

Standard Requirements for Analysis of Shallow Concrete Foundations on Expansive Soils

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1.0 - SCOPE

This standard provides minimum requirements for determining moments, shears and deflections for design of shallow concrete foundations on expansive soils that are subjected to climatic changes in soil moisture conditions. Internal forces and deflections specified in this standard shall be used for design of all ribbed and uniform thickness foundations within limitations specified in **4.0** through **4.5**.

R1.0 - SCOPE

This standard is based upon state-of-the-art principles of unsaturated soil mechanics for predicting support conditions, internal forces and deflections affecting shallow concrete foundations built on and interacting with expansive soils.

The soil-structure interaction codified herein is applicable to all shallow foundations built on expansive soils, regardless of type of reinforcement (prestressed or non-prestressed), within the limitations stated herein. Design methods for concrete foundations on expansive soils which yield smaller values of internal forces and deflections than those specified in this standard may result in inadequate foundation strength and underestimation of differential deflections.

The typical foundation design procedure for shallow concrete foundations on expansive soils involves the following: 1) determine primary soil parameters e_m and γ_m using this standard; 2) calculate superstructure loading, 3) select preliminary slab thickness and rib width, depth, and spacing; 4) calculate internal forces and deflections using the equations in **7.0**, **8.0**, and **9.0** of this standard; 5) determine the type, amount, and placement of foundation reinforcing, which is not addressed in this standard but can be accomplished with any generally accepted design procedure. If the results do not satisfy project design limits for internal forces and deflections, modify steps 2-5 until acceptable results are achieved.

On a properly drained, irrigated, and planted site, climatic conditions alone produce the maximum range of soil volume change. On such a site, this range is determined by the wettest and driest the soils at the edge of the slab are likely to become due to rainfall and evapotranspiration. Normal irrigation, when reasonably uniform around the slab perimeter, reduces the maximum range of soil volume change. In the driest climatic condition, normal irrigation prevents the soil from reaching the minimum volume which could result from climatic conditions

alone. In the wettest condition, irrigation is not normally used; therefore, it does not affect the maximum soil volume which results from climatic conditions alone. Design of foundations on an unusually wet or dry soil (due to drought or extended rainfall) may require consideration of soil profiles with extreme swell or shrink movements.

1.1 This standard is based upon "*Design of Post-Tensioned Slabs-on-Ground*", 3rd Edition, Post-Tensioning Institute, Phoenix, Arizona, 2004, Addendum No. 1, May 2007 and Addendum No. 2, May 2008. The user is referred to those documents and the commentary to this standard for background and interpretational information which clarify its application.

2.0 - NOTATION AND ABBREVIATIONS

2.1 Notation

b = Rib width, in.

E_c = Modulus of elasticity of concrete = $33w^{1.5}\sqrt{f'_c}$
psi

E_{cr} = Long-term or creep modulus of elasticity of concrete, psi. May be taken as one-half of E_c

E_{st} = Modulus of elasticity of non-prestressed reinforcement, psi

e_m = Edge moisture variation distance, distance measured inward from slab edge in which soil moisture content varies, ft

e = Base of natural (Naperian) logarithms

f_c = Fine clay

f'_c = Specified compressive strength of concrete, psi

F_f = Fabric factor used to modify unsaturated diffusion coefficient (α) for presence of roots, layers, fractures, and joints (See **Table 1**).

h = Total depth of rib, measured from top surface of slab to bottom of rib, in.

H = Thickness of a uniform thickness foundation, in.

I = Gross moment of inertia of cross-section, in⁴

I_e = Moment of inertia of transformed (cracked) cross-section using $E_{st}/E_c = 10$

I_m = Thornthwaite Moisture Index

L = Total slab length (or total length of design rectangle) in direction being considered (short or long), perpendicular to W , ft

L_L = Long dimension of design rectangle, ft

L_S = Short dimension of design rectangle, ft

M_L = Maximum applied service load moment in long direction from either center lift or edge lift swelling condition, positive if producing tension at bottom of foundation (edge lift), negative if producing tension at top of foundation (center lift), ft-kips/ft

M_S = Maximum applied service load moment in short direction from either center lift or edge lift swelling condition, positive if producing tension at bottom of foundation (edge lift), negative if producing tension at top of foundation (center lift), ft-kips/ft

P = A uniform unfactored service line load acting along entire length of the perimeter ribs representing weight of exterior wall and that portion of the superstructure dead and live loads which frame into exterior wall, excluding any portion of foundation concrete weight, lb/ft. When P varies significantly use largest value for center lift and smallest value for edge lift (see **4.3.3**).

pF = Soil suction value, the common logarithm of the height of water (in cm) that suction energy can support

S = Interior stiffening rib spacing used for moment and shear equations, ft. (see **4.3.2.2**)

SF = Shape Factor = $\frac{(\text{Foundation Perimeter})^2}{(\text{Foundation Area})}$
 where foundation perimeter is in ft and foundation area is in ft²

S_S = Slope of suction vs. volumetric water content curve³

t = Slab thickness in a ribbed foundation, in.

V = Controlling shear force under service load, larger of V_S or V_L , kips/ft

V_L = Maximum shear force in long direction under service load from either center lift or edge lift swelling condition, kips/ft

V_S = Maximum shear force in short direction under service load from either center lift or edge lift swelling condition, kips/ft

w = Unit weight of concrete, lb/ft³

W = Foundation width (or width of design rectangle) in direction being considered (short or long), perpendicular to L , ft

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

α' = Unsaturated diffusion coefficient modified by soil fabric factor, $\alpha' = \alpha F_f$

α'_{swell} = α' value for edge lift swell condition (swelling)

α'_{shrink} = α' value for center lift swell condition (shrinkage)

Δ_0 = Expected differential deflection of foundation, in.

y_m = Maximum unrestrained differential soil movement, in.

$y_{m \text{ swell}}$ = y_m value for edge lift swell condition (swelling), in.

$y_{m \text{ shrink}}$ = y_m value for center lift swell condition (shrinkage), in.

z_m = Depth below soil surface at which the suction varies by less than $0.027pF$ /ft

β = Approximate distance from edge of slab to point of maximum moment and/or shear, a function of the relative stiffness of the soil and the foundation, $= \frac{1}{12} \sqrt[4]{\frac{E_c I}{1,000}}$ ft

γ_0 = Change of soil volume for a unit change in suction for 100% fine clay

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

$\gamma_{h \text{ mod}}$ = γ_h weighted for layered soils

$\gamma_{h \text{ mod swell}}$ = $\gamma_{h \text{ mod}}$ value for edge lift swell condition (swelling)

$\gamma_{h \text{ mod shrink}}$ = $\gamma_{h \text{ mod}}$ value for center lift swell condition.(shrinkage)

2.1 Abbreviations

EI = Expansion Index

LL = Liquid Limit, %

PI = Plasticity Index

PL = Plastic Limit, %

SCF= Stress Change Factor, used in determination of γ_m

3.0 - DEFINITIONS

Center Lift = A soil distortion mode wherein soil moisture content at perimeter of foundation is less (drier) than soil beneath the center of the foundation.

Edge Lift = A soil distortion mode wherein soil moisture content at perimeter of foundation is more (wetter) than soil beneath the center of the foundation.

Ribbed Foundation = A foundation system consisting of a uniform thickness slab with ribs satisfying the requirements of **4.3.2** projecting from bottom of slab in both directions. Slab and ribs are considered to act monolithically.

Stiffness = For purposes of this standard, product of E_{cr} and I .

Uniform Thickness Foundation = A foundation system consisting of a solid slab of uniform thickness throughout, with no ribs.

PART 1 - GEOTECHNICAL REQUIREMENTS

4.0 - LIMITATIONS

Internal forces and deflections specified in this standard are based upon criteria in this section.

4.1 - Soils - This standard is applicable to foundations built on soils satisfying each of **4.1.1** through **4.1.4**, except that tests to show compliance with Items **4.1.1** through **4.1.3** shall not be required if the test prescribed in **4.1.4** is conducted:

4.1.1 - Plasticity Index (PI) is 15 or greater determined in accordance with ASTM D4318 and a weighting procedure using three five foot layers with a weight of three for top layer, two for middle layer and one for the bottom layer, or utilizing the PI of a two foot or thicker layer within the upper five feet having a PI of 15 or greater.

4.1.2 - More than 10 percent of the soil particles pass a No. 200 sieve (75 μm), determined in accordance with ASTM D 422 and a weighting procedure utilizing three 5-ft layers determined using the depth weighting procedures of 4.1.1, disregarding the two foot or thicker layer provisions.

4.1.3 - More than 10 percent of the soil particles are less than 5 micrometers in size, determined in accordance with ASTM D 422 and a weighting procedure utilizing three 5-ft layers determined using the depth weighting procedures of 4.1.1, disregarding the two foot or thicker layer provisions.

4.1.4 - Expansion index (*EI*) greater than 20 determined in accordance with ASTM D 4829 and a weighting procedure utilizing three 5-ft layers determined using the depth weighting procedures of 4.1.1, disregarding the two foot or thicker layer provisions.

R4.0 - LIMITATIONS

Part 1 of the standard consists of Sections **4.0** through **5.3**

R4.1 - Soils - This description of expansive soils is consistent with soil classification criteria presented in IBC 2003 Section 1802.3.2.

4.2 - Rectangular Plan Shape - Foundation plan shape is assumed to be a single square or rectangle. Other shapes shall be modeled with overlapping rectangles that are as large as possible within actual foundation perimeter, with each rectangle analyzed separately. Largest values of internal forces and deflections obtained from analysis of all individual rectangles shall be used for design.

R4.2 - Rectangular Plan Shape - Primary attention should be given to rectangles that most reasonably represents the main portion of the foundation. Long narrow rectangles may not represent the overall foundation and in most cases should not govern the design. See Reference 6 for examples of the overlapping rectangle method.

If SF exceeds 24, the designer should consider modifications to the foundation footprint, strengthened foundation systems, soil treatment to reduce swell or the use of additional non-prestressed reinforcement and/or additional ribs in areas of high torsional stresses. Analysis by finite element procedures may also be used in the case of SF>24. Geotechnical approaches should reduce $y_{m-center}$ to less than 2.0 in. and y_{m-edge} to less than 1.0 in. Techniques to accomplish this could include water injection, lime or chemical injection, removal and replacement with low expansive soil materials or perimeter barriers. Geotechnical analysis should also consider the reduction of e_m by the selected technique. The depth of removal and replacement with low expansive or moisture conditioned materials, or of moisture preconditioned soil depth may be considered as having an effect equal to a perimeter barrier of similar depth, but each treatment approach should be individually evaluated by the geotechnical engineer. When select fill or granular material is used in the removal and replacement method, extreme care needs to be taken so that an undrained “bathtub” is not created.

4.3 - Ribbed Foundations - Internal forces and deflections specified in this standard apply to ribbed foundations conforming to 4.3.1 and 4.3.2.

R4.3 - Ribbed Foundations - Equations in this standard for internal forces and deflections are based upon shallow ribbed foundations. Ribbed foundation variables appearing in these equations are L , S , h , P , e_m , and y_m , all defined in **2.0**. Limitations and constraints for these variables are stated in **4.0**. The equations are valid for ribbed foundations that are in conformance with these limitations. The equations can also be used for uniform thickness foundations. To use the equations for uniform thickness foundations, a theoretical ribbed foundation is defined with any set of conformant geometric parameters (L , S , h), that result in the same stiffness ($E_{cr}I$) as the uniform thickness foundation. When those parameters for the equivalent ribbed foundation are entered into the

4.3.1 - Minimum Slab Thickness - Minimum slab thickness t shall be 4 in.

4.3.2 - Ribs

4.3.2.1 - Minimum Size

(a) Depth - Minimum rib depth h shall be $(t+7)$ in. or 11 in., whichever is greater. When more than one rib depth is used in actual construction, the ratio between the deepest and the shallowest rib depth shall not exceed 1.2.

(b) Width - Rib width b used in section property calculations shall be the actual rib width, subject to a minimum of 6 in. and a maximum of 14 in. Rib widths may vary within the specified ranges.

4.3.2.2 - Spacing - S used in moment and shear equations shall be the average rib spacing if the ratio between the largest and the smallest spacing does not exceed 1.5. If the ratio between the largest and the smallest spacing exceeds 1.5, S used in moment and shear equations shall be 0.85 times the largest spacing. S used in the moment and shear equations shall not be less than 6 ft or greater than 15 ft. The rib spacing used in the section properties shall be the actual rib spacing but not greater than 15 ft.

4.3.2.3 - Continuity - Ribs shall be continuous between the edges of the foundation in both directions.

equations in this standard the resulting internal forces and deflections are applicable to the uniform thickness foundation. After conversion to a uniform thickness foundation, the design should be rechecked to confirm that it satisfies all project limits.

R4.3.2.3 - Continuity - To be considered as a continuous rib in the design rectangle the rib should (a) be continuous, or (b) overlap a parallel rib with adequate length and proximity so as to be effectively continuous, or (c) be connected to a parallel rib by a perpendicular rib which transfers by torsion the bending moment in the rib.

4.3.3 - Perimeter Load - When P varies, and the ratio of largest to smallest value exceeds 1.25, use the largest value for center lift and the smallest value for edge lift.

R4.3.3 - Perimeter Load - The mathematical analysis forming the basis for the equations for internal forces and deflections in this standard⁷ considered perimeter loads between 600 and 1,500 lb/ft. Based upon successful experience with foundations built with perimeter loads up to and exceeding 2,500 lb/ft and designed using these equations, the PTI Slab-on-Ground Committee is confident that the equations will yield reasonable results for perimeter loads in excess of those used in the research. It should be noted that the definition of P includes dead and live load in both swell modes. Removing live load in the edge lift swell mode may result in unnecessarily conservative edge lift moments, since the equations in this standard were derived from foundation deformation computations that considered the foundation loaded with both dead and live load.

In addition to the variable edge load P , internal forces and deflections specified in this standard are based upon uniform applied loads acting on entire foundation plan area of 40 lb/ft² live load and 65 lb/ft² dead load, representing weight of an assumed 4-inch slab plus 15 lb/ft² for non-bearing partitions and other interior dead loads.

4.4 - Uniform Thickness Foundations- Internal forces and deflections specified in this standard apply to uniform thickness foundations with same stiffness as a ribbed foundation conforming to geometric constraints in **4.3**.

4.5 - Stiffness - For designs based upon uncracked cross-sections, flexural concrete tensile stress f_t shall not exceed $6\sqrt{f'_c}$.

For designs based upon cracked sections, moment of inertia I_e of the transformed cross-section used for construction shall not be less than the moment of inertia I based upon gross cross-section properties used in design.

R4.5 - Stiffness - Internal forces and differential deflections specified in this standard in Sections **7.0**, **8.0**, and **9.0** may be used for any type of reinforcement and for cracked or uncracked cross-sections. However, these internal forces and deflections were based upon an analysis that assumed gross concrete section properties, i.e., an uncracked section, and are not valid unless the actual cross section selected for construction maintains that criteria. This can be accomplished by limiting flexural concrete tensile stresses to $6\sqrt{f'_c}$ in a design based upon an uncracked section, or by providing additional reinforcement or additional rib depth in designs based upon cracked sections.

5.0 - SOIL PARAMETERS

e_m and γ_m shall be determined by procedures in **5.1** and **5.2** or **5.3**.

5.1 - Edge Moisture Variation Distance e_m

5.1.1 - For each significant soil layer to a minimum depth of nine feet (greater if justified by geotechnical analysis), determine the following soil parameters:

5.1.1.1 - Liquid Limit = LL

5.1.1.2 - Plastic Limit = PL

5.1.1.3 - Plasticity Index = PI

5.1.1.4 - Percentage of soil passing No. 200 sieve = $\%_{-200}$

5.1.1.5 - Percentage of soil finer than 2 microns = $\%_{-2\mu}$, expressed as a percentage of total sample

5.1.1.6 - Percent fine clay:

$$\%fc = \left(\frac{\%_{-2\mu}}{\%_{-200}} \right) 100$$

5.1.2 - For each significant soil layer described in **5.1.1**, determine γ_h for swelling and shrinkage:

5.1.2.1 - Determine Mineral Classification Zone (I through VI) from **Figure 1**.

5.1.2.2 - Determine γ_0 from **Figures 2-7**.

5.1.2.3 - Calculate mean value of γ_h for actual percentage of fine clays:

$$\gamma_h = \gamma_0 (\%fc) / 100$$

5.1.2.4 - Correct γ_h for swelling or shrinkage:

For swelling (edge lift): $\gamma_h = \gamma_h e^{\gamma_h}$

For shrinkage (center lift): $\gamma_h = \gamma_h e^{-\gamma_h}$

R5.1.1.5 and R5.1.1.6 - For example, assume a total sample weight of 100 grams. 60 grams passes a #200 sieve, and of those 60 grams, 30 grams is smaller than 2 microns.

$$\%_{-200} = (60/100)100 = 60\%,$$

$$\%_{-2\mu} = (30/100)100 = 30\%, \text{ and}$$

$$\%fc = (30/60)100 = 50\%$$

R5.1.2.1 - If data does not fall within one of the six zones, use the nearest zone.

R5.1.2.2 - Interpolate between γ_0 lines. Beyond extreme contour values, use the nearest values for γ_0 . **Figures 1-7** were derived from National Soil Survey Center, USDA².

5.1.3 - For each significant soil layer described in **5.1.1**, calculate Modified Unsaturated Diffusion Coefficient α' for swelling and shrinkage:

$$\alpha'_{\text{swell}} = (0.0029 - 0.000162S_s - 0.0122\gamma_{h \text{ swell}})F_f$$

$$\alpha'_{\text{shrink}} = (0.0029 - 0.000162S_s - 0.0122\gamma_{h \text{ shrink}})F_f$$

where F_f is determined from **Table 1** and:

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

5.1.4 - For layered soils, calculate α' for swelling and shrinkage for each layer down to nine feet (or more if justified by geotechnical analysis). Divide the total soil profile into three sections, the top third, the middle third, and the bottom third. Soil layers, or parts of layers, within the top, middle, and bottom thirds of the soil profile shall be assigned a weighting factor of 3, 2, and 1 respectively. The weighted average of α' shall be determined for each swell mode as the sum of the products of the weighting factor times the thickness of the layer (or part of layer) times the value of α' for that layer divided by the sum of the products of the weighting factor times the thickness of the layer (or part of layer).

5.1.5 - Determine e_m for center lift and edge lift swell modes from **Figure 8**, using larger value from I_m or α' charts (using weighted α' as described in **5.1.4**).

5.1.5.1 - It shall be permitted to reduce e_m with vertical moisture barriers, properly designed to prevent significant moisture migration, around entire foundation perimeter. Reductions in e_m as a function of vertical moisture barrier depth shall be taken from **Table 3**.

5.2 - Differential Soil Movement γ_m

5.2.1 - γ_m shall be determined using computer methods that determine change in soil surface elevation at two locations separated by a distance e_m . Analysis shall model a layered soil profile with measured or estimated changes in

R5.1.4 - The weighting protocol is described in Section 3.2.9 of Reference 6. A specific example, with calculations, is presented in Section 3.6.3 of the same reference.

R5.2.1 - A commercially available computer program (VOLFLO) for determining γ_m in accordance with **5.2.1** is cited in Reference 5. In the absence of specific recommendations, controlling soil suction values at the ground surface are recommended as follows:

soil suction profile envelopes considering effects of trees, edge barriers, flower beds, irrigation, water tables and osmotic suction due to salts.

5.2.2 - In lieu of computer methods, it shall be permitted to calculate γ_m as follows:

1. Wettest: $3.0 pF$ which is a typical low value for a well drained site. A $2.5 pF$ is an extreme suction value that may be used to model long term saturation conditions, and should not be used for typical design conditions.

2. Driest: $4.5 pF$ which is a typical high value to be used for normal design conditions. A value of $6.0 pF$ is an extreme upper bound representing long term sun-baked bare ground and should not be used for typical design conditions.

3. In general, typical design practice for the Post-Construction Case should use a suction variance at the ground surface of $1.5 pF$ from wettest to driest or vice-versa. This design case is recommended for geographical areas with Thornthwaite Indices between +15 and -15. The Post-Construction Case assumes swell is calculated from the extreme dry profile to the extreme wet profile, with the reverse used for shrink.

4. Geographical areas with Thornthwaite Indices drier than -15 and wetter than +15 should generally use the Post-Equilibrium Case. Unless compelling geotechnical analysis indicates otherwise, a suction profile change of $1.5 pF$ should be used with the changes between equilibrium and dry and equilibrium and wet profiles allocated per local practice. In this case, swell ($\gamma_{m \text{ edge}}$) would be calculated from equilibrium to the wet profile and shrink ($\gamma_{m \text{ center}}$) would be calculated from equilibrium to the dry profile.

Controlling soil suction values below soil surface are as follows:

1. High Water Table: $2.0 pF$ at the water level unless there is a high osmotic component, in which case, use measured value of suction.

2. Climate-Controlled Suction: Determine by measurement at a depth below which the suction varies by less than $0.027 pF/ft$ (the Z depth).

3. Tree Root Zone: $4.5 pF$ under driest condition, tree near wilting point.

4. High Osmotic Suction or Cemented Soil: These suction values must be determined by measurement.

R5.2.2 - This method should only be used if a typical trumpet-shaped final suction profile can be assumed, and γ_h does not vary by more than 10% between layers in the soil profile. Otherwise, this method may not be accurate.

Table 2a assumes the initial suction to be at equilibrium from depth Z_m to the ground surface, then becoming wet or dry. This limitation would not yield accurate or

5.2.2.1 - For layered soils, calculate a weighted γ_h value ($\gamma_{h \text{ mod}}$) for swelling and shrinkage for each layer down to nine feet (or more if justified by geotechnical analysis). Divide the total soil profile into three sections: the top third, the middle third and the bottom third. Soil layers, or parts of layers, within the top, middle and bottom thirds of the soil profile shall be assigned a weighting factor of 3, 2 and 1 respectively. $\gamma_{h \text{ mod}}$ shall be determined, for each swell mode, as the sum of the products of the weighting factor times the thickness of the layer (or part of the layer) times the value of γ_h for that layer divided by the sum of the products of the weighting factor times the thickness of the layer (or part of layer). y_m for each swell mode shall be taken as:

$$y_{m \text{ swell}} = \gamma_{h \text{ mod swell}} (SCF)$$

$$y_{m \text{ shrink}} = \gamma_{h \text{ mod shrink}} (SCF)$$

5.2.2.2 - If γ_h varies by more than 10%, a computer modeling program is required to accurately calculate y_m . Non-expansive layers may be modeled using γ_h equal to 0.01.

5.3 - Alternatively, e_m and y_m shall be permitted to be calculated by the method specified in Appendix A.3 of "*Design and Construction of Post-Tensioned Slabs-on-Ground*", 2nd Edition, Post-Tensioning Institute, Phoenix, Arizona .1996⁴ until January 1, 2009. After this date, all new calculations of e_m and y_m shall be performed in accordance with **5.1** and **5.2** of this standard.

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.

R5.3 - The method for calculating e_m and y_m specified in **5.1** and **5.2** is the most current method available and was developed subsequent to the publication of the 2nd Edition in 1996. It is intended that this current method replace the method specified in **5.3**, which has been in the PTI document since it was first published in 1980. As with all updated technology, a transition period is advisable during which the current method replaces the old method. Thus the PTI Slab-on-Ground Committee recommends permitting the use of both methods in this standard until January 1, 2009, after which time, all new soil analyses must be done in accordance with Sections

PART II - SOIL-STRUCTURE ANALYSIS REQUIREMENTS

6.0 - METHOD OF CALCULATION

Internal forces and deflections shall be computed based upon **6.1** or **6.2**.

6.1 - Internal forces and deflections shall be calculated with equations specified in **7.0**, **8.0** and **9.0**.

6.2 - Alternatively, compute internal forces and deflections using a properly substantiated finite element analysis which considers the interaction of the foundation and the soil, and incorporates the e_m and y_m values determined in accordance with **5.0**.

7.0 - FLEXURE

Maximum bending moments shall be as specified in **7.1** and **7.2**:

7.1 - Center Lift

7.1.1 - Long Direction

$$M_L = A_o (Be_m^{1.238} + C)$$

where:

$$A_o = \frac{1}{727} (L^{0.013} S^{0.306} h^{0.686} P^{0.534} y_m^{0.193})$$

5.1 and 5.2 of this standard. However, the intent is not that existing soils analyses and the related determination of e_m and y_m be redone unless otherwise required by local codes and standards.

If e_m and y_m are calculated using the 2nd Edition method in accordance with this section, then the foundation must be designed using the 2nd Edition structural design procedure as required by Section 1.1 of the *Standard Requirements for Design of Shallow Post-Tensioned Concrete Foundations on Expansive Soils*.

Part II includes Sections **6.0 - 9.2**.

R7.0 - FLEXURE

See Reference 7 for background and derivations of the equations specified in **7.0**.

and for $0 \leq e_m \leq 5$:

$$B = 1 \text{ and } C = 0$$

and for $e_m > 5$:

$$B = \frac{y_m - 1}{3} \leq 1.0$$

$$C = \left(8 - \frac{P - 613}{255} \right) \left(\frac{4 - y_m}{3} \right) \geq 0$$

7.1.2 - Short Direction

For $L_V/L_S \geq 1.1$:

$$M_S = \left(\frac{58 + e_m}{60} \right) M_L$$

For $L_V/L_S < 1.1$:

$$M_S = M_L$$

7.2 - Edge Lift

7.2.1 - Long Direction

$$M_L = \frac{S^{0.10} (h e_m)^{0.78} y_m^{0.66}}{7.2 L^{0.0065} p^{0.04}}$$

7.2.2 - Short Direction

For $L_V/L_S \geq 1.1$:

$$M_S = h^{0.35} \left(\frac{19 + e_m}{57.75} \right) M_L$$

For $L_V/L_S < 1.1$:

$$M_S = M_L$$

8.0 - SHEAR

Maximum shear force shall be as specified in **8.1** and **8.2**:

8.1 - Center Lift

8.1.1 - Long Direction

$$V_L = \frac{1}{1940} (L^{0.09} S^{0.71} h^{0.43} P^{0.44} y_m^{0.16} e_m^{0.93})$$

8.1.2 - Short Direction

$$V_S = \frac{1}{1350} (L^{0.19} S^{0.45} h^{0.20} P^{0.54} y_m^{0.04} e_m^{0.97})$$

8.2 - Edge Lift

8.2.1 - Long and Short Direction

$$V = \frac{L^{0.07} h^{0.4} P^{0.03} e_m^{0.16} y_m^{0.67}}{3.0 S^{0.015}}$$

9.0 - DEFLECTION

Maximum differential deflection shall be as specified in **9.1** and **9.2**:

9.1 - Center lift

$$\Delta_o = \frac{(y_m L)^{0.205} S^{1.059} P^{0.523} e_m^{1.296}}{380 h^{1.214}}$$

9.2 - Edge Lift

$$\Delta_o = \frac{L^{0.35} S^{0.86} e_m^{0.74} y_m^{0.76}}{15.9 h^{0.85} P^{0.01}}$$

R8.0 - SHEAR

See Reference 7 for background and derivations of the equations specified in **8.0**

R9.0 - DEFLECTION

See Reference 7 for background and derivations of the equations specified in **9.0**.

Table 1 - Soil Fabric Factor

Condition		Ff
Non CH Soils		1.0
CH Soils	Profile 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

Table 2a - Stress Change Factor (SCF) for Use in determining γ_m - Post-Equilibrium Case

Measured Suction (pF) at Final Controlling Suction at Surface, pF	Final Controlling Suction at Surface, pF						
	2.5	2.7	3.0	3.5	4.0	4.2	4.5
Depth z							
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:

1. $Z_m = 9.0$ ft.
2. Post-Equilibrium case, which is recommended for use for areas of Thornthwaite Indices more negative than -15 and more positive than +15
3. Shaded boxes represent extreme cases.
4. Non-Typical trumpet-shaped suction envelopes or depths to Equilibrium Suction which may vary from 9 ft require use of a computer analysis.

Table 2b Stress Change Factor (SCF) for Use in determining γ_m - Post-Construction Case

Suction Change pF	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
Wetting (Swelling)	33.2	36.7	40.2	43.9	47.6	51.4	55.3	59.2
Drying (Shrinking)	-24.3	-26.7	-29.2	-31.7	-34.2	-36.7	-39.3	-41.9

Notes:

1. A suction change of 1.5 pF is recommended; this value has been found to produce designs which are typical and perform well in Slab-on-Ground design practice. Other values of suction change are offered for engineers to use for special cases or different local practice.
2. $Z_m = 9.0$ ft
3. **Table 2b** is based on Post-Construction Case which is recommended for areas of Thornthwaite Indices between -15 and +15.
4. Non-Typical trumpet-shaped suction envelopes or depths to Equilibrium Suction which may vary from 9ft require use of computer analysis.

Table 3 - Values of Reduced e_m for Various Perimeter Vertical Barriers

		Depth of Barrier (ft)					
		2.5	3.0	3.5	4.0	4.5	5.0
e_m (Center or Edge) (ft)	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

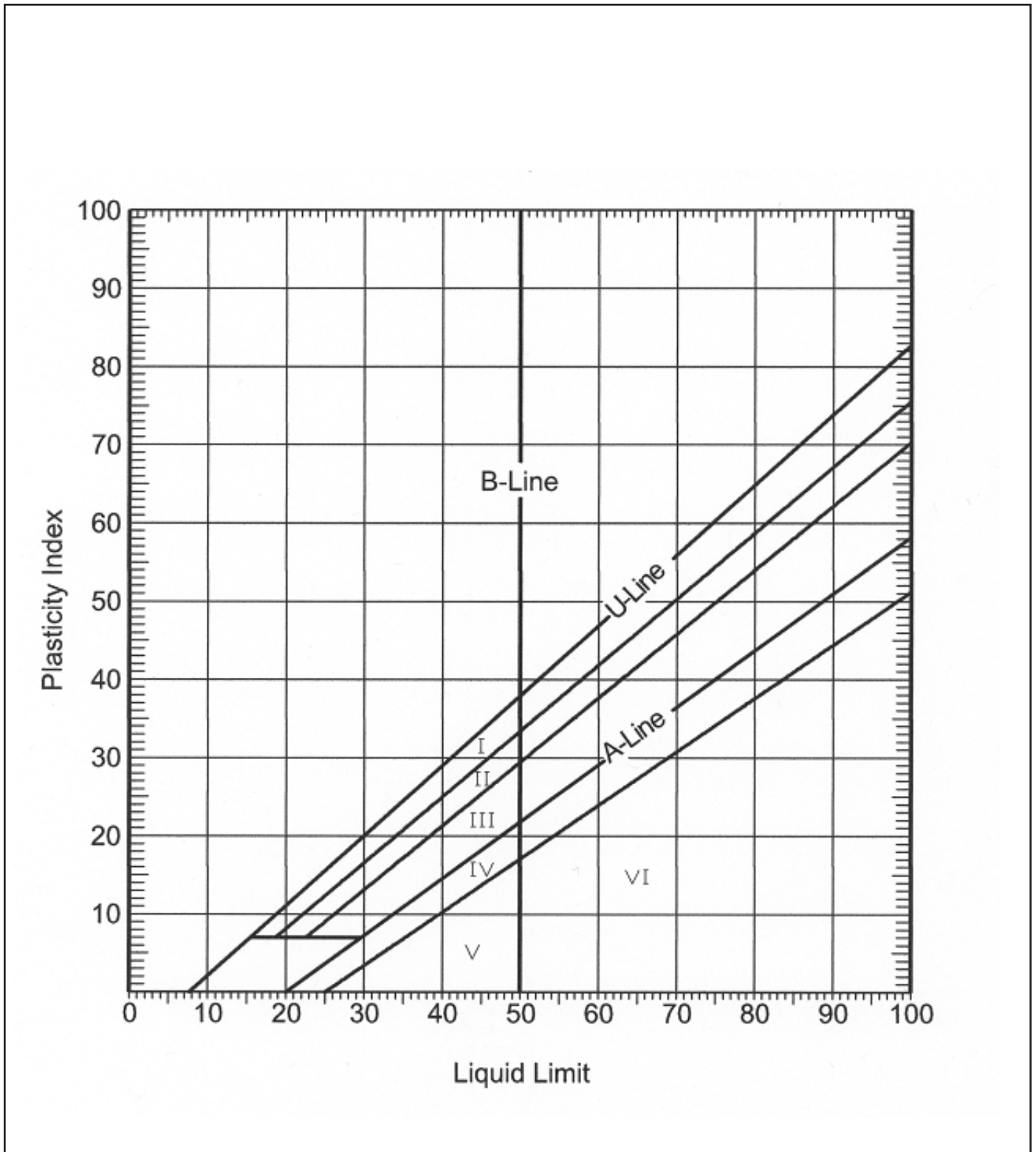


Figure 2 - Zone I Chart for Determining γ_o

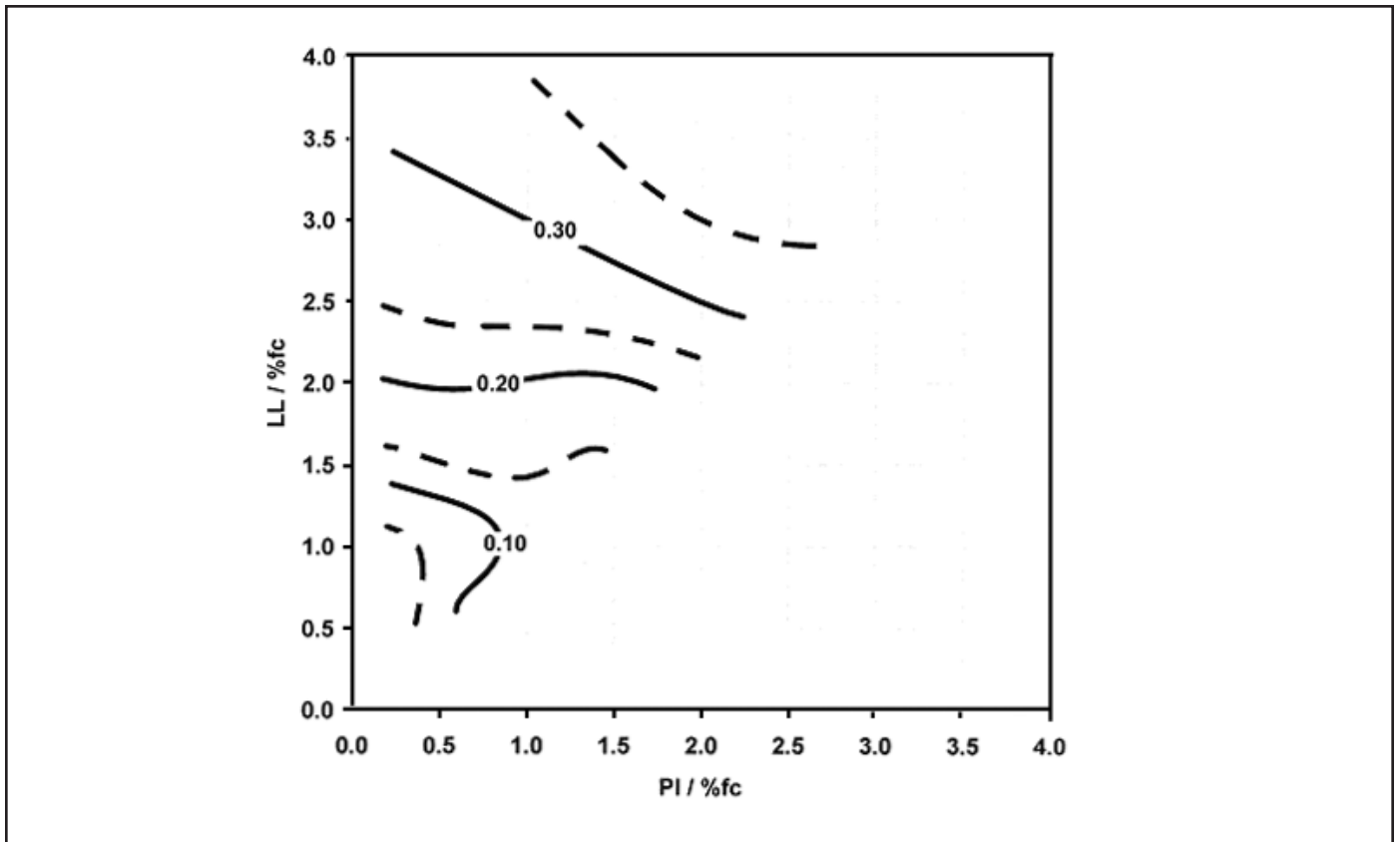


Figure 3 - Zone II Chart for Determining γ_o

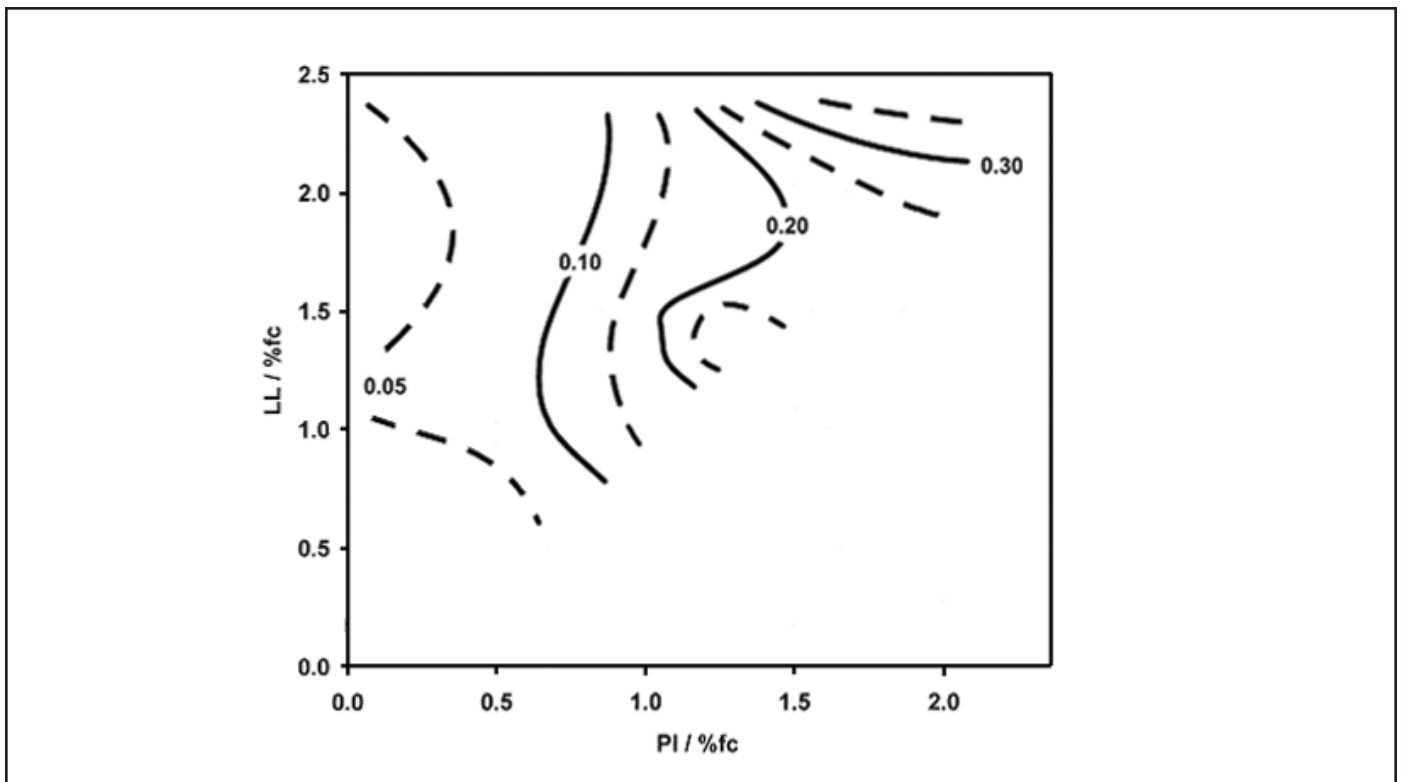


Figure 4 - Zone III Chart for Determining γ_o

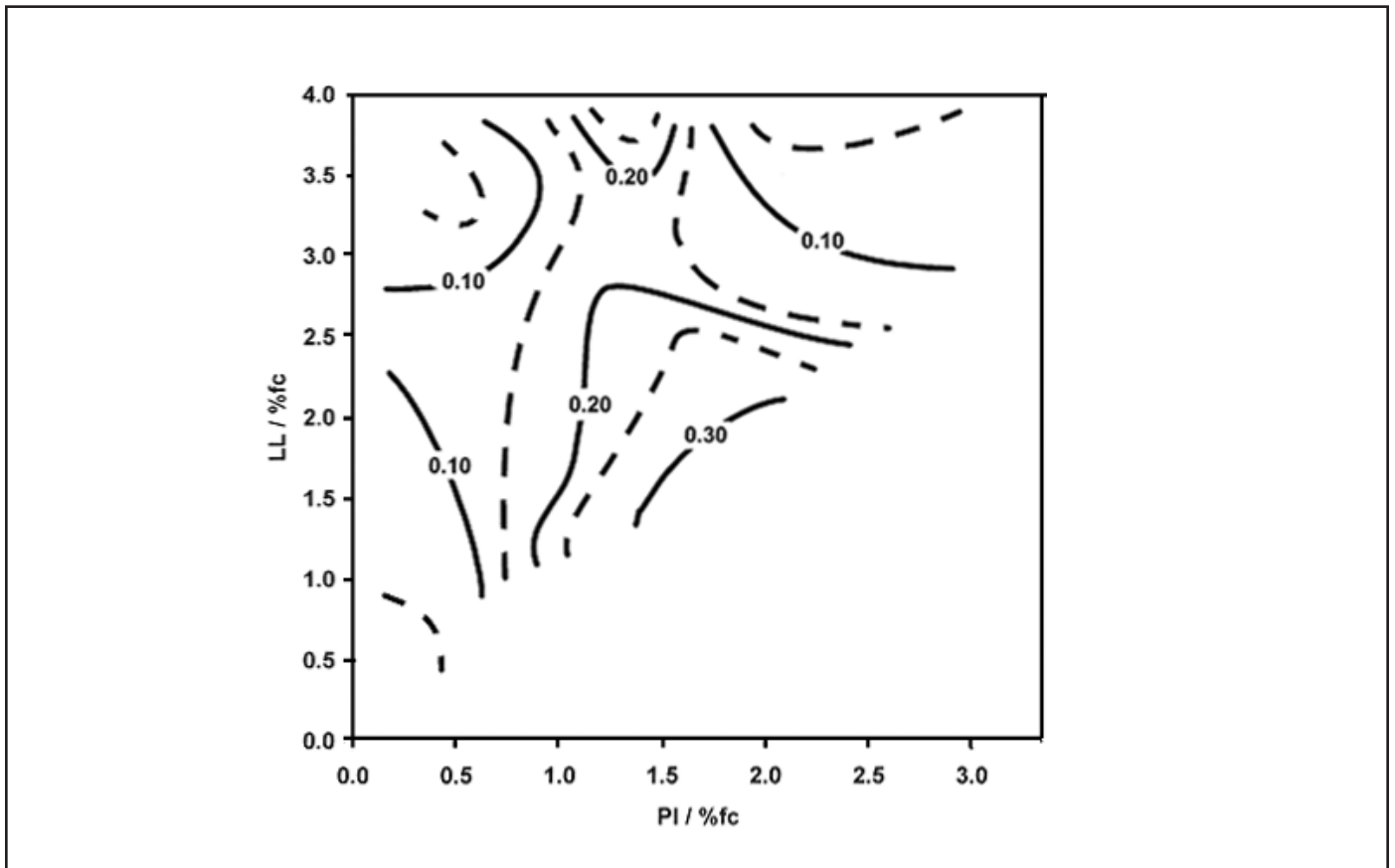


Figure 5 - Zone IV Chart for Determining γ_o

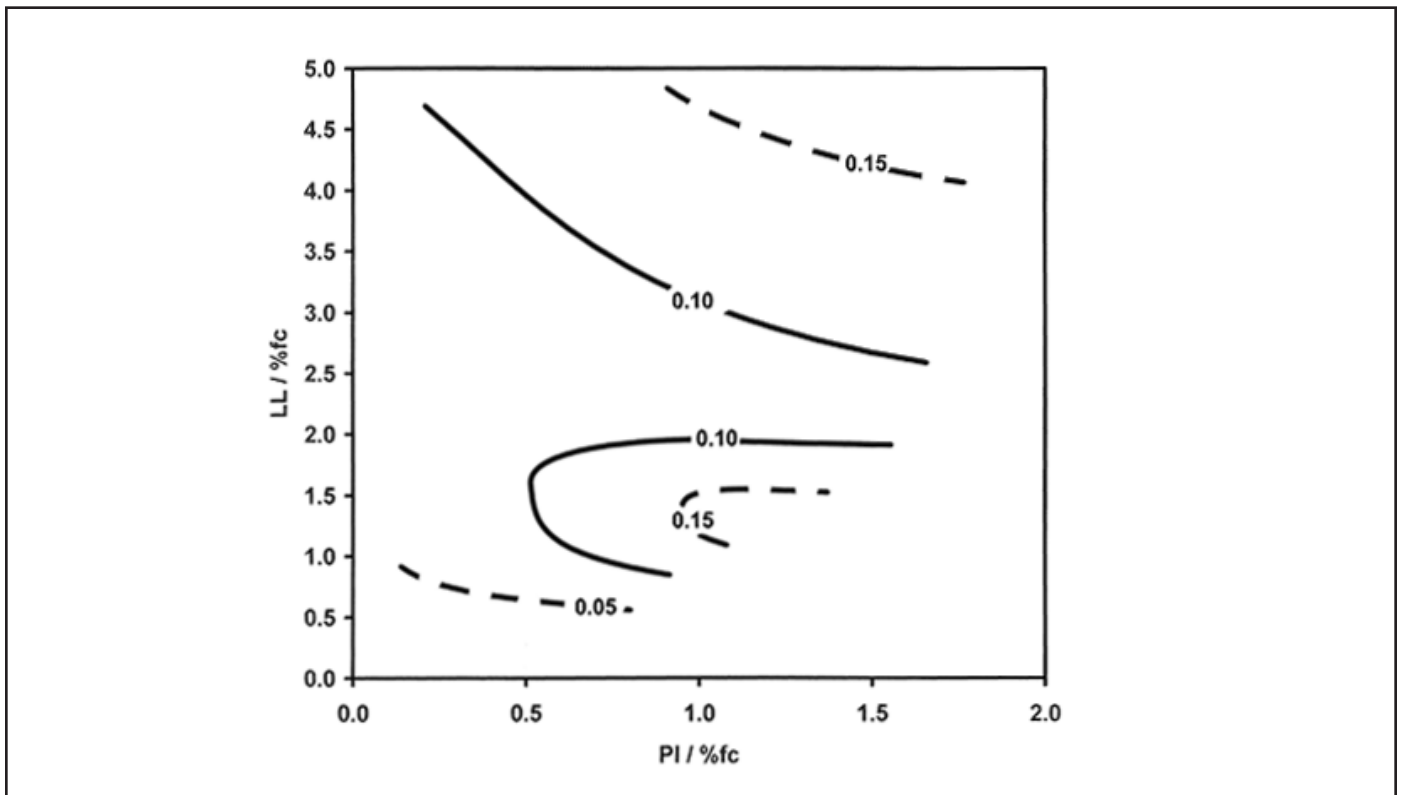


Figure 6 - Zone V Chart for Determining γ_o

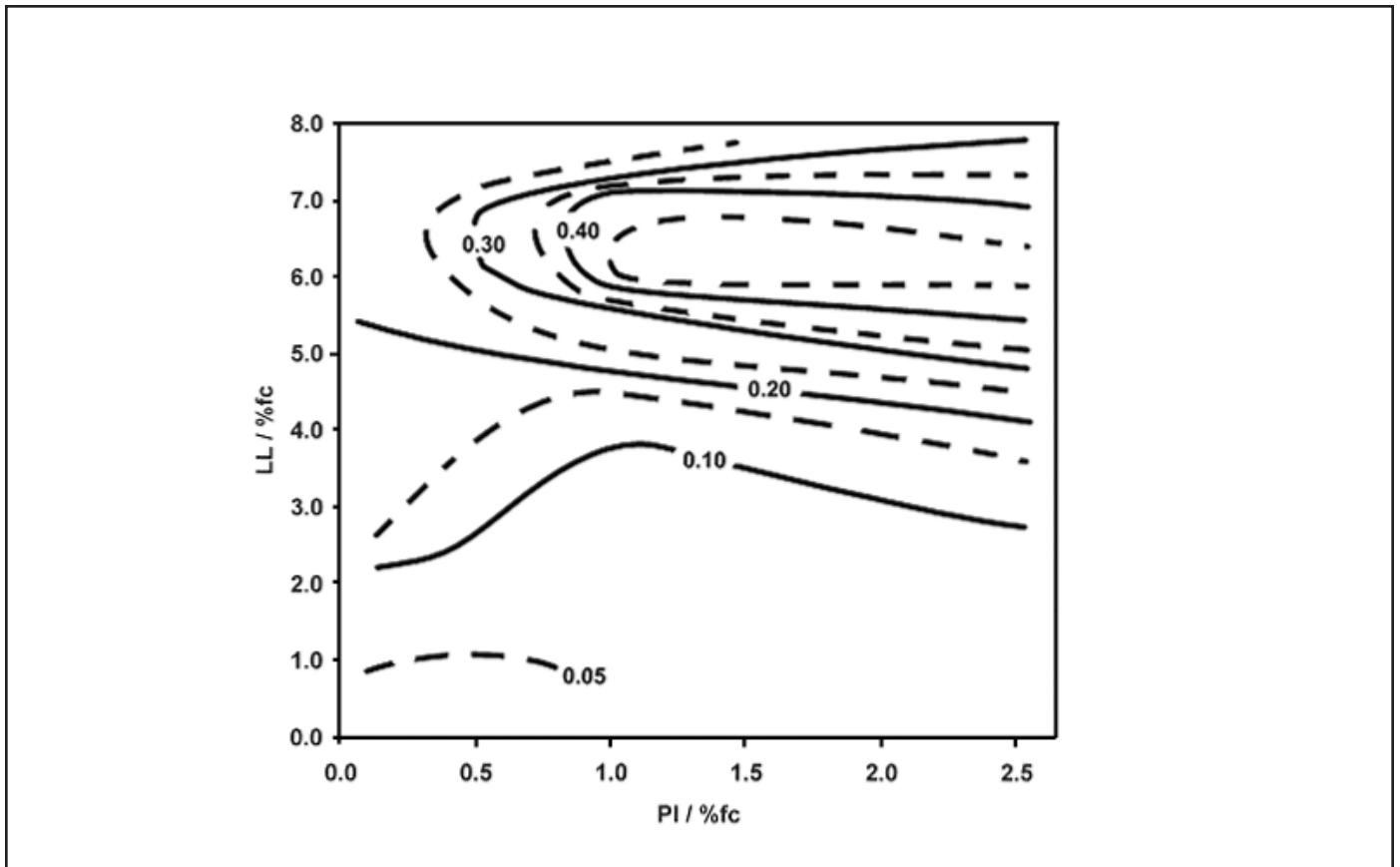


Figure 7 - Zone VI Chart for Determining γ_o

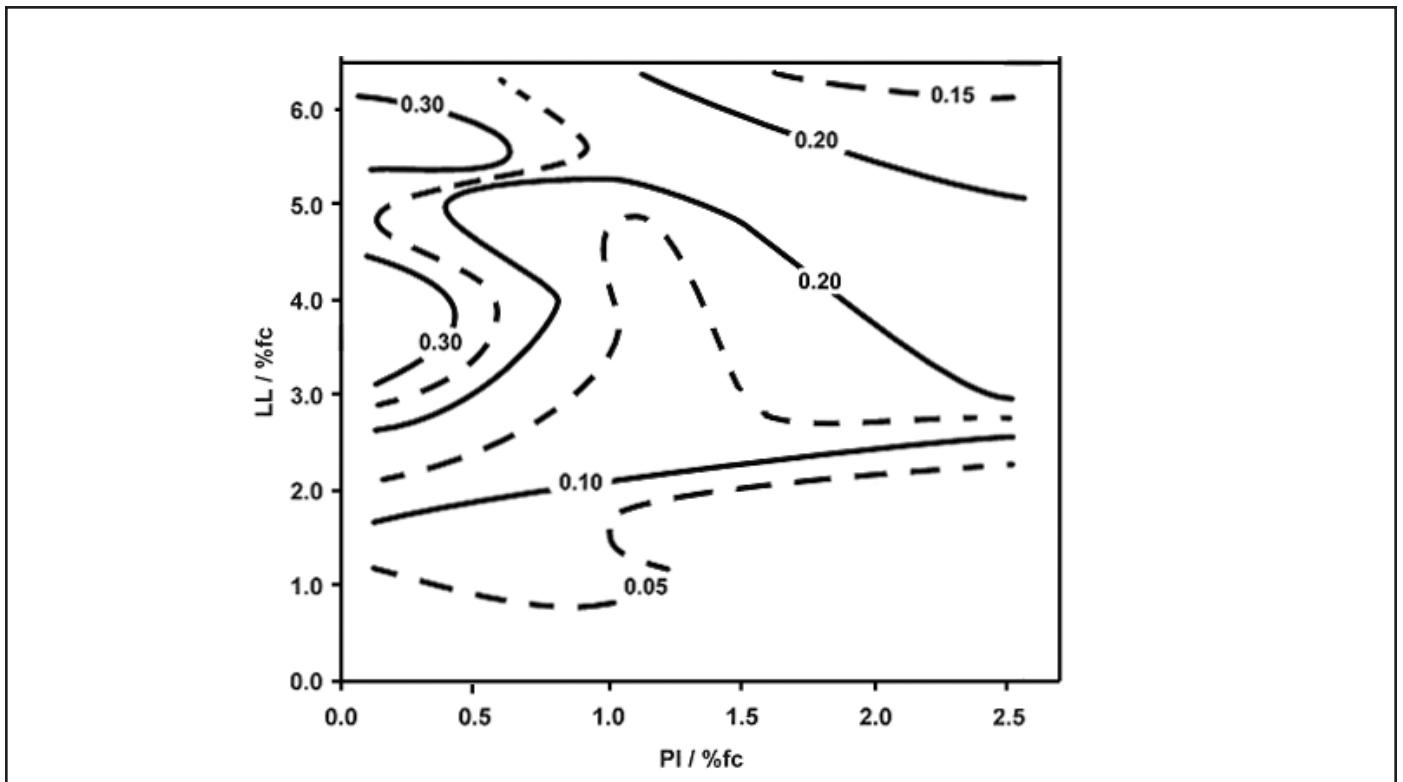
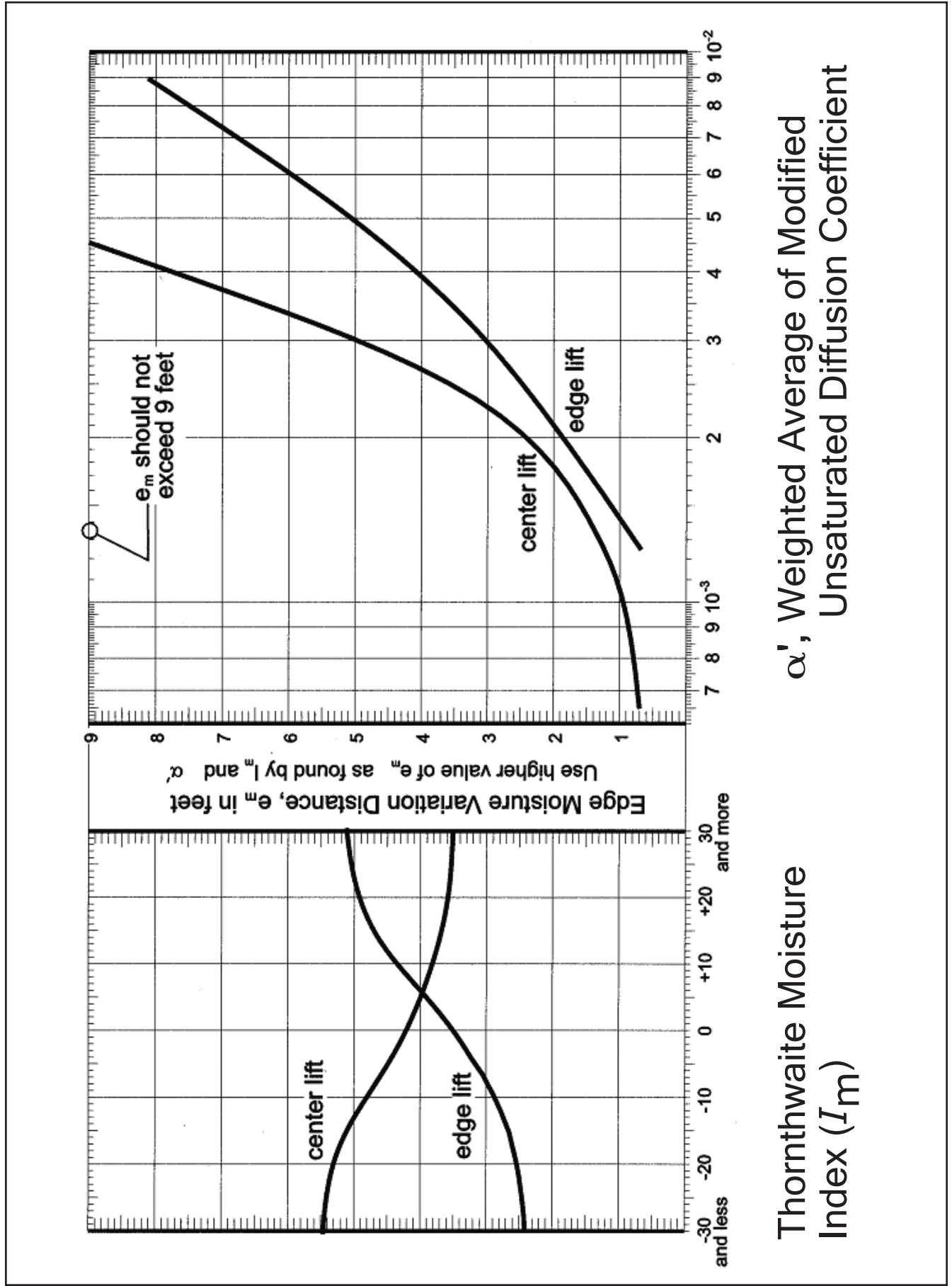


Figure 8 - e_m Selection Chart



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