**UNITED STATES DEPARTMENT OF AGRICULTURE**
**Rural Development Utilities Programs**

**RUS BULLETIN 1724E-205**

**SUBJECT:** **Design Guide: Preliminary Embedment Depths for Concrete and Steel Poles**

**TO:** All Electric Borrowers

**EFFECTIVE DATE:** Date of Approval

**EXPIRATION DATE:** Seven years from effective date

**OFFICE OF PRIMARY INTEREST:** Engineering Standards Branch; Office of Policy, Outreach, and Standards

**PREVIOUS INSTRUCTIONS:** None

**FILING INSTRUCTIONS:** This bulletin updates Bulletin 1724E-205, **"Design Guide: Embedment Depths for Concrete and Steel Poles"**, issued August 1995.

**AVAILABILITY:** This bulletin can be accessed via the internet at

http://www.rd.usda.gov/publications/regulations-guidelines/bulletins/electric

**PURPOSE:** This bulletin provides engineering information concerning selection of preliminary embedment depths, along with final embedment design criteria, for steel and concrete transmission poles subject to large overturning moments.

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5/2/17
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**ABBREVIATIONS**

| | |
|---|---|
| ACSR | Aluminum Conductor Steel Reinforced |
| MPH | Miles Per Hour |
| NESC | National Electrical Safety Code |
| OHGW | Overhead Ground Wire |
| RBS | Rated Breaking Strength |
| RUS | Rural Utilities Service |
| LF | Load Factor |
| SF | Strength Factor |
| ASTM | ASTM International |

**SYMBOLS**

| Symbol | Term | Units |
|---|---|---|
| C | Cohesion | psi, ksf |
| K | Subgrade modulus at bottom of pole | nhD, psi |
| $K_c^D$ | Earth pressure coefficient for cohesion | |
| $K_c^D$ | Earth pressure coefficient for overburden pressure | |
| d | Diameter of the pole | in, ft |
| D | Depth | ft |
| $D_d$ | Depth of dry soil | ft |
| $D_e$ | Embedment depth of pole | ft |
| $D_s$ | Depth of submerged soil from water table to pole butt | ft |
| $D_r$ | Depth from groundline to point of rotation of a rigid pile | ft |
| M | Moment | ft-kips, ft-lb, in-lb |
| n | Blow counts | Blows/ft |
| $n_h$ | Constant of horizontal subgrade modulus | $lb/in^3$ |
| P | Horizontal force | lb, kips |
| $p_D$ | Resultant pressure per unit front area on the embedded pole | psf |
| q | Effective overburden pressure | |
| $Y_g$ | Deflection at the groundline | in, ft |
| q | Unit weight of the soil | pcf |
| q' | Submerged unit weight of the soil | pcf |
| $\phi$ | Internal friction angle | Radians, degrees |

# 1 INTRODUCTION

a Purpose. Increasing use of steel and concrete poles has necessitated a more definitive method of determining pole embedment depths. The primary purpose of this bulletin is to furnish engineering information concerning preliminary selection of embedment depths for steel and concrete poles in different types of soils. The information in this bulletin may be used to approximate embedment depths for cost estimates, to make preliminary selection of embedment depths, and to verify or check selection of embedment depths based on other or more exact methods.

Computer design programs can be used for determining embedment depths for steel and concrete poles. Such programs may provide a more efficient selection of embedment depths, particularly for stratified soils, in preliminary design and their use should be considered in any final design.

b Scope. The engineering information in this bulletin is for use in preliminary selection of embedment depths for steel and concrete transmission poles sustaining relatively large overturning moments. The Rural Utilities Service (RUS) reviewed several methods of evaluating and approximating embedment depth requirements. As a result of this review, embedment charts have been developed for nine typical soil types. Sample calculations illustrating the use of these charts and illustrating the use of design methods for those occasions when the charts cannot be used, are also provided.

Since the RUS program is national in scope, it is necessary that designs be adaptable to various conditions and local requirements. In the design and selection of embedment depths the engineer should consider soil conditions, performance of existing embedded pole lines, local environmental conditions, and other pertinent factors, such as foundation movement and duration of loads.

A comparison of several techniques for determining embedment depths, groundline deflection and rotation were made. A brief discussion comparing the different design methods is included in Appendix B. As a result of this study, the Hansen method was selected for developing the embedment charts.

# 2 DISCUSSION OF DESIGN METHODS

a Lateral Resistance Using the Hansen Method. The advantage of the Hansen method is that it provides for foundation design and embedment evaluation in stratified soils. This may be an important consideration for soil formations with a relatively poor layer near the ground surface since the analysis permits utilization of the greater strength of the deeper soils without overstating the strength of the surface soils.

The following method of analysis was developed by Brinch Hansen and presented in the article, "The Ultimate Resistance of Rigid Piles Against Transversal Forces," Bulletin No. 12, The Danish Geotechnical Institute, Copenhagen, 1961.

A prerequisite to using the Hansen method to compute the ultimate lateral resistance is a knowledge of the different types and depths of soils underlying the site. The density q, submerged density q', angle of internal friction, ϕ, and cohesion "C" for each major soil type must be determined, preferably by subsurface soil investigations and soil lab tests. For preliminary embedment depth selections, these values can be estimated. The depth to the ground water table must be known if it is located above the bottom of the footing. In this event, the submerged weight of the soil can have a significant effect on the embedment depth. Water table depths can be estimated for preliminary design but, for final design, should be more accurately determined through the subsurface soil investigation process (ASTM D1586).

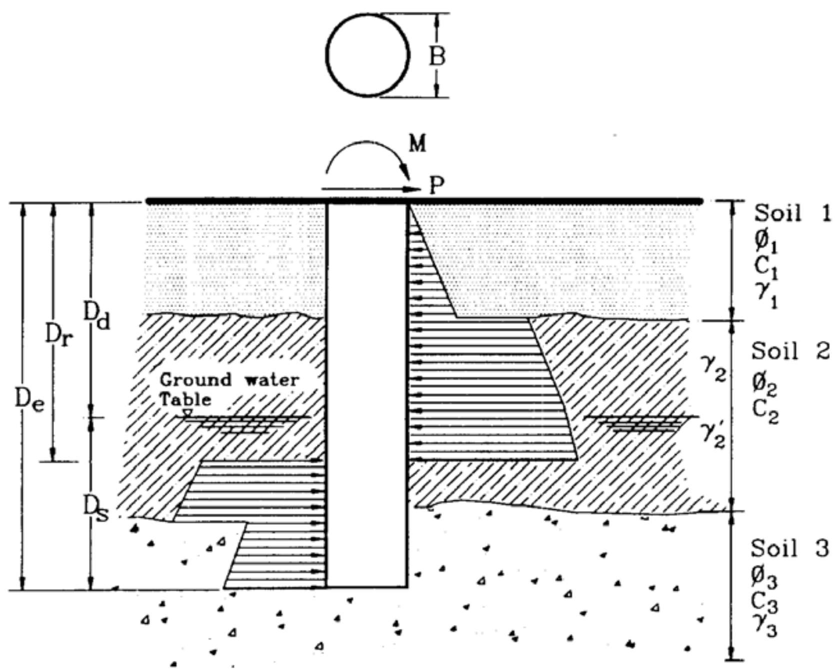


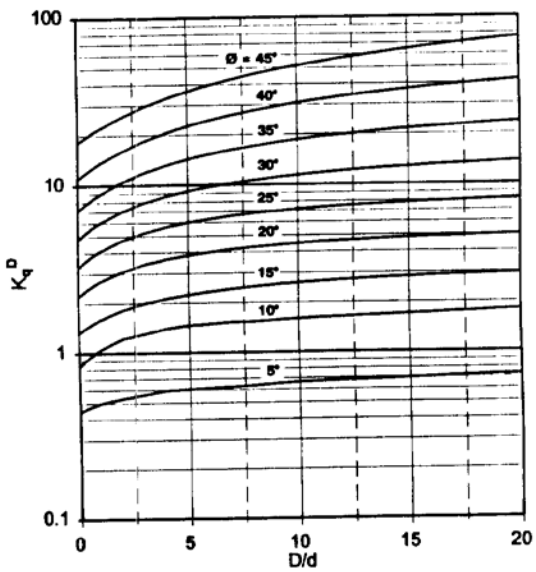

Figure 1

The resultant (passive minus active) pressure per unit front area on the embedded pole (pD) at an arbitrary depth "D" is given by:

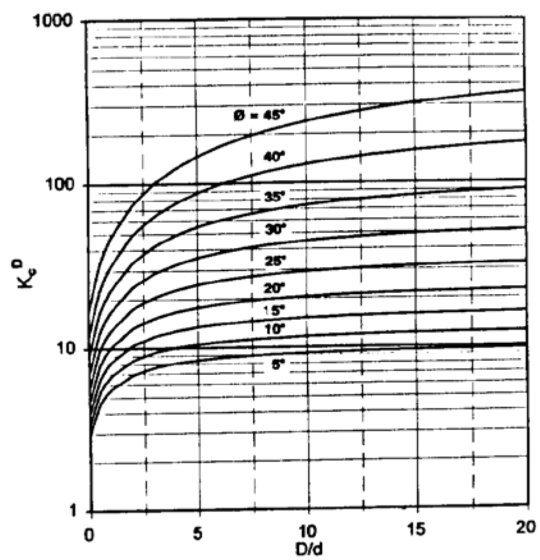
$$p_D = qK_qD + CK_cD \qquad \text{Eq. 1}$$

where:

| | |
|---|---|
| $q = qD_d + q'D_s$<br>(effective overburden pressure) | q,q' = Dry and submerged density of the soil |
| $D_d$ = Depth of dry soil | C = Cohesion of soil |
| $D_s$ = Depth of submerged soil from water table to pole butt | $(d)(p_D)$ = Pressure per unit length of pile |
| $K_qD$ = See figure 2 | Dr = depth to point of rotation of a rigid pile (See figure 5) |
| $K_cD$ = See figure 3 | |




Earth pressure coefficients for overburden pressure
Figure 2




Earth pressure coefficient for cohesion
Figure 3

The general procedure to compute the embedment depth $D_e$ is as follows given that the moment (M), horizontal load (P), diameter of the pole (d), and soil properties are known.

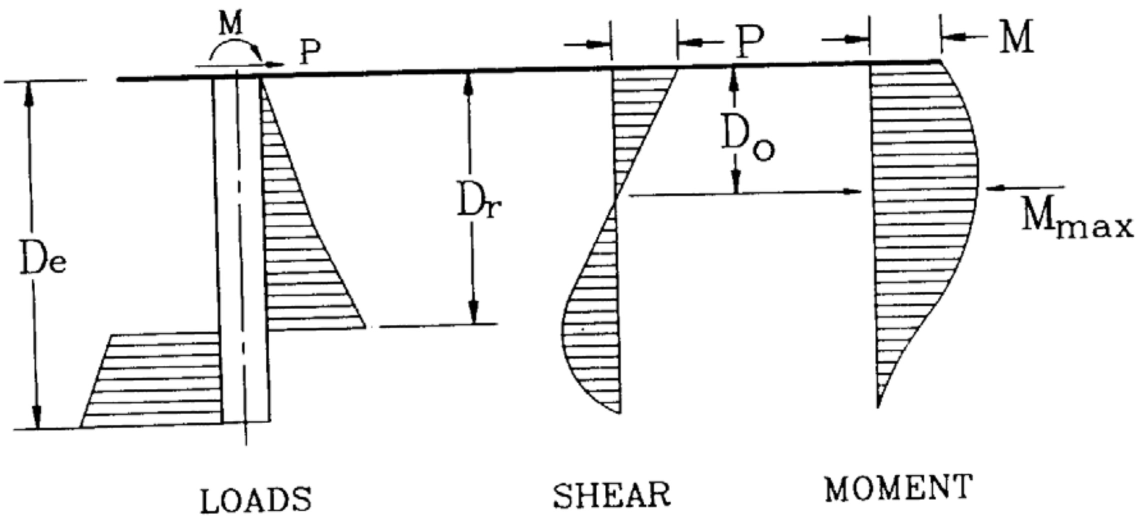



Figure 4

Compute embedment depth, $D_e$

(1) Compute $D_o$, the depth to point of zero shear and maximum moment. This can be done by equating the total earth pressure above this point to the force P.

(2) Compute Mmax by taking moments of all forces acting above this point.

(3) Assume $D_e$

(4) Assume $D_r$. For the first trial, try $D_r = 0.75\ D_e$ for granular soils and $D_r = 0.6\ D_e$ for clay soils.

(5) Compute the algebraic sum of all lateral earth forces below the point of zero shear. This should be equal to zero. If not, adjust $D_r$ so that it will be.

(6) Calculate moments of all forces acting below the point of zero shear. This should be equal to $M_{max}$ computed in Step 2. If not, start with Step 3 again by assuming a new De.

b Deflection Using Davisson's Method. Groundline deflections can be estimated based on a method developed by Davisson and Prakash in an article titled, "A Review of Soil-Pole Behavior," published in the Highway Research Record, Number 39. The equations are valid for loads in the range of 1/3 to 1/2 of the ultimate load. At higher load levels, the load deflection relationship becomes nonlinear.

Although it is not possible to compute the deflections near the range of the ultimate loads, Broms[1] states that maximum resistance is in general reached when the deflection at the ground surface is approximately equal to 20 percent of the diameter of the pile. The working loads, particularly for non-iced conductors, should be in the range of the load-deflection curves so that the preceding equations are valid.

No deflection limits are recommended. Each design case will have to be evaluated for the particular structure by itself and in relation to the other structures in the line.

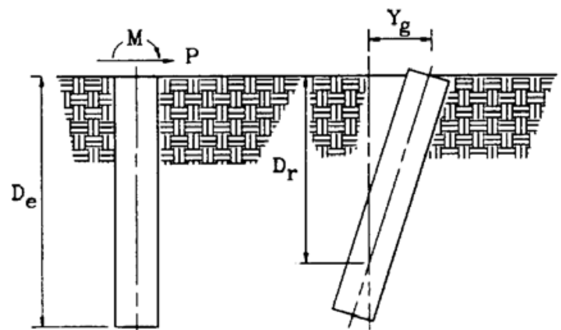



Figure 5
(P and M are less than 1/2 the ultimate loads.)

For clay soils:

$Y_g = [2.15PD_r/D_e] / [KD_e((1.87\ D_r/D_e) - 1)]$ Eq. 2

$D_r/D_e = [(M/(PD_e)) + .683] / [(1.87\ M/(PD_e)) +1]$ Eq. 3

For granular soils:

$Y_g = [3PDr/De] / [n_hD_e^2((1.5\ D_r/D_e) - 1)]$ Eq. 4

$D_r/D_e = [(M/(PD_e)) + .750] / [(1.5\ M/(PD_e)) + 1]$ Eq. 5

Values of K for clays

| Cohesion ($lb/ft^2$) | K psi |
|---|---|
| 1000 - 2000 | 700 |
| 2000 - 4000 | 1400 |
| >4000 | 2800 |

Values $n_h$ for granular soils
$n_h$ ($lb/in^3$)

| | Dry | Submerged |
|---|---|---|
| Loose | 9.4 | 5.3 |
| Medium | 28 | 19 |
| Dense | 75 | 45 |

## 3 EMBEDMENT CHARTS.

Nine charts have been developed which show embedment depths for pole diameters ranging from 1.0 to 4.0 feet. Ultimate moments at groundline range from 0 to 2000 ft-kips.

Because of the sensitivity of embedment depths to groundline moments and relative insensitivity of embedment depth to ground shears, the embedment charts were developed based on a horizontal load on the pole of 20 kips. In general, the degree of conservatism of the 20 kip load is greatest for very small groundline moments, and diminishes to a negligible value for a groundline moment of 300 ft-kips.

The nine embedment charts have been developed for nine soil types. These soil types and characteristics are shown in Table 1. Submergence significantly influences the strength of the sand foundations because they are weight-dependent. Submergence does not influence the strength of the clay foundations because they are not weight dependent.

Most soils are neither a pure sand nor a pure clay and may often be multilayer. In making preliminary selection of embedment depths, the user of these charts should select the predominant soil type based on the best available soils information. For example, if the soil type is a submerged silty sand, embedment depths estimated with these charts should be based on a submerged sand.

The designer should assume that the top 1 to 2 feet of soil provide little or no strength. When using these charts or when using computer programs, this assumption may be a consideration by the designer.

Table 1
Soil Parameters

| Chart No: | SOIL/TYPE & DESCRIPTION: | $\gamma$, Kip/CFt | C, Kip/SqFt | $\phi$, Degrees | Typical blow count Values ("n") |
|---|---|---|---|---|---|
| 1-DDS | DENSE DRY SAND | 0.14 | 0.0 | 41 | >30 |
| 2-DSS | DENSE SUBMERGED SAND | 0.085 | 0.0 | 41 | >30 |
| 3-MDS | MEDIUM DRY SAND | 0.12 | 0.0 | 33 | 10-30 |
| 4-MSS | MEDIUM SUBMERGED SAND | 0.065 | 0.0 | 33 | 10-30 |
| 5-LDS | LOOSE DRY SAND | 0.095 | 0.0 | 28 | 0-10 |
| 6-LSS | LOOSE SUBMERGED SAND | 0.055 | 0.0 | 28 | 0-10 |
| 7-SSC | STIFF SATURATED CLAY | 0.14 | 2.0 | 0.0 | >8 |
| 8-MSC | MEDIUM SATURATED CLAY | 0.12 | 0.75 | 0.0 | 4-8 |
| 9-SOSC | SOFT SATURATED CLAY | 0.10 | 0.25 | 0.0 | 0-4 |

When using the embedment charts the following are applicable:

a Moment values shown on the charts represent an ultimate capacity for embedment depths. Overturning moments should include structural loads multiplied by appropriate load factors. Strength reduction factors should be applied to the allowable moments. See RUS Bulletin 1724E-200, Section 13.

b Charts are based on a horizontal load of 20 kips acting at an equivalent load height for a given moment and are slightly conservative for horizontal loads less than 20 kips. For horizontal loads greater than 20 kips but less than 40 kips, the charts are marginal but are adequate for use. For horizontal loads greater than 40 kips or for stratified soils, embedment depths should be determined by the Hansen formulae instead of the charts.

c Recommended minimum embedment depth is three times either the pole diameter or pole's lateral dimension at the groundline. It is also recommended that the ratio of embedment depth to the pole diameter or pole's lateral dimension at groundline not exceed 10.

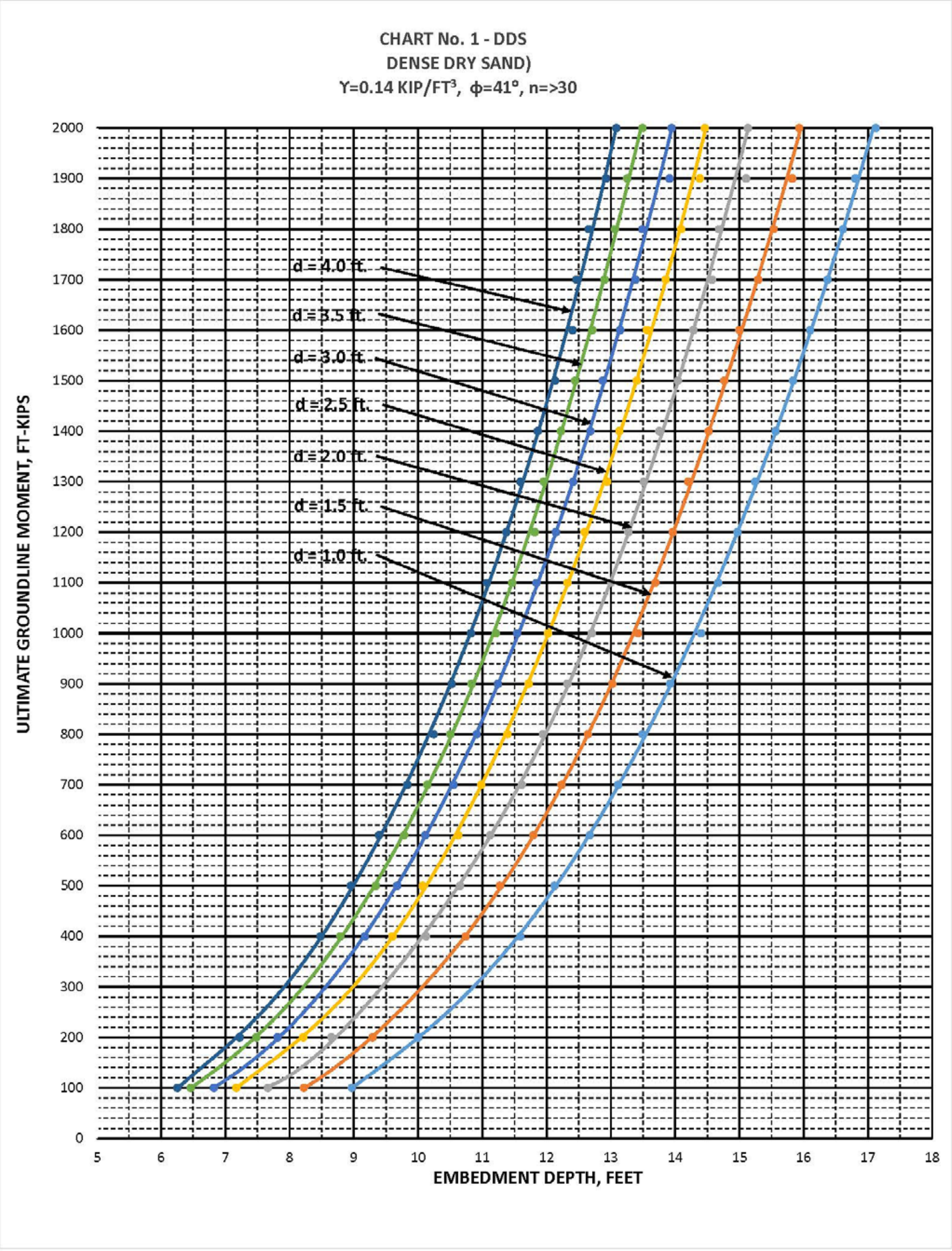


CHART No. 1 - DDS
DENSE DRY SAND)
ϒ=0.14 KIP/FT³, ϕ=41°, n=>30
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
d = 2.5 ft.
d = 2.0 ft.
d = 1.5 ft.
d = 1.0 ft.
ULTIMATE GROUNDLINE MOMENT, FT-KIPS
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EMBEDMENT DEPTH, FEET

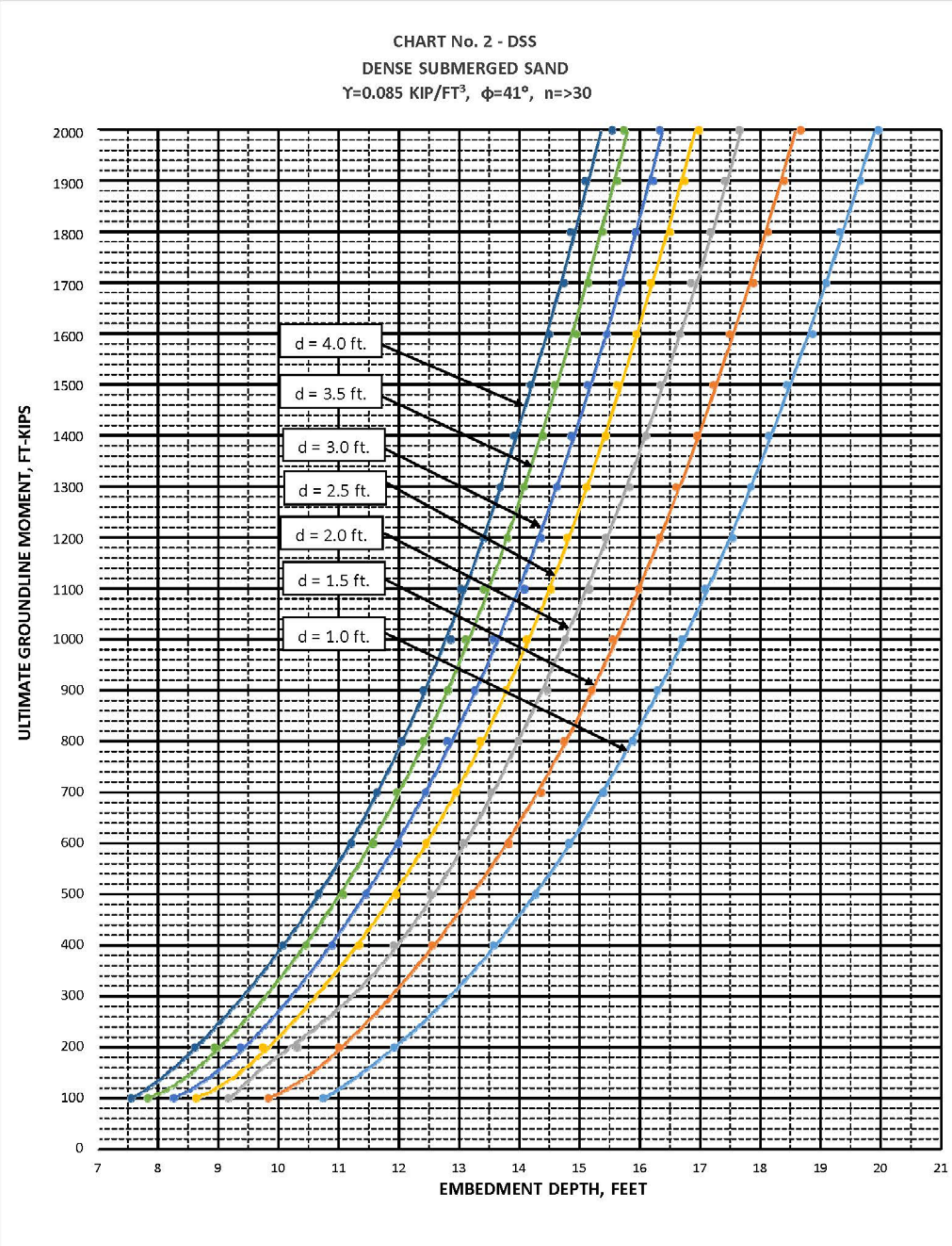
CHART No. 2 - DSS
DENSE SUBMERGED SAND
ϒ=0.085 KIP/FT³, ϕ=41°, n=>30
ULTIMATE GROUNDLINE MOMENT, FT-KIPS
EMBEDMENT DEPTH, FEET
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
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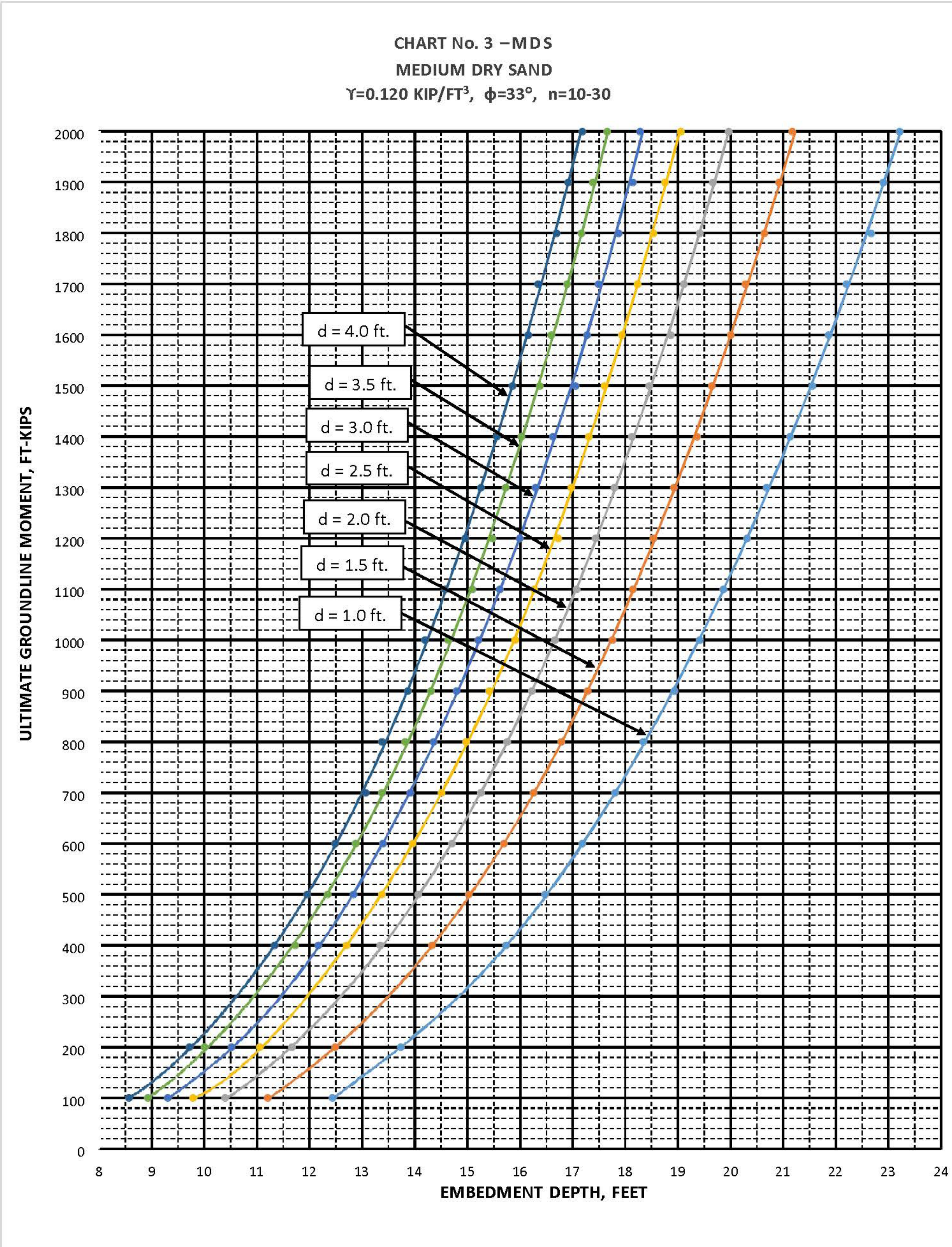
CHART No. 3 – MDS
MEDIUM DRY SAND
ϒ=0.120 KIP/FT³, ϕ=33°, n=10-30
ULTIMATE GROUNDLINE MOMENT, FT-KIPS
EMBEDMENT DEPTH, FEET
d = 4.0 ft.
d = 3.5 ft.
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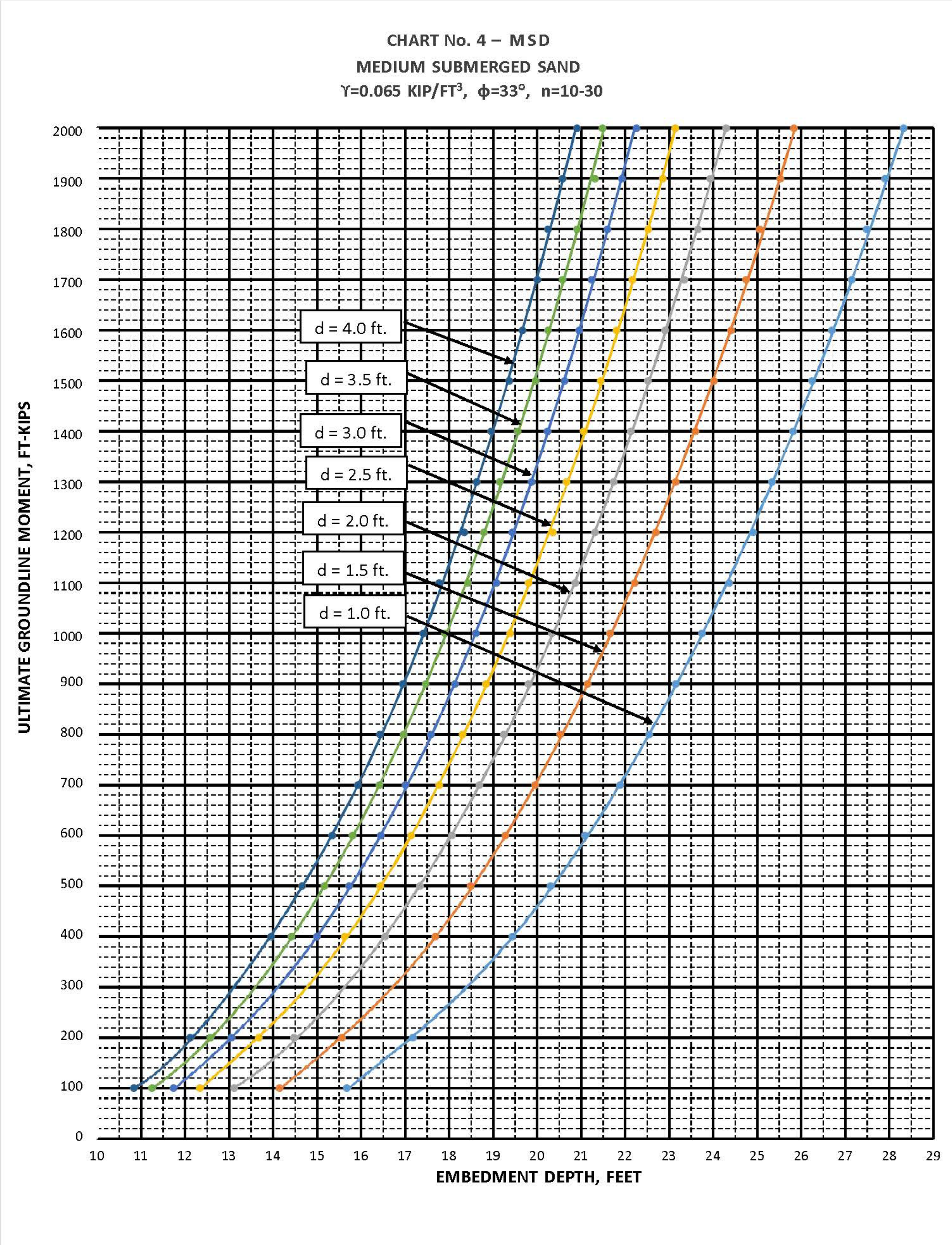
CHART No. 4 – MSD
MEDIUM SUBMERGED SAND
ϒ=0.065 KIP/FT³, ϕ=33°, n=10-30
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
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ULTIMATE GROUNDLINE MOMENT, FT-KIPS
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EMBEDMENT DEPTH, FEET

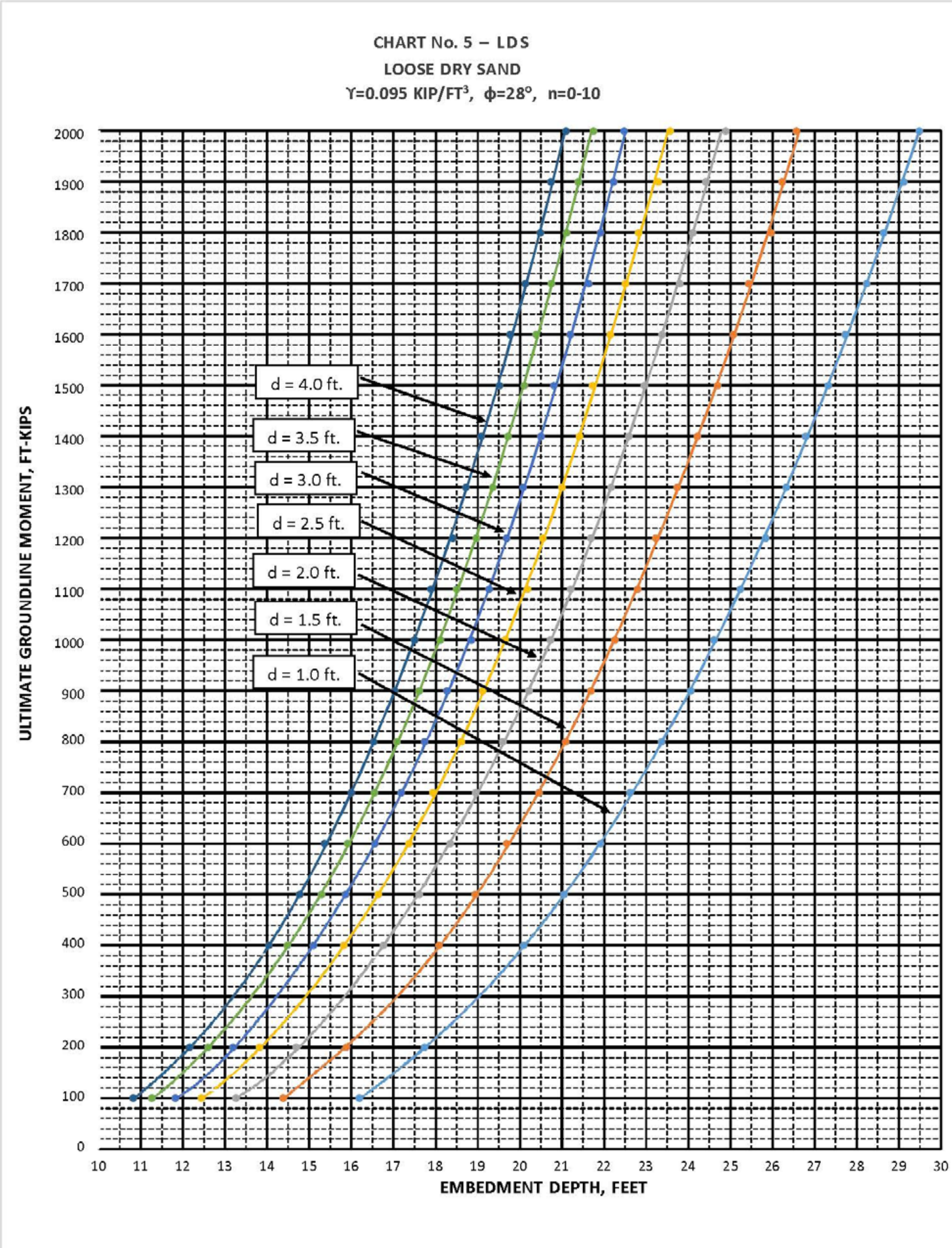
CHART No. 5 – LDS
LOOSE DRY SAND
Υ=0.095 KIP/FT³, ϕ=28°, n=0-10
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
d = 2.5 ft.
d = 2.0 ft.
d = 1.5 ft.
d = 1.0 ft.
ULTIMATE GROUNDLINE MOMENT, FT-KIPS
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EMBEDMENT DEPTH, FEET

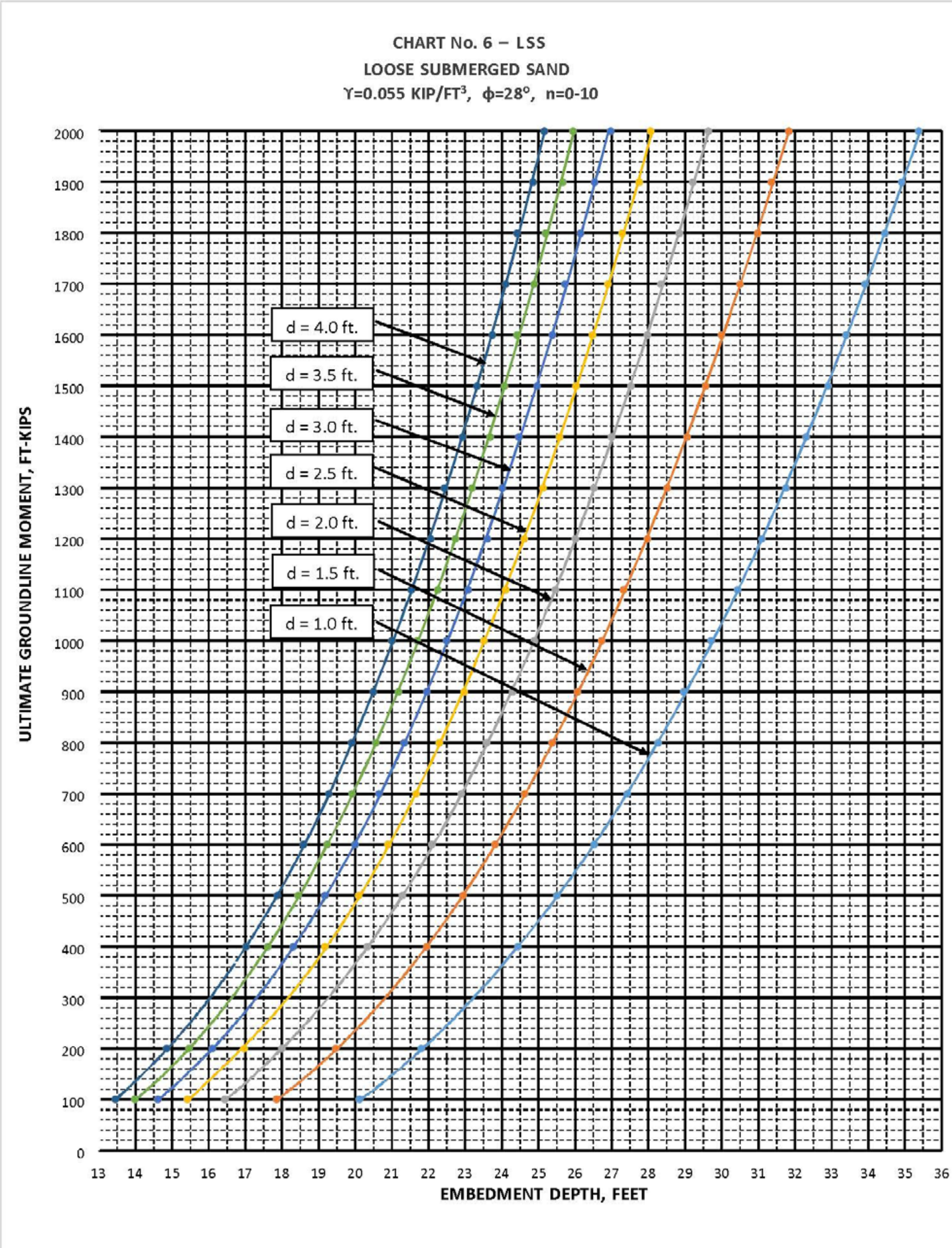
CHART No. 6 – LSS
LOOSE SUBMERGED SAND
ϒ=0.055 KIP/FT³, ϕ=28°, n=0-10
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
d = 2.5 ft.
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d = 1.5 ft.
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ULTIMATE GROUNDLINE MOMENT, FT-KIPS
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EMBEDMENT DEPTH, FEET

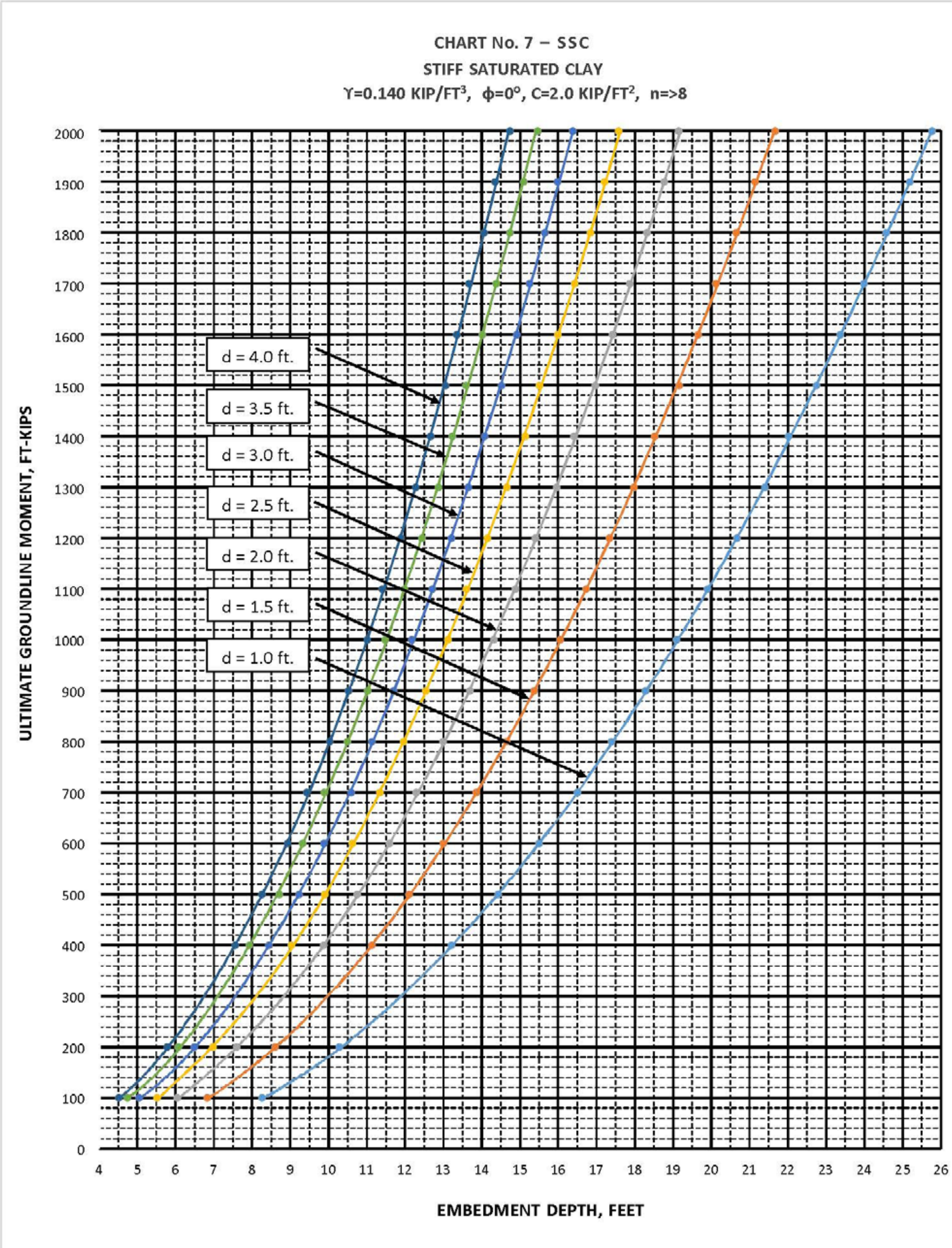
CHART No. 7 – SSC
STIFF SATURATED CLAY
ϒ=0.140 KIP/FT³, ϕ=0°, C=2.0 KIP/FT², n=>8
d = 4.0 ft.
d = 3.5 ft.
d = 3.0 ft.
d = 2.5 ft.
d = 2.0 ft.
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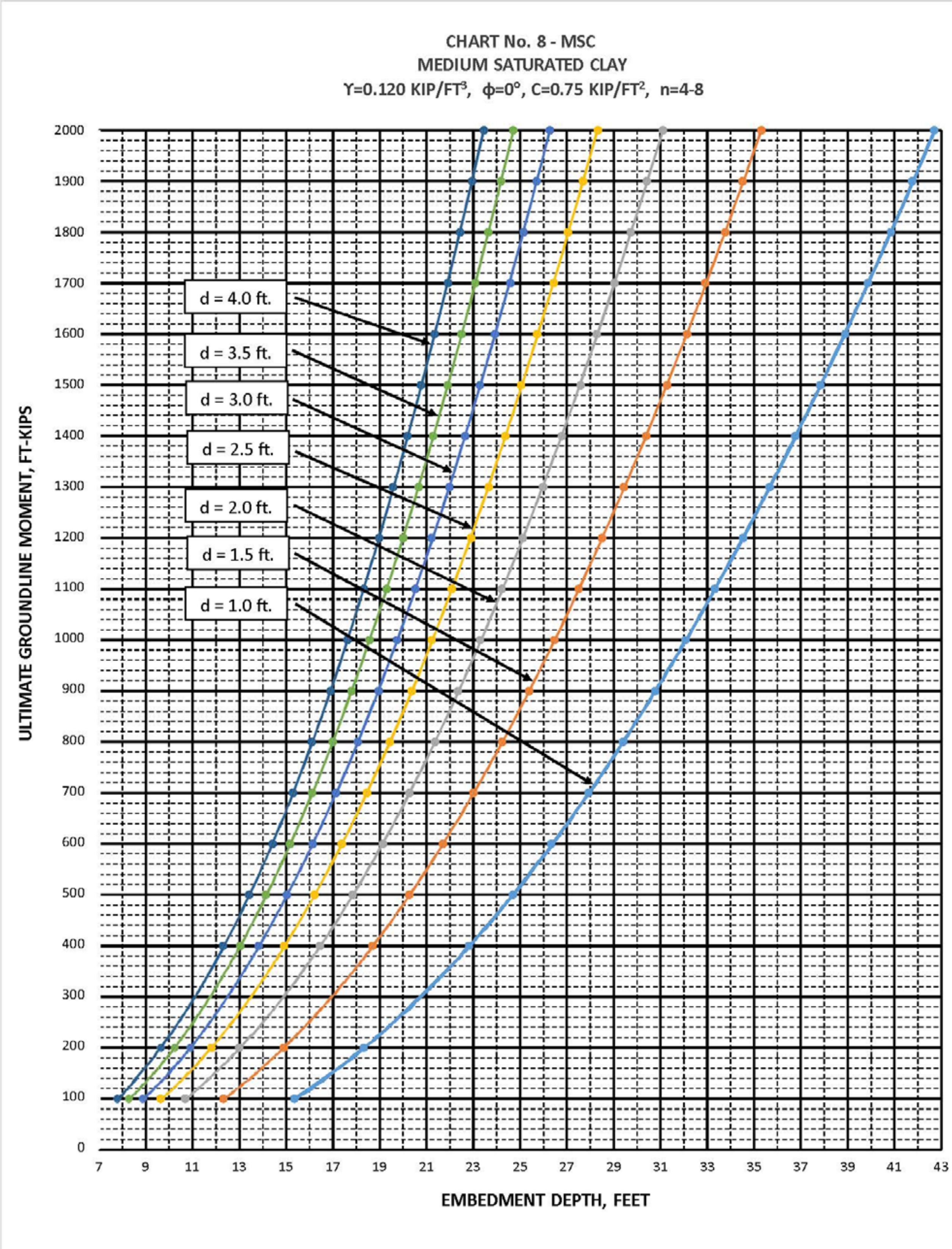
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MEDIUM SATURATED CLAY
ϒ=0.120 KIP/FT³, ϕ=0°, C=0.75 KIP/FT², n=4-8
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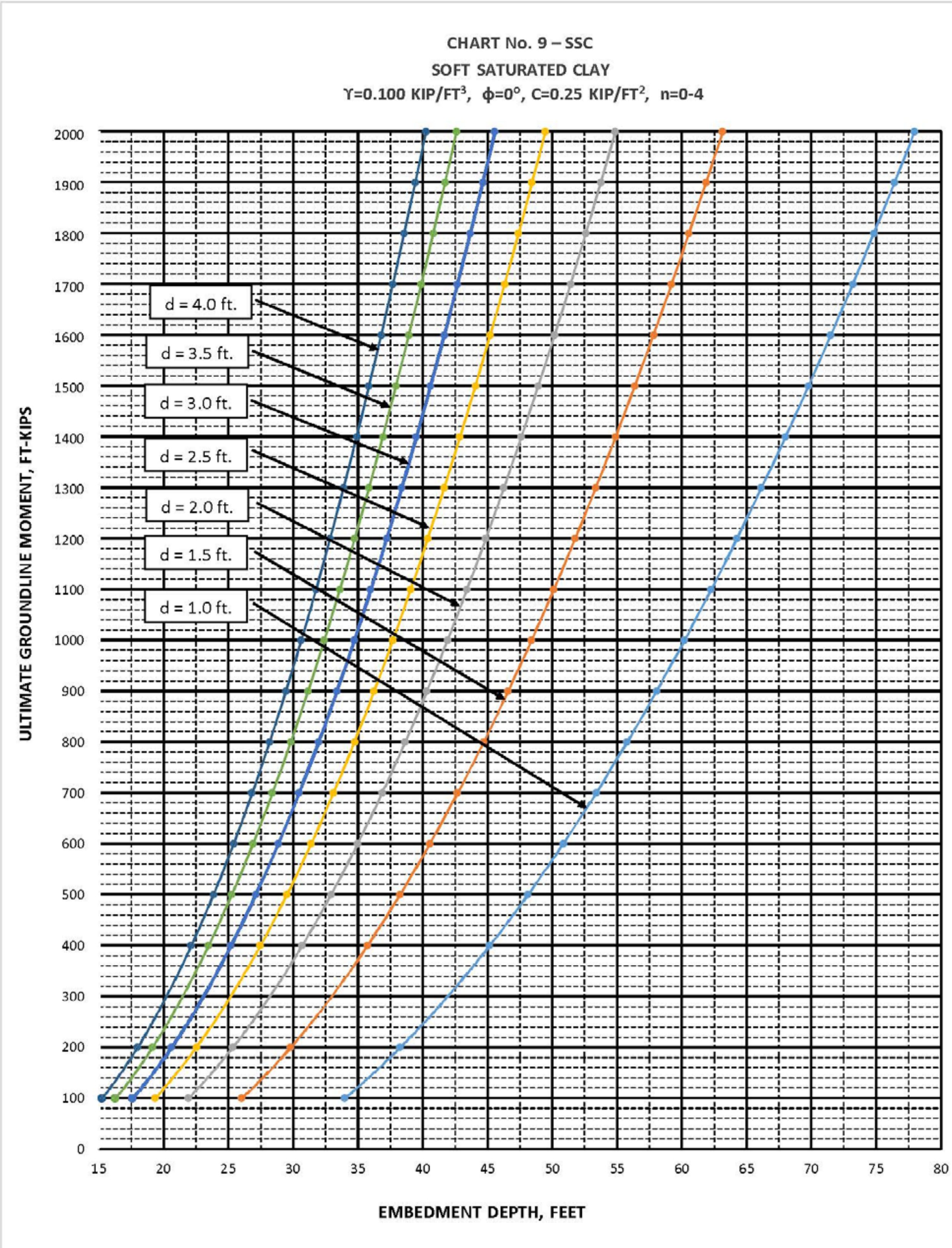
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SOFT SATURATED CLAY
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EMBEDMENT DEPTH, FEET

## 4 SUGGESTED PROCEDURE FOR USING THE CHARTS AND DETERMINING EMBEDMENT DEPTHS

a Define Pole Dimensions and Loading Positions. The user should first specify/tabulate the following: pole heights and dimensional data (above ground), wire or insulator attachment points and heights, and pole diameters at top and groundline (given or estimated).

b Specify Design Data, Load Cases/Conditions, Criteria and Requirements. For a given pole type, the user should name or designate the structure, define data on the vertical, horizontal spans, and maximum design line angle (if any), and tabulate design load cases or combinations being considered. At a minimum, NESC District loading extreme load cases as indicated in Chapter 11 of RUS Bulletin 1724E-200 should be used to determine structure loads. Other more extreme load cases should be included if necessary when considering local conditions.

For each load case, the following should be specified: (a) design wind pressures on wires and pole; (b) radial ice thickness/type on wires and conductors; (c) groundwire and conductor design tensions; and (d) required Load Factors (LF) for vertical, transverse and longitudinal loads, including separate load factors for components due to wire tensions, wind-on-wires and structure.

c Calculate Forces and Moments at Groundline. Section 13, RUS Bulletin 1724E-200 provides the methodology for determining forces and moments at the groundline. For each load case compute and combine forces and moments due to: transverse wind acting on conductors, wires and pole; pole moments due to vertical loads acting on lateral pole deflection (P-delta effect) and nonsymmetrical vertical conductor wire loads (two arms vs. one arm on each side of the pole); and any additional transverse or longitudinal loads from wire tension components caused by line angle or unbalanced/deadending conditions. Each load component is applied with its required LF as specified in the design criteria. From all the design cases, the maximum induced groundline moment, Mg, and maximum horizontal shear force should be determined.

d Determine Subsurface Soil Type and Condition. For preliminary design, the engineer may wish to estimate the soil type and condition (dry vs. saturated). For tangent structures, it may be sufficient to only list locations where there is similar soil. However, site investigation and soil testing is recommended at poles subject to long duration, high lateral loads and overturning moments.

During construction when the holes are augured for the poles, soil type and condition should be monitored. If the soil conditions during excavation and construction are different than the assumed conditions, alternatives may need to be considered in order to provide adequate overturning moment capacity.

e Select a Chart for the Soil and Determine Embedment Depth**.** In many instances, the engineer will be able to select an embedment chart which most clearly represents the soil and the state of the soil at the pole location. Occasionally, two charts may be used to bracket and average the required embedment depth.

Once the chart has been selected for the soil and the maximum induced groundline moment (includes overload factors) at groundline has been calculated, the embedment depth is determined in the chart for a given or estimated pole diameter at groundline.

## 5 POLE ANALYSIS AND FOUNDATION DESIGN EXAMPLES

a Example 1, Steel Pole Preliminary Embedment Design Using The Embedment Charts. For the TUS-1 steel pole structure and loading conditions given below, determine if 10 percent of height plus 2 feet is an adequate embedment depth. Assume medium-dense, dry sand is the soil.

(1) General information:

Line voltage: 138 kV/69 kV Double Circuit
Design by: RUS Engineers
Structure type: TUS-1 Steel Pole

Geometry of the structure and location of loads:

| | Distance from Pole Top, Ft. |
|---|---|
| OHGW | 0.25 |
| COND-1 | 7.50 |
| COND-2 | 17.50 |
| COND-3 | 27.50 |
| COND-69-1 | 7.50 |
| COND-69-2 | 17.50 |
| COND-69-3 | 27.50 |
| Underbuild-NONE | 97.00 |
| At Gd.Line-assumed | 97.00 |
| Pole-End | 110.00 |

Overall pole length is 110 feet. The above dimensions assume 13.0 foot embedment depth for the steel pole using the standard rule for wood poles of 10 percent pole length plus 2 feet. Assume top of the pole has a 12 inch diameter, and the groundline diameter is 30 inches.

(2) Load Factors (LFs) used in this example:

For NESC Light, Medium or Heavy Loading District Loads

| | | | |
|---|---|---|---|
| Vertical | 1.50 | Wind on Pole | 2.50 |
| Transverse wind | 2.50 | Transverse Line Angle | 1.65 |
| Longitudinal Loads | 1.65 | | |

For Extreme Wind Loads 1.10

(3) Conductor and OHGW Data:

OHGW: 3/8" HSS
R.B.S. - 10,800 lb.

138 kV Conductor: Drake (795 26/7 ACSR)
R.B.S. - 31,500 lb.

69 kV Conductor: Linnet (336-4 26/7 ACSR)
R.B.S. - 14,100 lb.

Ruling Span - 550 ft.
Vertical Span - 700 ft.
Horizontal Span - 750 ft.
Line Angle - 10 degrees

(4) Load Cases:

Load Case A: NESC Medium District Loads with an Unbalanced Longitudinal Load of 1,600 lb. at the Top Conductor (1.65 LF applied)

Load Case B: 100 Mph Extreme Wind Load (1.1 LF applied)

(5) Loading Information (summary):

NESC Medium Loading Data

| | Cond.Tension (kips) | Transverse lb/ft. | Vertical lb/ft. |
|---|---|---|---|
| Drake - 138 kV | 7.91 | .536 | 1.516 |
| Linnet- 69 kV | 4.15 | .407 | .765 |
| OHGW - 3/8 HSS | 2.56 | .287 | .463 |

Extreme Wind Loading Data (26 psf)

| | Cond.Tension (kips) | Transverse lb/ft. | Vertical lb/ft. |
|---|---|---|---|
| Drake - 138 kV | 8.54 | 2.4007 | 1.0940 |
| Linnet- 69 kV | 4.72 | 1.5622 | .4630 |
| OHGW - 3/8 HSS | 1.23 | .7800 | .2730 |

(6) Calculate forces and moments at the groundline:

NESC Medium District Loading

| | Load due to Wind on Wire (kips) | Load due to Line Angle (kips) | Total Transv. Load W/LF (kips) | Moment Arm (feet) | Ultimate Moments (ft kips) |
|---|---|---|---|---|---|
| OHGW | .22 | .45 | 1.27 | 96.75 | 123 |
| COND-1 | .40 | 1.38 | 3.28 | 89.50 | 294 |
| COND-2 | .40 | 1.38 | 3.28 | 79.50 | 261 |
| COND-3 | .40 | 1.38 | 3.28 | 69.50 | 228 |
| COND-69-1 | .31 | .72 | 1.96 | 89.50 | 175 |
| COND-69-2 | .31 | .72 | 1.96 | 79.50 | 156 |
| COND-69-3 | .31 | .72 | 1.96 | 69.50 | 136 |
| GROUNDLNE | | | | 0.0 | |
| Totals for Wire Loads | | | 16.99 | | 1373 |
| Wind on the Pole | | | 1.70 | | 71 |
| Moments due to unbalanced vertical load (Negligible if crossarms are all the same length) | | | | | 0 |
| Additional moment due to deflection (Approximated) | | | | | 140 |
| Total Transverse Shear and Moments at Groundline | | | 18.69 | | 1584 |

For the unbalanced longitudinal load - the shear is 1.6 kips and the longitudinal moment is 236.3 ft-kips (1.6 kips @ top cond, 89.5 ft. moment arm, 1.65 LF)

TOTAL RESULTANT GROUNDLINE MOMENT = 1600 ft kips

Extreme Wind Loading

Similar calculations are performed for the extreme wind load.

TOTAL GROUNDLINE MOMENT = 1560 ft-kips

Conclusions: The NESC Medium Loading case with a longitudinal load controls design.

(7) Select Embedment Chart and Determine Embedment Depth

| | Required Embedment Depth |
|---|---|
| Medium dry sand, Chart 3, dia. of 2.5 ft. | 18 ft. |
| Dense dry sand, Chart 1, dia. of 2.5 ft. | 13 ft. |

Average sand Med/Dense dry material, use 15 ft, or 10 percent of pole height plus 4 ft.

For identical data and medium/dense submerged sand, the charts indicate a required embedment depth of 22 ft.

b Example 2: For a single circuit, medium-angle 90 ft. steel pole, the maximum ultimate groundline moment has been determined to be 580 ft-kips.

For a pole groundline diameter of 2.0 ft. and a medium dry sand material the required embedment depth is 14.5 ft. (use 15 ft.).

c Example 3: For a prestressed concrete pole, determine the embedment depth. The concrete pole is designed so that the cracking moment is not exceeded by a 6,000 lb. load applied 2 feet from the top and the ultimate strength is not exceeded by a 12,000 lb. load applied 2 feet from the top.

In order to achieve the same ultimate strength for the foundation as the pole, the embedment depth is selected to sustain an ultimate load of 12 kips.

Characteristics of the pole follow:

height: 80 ft.
taper: .165 in/ft. of height
assumed embedded depth: 10% + 4 feet in dense dry sand
groundline diameter: 24.5" (use 24")
ult. groundline moment: 792 ft-kip (based on 12k x 66 ft.)

The chart for dense dry sand shows a required embedment of 11.9 feet for a 2 ft. diameter foundation to resist 792 ft-kips of overturning moment at groundline. This approximates the 12.0 foot embedment depth obtained from the 10 percent of pole length plus 4.0 feet originally estimated.

d Example 4: For the pole in example 3, calculate the deflection and rotation at the groundline for the working loads.
Since the working load is less than one half of the ultimate load, equations 2 to 5 are valid.

| | | |
|---|---|---|
| Given: | Horizontal working load, | P = 5.0 kips |
| | Embedment depth | D = 12.0 ft. |
| | Groundline working moment | M = 5 x 66 = 330 ft-kips |
| | Dense dry sand | $n_h$ = 75 lb/in$^3$ or 129 kcf |

(1) Calculations using Davisson's formulae for sandy soil:

$D_r$ = Depth to point of rotation, ft

$$D_r/D_e = [(M/PD_e) + .750]/[(1.5\ M/PD_e) + 1]$$

$$= [330/(5x12)) + 0.75]/[(1.5 \text{ x } 330)/(5x12)) + 1]$$

$$D_r/D_e = .676$$

(2) Groundline deflection, and rotation:

$Y_g = [3PD_r/D_e]/[n_hD_e^2((1.5\ D_r/D_e) - 1)]$

$= 3(5)\ (.676)/[(129)(12)^2(1.5 \times .676 - 1)]$

= 0.039 ft.

= 0.47 in.

$D_r = (D_r/D_e) \times De$

= 0.676 x 12 = 8.112

$\theta = Y_g/D_r = 0.039/8.112$

= 0.00481 Radian = 0.00481 x 57.3 degrees

= 0.28 degrees

(3) Estimated pole deflections at groundline:

Horizontal deflection = 0.5 inch (approximate)

Rotation about vertical axis = 0.28 degree (approximate)

These deflections are assumed to be reasonable because the loads are in the range between 1/3 and 1/2 of the ultimate load and, as such, the load deflection relationship is linear.

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## COMPARISON OF DESIGN METHODS

Comparisons were made of embedment requirements, groundline deflection and foundation rotation for tubular steel and concrete transmission poles, using various analytical techniques. The techniques used to evaluate and tabulate embedment depths are the Broms method, the Hansen method, and the method found in RUS Bulletin 1724E-200, "Design Manual for High Voltage Transmission Lines." The “Embedment Calculations Overview Table” which follows is a condensed tabulation of representative calculations for these three methods in nine soil types for steel and concrete poles. The horizontal loads in the table are 5, 35, and 50 kips applied at heights of 30, 60, and 90 feet, respectively. The Davisson method is used to evaluate groundline deflection and rotation for all embedment techniques. The method by Naik & Peyrot was compared to Broms and Hansen for one case.

Inspection of calculations shows very good correlation between the embedments required by the Hansen method and the Broms method, with the Hansen method being generally more conservative of the two. The RUS method for wood poles is in reasonable agreement with the other methods in good soils but is marginal in poor soils. The one sample calculation made using the Naik method is in agreement with Hansen and Broms.

In comparing the different methods, several general conclusions can be reached. Inspection of the calculations reveals that there is generally a slight reduction in the embedment depths associated with an increase in embedment diameter. The data also shows that there is a substantial increase in groundline rotations with a relatively small decrease in embedment depths resulting from doubling the embedment diameter. Capacity and rotation are affected more by the embedment depth rather than the diameter of the embedded pole.

The calculations also show the comparative insensitivity of the required embedment to groundline shear. For the range of shears from 10 kips to 40 kips, the required embedments based on the Hansen method, varied from 18 feet to 20 feet in medium sand and from 27.8 to 30.9 feet in medium clay. In medium sand and medium clay respectively, the depths required for 10 kips shear are
96.6 percent and 94.9 percent of the depths required for 25 kips, and the depths required for 40 kips shear are 103 percent and 105.5 percent of the depths required for 25 kips shear.

The comparison of various methods of evaluating embedment requirements resulted in using the Hansen method in developing the embedment charts in this bulletin.

# EMBEDMENT CALCULATIONS OVERVIEW TABLE

| Soil | POLE S = Steel C = Concrete Type | LOAD (KIPS) | HEIGHT (FT) | DIA. (FT) | HANSEN DEPTH (FT) | HANSEN ROT. (DEG.) | HANSEN bL | BROMS DEPTH (FT) | BROMS ROT. (DEG.) | BROMS L | REA DEPTH (FT) | REA ROT. (DEG.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dense Dry Sand | S | 5.0 | 30.0 | 1.01 | 8.19 | 0.63 | 2.87 | 8.25 | 0.61 | 2.89 | 6.55 | 1.49 |
| | C | 5.0 | 30.0 | 1.52 | 7.52 | 0.87 | 1.77 | 7.13 | 1.07 | 1.68 | 6.55 | 1.49 |
| | S | 35.0 | 60.0 | 2.43 | 15.19 | 0.73 | 2.63 | 14.71 | 0.83 | 2.55 | 13.24 | 1.25 |
| | C | 35.0 | 60.0 | 3.65 | 13.93 | 1.03 | 1.62 | 12.74 | 1.45 | 1.49 | 13.24 | 1.25 |
| | S | 50.0 | 90.0 | 3.14 | 18.03 | 0.77 | 2.55 | 17.17 | 0.93 | 2.43 | 16.17 | 1.17 |
| | C | 50.0 | 90.0 | 4.71 | 16.45 | 1.10 | 1.57 | 14.89 | 1.62 | 1.42 | 16.17 | 1.17 |
| Dense Submerged Sand | S | 5.0 | 30.0 | 1.01 | 9.53 | 0.58 | 3.01 | 9.88 | 0.51 | 3.12 | 6.55 | 2.48 |
| | C | 5.0 | 30.0 | 1.52 | 8.83 | 0.78 | 1.88 | 8.53 | 0.89 | 1.81 | 6.55 | 2.48 |
| | S | 35.0 | 60.0 | 2.43 | 17.84 | 0.66 | 2.79 | 17.60 | 0.69 | 2.75 | 13.24 | 2.08 |
| | C | 35.0 | 60.0 | 3.65 | 16.34 | 0.92 | 1.72 | 15.21 | 1.22 | 1.60 | 13.24 | 2.08 |
| | S | 50.0 | 90.0 | 3.14 | 21.02 | 0.71 | 2.69 | 20.48 | 0.78 | 2.62 | 16.17 | 1.96 |
| | C | 50.0 | 90.0 | 4.71 | 19.34 | 0.97 | 1.66 | 17.75 | 1.36 | 1.53 | 16.17 | 1.96 |
| Medium Dry Sand | S | 5.0 | 30.0 | 1.01 | 10.87 | 0.57 | 3.13 | 9.90 | 0.81 | 2.85 | 7.91 | 1.92 |
| | C | 5.0 | 30.0 | 1.52 | 9.87 | 0.82 | 1.91 | 8.95 | 1.43 | 1.65 | 7.91 | 1.92 |
| | S | 35.0 | 60.0 | 2.43 | 20.10 | 0.67 | 2.86 | 17.63 | 1.11 | 2.51 | 15.99 | 1.61 |
| | C | 35.0 | 60.0 | 3.65 | 18.29 | 0.96 | 1.75 | 15.24 | 1.94 | 1.46 | 15.99 | 1.61 |
| | S | 50.0 | 90.0 | 3.14 | 23.62 | 0.72 | 2.74 | 20.52 | 1.25 | 2.38 | 19.51 | 1.51 |
| | C | 50.0 | 90.0 | 4.71 | 21.59 | 1.02 | 1.69 | 17.78 | 2.17 | 1.39 | 19.51 | 1.51 |
| Medium Submerged Sand | S | 5.0 | 30.0 | 1.01 | 13.20 | 0.40 | 3.51 | 12.39 | 0.51 | 3.29 | 7.91 | 2.83 |
| | C | 5.0 | 30.0 | 1.52 | 12.11 | 0.56 | 2.17 | 10.67 | 0.90 | 1.91 | 7.91 | 2.83 |
| | S | 35.0 | 60.0 | 2.43 | 24.47 | 0.47 | 3.22 | 22.03 | 0.70 | 2.90 | 15.99 | 2.38 |
| | C | 35.0 | 60.0 | 3.65 | 22.44 | 0.65 | 1.99 | 19.01 | 1.23 | 1.68 | 15.99 | 2.38 |
| | S | 50.0 | 90.0 | 3.14 | 28.76 | 0.50 | 3.09 | 25.56 | 0.79 | 2.75 | 19.51 | 2.23 |
| | C | 50.0 | 90.0 | 4.71 | 26.30 | 0.71 | 1.90 | 22.10 | 1.38 | 1.60 | 19.51 | 2.23 |
| Loose Dry Sand | S | 5.0 | 30.0 | 1.01 | 13.61 | 0.72 | 3.14 | 11.61 | 1.32 | 2.68 | 9.56 | 2.77 |
| | C | 5.0 | 30.0 | 1.52 | 12.34 | 1.05 | 1.92 | 10.01 | 2.33 | 1.56 | 9.56 | 2.77 |
| | S | 35.0 | 60.0 | 2.43 | 24.95 | 0.88 | 2.85 | 20.65 | 1.81 | 2.36 | 19.33 | 2.33 |
| | C | 35.0 | 60.0 | 3.65 | 22.55 | 1.29 | 1.74 | 17.83 | 3.17 | 1.37 | 19.33 | 2.33 |
| | S | 50.0 | 90.0 | 3.14 | 29.24 | 0.95 | 2.73 | 23.99 | 2.04 | 2.24 | 23.56 | 2.18 |
| | C | 50.0 | 90.0 | 4.71 | 26.56 | 1.38 | 1.67 | 20.75 | 3.57 | 1.30 | 23.56 | 2.18 |
| Loose Submerged Sand | S | 5.0 | 30.0 | 1.01 | 16.37 | 0.64 | 3.38 | 14.21 | 1.09 | 2.93 | 9.56 | 4.89 |
| | C | 5.0 | 30.0 | 1.52 | 14.80 | 0.93 | 2.05 | 12.22 | 1.91 | 1.70 | 9.56 | 4.89 |
| | S | 35.0 | 60.0 | 2.43 | 29.87 | 0.79 | 3.05 | 25.24 | 1.49 | 2.58 | 19.33 | 4.10 |
| | C | 35.0 | 60.0 | 3.65 | 27.06 | 1.14 | 1.86 | 21.75 | 2.61 | 1.49 | 19.22 | 4.10 |
| | S | 50.0 | 90.0 | 3.14 | 35.02 | 0.84 | 2.92 | 29.21 | 1.69 | 2.44 | 23.56 | 3.84 |
| | C | 50.0 | 90.0 | 4.71 | 31.74 | 1.23 | 1.78 | 25.23 | 2.95 | 1.42 | 23.56 | 3.84 |

# EMBEDMENT CALCULATIONS OVERVIEW TABLE
# (Cont.)

| Soil | POLE Type (S = Steel, C = Concrete) | LOAD (KIPS) | HEIGHT (FT) | DIA. (FT) | HANSEN DEPTH (FT) | HANSEN ROT. (DEG.) | HANSEN bL | BROMS DEPTH (FT) | BROMS ROT. (DEG.) | BROMS L | REA DEPTH (FT) | REA ROT. (DEG.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stiff Saturated | S | 5.0 | 30.0 | 1.01 | 7.72 | 0.77 | 2.76 | 7.69 | 0.78 | 2.74 | 6.55 | 1.24 |
| Clay | C | 5.0 | 30.0 | 1.52 | 6.59 | 1.22 | 1.43 | 7.33 | 0.90 | 1.59 | 6.55 | 1.24 |
| | S | 35.0 | 60.0 | 2.43 | 18.72 | 0.78 | 2.78 | 18.75 | 0.77 | 2.78 | 13.24 | 2.10 |
| | C | 35.0 | 60.0 | 3.65 | 16.01 | 1.21 | 1.45 | 17.84 | 0.89 | 1.61 | 13.24 | 2.10 |
| | S | 50.0 | 90.0 | 3.14 | 23.89 | 0.78 | 2.75 | 23.95 | 0.78 | 2.75 | 16.17 | 2.43 |
| | C | 50.0 | 90.0 | 4.71 | 20.46 | 1.22 | 1.43 | 22.81 | 0.89 | 1.60 | 16.17 | 2.43 |
| Medium Saturated | S | 5.0 | 30.0 | 1.01 | 12.53 | 0.39 | 3.76 | 11.91 | 0.45 | 3.58 | 7.91 | 1.44 |
| Clay | C | 5.0 | 30.0 | 1.52 | 10.60 | 0.62 | 1.94 | 10.73 | 0.60 | 1.96 | 7.91 | 1.44 |
| | S | 35.0 | 60.0 | 2.43 | 30.72 | 0.38 | 3.83 | 29.26 | 0.44 | 3.65 | 15.99 | 2.44 |
| | C | 35.0 | 60.0 | 3.65 | 25.92 | 0.62 | 1.97 | 26.29 | 0.59 | 2.00 | 15.99 | 2.44 |
| | S | 50.0 | 90.0 | 3.14 | 38.89 | 0.39 | 3.76 | 37.16 | 0.44 | 3.59 | 19.51 | 2.81 |
| | C | 50.0 | 90.0 | 4.71 | 32.84 | 0.63 | 1.94 | 33.45 | 0.60 | 1.97 | 19.51 | 2.81 |
| Soft Saturated | S | 5.0 | 30.0 | 1.01 | 22.29 | 0.16 | 5.63 | 20.65 | 0.19 | 5.21 | 9.56 | 1.67 |
| Clay | C | 5.0 | 30.0 | 1.52 | 18.50 | 0.26 | 2.85 | 17.65 | 0.30 | 1.72 | 9.56 | 1.67 |
| | S | 35.0 | 60.0 | 2.43 | 55.70 | 0.15 | 5.84 | 51.37 | 0.19 | 5.38 | 19.33 | 2.83 |
| | C | 35.0 | 60.0 | 3.65 | 45.89 | 0.25 | 2.93 | 43.68 | 0.29 | 2.79 | 19.33 | 2.83 |
| | S | 50.0 | 90.0 | 3.14 | 69.73 | 0.16 | 5.67 | 64.54 | 0.19 | 5.25 | 23.56 | 3.26 |
| | C | 50.0 | 90.0 | 4.71 | 57.72 | 0.26 | 2.86 | 55.11 | 0.30 | 2.73 | 23.56 | 3.26 |

## ABSTRACT OF HANSEN METHOD

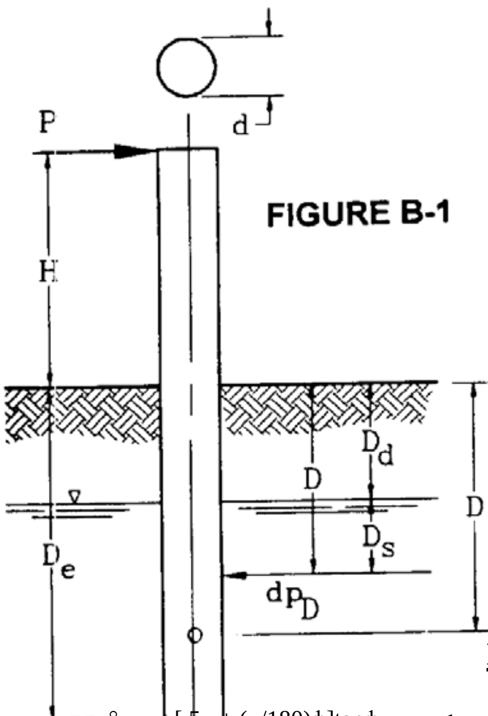


FIGURE B-1

P = Transverse Load in kips
H = Load height above grade in ft.
d = diameter of foundation in ft.
D = arbitrary depth below ground
q = effective overburden pressure at depth in ksf
$p_D$ = resultant (passive minus active) pressure per unit frontal area of foundation in ksf

$\phi$ = soil friction angle in degrees
C = cohesion
$\gamma$ = unit weight above ground water table in pcf
$\gamma'$ = unit weight below ground water table in pcf

**Hansen Formulas**

( 1) $K_q^{\circ} = e^{[.5\pi + (\pi/180)\phi]\tan\phi} \cos\phi\tan(45^{\circ}+.5\phi) - e^{-[.5\pi-(\pi/180)\phi\tan\phi]} \cos\phi\tan(45^{\circ} + .5\phi)$

( 2) $K_c^{\circ} = [e^{[.5\pi+(\pi/180)\phi\tan\phi]} \cos\phi \tan(45^{\circ} + .5\phi)-1]\cot\phi$

( 3) $A = 1.58 + 4.09 \tan^4 \phi$

( 4) $B = [e^{\pi\tan\phi}\tan^2(45 + .5 \phi)-1]\cot\phi$

( 5) $K_o = 1-\sin\phi$

( 6) $K_c\infty = (A)(B)$

( 7) $K_q\infty = (A)(B) K_o\tan\phi$

( 8) $a_q = [K_q^{\circ}/( K_q\infty- K_q^{\circ})][K_o\sin\phi /\sin(45 + .5 \phi)]$

( 9) $a_c = [K_c^{\circ}/( K_c\infty- K_c^{\circ})][2\sin(45 + .5 \phi)]$

(10) $K_q^D = [K_q^{\circ} - K_q\infty (a_q)(D/d)]/[1+(a_q)(D/d)]$

(11) $K_c^D = [K_c^{\circ} + K_c\infty (a_c)(D/d)]/[1 + a_c(D/d)]$

(12) $q = \gamma D_d + \gamma' D_s$

(13) $p_D = qK_q^D + CK_cD$

# SAMPLE CALCULATIONS: HANSEN METHOD

### Medium Dry Sand

Medium Dry Sand: $\gamma = 0.120$ kcf, $\phi = 33°$, $C = n_h = 48.4$ kcf

Working Lateral Load, P = 17.5 kips
Height of P Acting Above Ground = 60.0 ft.
Use Overload Factor = 2.0
Ultimate Lateral Load = 17.5 x 2.0 = 35.0 kips
Ultimate Moment at Ground Line = 35 x 60 = 2100.0 k-ft.
$A1 = .5\pi + (\phi\pi/180) = 2.14675498$

$A2 = .5\pi - (\phi\pi/180) = 0.99483767$

$e^{(A1)\tan\phi} = 4.03142127$

$-e^{-(A2)\tan\phi} = -0.52410924$

$\tan(45 + \phi/2) = 184177089$

$\tan(45 - \phi/2) = 0.54295570$

1) $K_q^{\circ} = 5.98843176$

2) $K_c^{\circ} = 8.04901376$

3) A = 2.30743260

4) B = 28.63831029

5) $K_o = 0.45536097$

6) $K_c\infty = 89.15529677$

7) $K_q\infty = 26.36454713$

8) $a_q = 0.08293881$

9) $a_c = 0.17442819$

**SAMPLE CALCULATIONS: HANSEN METHOD (Cont.) - Medium Dry Sand**

Assume the pole is steel and the pole ground line diameter = $1.0\,(M)^{0.333}$

DIAMETER(d)=1.0(35k x 60ft x12 in/ft) 2.43

| DEPTH D | D/d | $K_q^D$ | $K_c^D$ | q (kcf) | $p_D$ (ksf) | $dp_D$(k/ft) |
|---|---|---|---|---|---|---|
| 0 | 0 | 5.968 | 8.05 | 0 | 0 | 0 |
| 2 | 0.823 | 7.266 | 18.2 | 0.24 | 1.75 | 4.25 |
| 4 | 1.646 | 8.408 | 26.1 | 0.48 | 4.05 | 9.84 |
| 6 | 2.469 | 9.422 | 32.5 | 0.72 | 6.81 | 16.5 |
| 8 | 3.292 | 10.33 | 37.6 | 0.96 | 9.94 | 24.2 |
| 10 | 4.115 | 11.14 | 41.9 | 1.2 | 13.4 | 32.6 |
| 12 | 4.938 | 11.88 | 45.6 | 1.44 | 17.1 | 41.7 |
| 14 | 5.761 | 12.54 | 48.7 | 1.68 | 21.1 | 51.3 |
| 16 | 6.584 | 13.15 | 51.4 | 1.92 | 25.3 | 61.5 |
| 18 | 7.407 | 13.71 | 53.8 | 2.16 | 29.7 | 72.1 |
| 20 | 8.23 | 14.22 | 55.9 | 2.4 | 34.2 | 83.1 |
| 22 | 9.053 | 14.69 | 57.7 | 2.64 | 38.9 | 94.5 |
| 24 | 9.877 | 15.13 | 59.4 | 2.88 | 43.7 | 106 |
| 26 | 10.7 | 15.54 | 60.9 | 3.12 | 48.6 | 118 |
| 28 | 11.52 | 15.91 | 62.2 | 3.36 | 53.6 | 130 |
| 30 | 12.35 | 16.26 | 63.4 | 3.6 | 58.7 | 143 |
| 32 | 13.17 | 16.59 | 64.6 | 3.84 | 63.8 | 155 |
| 34 | 13.99 | 16.9 | 65.6 | 4.08 | 69.1 | 168 |
| 36 | 14.81 | 17.19 | 66.5 | 4.32 | 74.4 | 181 |
| 38 | 15.64 | 17.46 | 67.4 | 4.56 | 79.8 | 194 |
| 40 | 16.46 | 17.72 | 68.2 | 4.8 | 85.2 | 207 |

## SAMPLE CALCULATIONS: HANSEN METHOD (Cont.) - Medium Dry Sand

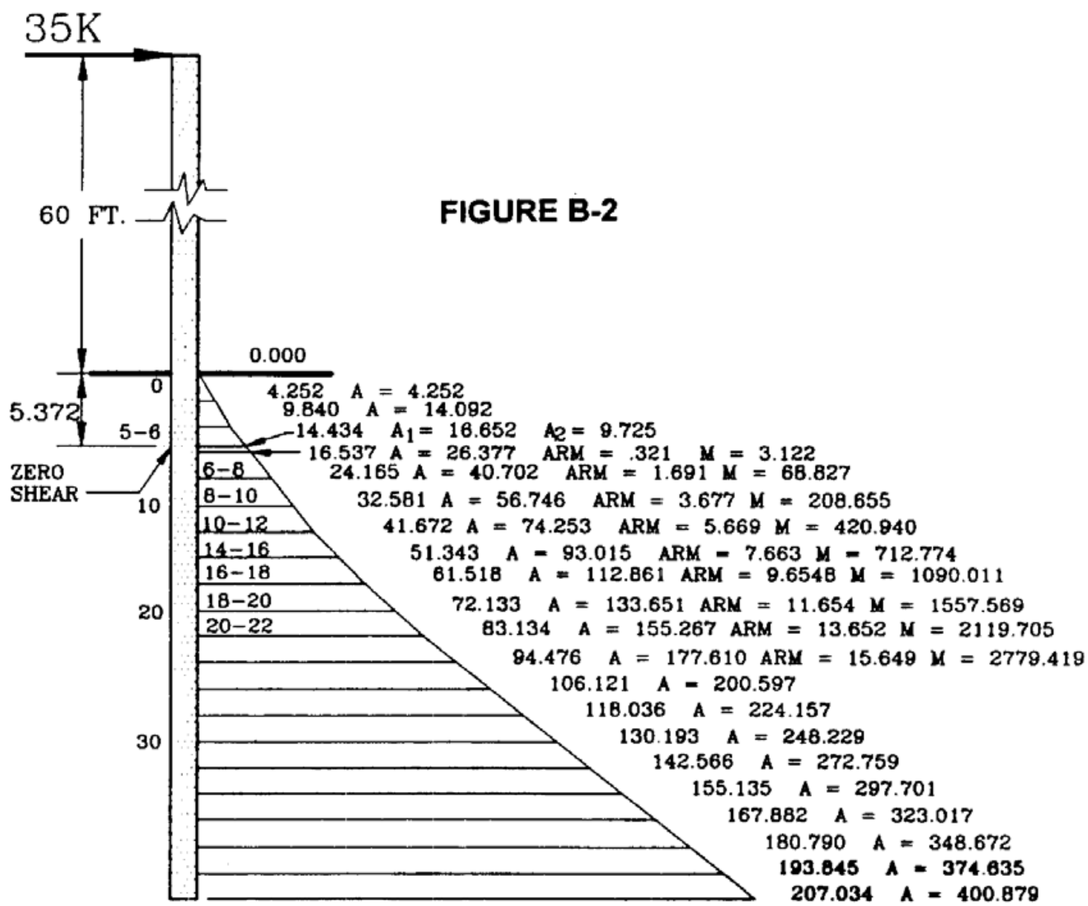


FIGURE B-2

Point of Zero Shear

$9.84y + 0.25(16.537 - 9.84)y^2 = 35 - 4.252 - 14.092$
$y^2 + 5.877y - 9.948 = 0$
$y = 1.372$
Zero Shear Distance from Ground = 4.0 + 1.372 = 5.372'

Soil Load Ordinate at Point of Zero Shear:
9.84 + 1.372(16.537- 9.84)/2.0 = 14.434

Moment at Point of Zero Shear:
$35 \times 65.372 - 4.252(2/3 + 3.372)-4.252(1 + 1.372)2 - 5.588(2/3 + 1.372) - 9.840 (1.372/2)^2 + 4.594/6) \times (1.372^2 = 2228.58$ kip-ft.
***ARM tabulated above are distance from centroid to point of zero shear. Moments M are about point of zero shear.**

**SAMPLE CALCULATIONS: HANSEN METHOD (Cont.) - Medium Dry Sand**
The summation of soil pressures below the point of zero shear must be equal to zero. The summation of moments of the soil pressures below the point of zero shear, about the point of zero shear, must equal the moment in the pole at the point of zero shear (2228.58 kip-ft. in this case).

| ZONE | AREA | MOMENT | ΣA | ΣM |
|---|---|---|---|---|
| 5-6 | 9.725 | 3.122 | 9.725 | 3.122 |
| 6-8 | 40.702 | 68.827 | 50.427 | 71.949 |
| 8-10 | 56.746 | 208.655 | 107.173 | 280.604 |
| 10-1 | 74.253 | 420.940 | 181.426 | 701.544 |
| 12-14 | 93.015 | 712.774 | 274.441 | 1414.318 |
| 14-16 | 112.861 | 1090.011 | 387.302 | 2504.329 |
| 16-18 | 133.651 | 1557.569 | 520.953 | 4061.898 |
| 18-20 | 155.267 | 2119.705 | 676.220 | 6181.603 |
| 20-22 | 177.610 | 2779.419 | 853.830 | 8961.022 |

**First Trial: Depth = 20'** (to bottom of zone 18-20)
as total area is 676.220, point of rotation (where ΣA - 338.11) is in zone 14-16, at about (338110 - 274.441)/112.861 = 0.564 of zone depth.
Say $M_1$ = 1414.318 + 0.564 x 1090.011 = 2029.233
Say $M_2$ = 6181.603 - 2029.233 = 4152.370
$M_2 - M_1$ = 2123.137 <2228.580. So 20.0' is not enough.

**Second Trial: Depth = 20.2'**
Ordinate = 83.134 + 0.2(94.476 - 83.134)/2 = 84.268
Area of zone 20-21, A = (83.134 + 84.268) x 0.5 x 0.2 = 16.740
ARM = 14.728, M = 246.550
ΣA = 692.96, ΣM = 6428.153
Point rotation, where ΣA =0.5 x 692.960=346.480 is in zone 14-16.
$51.343y + 0.25(61.518 - 51.343)\ y^2 = 346.480 - 274.441$,
y = 1.317
Ordinate = 51.343 + 1.317 (61.518 - 51.343)/2 = 58.043
ARM = 9.300, A = 72.031, M = 669.881,
ΣM = 2084.199
$M_1$ = 2084.199
$M_2$ = 6428.153 - 2084.199 = 4343.954
$M_2 - M_1$ = 2259.76 > 2228.58 so 20.2 is slightly too deep

**SAMPLE CALCULATIONS: HANSEN METHOD (Cont.) - Medium Dry Sand**

**<u>For Rotation and Deflection of the Pole, Assume an Embedment Depth of 20.10 feet</u>**

$n_h$ = 48.4 kcf, E - 30000 x 144 = 4,320,000 ksf

$I = \pi R^3 t = \pi d^3 t/8$

when d = 72t, $I = \pi^{d4}/576$

say EI = $(4320.000)(2.43^4\pi/576)$ = 821554.0 k-ft.$^2$

$1/T = (n_h/EI)^{1/5} = (48.4/821554)^{1/5} = 0.143$

$\beta$ = De/T = (20.10)(0.143) = 2.8743

$D_r/D_e$ = [(60/20.1) + 0.75]/[1.5(60/20.1) + 1] = 0.682

Working Load, P = $17.5^k$

$Y_g = (3 \times 17.5 \times 0.682)/[48.4 \times (20.1)^2\{(1.5 \times 0.682)-1\}]$

= 0.0796 ft. = 0.96 in.

Rotation = $Y_g/D_r$ = 0.0796/(0.682 x 20.1) = 0.00581 rad.

= 0.33 degrees

NOTE: Had this problem been solved using the chart for medium dry sand, the embedment depth of a 2.4 ft. pier for 60 ft. x 35 kips = 2100 kip-feet is about 19.5 ft.

This illustrates the order of magnitude of the error in using the 20 kip charts for a load of 35 kips. The amount of error is negligible.

**SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS**

Soil Parameters: Soft Dry Clay, Depth = 0-4'
Medium Dry Sand, Depth = 4'-10'
Medium Dry Clay, Depth = 10'-16'

Working Lateral Load, P = 17.5 kips
Height of P Acting Above Ground = 60.0 ft.
Use Overload Factor = 2.0
Ultimate Lateral Load = 17.5 x 2.0 = 35.0 kips
Ultimate Moment at Ground Line = 35 x 60 = 2100 k-ft.

Dry Soft Clay:
$\gamma = 0.100$ kcf, $\phi = 0.001°$, c = 0.25ksf, K - 100 ksf
(following parameters can be applied both to soft and medium clay)

$A1 = (\pi/2) + (\pi\phi/180) = 1.570813780$

$A2 = (\pi/2) - (\pi\phi/180) = 1.570778874$

$e^{(A1)\tan\phi} = 1.000027416$

$-e^{-(A2)\tan\phi} = 0.999972585$

$\tan(45 + \phi/2) = 1.000017453$

$\tan(45 - \phi/2) = 0.999982547$

1) $K_q^{\circ} = 0.00089737$

2) $K_c^{\circ} = 2.570804331$

3) $A = 1.580000000$

4) $B = 5.141780549$

5) $K_o = 0.999982547$

6) $K_c\infty = 8.124025125$

7) $K_q\infty = 0.000141788$

8) $a_q^{\circ} = 0.000042552$

9) $a_c^{\circ} = 0.654700797$

Note 1: $\phi$ is revised from 0° to .001° to keep Hansen's coefficients for $K_c^{\circ}$ and $N_c$ from disappearing.

**SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS**

<u>Medium Dry Sand</u>: $\gamma$= 0.120 kcf, $\phi$ = 33° , c = 0, $n_h$ = 48.4 kcf

$A1 = (\pi/2) + (\pi\phi/180) = 2.146754980$

$A2 = (\pi/2) - (\pi\phi/180) = 0.994837674$

$e^{(A1)\tan\phi} = 4.031421265$

$-e^{-(A2)\tan\phi} = 0.524109242$

$\tan(45 + \phi/2) = 1.841770886$

$\tan(45 - \phi/2) = 0.542955700$

1) $K_q^\circ$ = 5.988431762

2) $K_c^\circ$ = 8.049013758

3) A = 2.307432595

4) B = 38.63831030

5) $K_o$ = 0.455360965

6) $K_c\infty$ = 89.15529660

7) $K_q\infty$ = 26.36454679

8) $a_q^\circ$ = 0.082938806

9) $a_c^\circ$ = 0.174428189

**SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS**

Medium Dry Sand: $\gamma = 0.085$ kcf, $\phi = 41^\circ$ , c = 0, $n_h = 77.8$ kcf

$A1 = (\pi/2) + (\pi\phi/180) = 2.286381320$

$A2 = (\pi/2) - (\pi\phi/180) = 0.855211334$

$e^{(A1) \tan \phi} = 7.297420715$

$-e^{-(A2) \tan \phi} = -0.475483133$

$\tan (45 + \phi /2) = 2.194299731$

$\tan (45 - \phi /2) = 0.455726256$

1) $K_q^\circ = 11.92142133$

2) $K_c^\circ = 12.75178716$

3) $A = 3.915476618$

4) $B = 83.85828093$

5) $K_o = 0.343940971$

6) $K_c\infty = 328.3451382$

7) $K_q\infty = 98.16972110$

8) $a_q^\circ = 0.034275312$

9) $a_c^\circ = 0.073535342$

## SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS

Pole is steel and pole ground line diameter = 1.0 (M)$^{.333}$

B = 1.0(35$^{k}$ x 60' x 12$^{"/'}$)$^{.333}$ = 29.22 inc. = 2.43 ft.

| D | D/d | $K_q^D$ | $K_c^D$ | q(kcf) | $P_D$ | $dP_D$ |
|---|---|---|---|---|---|---|
| 0 | 0.00 | 0.00009 | 2.57080 | 0.00 | 0.64270 | 1.56176 |
| 2 | 0.82305 | 0.00009 | 4.51534 | 0.2000 | 1.12885 | 2.74311 |
| 4 | 1.64609 | 0.00009 | 5.45125 | 0.4000 | 1.36285 | 3.31172 |
| 4 | 1.64609 | 8.43611 | 26.14175 | 0.4000 | 3.37444 | 8.1990 |
| 6 | 2.46914 | 9.45192 | 32.46485 | 0.64000 | 6.04923 | 14.69963 |
| 8 | 3.29218 | 10.35880 | 37.63468 | 0.88000 | 9.11574 | 22.15126 |
| 10 | 4.11523 | 11.17336 | 41.94040 | 1.12000 | 12.51416 | 30.40942 |
| 10 | 4.11523 | 0.00009 | 6.62082 | 1.12000 | 4.96572 | 12.06669 |
| 12 | 4.93827 | 0.00009 | 6.81217 | 1.36000 | 5.10925 | 12.41548 |
| 14 | 5.76132 | 0.00009 | 6.96030 | 1.60000 | 5.22037 | 12.68550 |
| 16 | 6.58436 | 0.00009 | 7.07838 | 1.84000 | 5.30895 | 12.90075 |
| 16 | 6.58436 | 27.80207 | 115.70742 | 1.84000 | 51.15581 | 124.30862 |
| 18 | 7.40741 | 29.38520 | 124.03875 | 2.01000 | 59.06425 | 143.52613 |
| 20 | 8.23045 | 30.89867 | 131.74184 | 2.18000 | 67.35910 | 163.68261 |
| 22 | 9.05350 | 32.34697 | 138.88516 | 2.3500 | 76.01538 | 184.71737 |
| 24 | 9.87654 | 33.73423 | 145.52760 | 2.52000 | 85.01026 | 206.57493 |
| 26 | 10.69959 | 35.06421 | 151.72004 | 2.69000 | 94.32272 | 229.20422 |
| 28 | 11.52263 | 36.34041 | 157.50673 | 2.86000 | 103.93357 | 252.55858 |
| 30 | 12.34568 | 37.5600 | 162.92627 | 3.03000 | 113.82498 | 276.59470 |
| 32 | 13.16872 | 38.74396 | 168.01253 | 3.2000 | 123.98067 | 301.27303 |
| 34 | 13.99177 | 39.87700 | 172.79535 | 3.37000 | 134.38549 | 326.55674 |
| 36 | 14.81481 | 40.96763 | 177.30107 | 3.54000 | 145.02541 | 352.41175 |
| 38 | 15.63786 | 42.01821 | 181.55312 | 3.71000 | 155.88756 | 378.80677 |
| 40 | 16.46091 | 43.03089 | 185.57232 | 3.88000 | 166.95985 | 405.71244 |
| 0.5 | 0.20576 | 0.00009 | 3.23008 | 0.05000 | 0.80752 | 1.96228 |
| 1.0 | 0.41152 | 0.00009 | 3.74943 | 0.10000 | 0.93737 | 2.27780 |
| 1.5 | 0.61728 | 0.00009 | 4.16912 | 0.15000 | 1.04229 | 2.53278 |
| 2.5 | 1.02881 | 0.00009 | 4.80582 | 0.25000 | 1.20148 | 2.91959 |
| 3.0 | 1.23457 | 0.00009 | 5.05302 | 0.30000 | 1.26328 | 3.06977 |
| 3.5 | 1.44033 | 0.00009 | 5.26594 | 0.35000 | 1.31652 | 3.19913 |

**SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS**

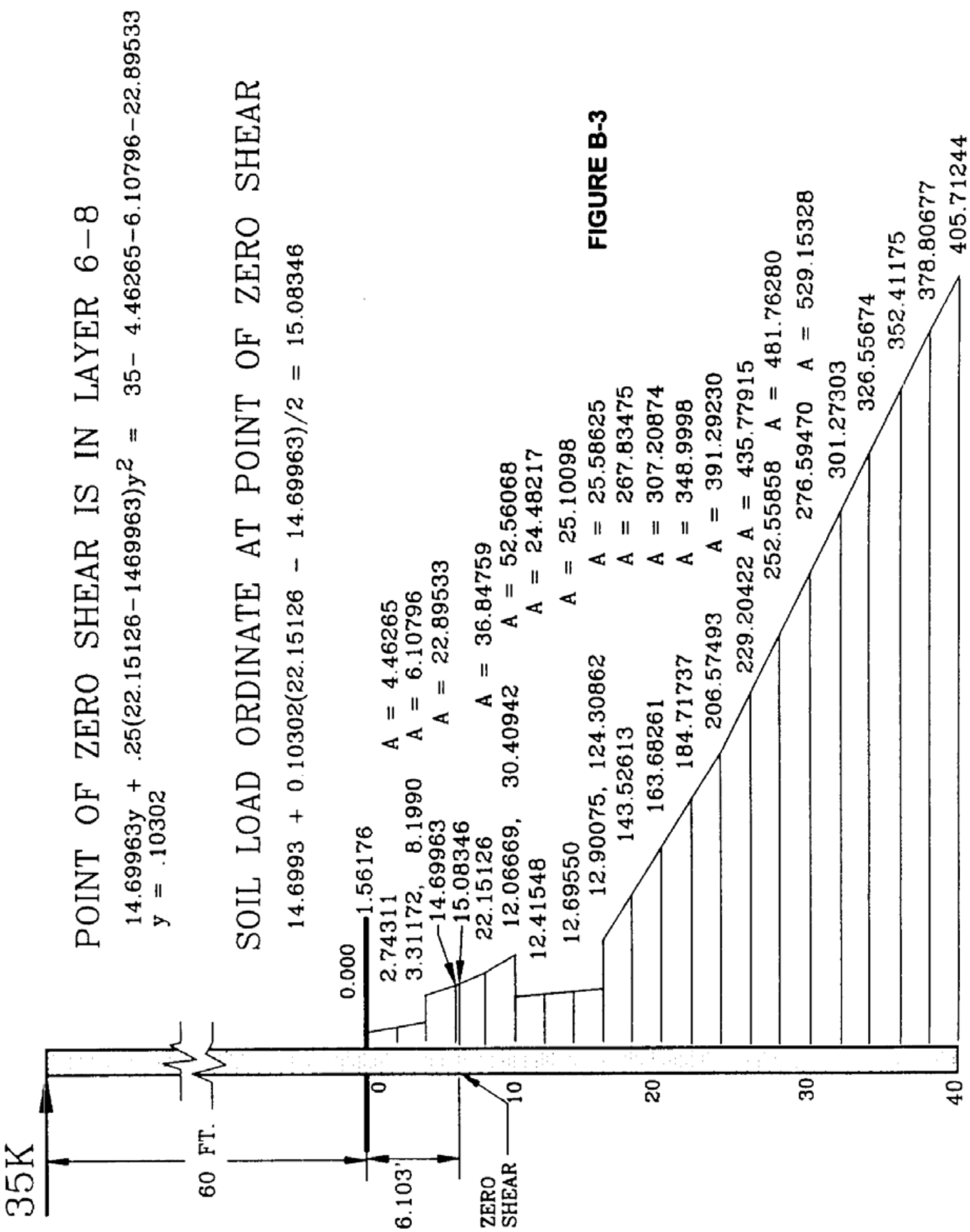


**FIGURE B-3**

## SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS

Moment at Point of Zero Shear

$35^k$ (60 + 6.103) - 1.56176(.5)(5.853) - ½ (.5)(.40052)(5.770)

- 1.96228(.5)(5.353) - ½ (.5)(.31552)(5.270)

- 2.27780(.5)(4.853) - ½ (.5)(.25498)(4.770)

- 2.53278(.5)(4.353) - ½ (.5)(.21033)(4.270)

- 2.74311(.5)(3.853) - ½ (.5)(.17648)(3.770)

- 2.91959(.5)(3.353) - ½ (.5)(.15018)(3.270)

- 3.06977(.5)(2.853) - ½ (.5)(11259)(2.270)

- 8.19900(2)(1.103) - ½ (2)(6.50063)(.770)

- 14.69963(.103)(.103/2) - ½(.103)(.38383)(.103/3)

= 2249.285 k-ft.

The summation of soil pressures below the point of zero shear must equal zero. The summation of moments of the soil pressures below the point of zero shear, about the point of zero shear, must equal the moment in the pole at the point of zero shear.

| ZONE | AREA | MOMENT | ∑ AREA | ∑ MOMENT |
|---|---|---|---|---|
| 6.1-8 | 35.31713 | 35.61782 | 35.31713 | 35.61782 |
| 8-10 | 52.56068 | 155.01826 | 87.87781 | 190.63608 |
| 10-12 | 24.48217 | 120.00533 | 112.35998 | 310.64141 |
| 12-14 | 25.10098 | 173.21138 | 137.46096 | 483.85279 |
| 14-16 | 25.58625 | 227.71254 | 163.04721 | 711.56533 |
| 16-18 | 267.83475 | 2924.99470 | 430.88196 | 3636.56003 |
| 18-20 | 307.20874 | 3968.78323 | 738.09070 | 7605.34326 |
| 20-22 | 348.39998 | 5197.11908 | 1086.49068 | 12802.46234 |
| 22-24 | 391.29230 | 6618.94456 | 1477.78298 | 19421.40690 |
| 24-26 | 435.77915 | 8242.45415 | 1913.56213 | 27633.86105 |
| 26-28 | 481.76280 | 10075.17423 | 2395.32493 | 37739.03528 |
| 28-30 | 529.15328 | 12124.02668 | 2924.47821 | 49863.06196 |

## SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS

First Trial: Depth = 20'

As total area is 738.09070, point of rotation where ½ ΣA = 369.04535 is in zone 16-18, at about (369.04535-163.04721)/267.83475 = 0.76912 of zone depth.

Say $M_1$ = 71156533 + .76912(2924.99470) = 2961.24902

$M_2$ = 7605.34326 - 2961.24902 = 4644.09424

$M_2 - M_1$ = 1682.84522 < 2249.285, too shallow.

Second Trial: Depth = 22'

As total area is 1086.49068, point of rotation where ½ Σ = 543.24534 is in zone 18-20, at about (543.24534-430.88196)/307.20874 = 0.36576 of zone depth.

Say $M_1$ = 3636.56003 + .36576(3968.78323) = 5088.16554

$M_2$ = 12,802.46234 - 5088.16554 = 7714.29681

$M_2 - M_1$ = 2626.13127 > 2249.285, too deep.

Third Trial: Depth = 21.2'

Ordinate = 163.68261 + ½ (1.2)(18471737 - 163.68261) = 176.30347

zone 20'-21.1'

Area = 163.68261(1.2) + ½ (1.2)(176.30347 - 163.68261) = 203.99165

Moment = 163.68261(1.2)(14.497) + ½ (1.2)(12.62086)(14.697) = 2958.78143

ΣA = 738.09070 + 203.99165 = 942.08235

ΣM = 7605.34326 + 2958.78143 = 10,564.12469

Point of rotation where ½ ΣA = 471.04117 is in zone 18-20

143.52613 y + ¼ (163.68261 - 143.52612) $y^2$ = 471.04117 - 430.88196

y = .27711

Ordinate = 143.52613 + ½(0.27711)(20.15648) = 146.31889

Moment = 143.52613(.27711)(12.036) + ½(.27711)(2.79276)(12.082)

= 483.37716

ΣM = $M_1$ = 3636.56003 + 483.37716 = 4119.93719

$M_2$ = 10,564.12469 - 4119.93719 = 6444.18750

$M_2 - M_1$ = 2324.25031 > 2249.285, too deep.

## SAMPLE CALCULATIONS: HANSEN METHOD - STRATIFIED SOILS

Fourth Trial: Depth = 21.1'

Ordinate = 163.68261 + ½ (1.1)(184.71737 - 163.68261) = 175.25173

zone 10-21.1

Area = 163.68261 + ½ (1.1)(175.25173 - 163.68261) = 186.41389

Moment = 163.68261(1.1)(14.447) + ½(1.1)(11.569)(14.630) = 2694.28586

$\Sigma$A = 738.09070 + 186.41389 = 924.50459

$\Sigma$M = 7605.34326 + 2694.28586 = 10,299.62912

Point of rotation where ½ $\Sigma$A = 462.25229 is in zone 18-20

$143.52613\,y + ¼\,(163.68261 - 143.52613)\,y^2 = 462.25229 - 430.88196$

y = 0.21692

Ordinate = 143.52613 + ½ (0.21692)(20.15648) = 145.71227

Moment = 143.52613(2.692)(2.005) + ½ (.21692)(2.18614)(12.042) = 376.61510

$\Sigma M = M_1$ = 3656.56003 + 376.61510 = 4033.17513

$M_2$ = 10,299.62912 - 4033.17513 = 6266.45399

$M_2 - M_1$ = 2233.27886 <2249.285, too shallow.

Say Depth between 21.1 to 21.2

## SOIL PROPERTIES CORRELATION

| SOIL DESCRIPTIONS | | SOIL PARAMETERS | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | (1) $\gamma$ (KCF) | (1) C (KCF) | (1) $\phi$ (DEG.) | (3) Se (LBS.) | (2) $n_h$ (KCF) | (2) K (KSF) | (1) BLOWS PER FT.* | PROBE (4) TORQUE (IN-LBS.) |
| A. SAND | | | | | | | | | |
| LOOSE | Dry | 0.095 | - | 28.0 | 35.0 | 16.2 | - | 4 | 100.0 - 300.0 |
| | Submerged | 0.055 | - | 28.0 | 35.0 | 9.2 | - | 4 | |
| MEDIUM | Dry | 0.120 | - | 33.0 | 70.0 | 48.4 | - | 20 | 300.0 - 500.0 |
| | Submerged | 0.065 | - | 33.0 | 70.0 | 32.8 | - | 20 | |
| DENSE | Dry | 0.140 | - | 41.0 | 140.0 | 129.6 | - | 50 | >500.0 |
| | Submerged | 0.085 | - | 41.0 | 140.0 | 77.8 | - | 50 | |
| B. CLAY | | | | | | | | | |
| SOFT | Dry | 0.100 | 0.25 | - | 35.0 | - | 100.0 | 2 | 100 - 300.0 |
| | Submerged | 0.050 | † | - | † | - | † | | † |
| MEDIUM | Dry | 0.120 | 0.75 | - | 70.0 | - | 200.0 | 6 | 300.0 - 500.0 |
| | Submerged | 0.060 | † | - | † | - | † | † | † |
| STIFF | Dry | 0.140 | 2.0 | - | 140.0 | - | 400.0 | 16 | >500.0 |
| | Submerged | .080 | † | - | † | - | † | † | † |

* Standard Penetration Test - ASTM D-1586
† Submergence as such does not affect the true cohesion of clays, (5) P. 127

# Selected SI-Metric Conversions and Other Conversions

## AREA

| To Convert From | To | Multiply by |
|---|---|---|
| circular mil (cmil) | square meter ($m^2$) | 5.067075 E-10 |
| square centimeter ($cm^2$) | square meter (m2) | *1.000 E-04 |
| square foot ($ft^2$) | square meter (m2) | *9.290304 E-02 |
| square inch ($in^2$) | square meter (m2) | *6.451600 E-04 |
| square kilometer ($km^2$) | square meter (m2) | *1.000 E+06 |
| square mile ($mi^2$) | square meter (m2) | 2.589988 E+06 |

## FORCE

| To Convert From | To | Multiply by |
|---|---|---|
| kilogram force(kgf) | newton (N) | *9.806650 |
| kip | newton (N) | 4.448222 E+03 |
| pound force (lbf) | newton (N) | 4.448222 |

## FORCE PER LENGTH

| To Convert From | To | Multiply by |
|---|---|---|
| kilogram force per meter (kgf/m) | newton per meter (N/m) | *9.806650 |
| pound per foot (lb/ft) | newton per meter (N/m) | 1.459390 E+01 |

## DENSITY

| To Convert From | To | Multiply by |
|---|---|---|
| pound per cubic inch (lb/in3) | kilogram per cubic meter (kg/m3) | 2.767990 E+04 |
| pound per cubic foot (lb/ft3) | kilogram per cubic meter (kg/m3) | 1.601846 E+01 |

## LENGTH

| To Convert From | To | Multiply by |
|---|---|---|
| foot (ft) | meter (m) | 3.048 E-01 |
| inch (in) | meter (m) | *2.540 E-02 |
| kilometer (km) | meter (m) | *1.000 E+03 |
| mile (mi) | meter (m) | *1.609344 E+03 |

## LOAD CONCENTRATION

| To Convert From | To | Multiply by |
|---|---|---|
| pound per square inch ($lb/in^2$) | kilogram per square meter ($kg/m^2$) | 7.030696 E+02 |
| pound per square foot ($lb/ft^2$) | kilogram per square meter ($kg/m^2$) | 4.882428 |
| ton per square foot ($ton/ft^2$) | kilogram per square meter ($kg/m^2$) | 9.071847 E+02 |

## MASS

| To Convert From | To | Multiply by |
|---|---|---|
| pound (avoirdupois)(lb) | kilogram (kg) | 4.534924 E-01 |

## PRESSURE

| To Convert From | To | Multiply by |
|---|---|---|
| kip per square inch ($kip/in^2$) | pascal (Pa) | 6.894757 E+06 |
| kip per square foot ($kip/ft^2$) | pascal (Pa) | 4.788026 E+04 |
| newton per square meter ($N/m^2$) | pascal (Pa) | *1.000 |
| pound per square foot ($lb/ft^2$) | pascal (Pa) | 4.788026 E+01 |
| pound per square inch ($lb/in^2$) | pascal (Pa) | 6.894757 E+03 |

## BENDING MOMENT

| To Convert From | To | Multiply by |
|---|---|---|
| kilogram force meter (kgf-m) | newton meter (N-m) | *9.806650 |
| kip-foot (kip-ft) | newton meter (N-m) | 1.355818 E+03 |
| pound-foot (lb-ft) | newton meter (N-m) | 1.355818 |

## DEGREE/RADIANS

| To Convert From | To | Multiply by |
|---|---|---|
| degree | radians | $\pi/180$ |
| radians | degrees | 57.3 |

*Exact Conversion

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