pti Technical Notes

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For Professionals Engaged in Post-Tensioning Design *Issue 12 • May 2003*

ALTERNATE PROCEDURES FOR DETERMINING SOIL SUPPORT PARAMETERS FOR SHALLOW FOUNDATIONS ON EXPANSIVE CLAY SOIL SITES

(Relating to the Post-Tensioning Institute Manual *Design and Construction of Post-Tensioned Slabs-on-Ground* 2nd Edition)

By the Post-Tensioning Institute Slab-on-Ground Committee

1.0 Introduction

An alternate procedure for the determination of soil support parameters for shallow foundations on expansive clay soil sites has been developed by PTI's Slab-On-Ground Committee and others. This procedure provides rational means for evaluating the edge moisture variation distance e_m and the differential soil movement y_m. The procedure provides the ability to model soil conditions more accurately by incorporating extensive databases and research from the USDA Soil Conservation Service and by allowing for more flexibility in evaluating vertical moisture barriers, planter areas and variable soil suction values controlling the suction conditions at the surface of the soil profile.

The support parameters in the document are equally applicable to all ribbed or uniform thickness slab foundations, whether reinforced with conventional reinforcing steel or post-tensioning, constructed on expansive soil sites. The procedures are not applicable to compressible or collapsing soils. The values of e_m and y_m determined by this procedure shall be used as a basis for structural design using the methods of Section 6.0 of the Post-Tensioning Institute manual *Design and Construction of Post-Tensioned Slabs-On-Ground* 2nd Edition. If this procedure is used for calculating soil support parameters, it is intended to partially replace Appendix A.3 of the manual.

Enhancements for calculating e_m fundamentally involve the ability to use the Thornthwaite Moisture Index (TMI) in conjunction with estimates of the in-situ soil unsaturated diffusion coefficient calculated from simple soil properties. This value of the soil unsaturated diffusion coefficient is also modified by the soil fabric factor, ranging from 1 to 1.4, which takes into account the presence of horizontal flow discontinuities including roots, layers, fractures and joints. The procedure does not allow e_m to exceed 9-feet for any case of center or edge lifts.

Enhancements for calculating y_m involve the combination of current tables in Appendix A.3 of the 2nd edition of PTI's *Design and Construction of Post-Tensioned Slabs-On-Ground* manual (Ref. 4) into a single Table II using the concept of a Stress Change Factor (SCF). Further, in the absence of site specific soil suction information, the procedure allows for use of controlling suctions at the surface to calculate movement based upon changes in soil suction from initial to final profile values. However, the procedure emphasizes that measures for estimating differential soil movements should most ideally be based upon computer methods to generate the values of e_m and y_m for edge lift and center lift conditions (Ref. 5).

As with previous PTI soil parameter information, the new procedure for determining of y_m found in Table II is limited to horizontal moisture flow (i.e., no moisture flow vertically) where the equilibrium soil suction is known at a given depth with the suction changing to either drier or wetter conditions from this depth "z" to the ground surface. Due to this limitation, Table II should be used to determine design values of y_m assuming a typical trumpet-shape suction profile for ending conditions. Table II also assumes that γ_h (matrix suction compression index) is constant and further is limited to active soil depths up to 9-feet.

For active soil depths greater than 9-feet or to model post-equilibrium conditions using assumed or known soil suction profiles, the procedure requires the use of a two-dimensional analysis, which can be accomplished by using a computer solution.

1.1 Expansive Soil Sites

Sites for which this procedure is applicable should meet either of the following criteria:

- One foot or more of soil classified as CL or CH by the Unified Soil Classification System having a PI of 15 or greater within the upper 5 feet of the soil profile.
- An equivalent weighted PI computed by the methods found in Building Research Advisory Board Report #33 (Ref. 1) of 15 or greater.

If neither of these criteria is met, the foundation should be designed as a non-stiffened slab foundation, such as the BRAB Type II foundation, defined as one that is lightly reinforced with prestressed or non-prestressed reinforcing steel against shrinkage and temperature cracking.

2.0 Edge Moisture Variation Distance (e_m)

The edge moisture variation distance is the distance beneath the edge of a shallow foundation within which moisture will change due to wetting or drying influences around the perimeter. In an edge lift case, the moisture in the soil is higher at the edges than in the center. The center lift case is one in which the moisture is higher in the center than the edges. The major factor in determining the edge moisture variation distance is the unsaturated diffusion coefficient, α. This, in turn, depends on the level of suction, the permeability, and the cracks in the soil. For the same diffusion coefficient, the e_m value will be larger for the center lift case in which moisture is withdrawn from wetter soil around the center of the foundation. The e_m value will be smaller for the edge lift case in which moisture is drawn beneath the building into drier soil. Roots, layers, fractures or joints in the soil will increase the diffusion coefficient and increase the e_m value for both the edge lift and center lift conditions. Using representative values based on laboratory test results in each layer, the following values are required to determine edge moisture variation distance, e_m:

- Liquid Limit, LL
- Plastic Limit, PL
- Plasticity Index, PI
- Percentage of soil passing No. 200 sieve (%-#200)
- Percentage of soil finer than 2 microns (%-2μ) expressed as a percentage of the total sample.
- Percent fine clay $\left(\frac{\%-2\mu}{\%\text{–\#200}}\right)$ reported as %fc, report as a percentage.

For example: 45% / 80% = 0.56, report as 56%

2.1 Calculate γ_h

Calculate γ_h for each significant soil layer to a minimum depth of 9-feet.

For swelling:

$$\gamma_h = (\gamma_o e^{\gamma_o})(\%fc)$$

For shrinkage:

$$\gamma_h = (\gamma_o e^{-\gamma_o})(\%fc)$$

Terms: e is the base of natural logarithms

γ_h is the correction of γ_o for the actual % of fine clay (%fc).

γ_o is the change of soil volume for a change in suction for 100% fine clay content and is determined using the following steps:

Step 1 Determine Mineral Classification Zone I, II, III, IV, V or VI from the Mineral Classification Chart, (See Figure 1). If the data does not fall within one of the six zones, use the nearest zone. No data should plot above the U-Line.

Step 2 Proceed to the chart corresponding to the zone determined in Step 1 to determine γ_o. (See Figure 2,3,4,5,6,7)

The modified value of γ_h, $\gamma_{h\ mod}$, is the average volume change coefficient of the soil supporting the slab. This should be calculated as a weighted average of the γ_h values in each of the layers of soil to a depth of nine feet. Depths greater than nine feet may be used if justified by geotechnical analysis. The γ_h values in the upper one-third have a weight of three, in the next third a weight of two, and in the bottom third a weight of one. The sum of the products of layer thickness (feet), γ_h and weight for all layers should be used to obtain the weighted average as the modified value $\gamma_{h\ mod}$.

Interpolate between γ_o lines. Beyond extreme values of the contours, use the nearest values for γ_o. Figures 1, 2, 3, 4, 5, 6 and 7 were derived from data available from the National Soil Survey Center, USDA with analysis reported by Covar and Lytton (Ref. 2).

2.2 Calculate the unsaturated diffusion coefficient, α

$$\alpha = 0.0029 - 0.000162\,(S) - 0.0122\,(\gamma_{h\ mod})$$

Where S = -20.29+ 0.1555 (LL%) - 0.117 (PI%) + 0.0684 (%-#200)

The resulting unsaturated diffusion coefficient, α, for each significant layer should be converted to the modified unsaturated diffusion coefficient, α', using F_f. $\alpha' = \alpha F_f$, where F_f is the soil fabric factor from Table I.

Determine edge moisture variation distance, e_m for both center lift and edge lift from the e_m Selection Chart, Figure 8, using the larger value obtained from I_m chart or α' chart.

3.0 Differential Soil Movement (y_m)

Differential soil movement should be estimated using the change in soil surface elevation at two locations separated by a distance e_m within which the differential movement will occur. An initial and a final suction profile should be used at each of the two locations to determine differential movement. For general analysis, the initial suction profile should be the same at both locations.

The final suction profile at each location should be determined from controlling suction conditions at the surface. A computer analysis of the layered profile with measured or estimated suction profile envelopes may be used to yield estimates of movement for the purpose of design and analysis, and to study the effects of trees, edge barriers, flower beds, or lawn watering.

In absence of local observations, controlling soil suction values at the ground surface are recommended as follows:

1. Wettest: 2.5 pF, if measured under soaking conditions, which is typical of poor drainage or excessive watering.

2. Driest 4.5 pF, if the surface suction is controlled by vegetation or 6.0 pF, if the surface suction is controlled by evaporation from bare soil, or soil with wilted vegetation.

Controlling soil suction values below the soil surface occur at depths that are remote from the surface (z) and are as follows:

1. High Water Table: 2.0 pF at the water table unless there is a high osmotic component, in which case, the measured value of suction should be used.

2. Climate-Controlled Suction: This suction may be determined by measurement at a depth below which the suction varies by less than 0.027 pF per ft. This is also the z depth.

3. Tree Root Zone: 4.5 pF under driest conditions, when the tree is near the wilting point.

4. High Osmotic Suction or Cemented Soil: These suction values must be determined by measurement. Suction at depths that are substantially different than those estimated by the Soil Suction vs Thornthwaite Moisture Index curve in Figure A.3.6 of Ref. 4 indicates dissolved salts in the pore water, and possible formation from deposition in a marine environment, or cementation.

A typical vertical suction profile is computed by using the principles of steady state unsaturated flow which links the controlling suction values at the soil surface to the controlling suction below the surface. The principles of steady-state unsaturated flow may be found in Ref. 3.

Differential soil movements may be estimated using computer methods to generate the design values of y_m for edge and center lift conditions.

In the absence of computer methods (see Ref. 5), Table II may be used to estimate approximate design values of y_m. This method should only be attempted if a typical trumpet-shape suction profile can be assumed for the final suction profile and γ_h is not highly variable. Otherwise, this procedure may not be accurate or conservative. In addition, the Table II values assume the initial suctions to be at equilibrium from depth z to the ground surface, then either becoming wet or dry. This limitation would not permit accurate or conservative results in the case of a dry or wet initial suction profile, followed by significant wetting or drying, tree effects or other moisture anomalies.

The estimated value of y_m can be determined from

$y_m = \gamma_{h\ mod} \times$ SCF (from Table II)

The modified value of γ_h, $\gamma_{h\ mod}$, is the average volume change coefficient of the soil supporting the slab. This should be calculated as a weighted average of the γ_h values in each of the layers of soil to a depth of nine feet. Depths greater than nine feet may be used if justified by geotechnical analysis. The γ_h values in the upper one-third have a weight of three, in the next third a weight of two, and in the bottom third a weight of one. The sum of the products of layer thickness (feet), γ_h and weight for all layers should be used to obtain the weighted average as the modified value $\gamma_{h\ mod}$, which is to be used to determine the y_m value for edge lift (positive value) and center lift (negative value). The value of $\gamma_{h\ mod}$ calculated previously for swelling should be used with positive SCF and the $\gamma_{h\ mod}$ value for shrinkage should be used with negative SCF. If less than nine feet of active soil is present, or if significant variations occur in γ_h, use γ_h for each layer to calculate y_m.

4.0 Barriers

Vertical moisture barriers may be used to reduce the soil support parameters (e_m and y_m) provided the barriers are properly designed to virtually stop moisture migration to or from the under slab area on a permanent basis, around the entire perimeter.

The effect of a barrier on e_m and y_m may be estimated by the principles of un-saturated soil mechanics, most easily by the use of two-dimensional moisture flow analysis computer program, such as VOLFLO (Ref. 5).

A vertical barrier should extend at least 2.5 feet below adjacent ground surface to be considered as having any effect.

An approximation of the effect of a vertical barrier on e_m can be obtained by using Table III.

The change of y_m for various barrier depths requires analysis using a computer program, such as Ref. 5.

5.0 Conclusion

Three sample calculations for e_m and y_m are included (Appendix A, B, and C) to demonstrate the procedures specified in this document:

1. Using stress change factors from Table II (Appendix A)
2. Using VOLFLO for y_m starting at equilibrium suction profile (Appendix B)
3. Using VOLFLO for y_m starting at extreme wet and dry suction profiles (Appendix C).

6.0 References

1. Building Research Advisory Board, Report #33. (1968). *Criteria for Selection and Design of Residential Slabs-on-Ground*, National Research Council, Washington, D.C.

2. Covar, A.P. and Lytton, R.L. (2001), "Estimating Soil Swelling Behavior Using Soil Classification Properties", ASCE Geotechnical Publication No. 115, American Society of Civil Engineers, Reston, VA, pages 44-63.

3. Lytton, R.L. (1994). "Prediction of Movement of Expansive Clays", ASCE Geotechnical Special Publication No. 40, Vol. 2, American Society of Civil Engineers, Reston, VA, pages 1827-1845.

4. Post-Tensioning Institute. (1996). *Design and Construction of Post-Tensioned Slabs-on-Ground*, 2nd Ed, Phoenix, AZ.

5. VOLFLO Win 1.0. (2002). A computer program available through the Post-Tensioning Institute or Geostructural Tool Kit, Inc., Austin, Texas.

7.0 List of Symbols and Notations
(not defined in Ref. 4)

α Unsaturated diffusion coefficient, a measure of moisture movement in unsaturated soils.

α' Modified unsaturated diffusion coefficient. The modified unsaturated diffusion coefficient is calculated as : $\alpha' = \alpha\,(Ff)$

e Base of the natural logarithm (approximated as 2.7183).

%fc Percent fine clay defined as percentage of soil passing the U.S. No. 200 sieve which is smaller than 2 microns (2μ). The percent fine clay is calculated as shown below:

$$\%fc = \left(\frac{\% - 2\mu}{\% - \#200}\right) \text{ reported as a percentage.}$$

γ_o Change of soil volume for a change in suction for 100% fine clay.

γ_h Change of soil volume for a change in suction corrected for the actual % fine clay. Also referred to as the matrix suction compression index.

$\gamma_{h\ mod}$ Change of soil volume for a change in suction corrected for the actual % fine clay, weighted for layered soils.

F_f Fabric factor. Factor used to modify the unsaturated diffusion coefficient (α) for the presence of roots, layers, fractures and joints. See Table I.

S Slope of the Suction versus Volumetric Water Content Curve. See Ref. 3.

SCF Stress Change Factor. Factor used in the determination of y_m. See Table II.

Table I - Soil Fabric Factor

Condition	F_f
Soil profiles contain **few** roots, layers, fractures or joints (No more than 1 per vertical foot)	1.0
Soil profiles contain **some** roots, layers, fractures or joints (2 to 4 per vertical foot)	1.3
Soil profiles contain **many** roots, layers, fractures or joints (5 or more per vertical foot)	1.4

Table II - Stress Change Factor (SCF) for Use in determining y_m

Measured Suction (pF) at Depth z	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

Notes for Table 2: The positive sign indicates edge lift (swelling) and the negative sign indicates center lift (shrinkage). Measured suction at depth is the equilibrium suction. Z is the depth to constant suction.

Table III – Values of Reduced e_m for Various Perimeter Vertical Barriers

		Depth of Barrier (feet)					
		2.5	3.0	3.5	4.0	4.5	5.0
e_m (feet) (Center or Edge)	2	2.0	2.0	2.0	2.0	2.0	2.0
	3	2.0	2.0	2.0	2.0	2.0	2.0
	4	3.1	2.6	2.0	2.0	2.0	2.0
	5	4.3	4.0	2.8	2.0	2.0	2.0
	6	5.5	5.2	4.2	3.0	2.0	2.0
	7	6.5	6.3	5.5	4.5	3.2	2.0
	8	7.6	7.4	6.6	5.7	4.7	3.3
	9	8.6	8.5	7.7	6.9	6.0	4.9

Figure 1 - Mineral Classification Chart

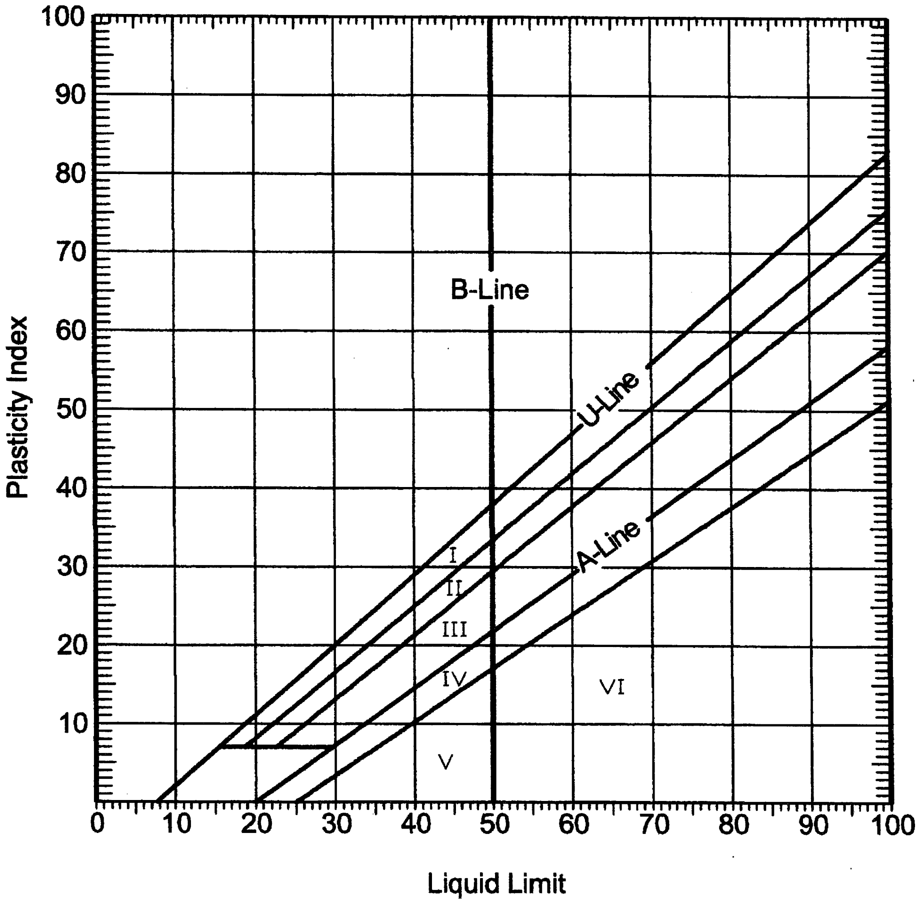


Figure 2 – Zone I Chart for Determining γ_o

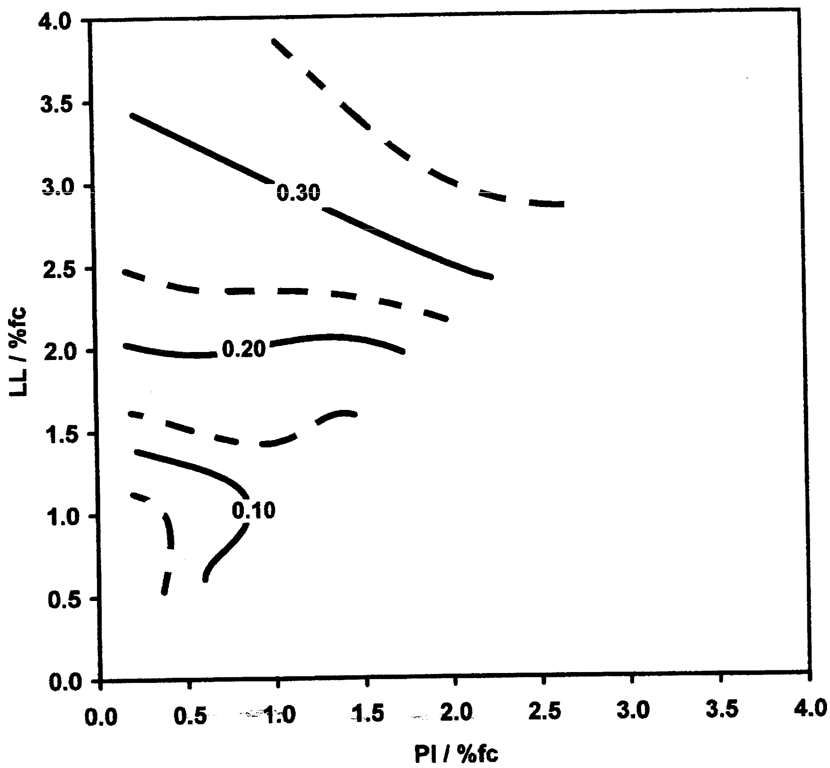


Figure 3 – Zone II Chart for Determining γ_o

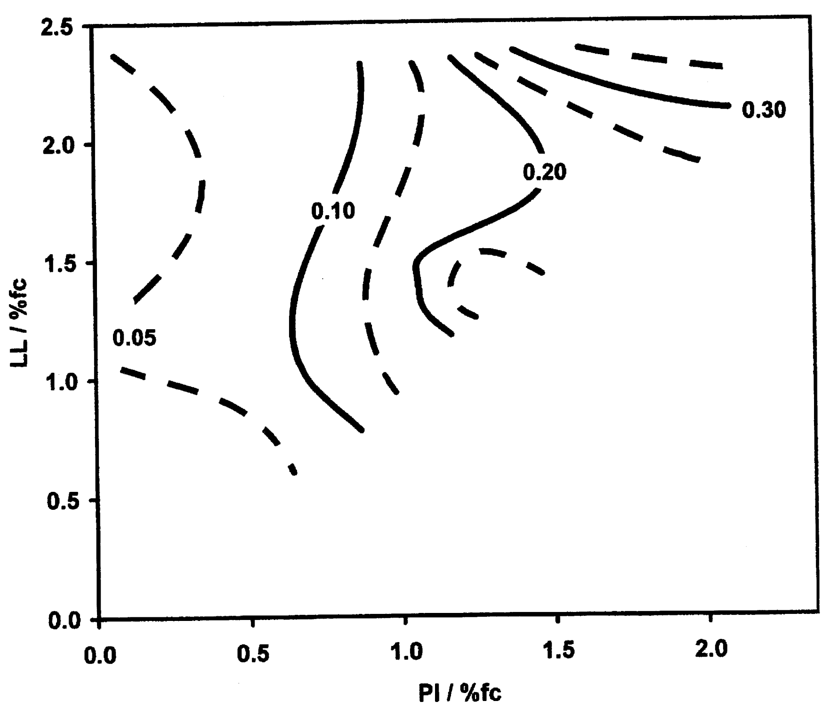


Figure 4 – Zone III Chart for Determining γ_o

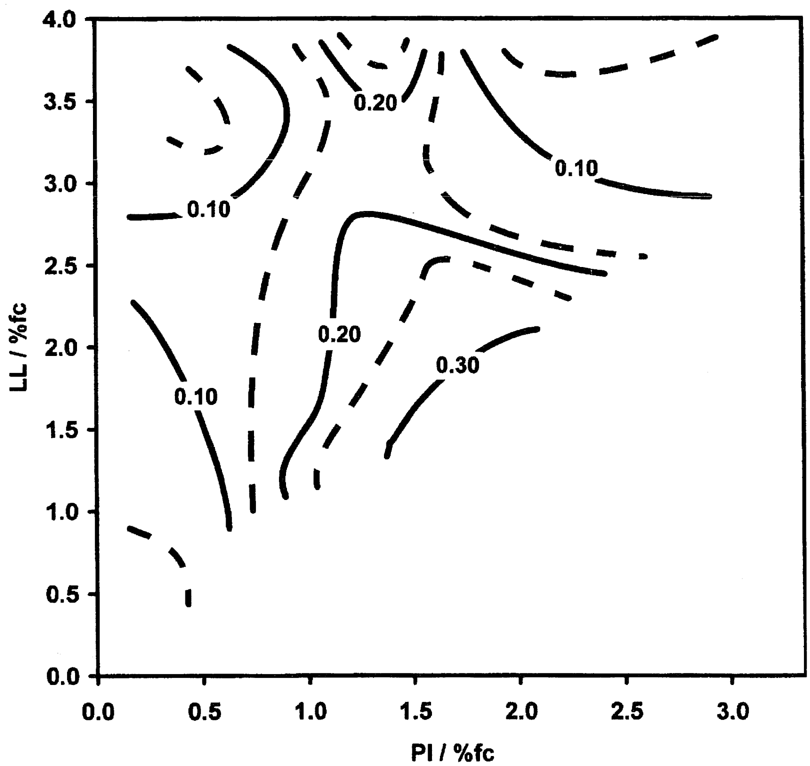


Figure 5 – Zone IV Chart for Determining γ_o

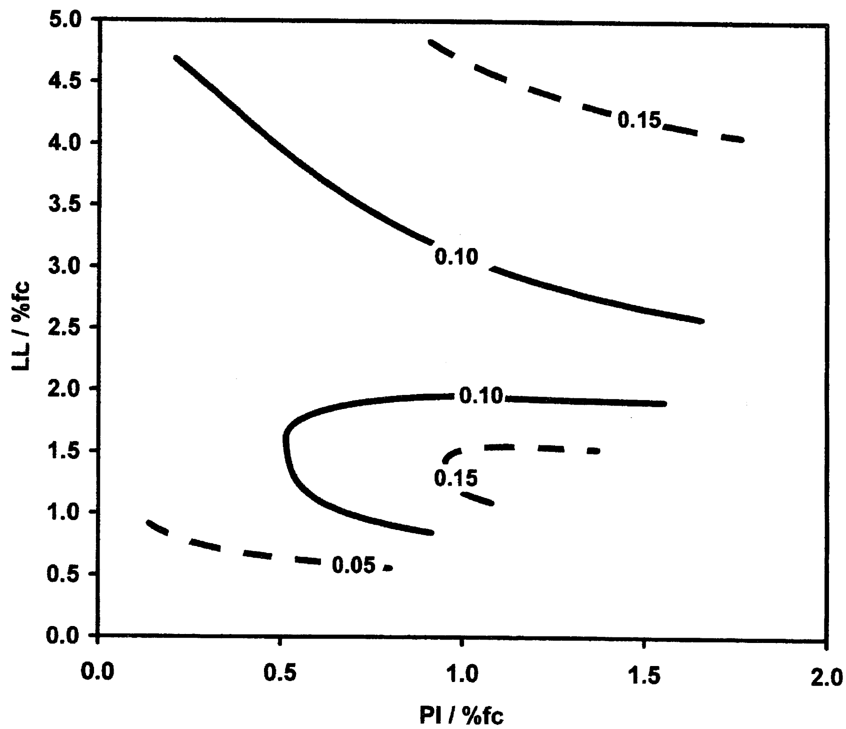


Figure 6 – Zone V Chart for Determining γ_o

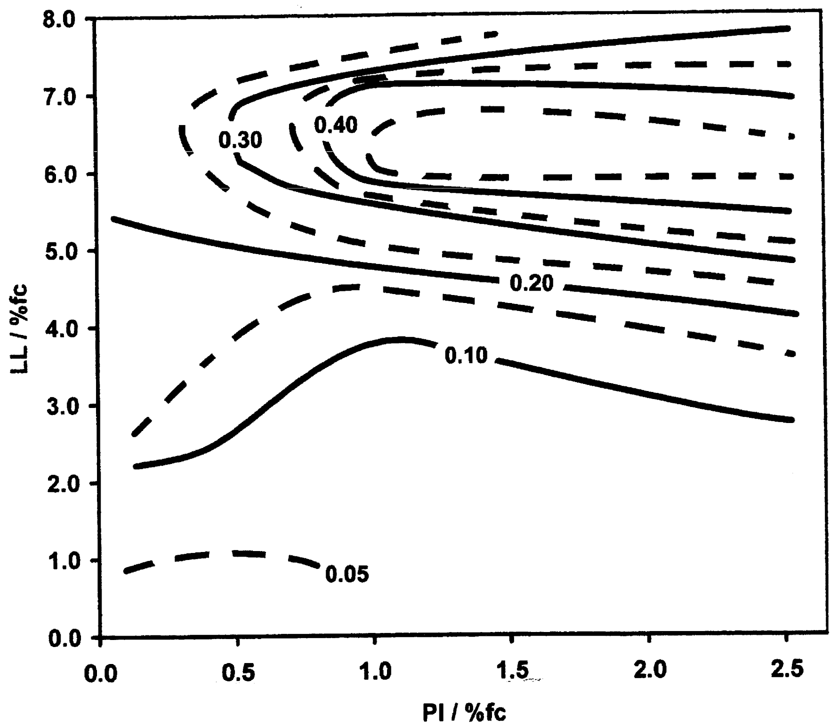


Figure 7 – Zone VI Chart for Determining γ_o

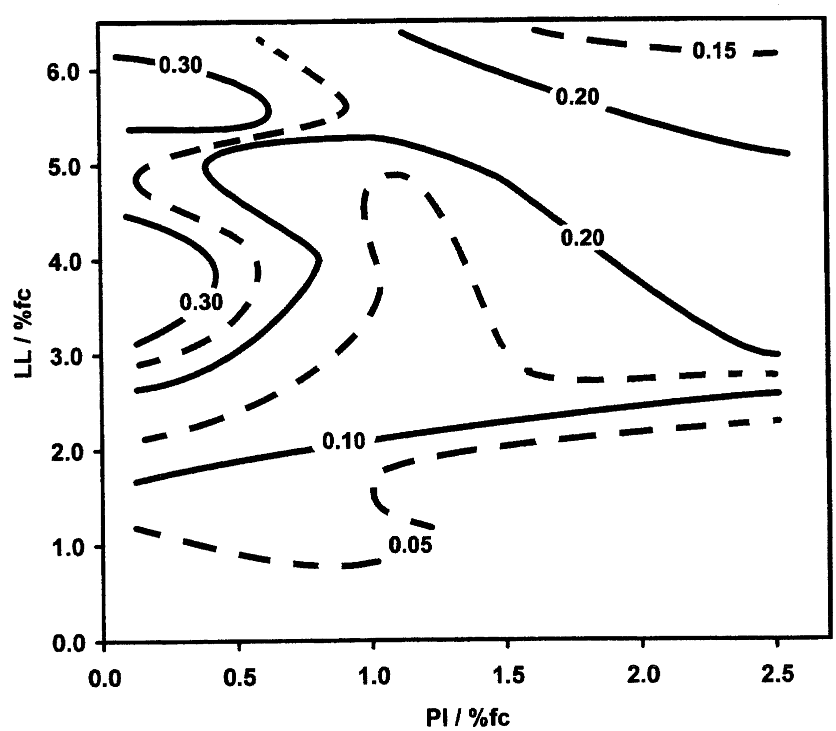
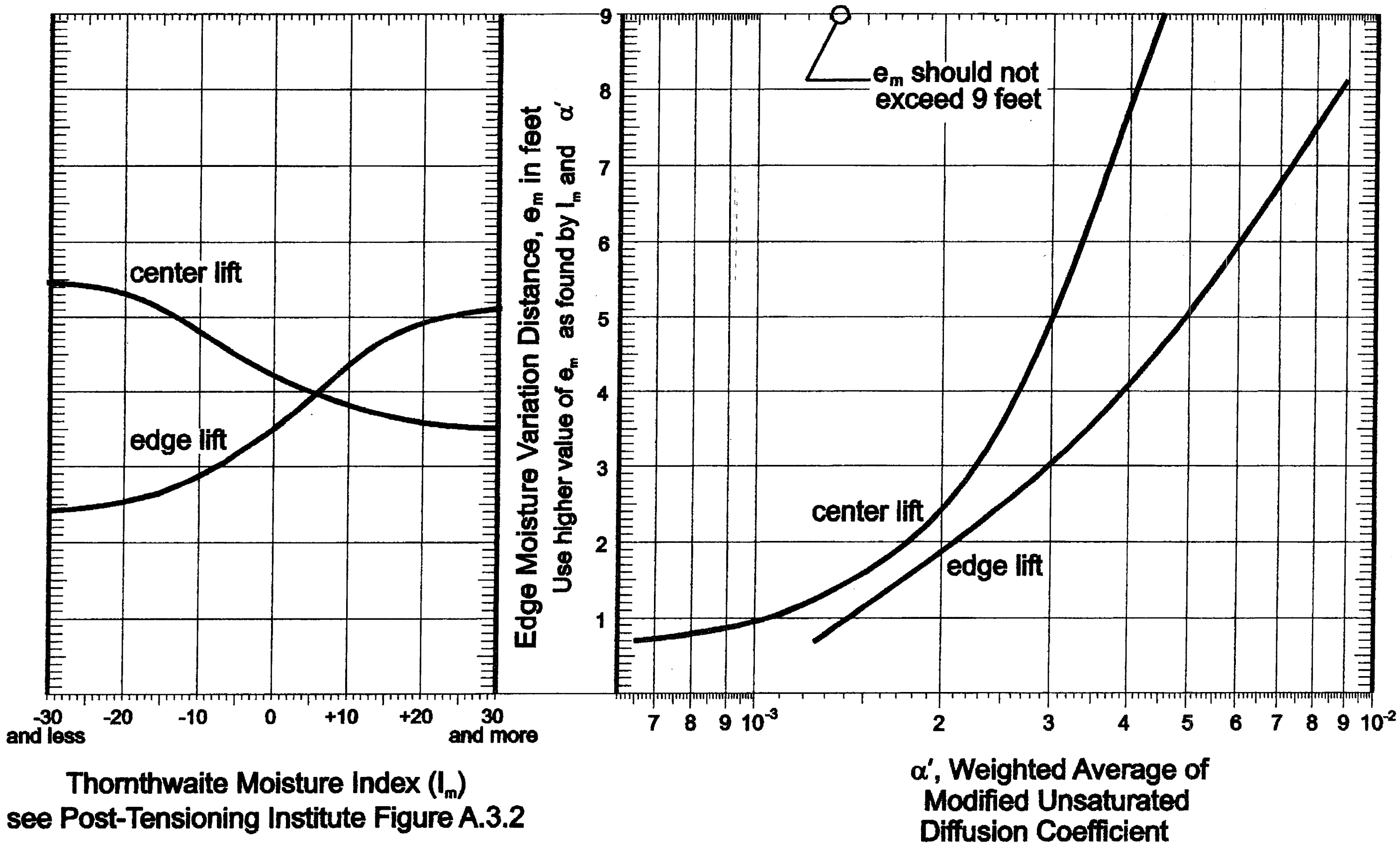


Figure 8 - e_m Selection Chart



APPENDIX A

SAMPLE CALCULATION USING STRESS CHANGE FACTORS (TABLE II) with swelling and shrinking suction profile changes starting at the Equilibrium Profile (Post-Equilibrium Case)

Laboratory Results and other Inputs

LL = 75
PL = 24
% passing 200 sieve (%-#200) = 88%
% passing 2 micron (%-2μ) = 63%
Fabric Factor (Table 1) from examination of sample = 1.0
Location: Austin, Texas
Soil Profile: Homogeneous
Soil Unit Weight: Internal in procedure
Ko: Drying and wetting internal in procedure

Determine e_m

1. Calculate the Plasticity Index (PI):
   Plasticity Index (PI) = LL – PL = 75 – 24 = 51

2. Calculate % fine clay (%fc):
   %fc = %-2μ / %-#200= 63% / 88% = 0.716 (100) = 71.6%

3. Determine Zone using the Mineral Classification Chart (Figure 1):
   The soil sample plots in Zone II (see attached)

4. Calculate the Activity Ratio (PI / %fc):
   PI / %fc = 51 / 71.6 = 0.71 (Note %fc is a percentage)

5. Calculate LL / %fc:
   LL / %fc = 75 / 71.6 = 1.05 (Note %fc is a percentage)

6. Determine γ_o using the Zone II chart (Figure 3):

   γ_o = 0.11 (see attached)

7. Calculate γ_h:

   $\gamma_{h\ swell} = \gamma_o\, e^{\gamma o}$ (%fc/100) = 0.11 $e^{0.11}$ (71.6 / 100) = 0.088

   $\gamma_{h\ shrink} = \gamma_o\, e^{-\gamma o}$ (%fc/100) = 0.11 $e^{-0.11}$ (71.6 / 100) = 0.071

8. Calculate S:
   S = -20.29 + 0.1555 (LL) – 0.117 (PI) + 0.0684 (%-#200)
   S = -20.29 + 0.1555 (75) – 0.117 (51) + 0.0684 (88)
   S = -8.575

9. Calculate Unsaturated Diffusion Coefficient (α):

APPENDIX A

SAMPLE CALCULATION USING STRESS CHANGE FACTORS (TABLE II) with swelling and shrinking suction profile changes starting at the Equilibrium Profile (Post-Equilibrium Case)

α_{swell} = 0.0029 – 0.000162 (S) – 0.0122 (γ_h swell)

α_{swell} = 0.0029 – 0.000162 (-8.575) – 0.0122 (0.088)

α_{swell} = 0.0032 = 3.2×10^{-3}

α_{shrink} = 0.0029 – 0.000162 (S) – 0.0122 (γ_h shrink)

α_{shrink} = 0.0029 – 0.000162 (-8.575) – 0.0122 (0.071)

α_{shrink} = 0.0034 = 3.4×10^{-3}

10. Fabric Factor (Ff):
    Ff = 1.0

11. Calculate Modified Unsaturated Diffusion Coefficient (α'):
    $\alpha'_{swell} = \alpha_{swell}$ (Ff) = 0.0032 (1.0) = 0.0032 = 3.2×10^{-3}
    $\alpha'_{shrink} = \alpha_{shrink}$ (Ff) = 0.0034 (1.0) = 0.0034 = 3.4×10^{-3}

12. Determine Thornthwaite Moisture Index (I_m) from PTI Manual (1996) (Figure A.3.2 and A.3.3 a and b):
    I_m = -14

13. Determine e_m based on I_m for center and edge lift (Figure 6):
    e_m center (I_m) = 5.0 ft (see attached)
    e_m edge (I_m) = 2.7 ft (see attached)

14. Determine e_m based on α' for center and edge lift:
    e_m center (α'_{shrink}) = 6.1 ft (see attached)
    e_m edge (α'_{swell}) = 3.2 ft (see attached)

15. Use maximum values of e_m:
    e_m center = 6.1 ft
    e_m edge = 3.2 ft

APPENDIX A

SAMPLE CALCULATION USING STRESS CHANGE FACTORS (TABLE II) with swelling and shrinking suction profile changes starting at the Equilibrium Profile (Post-Equilibrium Case)

Determine Y_m

1. Determine Measured Suction at Depth:
   Using the PTI Manual (1996) Constant Soil Suction versus Thornthwaite Index Chart (Figure A.3.6) the Suction at Depth = 3.6 pF

2. Determine Dryest Suction:
   Dryest Suction = 4.5 pF

3. Determine Wettest Suction:
   Wettest Suction = 2.5 pF

4. Determine Stress Change Factors (SCF) for center and edge Lift (Table II):
   SCF – center = -15.8
   SCF – edge = +27.1 (see attached)

5. Calculate y_m for center and edge lift:

   y_m center = (SCF-center) ($\gamma_{h\ shrink}$) = (-15.8) (0.071) = -1.12 in (use +1.12 in for y_m center)

   y_m edge = (SCF-edge) ($\gamma_{h\ swell}$) = 27.1 (0.088) = 2.38 in

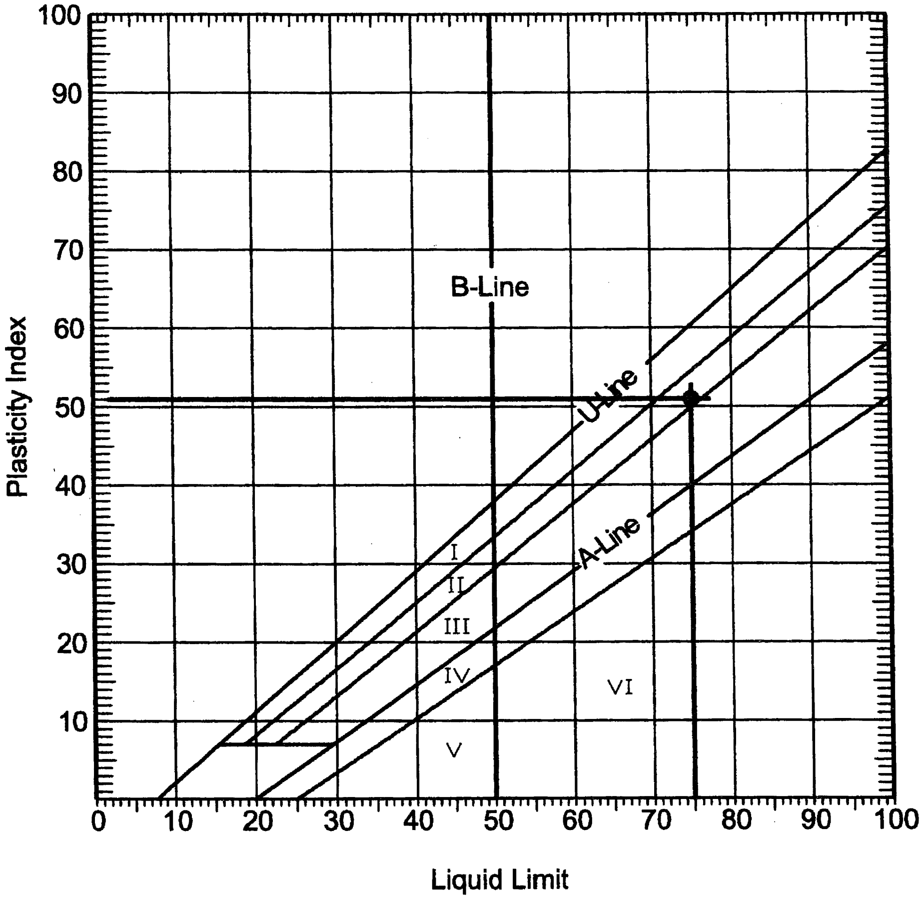
<u>Soil Parameter Summary</u>

e_m center = 6.1 ft
e_m edge = 3.2 ft
y_m center = 1.12 in
y_m edge = 2.38 in

APPENDIX A

Sample Calculation

Figure 1 - Mineral Classification Chart



APPENDIX A

Figure 2 – Zone I Chart for Determining γ_o

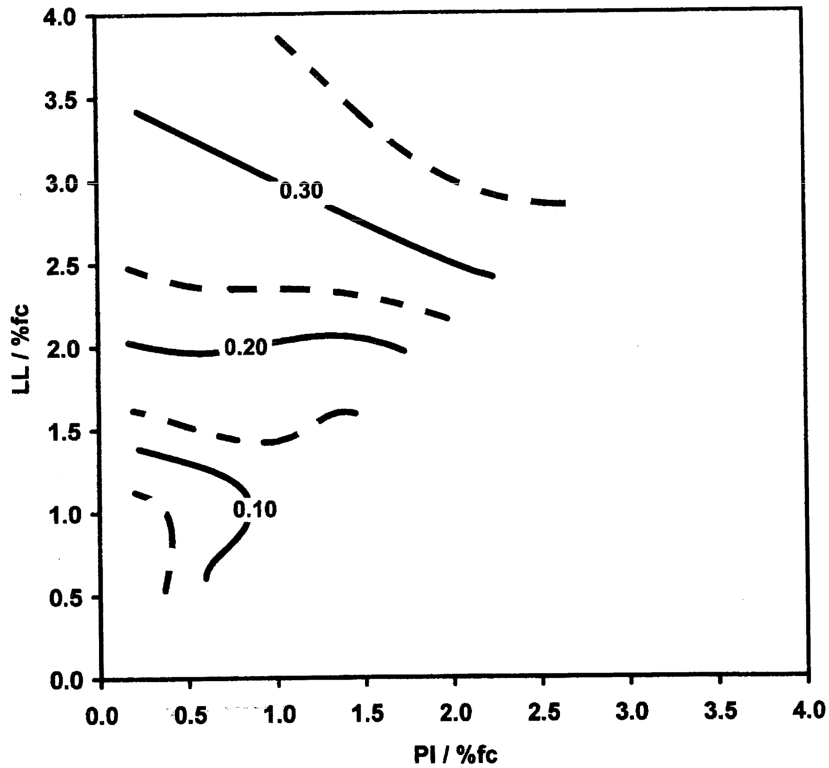
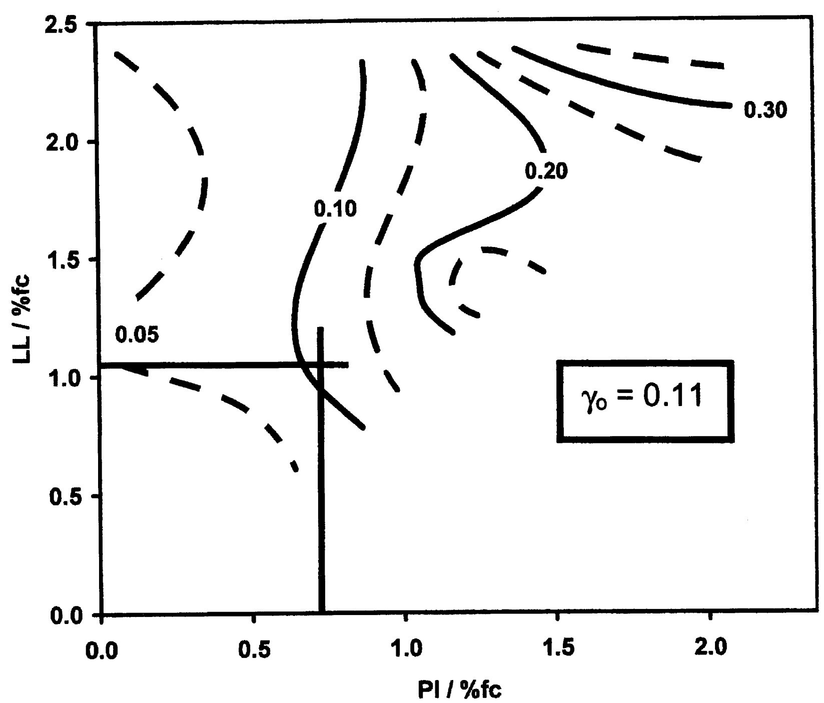
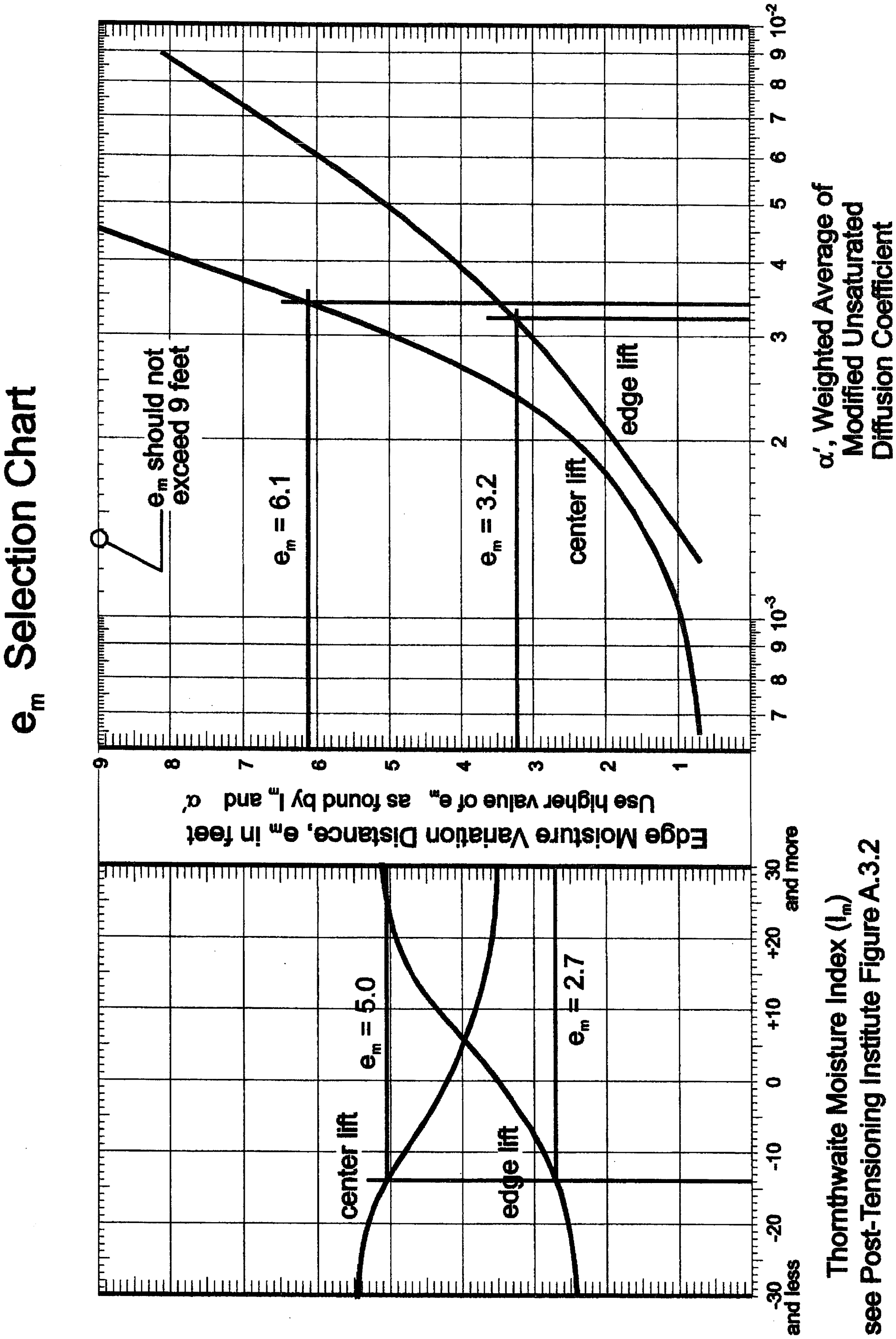


Figure 3 – Zone II Chart for Determining γ_o



SAMPLE CALCULATION



APPENDIX A

SAMPLE CALCULATION

Measured suction (pF) at Depth z	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 Edge = +27.1
SCF Center = -15.8

APPENDIX B

SAMPLE CALCULATION USING VOLFLO Win 1.0
with swelling and shrinking suction profile changes starting at the Equilibrium Profile (Post-Equilibrium Case)

Laboratory Results and other Inputs

LL = 75
PL = 24
% passing 200 sieve (%-#200) = 88%
% passing 2 micron (%-2μ) = 63%
Fabric Factor (Table 1) from examination of sample = 1.0
Location: Austin, Texas
Soil Profile: Homogeneous
Soil Unit Weight: 120 PCF
Ko drying = 0.33
Ko wetting = 0.67

Soil Parameter Summary

e_m center = 6.1 feet
e_m edge = 3.2 feet
y_m center = 1.09 inches
y_m edge = 2.31 inches

Note: The differences in results are due to simplifying assumptions used to generate the Stress Change Factors (Table II).

APPENDIX B

Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Swelling
Project Engineer :

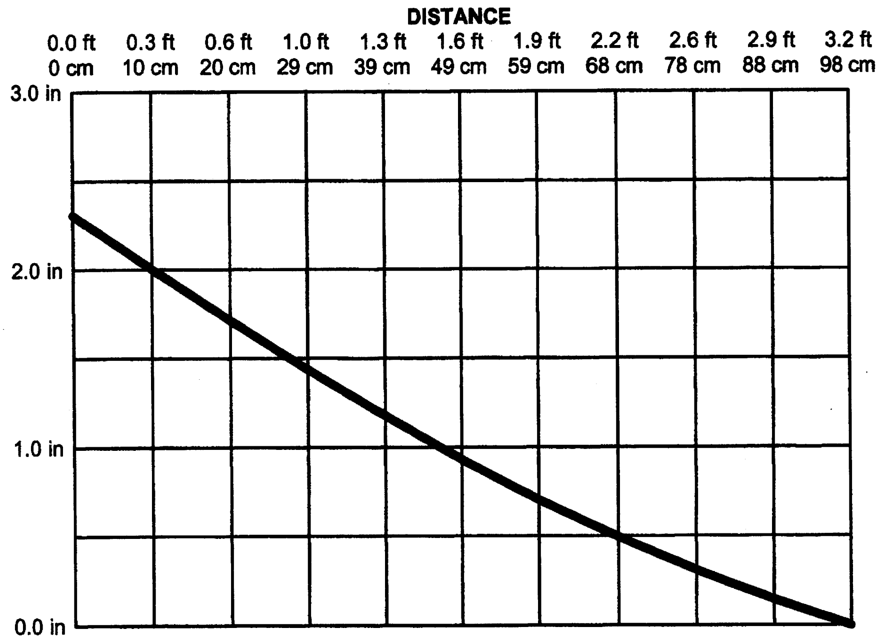
Project Number :
Project Date : June 30, 2002

Geotechnical Report :

Report Date :
Report Number :

SWELL CALCULATION

Ym Edge (Swell) = 2.31 inches (5.86 centimeters)
Em Edge = 3.20 feet (97.54 centimeters)



	Swell at Slab Edge	Swell at distance X from edge of slab									Swell at Em
	0.0 ft	0.3 ft	0.6 ft	1.0 ft	1.3 ft	1.6 ft	1.9 ft	2.2 ft	2.6 ft	2.9 ft	3.2 ft
	0 cm	10 cm	20 cm	29 cm	39 cm	49 cm	59 cm	68 cm	78 cm	88 cm	98 cm
inches	2.31	2.00	1.71	1.44	1.18	0.93	0.70	0.50	0.31	0.14	0.00
cm	5.86	5.09	4.35	3.65	2.99	2.36	1.79	1.26	0.78	0.36	0.00

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APPENDIX B

Build 052902

VOLFLO Win 1.0

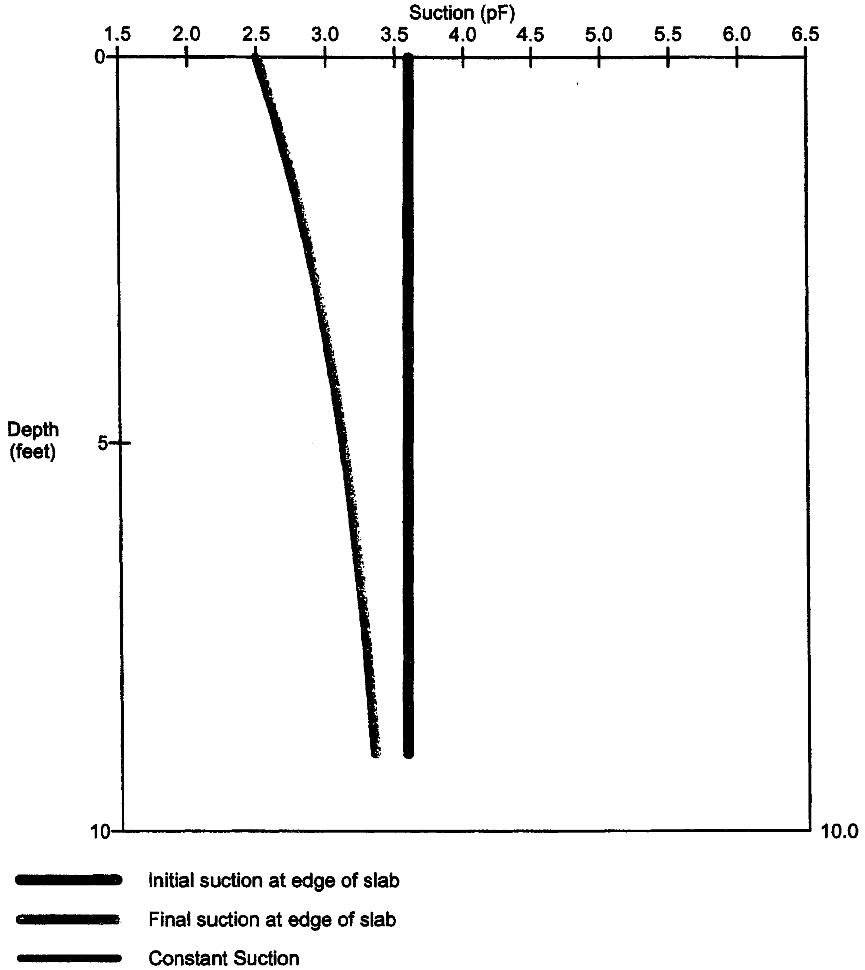
Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUCTION PROFILES



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Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002

Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Soil Properties

Layer Thickness and description

Layer Number	Layer Thickness	Depth to Bottom	Layer Description
1	10.0 ft	10.0 ft	

Layer Geotechnical Properties

Layer Number	Liquid Limit	Plastic Limit	% Pass. #200	% Finer 2 mic.	Density (lb/ft^3)	Gamma 100	Ko Drying	Ko Wetting	Fabric Factor
1	75	24	88	63	120.0	0.12	0.33	0.67	1.0

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Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Suction at Edge of Slab

Initial Suction Profile — Constant Suction Profile

Final Suction Profile — Default Wet Design Envelope

Suction value at surface	2.5 pF

Constant Suction

Constant suction :	3.6 pF
Depth to constant suction :	9.0 ft

Moisture Barriers

Vertical barrier depth :	0.0 ft
Apply vertical barrier to :	Neither Profile
Horizontal barrier length :	0.0 ft

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Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Em

Em Distance

User Input :

Center Lift	6.1 ft
Edge Lift	3.2 ft

Suction Profile at Em ---- Constant Suction Profile

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Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

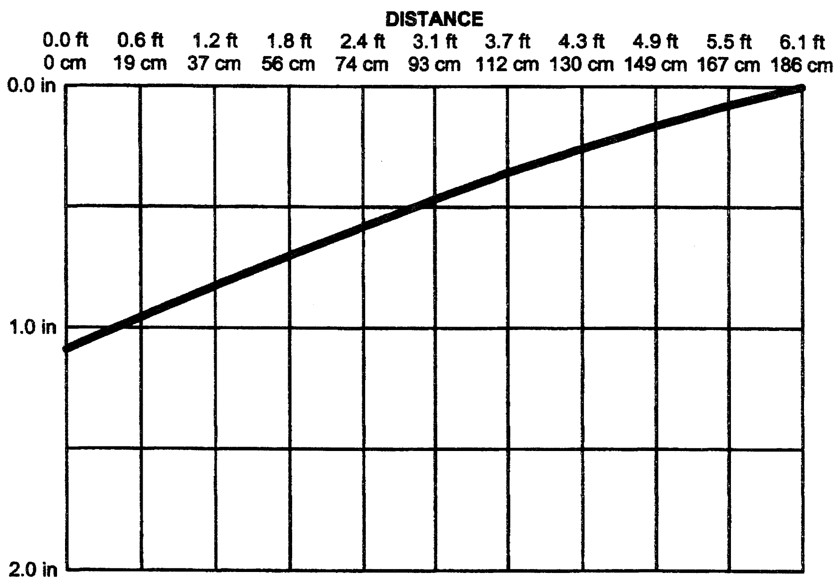
Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Shrinking
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SHRINK CALCULATION

Ym Center (Shrink) =	**-1.09 inches**	**(-2.77 centimeters)**
Em Center =	**6.10 feet**	**(185.93 centimeters)**



	Shrink at Slab Edge	Shrink at distance X from edge of slab									Shrink at Em
	0.0 ft	0.6 ft	1.2 ft	1.8 ft	2.4 ft	3.1 ft	3.7 ft	4.3 ft	4.9 ft	5.5 ft	6.1 ft
	0 cm	19 cm	37 cm	56 cm	74 cm	93 cm	112 cm	130 cm	149 cm	167 cm	186 cm
inches	-1.09	-0.96	-0.83	-0.70	-0.58	-0.47	-0.36	-0.26	-0.16	-0.08	0.00
cm	-2.77	-2.43	-2.10	-1.78	-1.47	-1.18	-0.91	-0.65	-0.41	-0.20	0.00

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APPENDIX B

Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Shrinking
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
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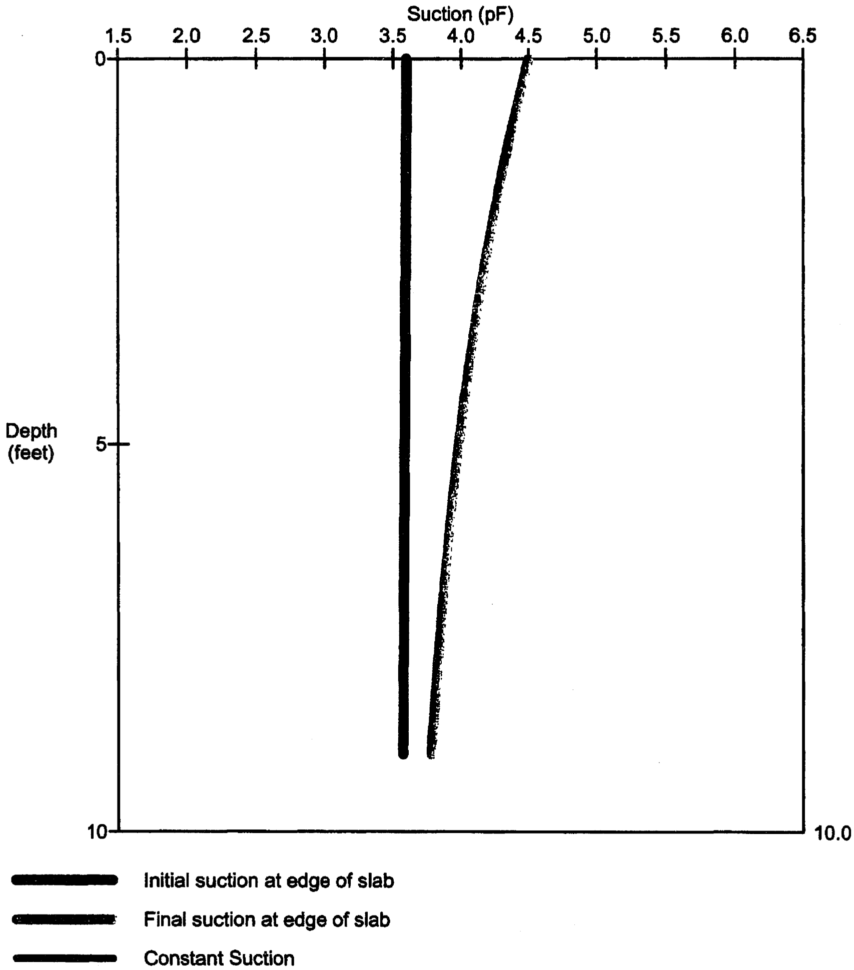
SUCTION PROFILES



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Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Shrinking
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Soil Properties

Layer Thickness and description

Layer Number	Layer Thickness	Depth to Bottom	Layer Description
1	10.0 ft	10.0 ft	

Layer Geotechnical Properties

Layer Number	Liquid Limit	Plastic Limit	% Pass. #200	% Finer 2 mic.	Density (lb/ft^3)	Gamma 100	Ko Drying	Ko Wetting	Fabric Factor
1	75	24	88	63	120.0	0.10	0.33	0.67	1.0

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APPENDIX B

Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Shrinking
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Suction at Edge of Slab

Initial Suction Profile — Constant Suction Profile

Final Suction Profile — Default Dry Design Envelope

Suction Value at Surface :	4.5 pF

Constant Suction

Constant suction :	3.6 pF
Depth to constant suction :	9.0 ft

Moisture Barriers

Vertical barrier depth :	0.0 ft
Apply vertical barrier to :	Neither Profile
Horizontal barrier length :	0.0 ft

Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

Registered To :

Serial Number : 200-100-999

Project Title : Sample Calculation - Post Equilibrium Case - Shrinking
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Em

Em Distance

User Input :

Center Lift	6.1 ft
Edge Lift	3.2 ft

Suction Profile at Em — Constant Suction Profile

Page 5 of 5

APPENDIX C

SAMPLE CALCULATION USING VOLFLO Win 1.0
with swelling and shrinking suction profile changes starting at Extreme Wet or Dry Profiles (Post-Construction Case)

Laboratory Results and other Inputs

LL = 75
PL = 24
% passing 200 sieve (%-#200) = 88%
% passing 2 micron (%-2μ) = 63%
Fabric Factor (Table 1) from examination of sample = 1.0
Location: Austin, Texas
Soil Profile: Homogeneous
Soil Unit Weight: 120 PCF
Ko drying = 0.33
Ko wetting = 0.67
Suction Profiles: Wetting - 4.5 pF to 2.9 pF
Drying – 2.9 pF to 4.5 pF

Soil Parameter Summary

e_m center = 6.1 feet
e_m edge = 3.2 feet
y_m center = 2.25 inches
y_m edge = 3.81 inches

Note: The differences in results from the other sample calculations are in a major way due to using extreme suction profiles. This case could control if the soil surface is very dry or very wet at the time of construction. Interior equilibrium suction profiles may not be reached for several years.

Build 052902

VOLFLO Win 1.0

Geostructural Tool Kit, Inc.

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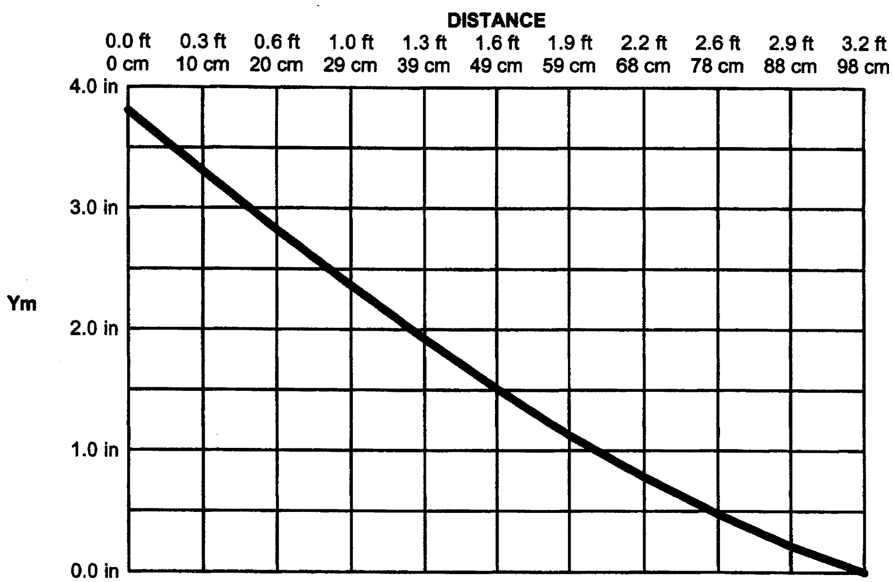
Report Date :
Report Number :

SWELL CALCULATION

Ym Edge (Swell) = 3.81 inches (9.67 centimeters)
Em Edge = 3.20 feet (97.54 centimeters)



	Swell at Slab Edge	Swell at distance X from edge of slab									Swell at Em
	0.0 ft 0 cm	0.3 ft 10 cm	0.6 ft 20 cm	1.0 ft 29 cm	1.3 ft 39 cm	1.6 ft 49 cm	1.9 ft 59 cm	2.2 ft 68 cm	2.6 ft 78 cm	2.9 ft 88 cm	3.2 ft 98 cm
inches	3.81	3.31	2.82	2.36	1.92	1.51	1.13	0.78	0.48	0.22	0.00
cm	9.67	8.40	7.17	6.00	4.88	3.84	2.87	1.99	1.21	0.55	0.00

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Build 052902

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Project Engineer :
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Project Date : June 30, 2002
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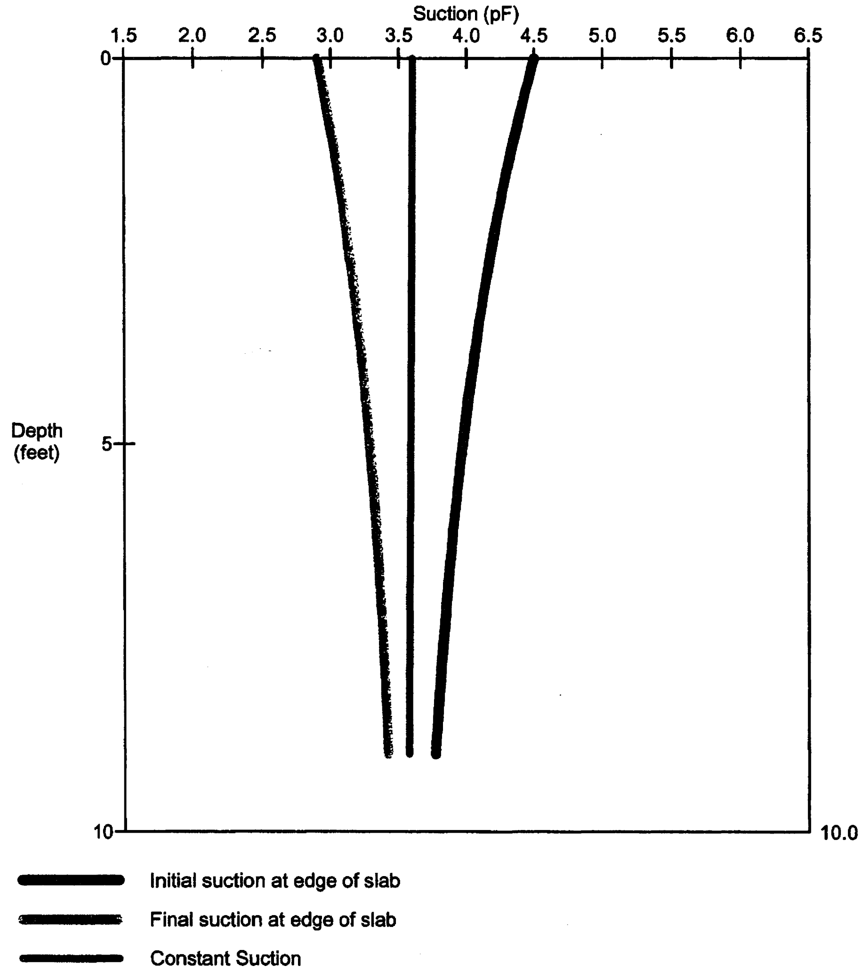
SUCTION PROFILES



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Project Title : Sample Calculation - Extreme Post Construction Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Soil Properties

Layer Thickness and description

Layer Number	Layer Thickness	Depth to Bottom	Layer Description
1	10.0 ft	10.0 ft	

Layer Geotechnical Properties

Layer Number	Liquid Limit	Plastic Limit	% Pass. #200	% Finer 2 mic.	Density (lb/ft^3)	Gamma 100	Ko Drying	Ko Wetting	Fabric Factor
1	75	24	88	63	120.0	0.12	0.33	0.67	1.0

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Build 052902

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Project Title : Sample Calculation - Extreme Post Construction Case - Swelling
Project Engineer :
Project Number :
Project Date : June 30, 2002
Geotechnical Report :
Report Date :
Report Number :

SUMMARY OF INPUT DATA - Suction at Edge of Slab

Initial Suction Profile --- Default Dry Design Envelope

Suction value at surface :	4.5 pF

Final Suction Profile --- Default Wet Design Envelope

Suction value at surface	2.9 pF

Constant Suction

Constant suction :	3.6 pF
Depth to constant suction :	9.0 ft

Moisture Barriers

Vertical barrier depth :	0.0 ft
Apply vertical barrier to :	Neither Profile
Horizontal barrier length :	0.0 ft

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SUMMARY OF INPUT DATA - Em

Em Distance

User Input :

Center Lift	6.1 ft
Edge Lift	3.2 ft

Suction Profile at Em — Constant Suction Profile

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APPENDIX C

Build 052902

VOLFLO Win 1.0

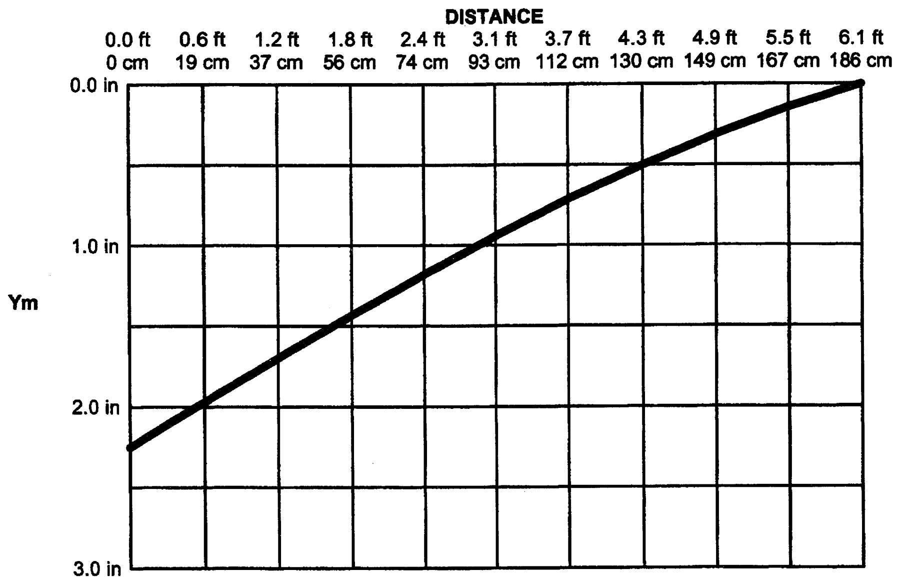
Geostructural Tool Kit, Inc.

Registered To : Serial Number : 200-100-999

Project Title : Sample Calculation - Extreme Post Construction Case - Shrinking
Project Engineer : Project Number :
Project Date : June 30, 2002
Geotechnical Report : Report Date :
Report Number :

SHRINK CALCULATION

Ym Center (Shrink) = -2.25 inches (-5.72 centimeters)
Em Center = 6.10 feet (185.93 centimeters)



	Shrink at Slab Edge	Shrink at distance X from edge of slab									Shrink at Em
	0.0 ft	0.6 ft	1.2 ft	1.8 ft	2.4 ft	3.1 ft	3.7 ft	4.3 ft	4.9 ft	5.5 ft	6.1 ft
	0 cm	19 cm	37 cm	56 cm	74 cm	93 cm	112 cm	130 cm	149 cm	167 cm	186 cm
inches	-2.25	-1.97	-1.70	-1.43	-1.18	-0.94	-0.71	-0.50	-0.31	-0.14	0.00
cm	-5.72	-5.01	-4.31	-3.64	-3.00	-2.39	-1.81	-1.28	-0.79	-0.36	0.00

Page 1 of 5

Build 052902

VOLFLO Win 1.0

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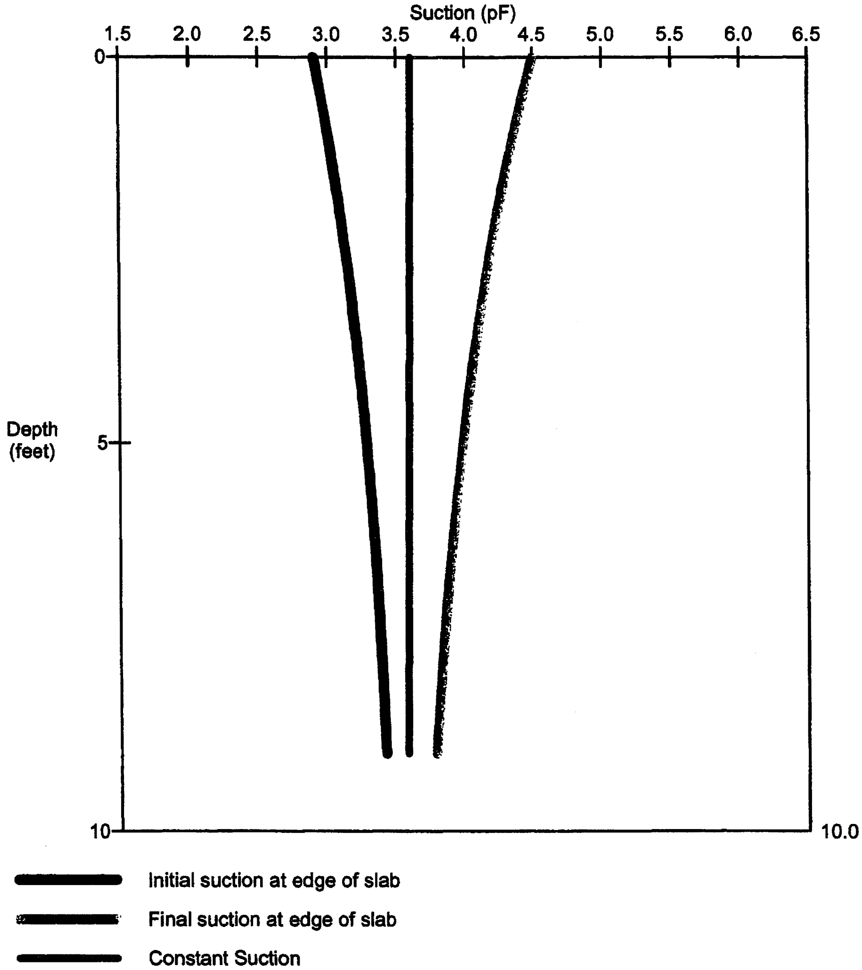
SUCTION PROFILES



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Project Title : Sample Calculation - Extreme Post Construction Case - Shrinking
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SUMMARY OF INPUT DATA - Soil Properties

Layer Thickness and description

Layer Number	Layer Thickness	Depth to Bottom	Layer Description
1	10.0 ft	10.0 ft	

Layer Geotechnical Properties

Layer Number	Liquid Limit	Plastic Limit	% Pass. #200	% Finer 2 mic.	Density (lb/ft^3)	Gamma 100	Ko Drying	Ko Wetting	Fabric Factor
1	75	24	88	63	120.0	0.10	0.33	0.67	1.0

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Project Title :	Sample Calculation - Extreme Post Construction Case - Shrinking		
Project Engineer :		Project Number :	
		Project Date :	June 30, 2002
Geotechnical Report :		Report Date :	
		Report Number :	

SUMMARY OF INPUT DATA - Suction at Edge of Slab

Initial Suction Profile — Default Wet Design Envelope

Suction value at surface :	2.9 pF

Final Suction Profile — Default Dry Design Envelope

Suction Value at Surface :	4.5 pF

Constant Suction

Constant suction :	3.6 pF
Depth to constant suction :	9.0 ft

Moisture Barriers

Vertical barrier depth :	0.0 ft
Apply vertical barrier to :	Neither Profile
Horizontal barrier length :	0.0 ft

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SUMMARY OF INPUT DATA - Em

Em Distance

User Input :

Center Lift	6.1 ft
Edge Lift	3.2 ft

Suction Profile at Em — Constant Suction Profile

POST-TENSIONING INSTITUTE

Technical Notes

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