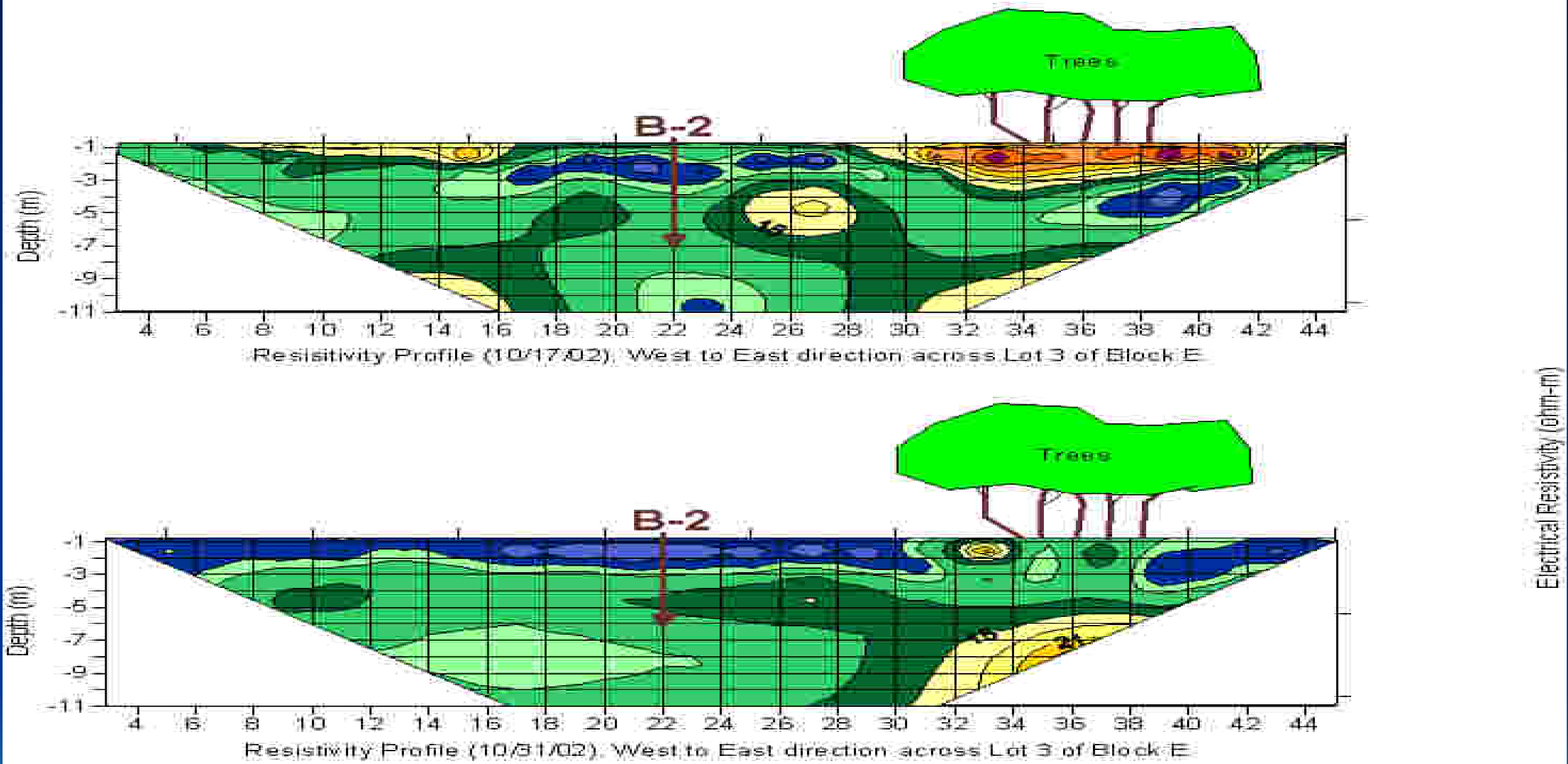


Unsaturated Soil Mechanics

Removed Tree Envelope



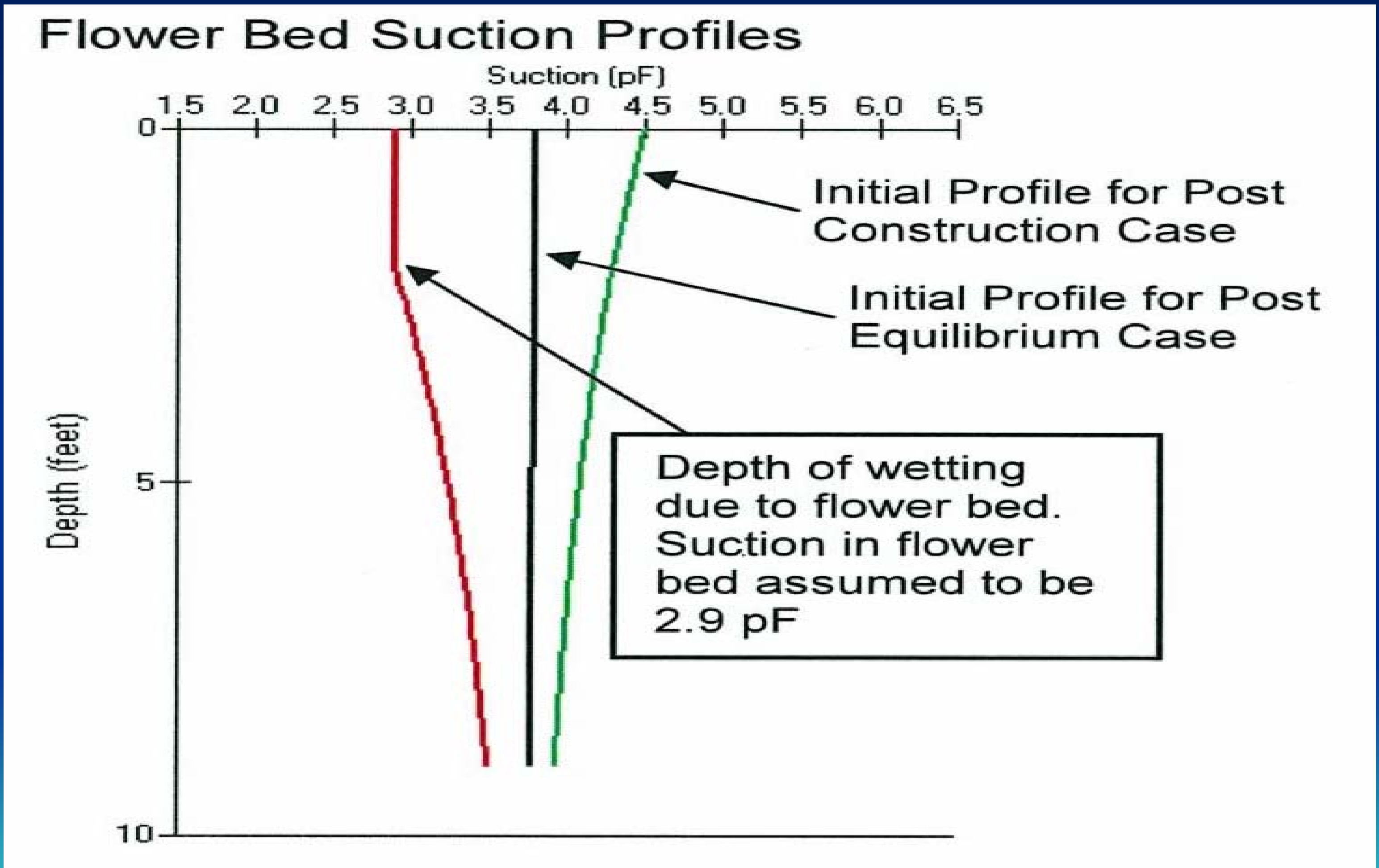
The influence of Trees and effects of a significant rainfall event on a particular lot.



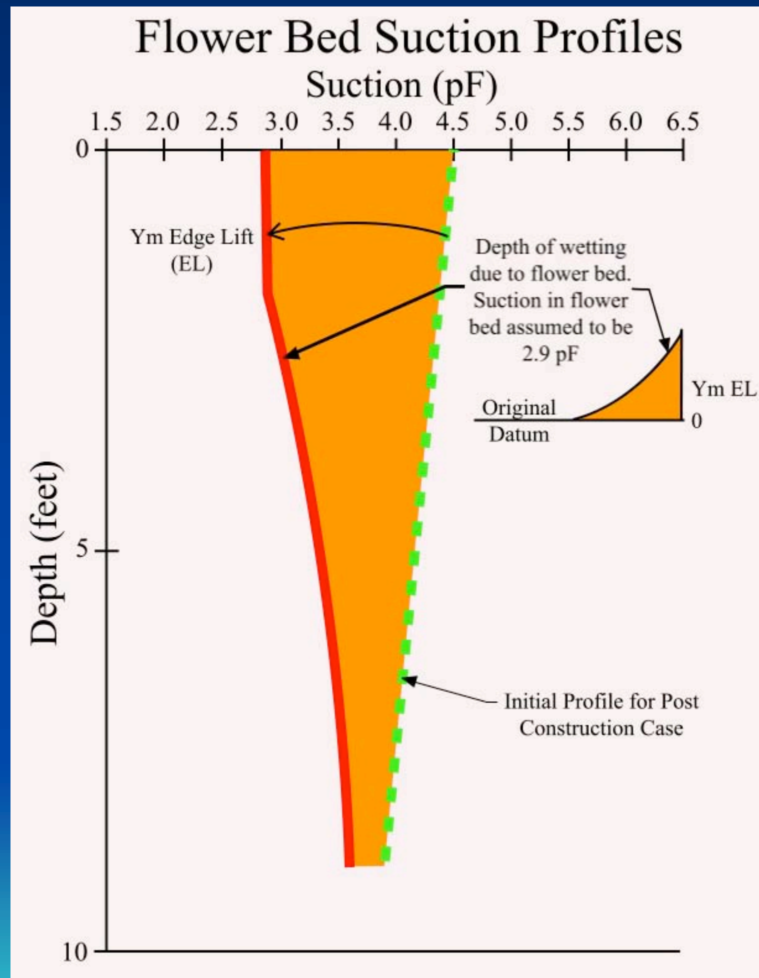
Notes: 1. Data at lower corners is interpolated.
2. Structure, Boring and Vegetation positions are approximate.
3. Patent Process. All Rights Reserved.
US Patent S/N 6,295,512

Unsaturated Soil Mechanics

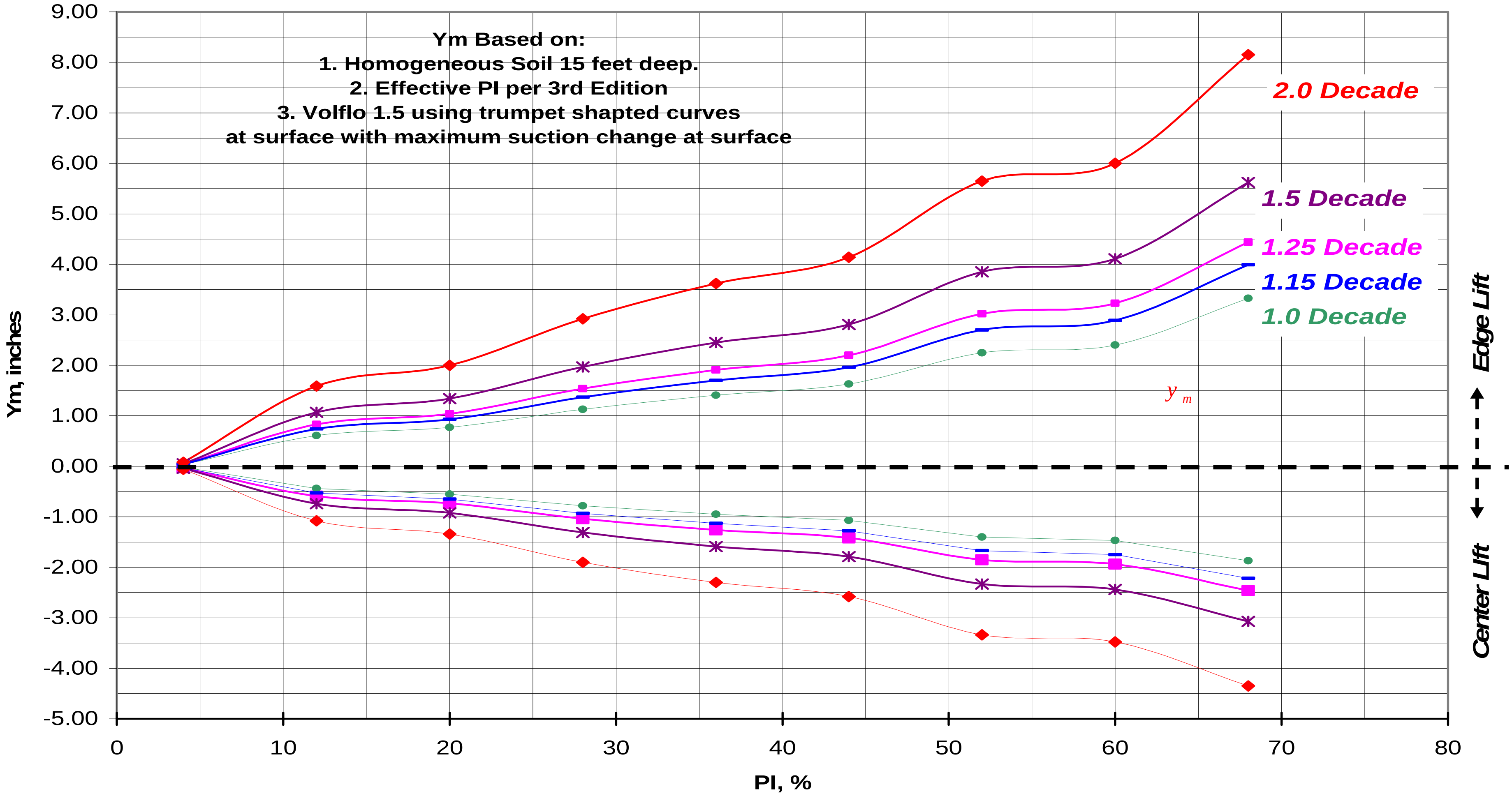
Flower Bed Envelope



Flower Bed Envelope



Ym values as a function of PI



Example of e_m Determination

Steps to determine e_m

- Step 1 – Calculate S_s
- Step 2 – Calculate Unsaturated Diffusion Coefficient (α)
  - 2a – Calculate Modified Unsaturated Diffusion Coefficient (α')
  - 2b – Calculate Weighted Modified Unsaturated Diffusion Coefficient (weighted α')
- Step 3 – Determine e_m

e_m Step 1 – Calculate S_s

- S_s is the slope of the suction vs. gravimetric water content curve.

- Can be determined from soil-water characteristic curve or be estimated with the following equation.

$$S_s = -20.29 + 0.1555\,LL - 0.117\,PI + 0.0684\,(\%\text{-}\#200)$$

$$S_s = -20.29 + 0.1555(55) - 0.117(27) + 0.0684(79)$$

$$S_s = -9.5$$

e_m Step 2 –
Calculate Unsaturated Diffusion Coefficient

The Unsaturated Diffusion Coefficient (α) for shrinking and swelling can be estimated with the following equations (based on field observations):

$$\alpha_{shrinking} = 0.0029 - 0.000162(S_s) - 0.0122(\gamma_{h\ shrinking})$$

$$\alpha_{shrinking} = 0.0029 - 0.000162(-9.5) - 0.0122(0.050)$$

$$\alpha_{shrinking} = 0.0038$$

$$\alpha_{swelling} = 0.0029 - 0.000162(S_s) - 0.0122(\gamma_{h\ swelling})$$

$$\alpha_{swelling} = 0.0029 - 0.000162(-9.5) - 0.0122(0.056)$$

$$\alpha_{swelling} = 0.0038$$

e_m Step 2a –

Calculate Modified Unsaturated Diffusion Coefficient

$$\alpha' = \alpha\,(F_f)$$

Condition		Ff
Non CH Soils		1.0
CH Soils	Profiles with 1 root, crack, sand/silt seam all less than or equal to 1/8" width/dimension in any combination	1.0
	Profile with 2 to 4 roots, cracks, sand/silt seams all larger than 1/8" width/dimension in any combination	1.1
	Profile with more than 4 roots, cracks, sand/silt seams all larger than 1/8" width/dimension in any combination	1.2

Modified Ff values included in Addendum #2.

Reason for Fabric Factor

Reason for Fabric Factor

e_m Step 2a –
Calculate Modified Unsaturated Diffusion Coefficient

Since soil is a CH clay and number of cracks, roots, etc unknown – Use 1.2.

Condition		Ff
Non CH Soils		1.0
CH Soils	Profiles with 1 root, crack, sand/silt seam all less than or equal to 1/8" width/dimension in any combination	1.0
	Profile with 2 to 4 roots, cracks, sand/silt seams all larger than 1/8" width/dimension in any combination	1.1
	Profile with more than 4 roots, cracks, sand/silt seams all larger than 1/8" width/dimension in any combination	1.2

e_m Step 2a –
Calculate Modified Unsaturated Diffusion Coefficient

$$\alpha'_{shrinking} = \alpha_{shrinking}\,(F_f)$$

$$\alpha'_{shrinking} = 0.0038\,(1.2) = 0.0046$$

$$\alpha'_{swelling} = \alpha_{swelling}\,(F_f)$$

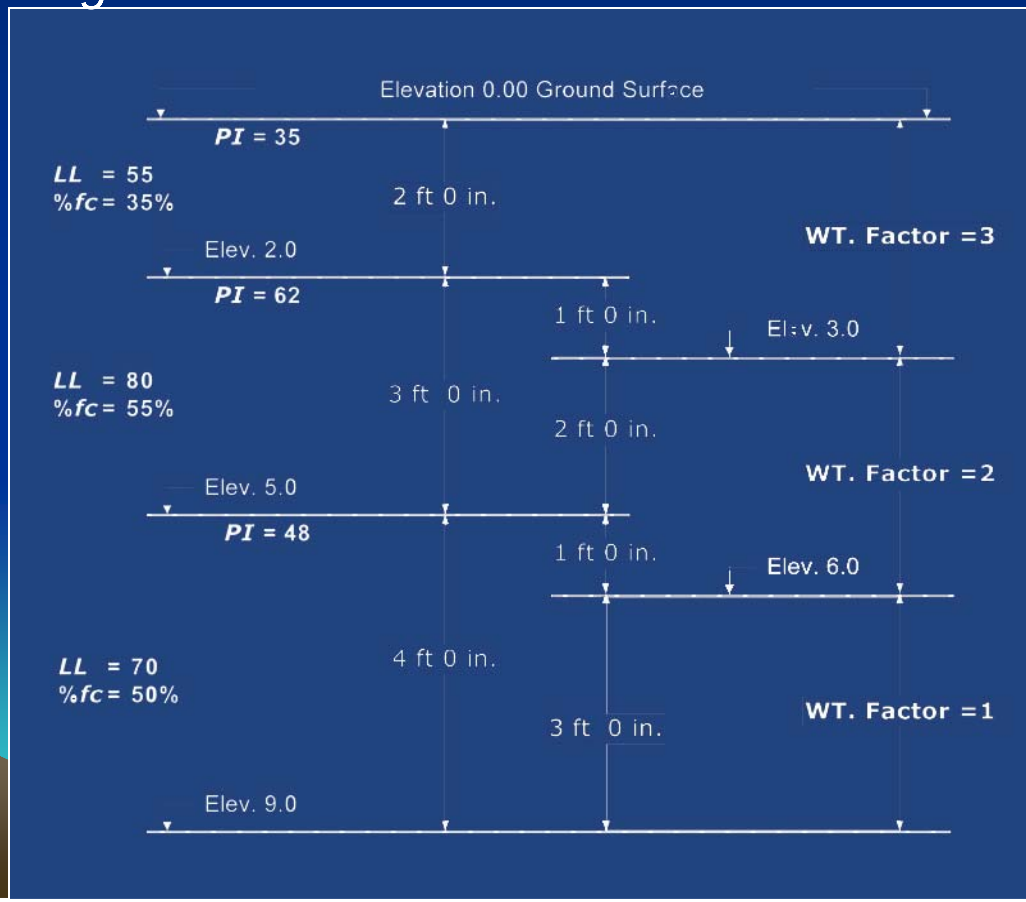
$$\alpha'_{swelling} = 0.0038\,(1.2) = 0.0046$$

e_m Step 2b –

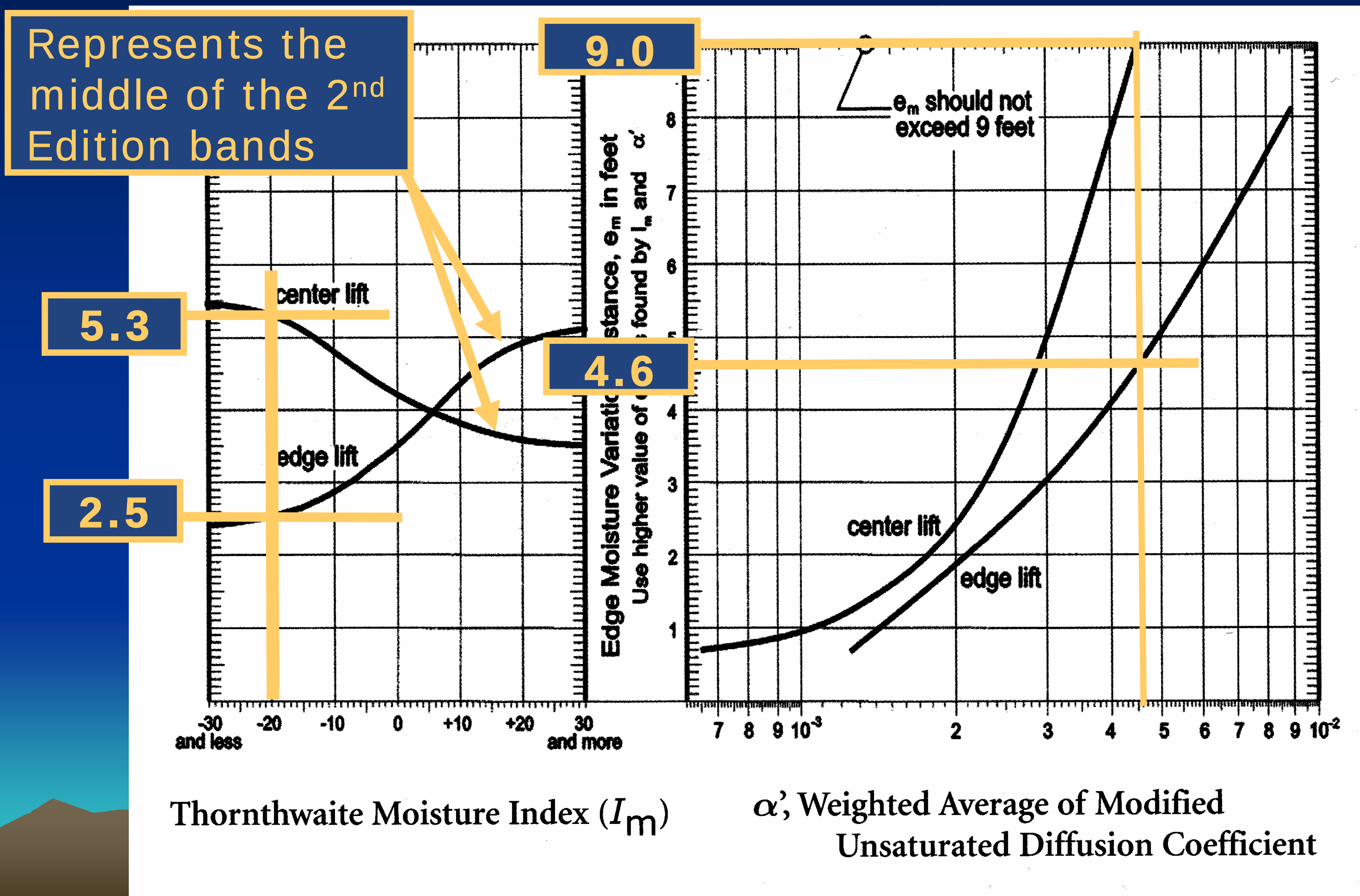
Calculate Weighted Modified Unsaturated Diffusion Coefficient

For layered soil profiles $(\alpha')_{weighted}$ to be calculated per the following equation:

$$(\alpha')_{weighted} = (\Sigma F_i \times D_i \times \alpha_i) / (\Sigma F_i \times D_i)$$



e_m Step 3 – Determine e_m



Summary of Soil Support Parameters (SCF)

near Sacramento, CA

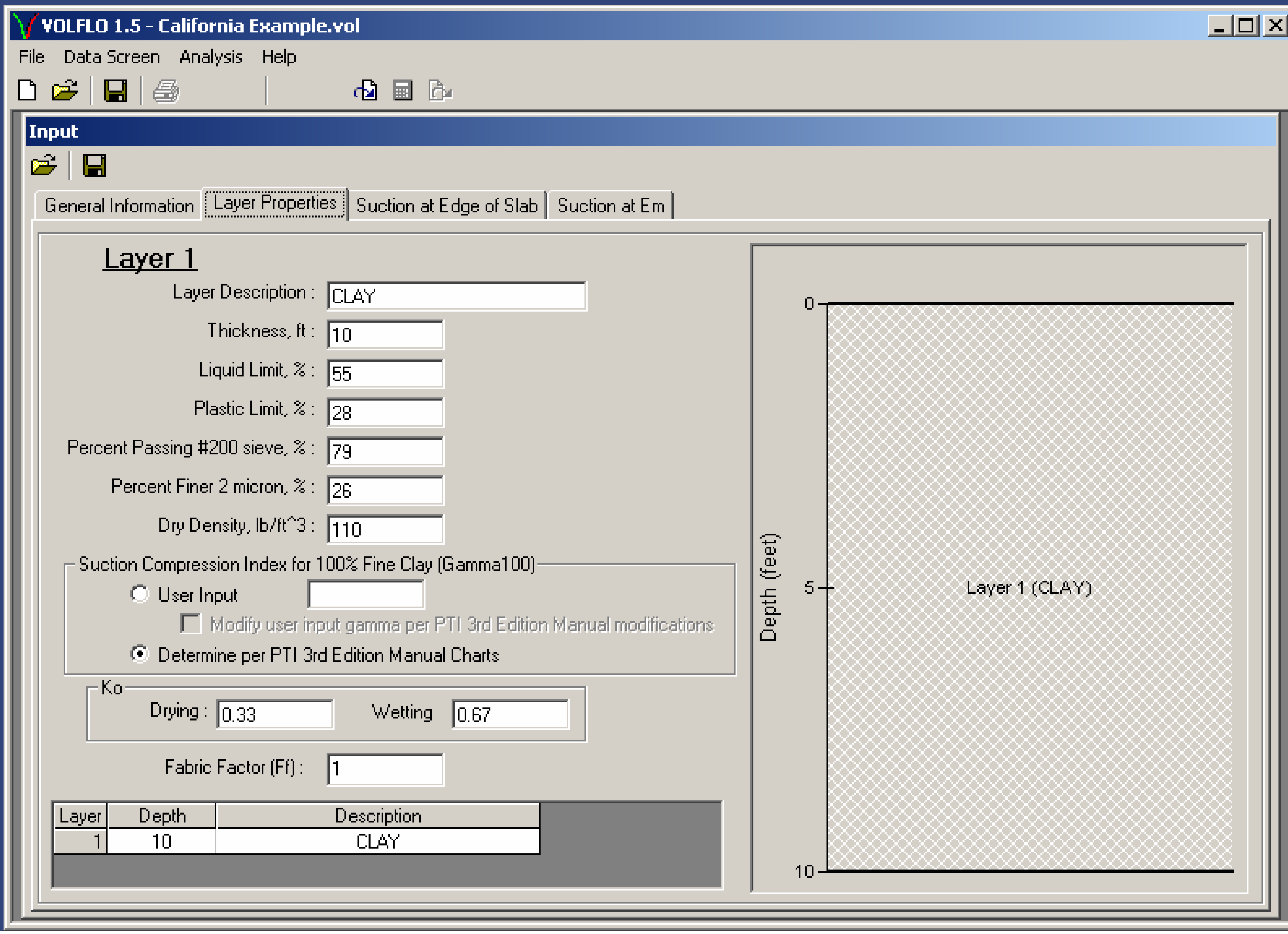
$e_{m\ Center}$ = 9.0 feet

$e_{m\ Edge}$ = 4.6 feet

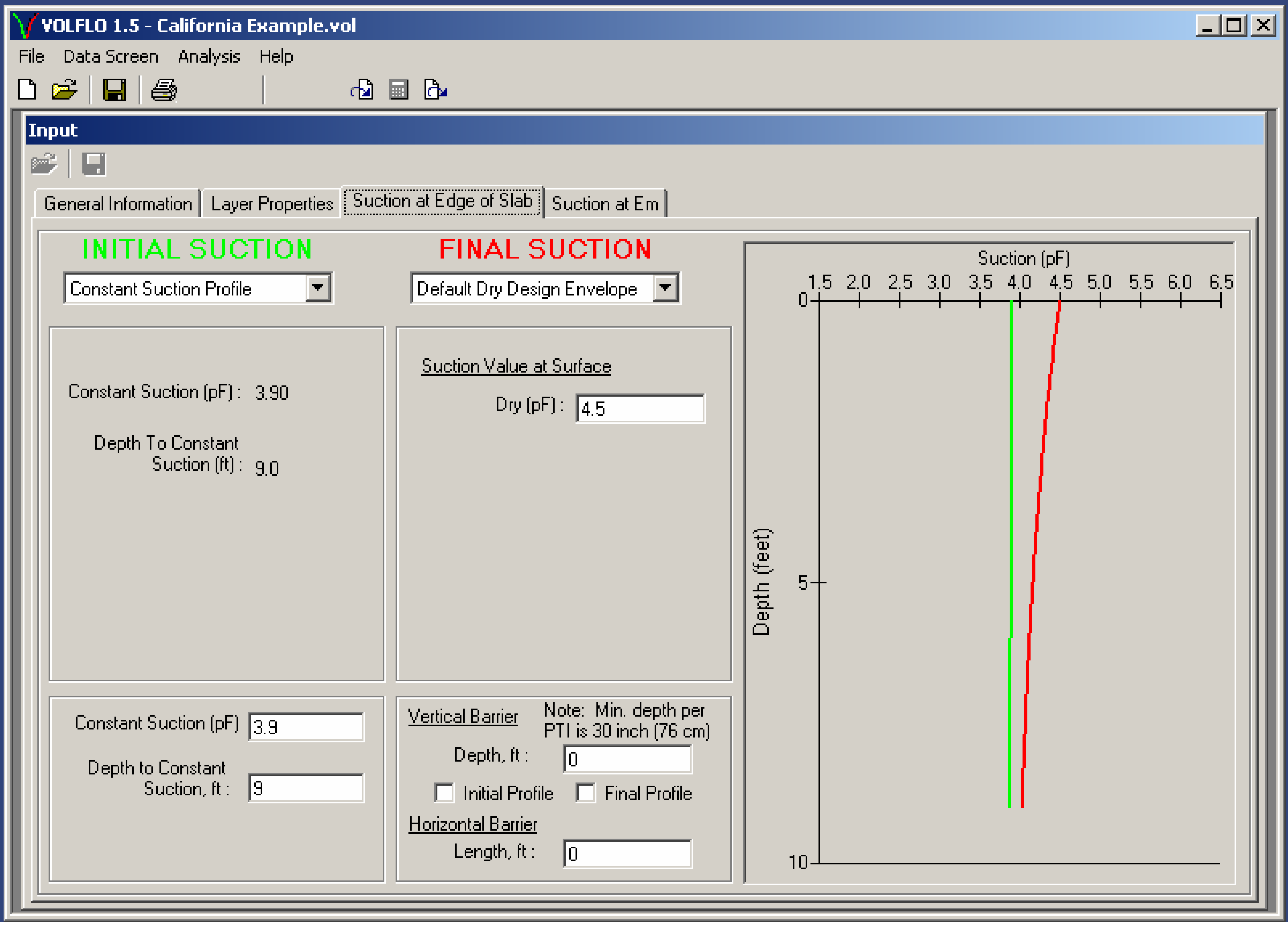
$y_{m\ Center}$ = 0.5 inches

$y_{m\ Edge}$ = 1.2 inches

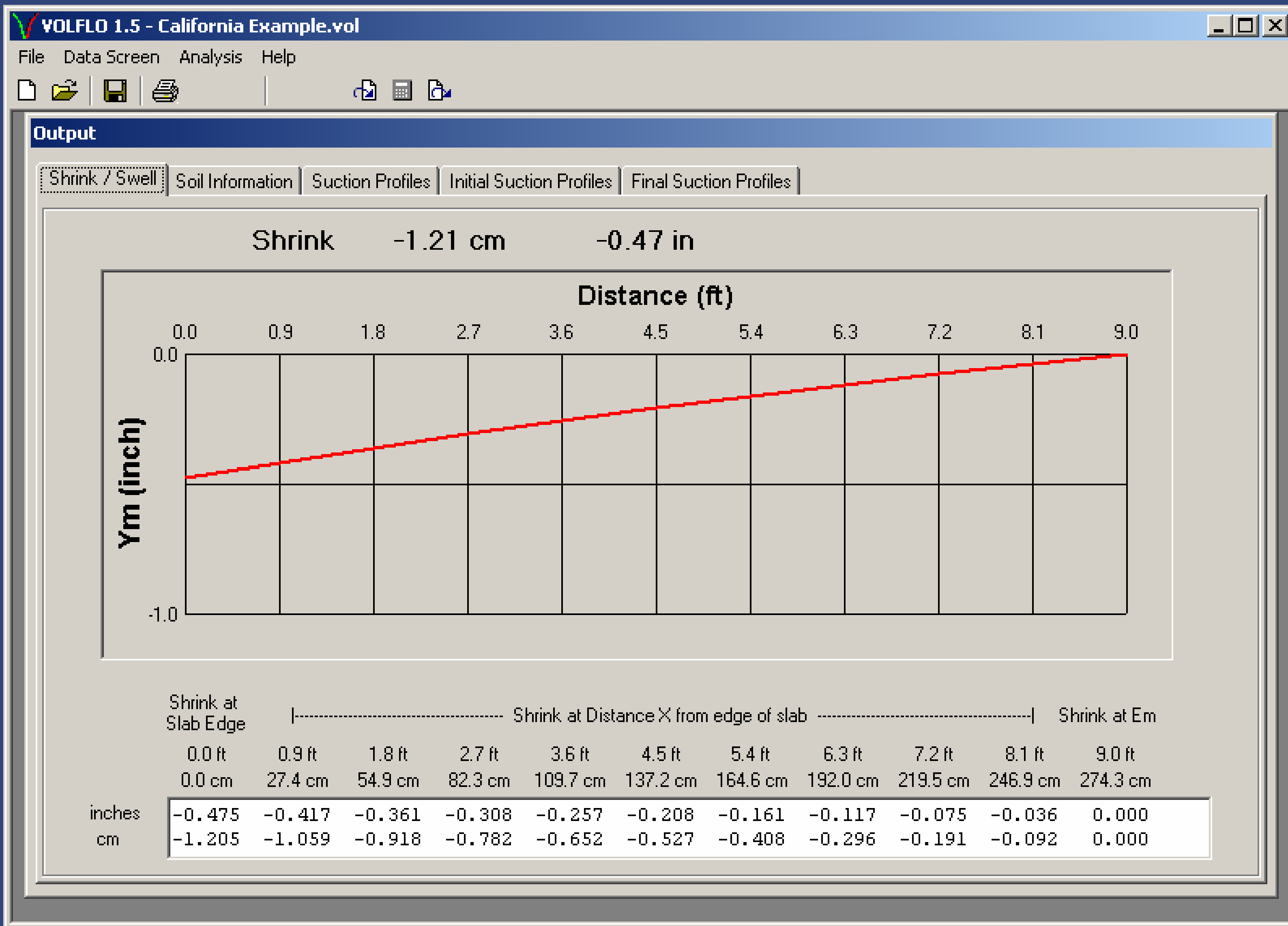
VOLFLO 1.5 - Shrinking



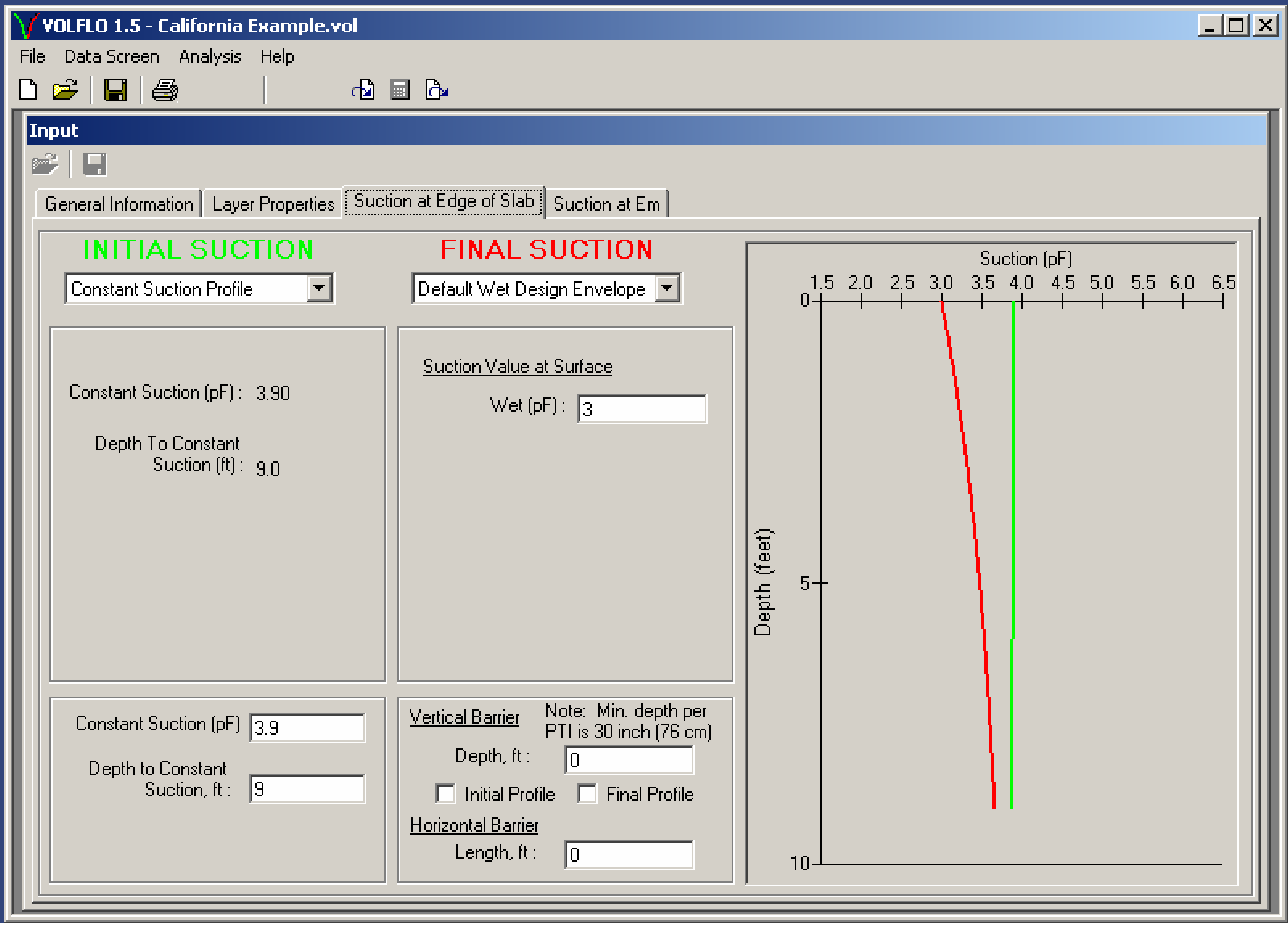
VOLFLO 1.5 - Shrinking



VOLFLO 1.5 - Shrinking



VOLFLO 1.5 - Swelling



VOLFLO 1.5 - Swelling

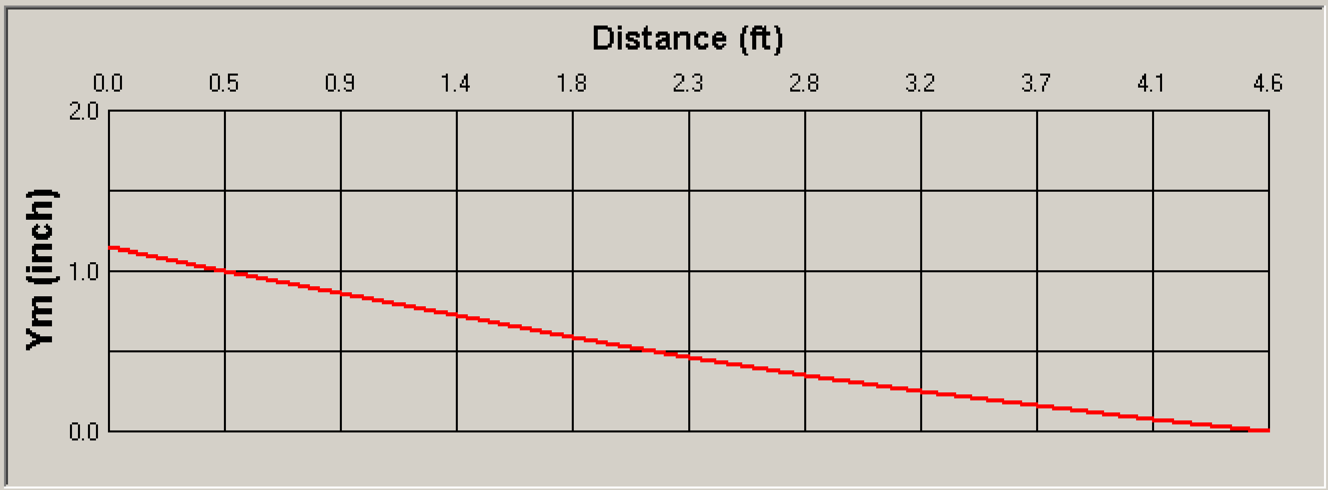
VOLFLO 1.5 - California Example.vol

File Data Screen Analysis Help

Output

Shrink / Swell | Soil Information | Suction Profiles | Initial Suction Profiles | Final Suction Profiles

Swell 2.93 cm 1.15 in



Swell at Slab Edge |---------- Swell at Distance X from edge of slab ----------| Swell at Em

	0.0 ft	0.5 ft	0.9 ft	1.4 ft	1.8 ft	2.3 ft	2.8 ft	3.2 ft	3.7 ft	4.1 ft	4.6 ft
	0.0 cm	14.0 cm	28.0 cm	42.1 cm	56.1 cm	70.1 cm	84.1 cm	98.1 cm	112.2 cm	126.2 cm	140.2 cm
inches	1.154	1.002	0.857	0.719	0.589	0.467	0.354	0.251	0.157	0.074	0.000
cm	2.931	2.545	2.176	1.826	1.496	1.186	0.900	0.637	0.399	0.187	0.000

Comparison of Soil Support Parameters

Mesquite, TX

Layered Soil Profile

Post-Equilibrium Suction Envelopes

Layer 1 : γ_h = 0.028

Layer 2 : γ_h = 0.065

Layer 3 : γ_h = 0.052

	e_m		y_m	
	Center	Edge	Center	Edge
SCF	7.8	4.0	0.66	0.97
VOLFLO 1.5	7.8	4.0	0.58	0.73
% Difference	0%	0%	14%	33%

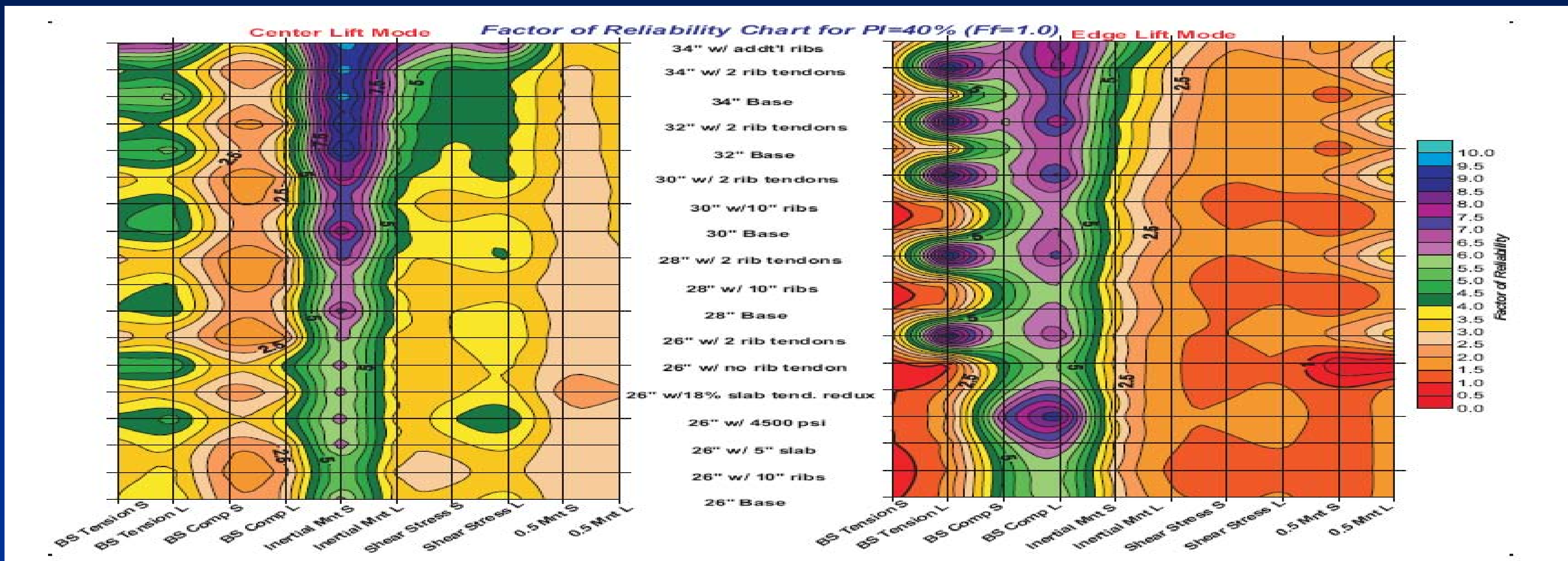
The SCF method should only be attempted for layered profiles if " γ_h does not vary by more than 10%. Otherwise, this procedure may not be accurate or conservative."

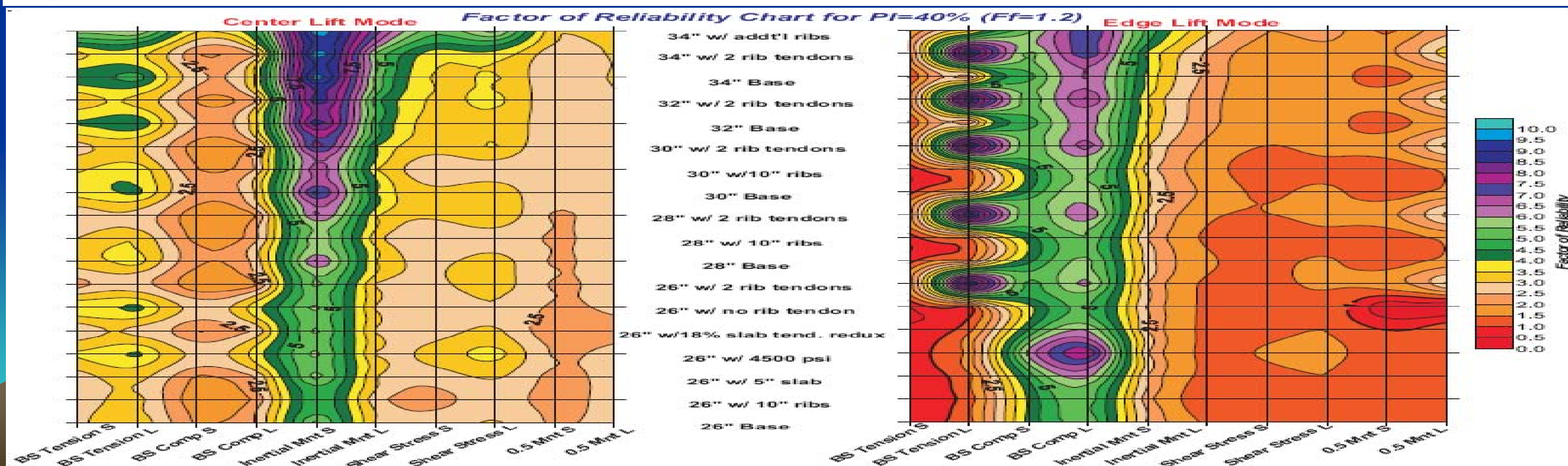
Simplified Approach
Soil Design Parameters and Soil Data

Table 1. Geotechnical Soil Parameters

Dry Density, pcf	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	-200, %	2 micron, %	Fine Clay, %	e_m (FF=1) cl, ft	e_m (FF=1) el, ft	e_m (FF=1.2) cl, ft	e_m (FF=1.2) el, ft	y_m cl, in	y_m el, in
110	20	16	4	43.4	5	11.5	9	5.3	9	6.36	-0.04	0.05
110	30	18	12	51.4	10	19.5	9	4.9	9	5.88	-0.74	1.07
105	40	20	20	59.4	22	37.0	9	4.6	9	5.52	-0.92	1.34
105	50	22	28	67.4	37	54.9	8.3	4.2	9	5.04	-1.31	1.97
100	60	24	36	75.4	52	69.0	7.5	3.9	9	4.68	-1.59	2.45
100	70	26	44	83.4	67	80.3	6.7	3.6	8.04	4.32	-1.79	2.81
95	80	28	52	91.4	82	89.7	5.5	3.5	6.6	4.2	-2.33	3.85
95	90	30	60	99.4	97	97.6	4.2	3.5	5.04	4.2	-2.44	4.11
92	100	32	68	100	99	99.0	4.2	3.5	5.04	4.2	-3.07	5.62

Simplified Approach
PI = 40

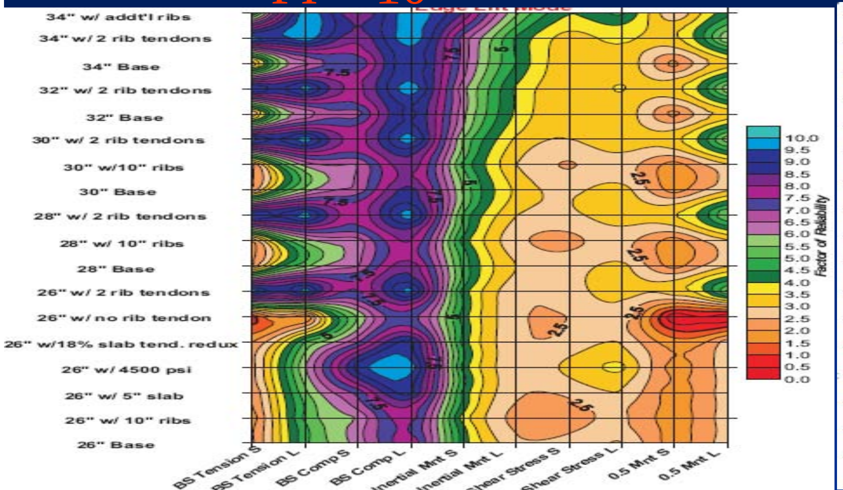




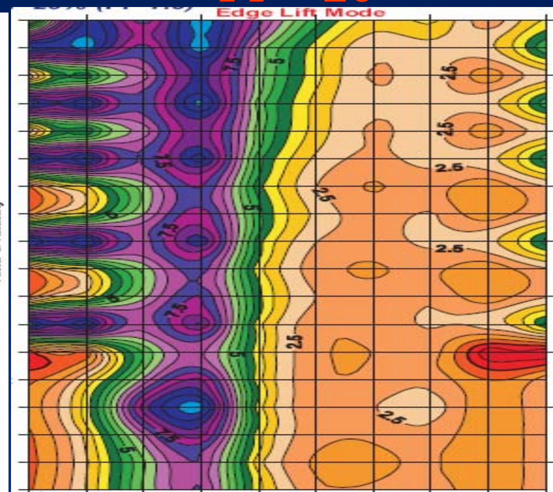
Legend:
PI – Plasticity index   Ff – Fabric factor   BS – Bending Stress   Comp – Compression
S – Short side of slab   L – Long side of slab   Inertial Mnt – Stiffness criteria   0.5 Mnt – Crack moment capacity

Variation of PI on Reliability

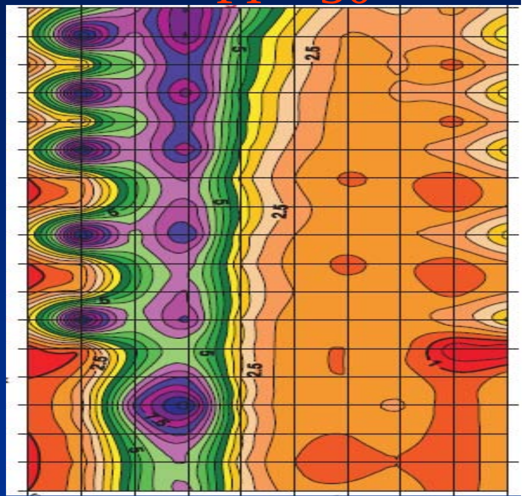
PI = 10



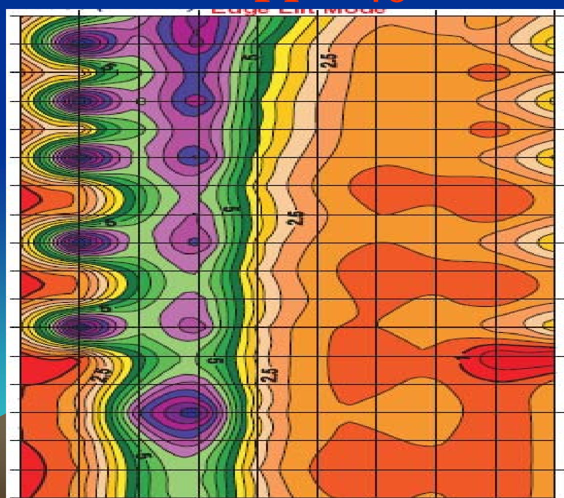
PI = 20



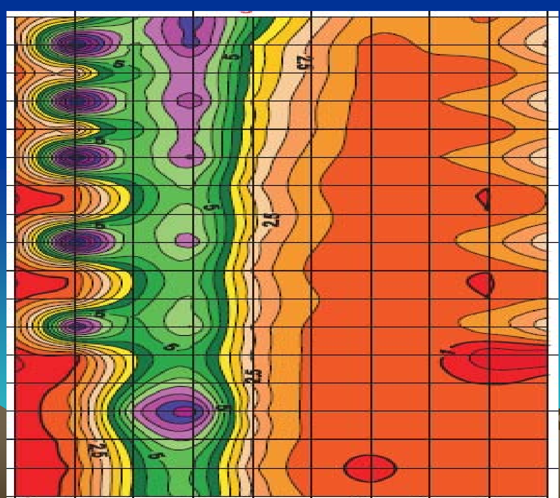
PI = 30



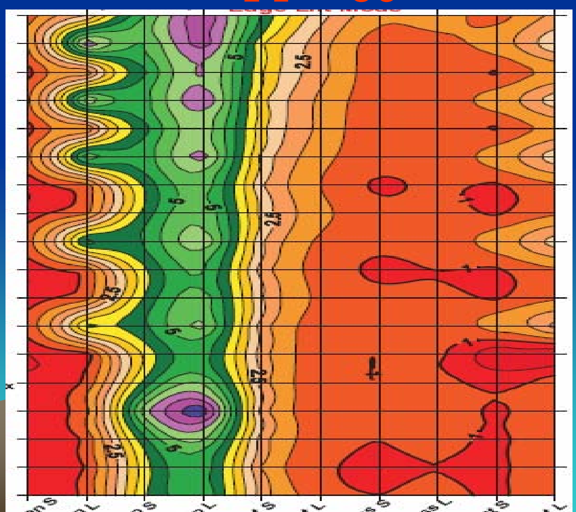
PI = 40



PI = 50



PI = 60

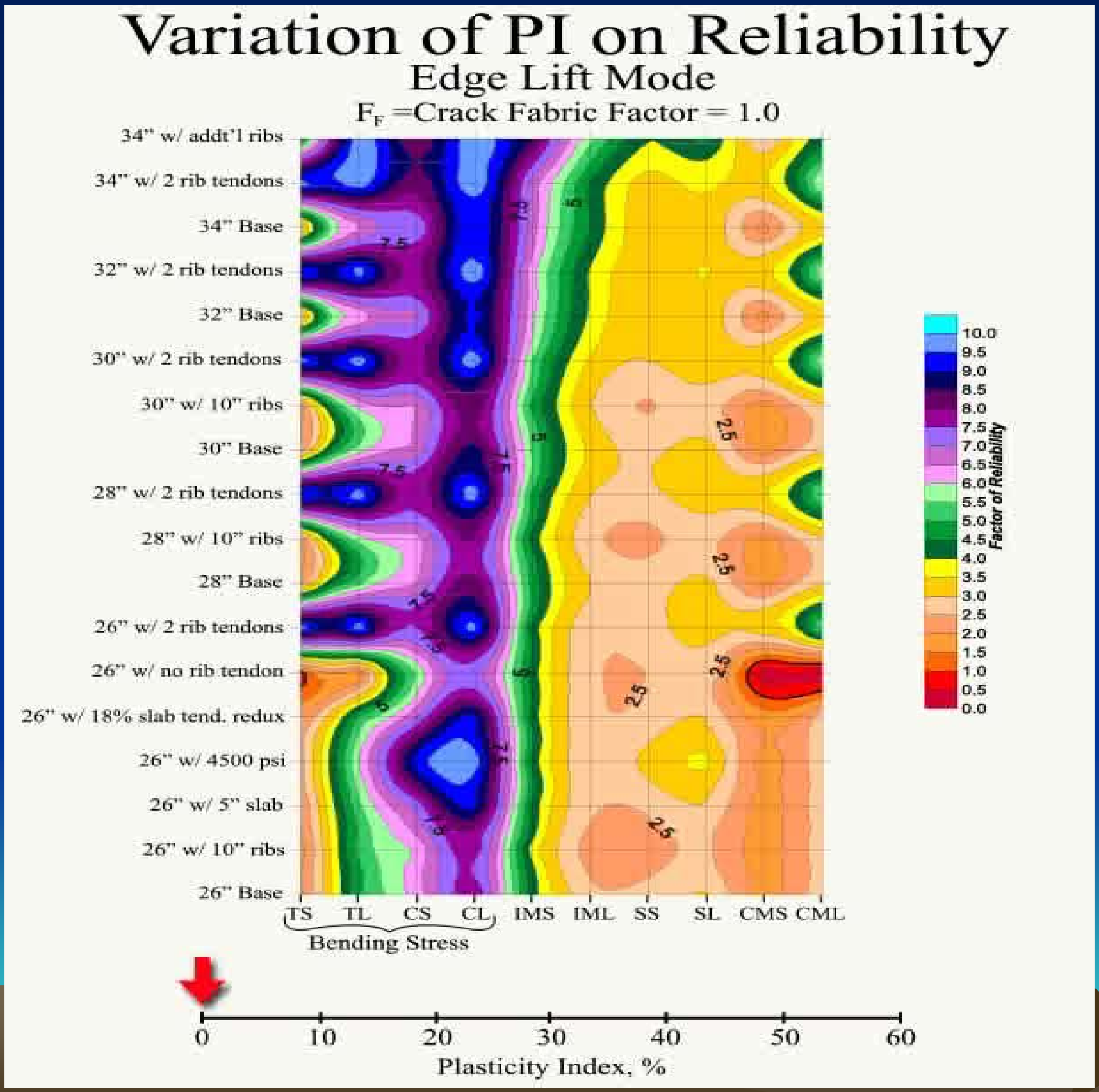


Simplified Approach
Soil Design Parameters and Soil Data

Table 1. Geotechnical Soil Parameters

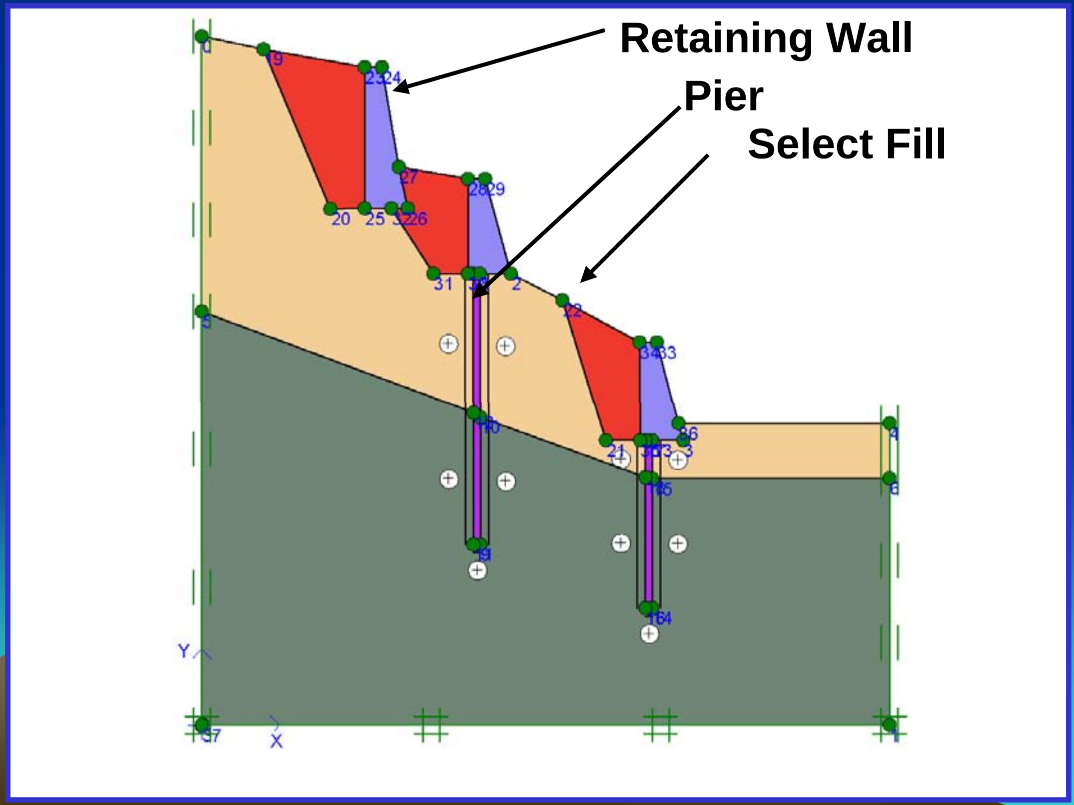
Dry Density, pcf	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	-200, %	2 micron, %	Fine Clay, %	e_m (FF=1) cl, ft	e_m (FF=1) el, ft	e_m (FF=1.2) cl, ft	e_m (FF=1.2) el, ft	y_m cl, in	y_m el, in
110	20	16	4	43.4	5	11.5	9	5.3	9	6.36	-0.04	0.05
110	30	18	12	51.4	10	19.5	9	4.9	9	5.88	-0.74	1.07
105	40	20	20	59.4	22	37.0	9	4.6	9	5.52	-0.92	1.34
105	50	22	28	67.4	37	54.9	8.3	4.2	9	5.04	-1.31	1.97
100	60	24	36	75.4	52	69.0	7.5	3.9	9	4.68	-1.59	2.45
100	70	26	44	83.4	67	80.3	6.7	3.6	8.04	4.32	-1.79	2.81
95	80	28	52	91.4	82	89.7	5.5	3.5	6.6	4.2	-2.33	3.85
95	90	30	60	99.4	97	97.6	4.2	3.5	5.04	4.2	-2.44	4.11
92	100	32	68	100	99	99.0	4.2	3.5	5.04	4.2	-3.07	5.62

Variation of PI on Reliability



Finite Element Modeling

- 2D/3D Stress/Strain Deformation
- Saturated/Unsaturated Flow
- 2D/3D Slope Stability
- Settlement Study



Animation Reconstruction