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DESIGN CHARTS FOR MINOR SERVICE STRUCTURE FOUNDATIONS

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RESEARCH REPORT 506-1F
STUDY 2-18-71-506
DESIGN CHARTS FOR MINOR SERVICE STRUCTURE FOUNDATIONS

DESIGN CHARTS FOR MINOR SERVICE STRUCTURE FOUNDATIONS

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Research Report No. 506-1F

Development of Design Charts for Minor Service Structure Foundations

Research Study 2-18-71-506

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ABSTRACT

This report presents a series of design charts which allow an entirely graphical procedure to be followed in selecting the proper size of drilled shaft foundation for standard Texas Highway Department signs. The procedure uses a boring log of Texas Highway Department cone penetrometer measurements and a graphical overlay-slide device which was developed in this project to determine the soil shear strength parameters, c and ϕ. These data are used to select one of five typical soil types which span the range of soil properties normally encountered and this determines the footing design chart to use. The footing is sized to carry the moment for which the sign support column is designed.

The procedure is simple, and while only an approximation of the more complex and more exact theory developed and verified in Research Study 2-5-67-105 "Design of Footings for Minor Service Structures," it will produce designs that are slightly more conservative than those given by the more exact theory.

A detailed discussion of the assumptions involved is given and a user's guide is presented. Recommendations are made on how to design footings to rest in a non-uniform soil profile. There are 21 design charts which have been tailored for Texas Highway Department design standards but five additional basic design charts permit the design of footings for non-standard sign supports.

Key Words: Graphical design, drilled shafts, sign supports, shear strength, THD cone penetrometer, wind loading.

IMPLEMENTATION STATEMENT

The 21 design charts in this report are drawn for immediate incorporation into Texas Highway Department design standards. Black line copies of the masters for the overlay-slide device used in determining c and Ø from THD cone penetrometer measurements are provided. These copies may be used with an ozalid process or equivalent to reproduce the clear plastic overlay slides. The five basic design charts in Appendix B may be used for design of footings for non-standard sign supports, which are usually permitted by specifications.

This report is in direct response to the design needs of File D-18, Maintenance Division of the Texas Highway Department.

SUMMARY

This report contains 21 design charts for minor service structure foundations which were developed using the theory and approach presented in Study 2-5-67-105, "Design Footings for Minor Service Structures." The report is divided in to four sections: the introductory chapter; a chapter outlining the assumption underlying the design charts and their validity; a chapter on the use of the design charts which is intended as a users' guide; and the appendices which contain the design charts themselves.

The design charts in Appendix A of this report are graphs of the depth of embedment of a standard drilled shaft footing as a function of a soil shear strength parameter, c or ϕ. The charts are based on an approximation to the more exact theory presented in Research Report 105-1, "Theory, Resistance of a Drilled Shaft Footing to Overturning Loads," and they remain slightly on the conservative side of that theory.

There are limitations to these design charts which are results of the assumptions made in developing the theory. It is assumed that the drilled shaft is rigid with respect to the soil and it is shown that this occurs only when the embedment depth-to-diameter ratio is between about 5 and 12. To make certain that a minimum embedment is provided to account for the loss of lateral support in surface soils caused by drying and shrinking, a minimum depth-to-diameter ratio of 2 was used in the design charts.

Basic design charts in Appendix B are included as an aid in the design of footings for sign support columns which are equivalent to Texas Highway Department standards and are permissible substitutes in contract specifications.

The masters of the overlay slide device developed in this project are in Appendix C. These masters can be reproduced by ammonia process or by photography on a clear plastic film which will permit a graphical determination of the soil shear strength parameters, c and ϕ.

Drilled shaft footings for minor service structures can be designed conveniently by the graphical method of this report with the assurance that the procedure produces a slightly conservative design.

PREFACE

This report presents a series of design charts for drilled shaft foundations of minor service structures which usually support highway signs. The basic work from which the data in these design charts is drawn was done in Study 2-5-67-105, "Design of Footings for Minor Service Structures". Five reports were completed in that study outlining a completed research cycle of theory, model and field testing, and development of footing design charts. Personnel of the Texas Highway Department Maintenance Division, File D-18 had immediate practical use for such information and suggested certain changes in the manner of presenting the information which would make the charts thus produced applicable to their detailed design aims. Consequently, Study 2-18-71-506 was initiated and this report is prepared in response to the design needs of File D-18. The close cooperation and helpful suggestions of Mr. Ralph Banks, the contact representative, are gratefully acknowledged.

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Chapter I

INTRODUCTION

This report contains 21 design charts for minor service structure foundations which were developed using the theory and approach presented in Study 2-5-67-105, "Design of Footings for Minor Service Structures." This report is divided into four sections: the introductory chapter; a chapter outlining the assumptions underlying the design charts and their validity; a chapter on the use of the design charts which is intended as a users guide; and the appendices which contain the design charts themselves.

Although design charts were prepared and included in Research Report 105-3, personnel of File D-18 concluded that the same data would be more readily applied to field use if design charts could be tailored to provide embedment depths of the standard footings for steel columns commonly used by the Texas Highway Department. The diameters of these footings are chosen primarily to fit the anchor bolt circles of the sign support columns rather than for structural reasons. Varying amounts of vertical deformed steel bars are included in the reinforcing cage to make certain that the column will reach its maximum design moment (slightly less than plastic moment) before the drilled shaft will fail in bending.

Because it is not within the scope of this report to provide guidelines for proper structural reinforcing of drilled shafts, it is assumed that they are designed to reach at least ultimate moment at the same time the sign support column reaches its design moment. Thus, the curves shown in the design charts consider only the soil mechanics problem of determining the limiting moment which can be sustained by a rigid drilled shaft embedded in the soil.

The occasional user of the design charts presented herein needs to be only slightly familiar with the assumptions made in constructing the charts and with their ranges of validity. Chapter 3 will provide adequate explanation for use of the design charts. The person who wishes to extend the charts or to use some non-standard drilled shaft or sign supporting column will wish to read Chapter 2 with some care, for it contains the basis upon which the design charts are constructed.

Chapter II

CONSTRUCTION OF DESIGN CHARTS

The design of drilled shafts for sign support foundations is based upon an ultimate load-ultimate strength concept as illustrated in Figure 1. The wind load that is applied to the sign is the maximum that can be reasonably expected in a fifty-year period and is determined from a design chart map of the State of Texas which divides the state into three wind load zones (Ref. 6). The column supporting the sign, the anchor bolts, and the drilled shaft itself are then designed structurally to sustain the loads and moments imposed by this maximum design wind at a limiting (or ultimate) stress condition.

Sign Support Column Design

The sign support column design wind stress as given in AASHO Specifications (1971) is 1.45 times the allowable stress which is 0.6 times the yield stress. Multiplying these factors gives a wind design stress that is 0.87 times the yield stress. Wind design moments for the standard Texas Highway Department column sections used in this report are given in Table 1. These moments were used in determining the required embedment for drilled shafts at the limiting equilibrium condition to be described later in this chapter.

Structural Design of Drilled Shaft and Anchor Rods

It is assumed in this report that the anchor bolts and the reinforcing steel in any drilled shaft have been designed structurally to carry the column design moment without failing. It is recommended that the factor of safety against reaching "yield stress in the anchor bolts" should be chosen equal to or greater than the column factor of safety, 1.15 (=1/0.87).

Table 1: Wind Design Moments for Standard Column Sections

Section	Section Modulus (in.^{3})	Wind Design Moment KIP-FT
3 I 5.7	1.7	6.16
5 I 7.7	1.9	6.89
6 B 8.5	5.07	18.4
6 B 12	7.24	26.2
6 WF 15.5	10.1	36.6
8 WF 17	14.1	51.1
8 WF 20	17.0	61.6
10 WF 21	21.5	77.9
K*	30.1	84.1
10 WF 25	26.4	95.8
12 WF 27	34.1	123
L*	47.1	132
M*	74.5	208
J*	75.6	211
H*	111.3	311
16 WF 36L	142	371
G*	145.7	407
16 WF 36H	165	431
18 WF 50	223	581
21 WF 62	302	787

*Round Column

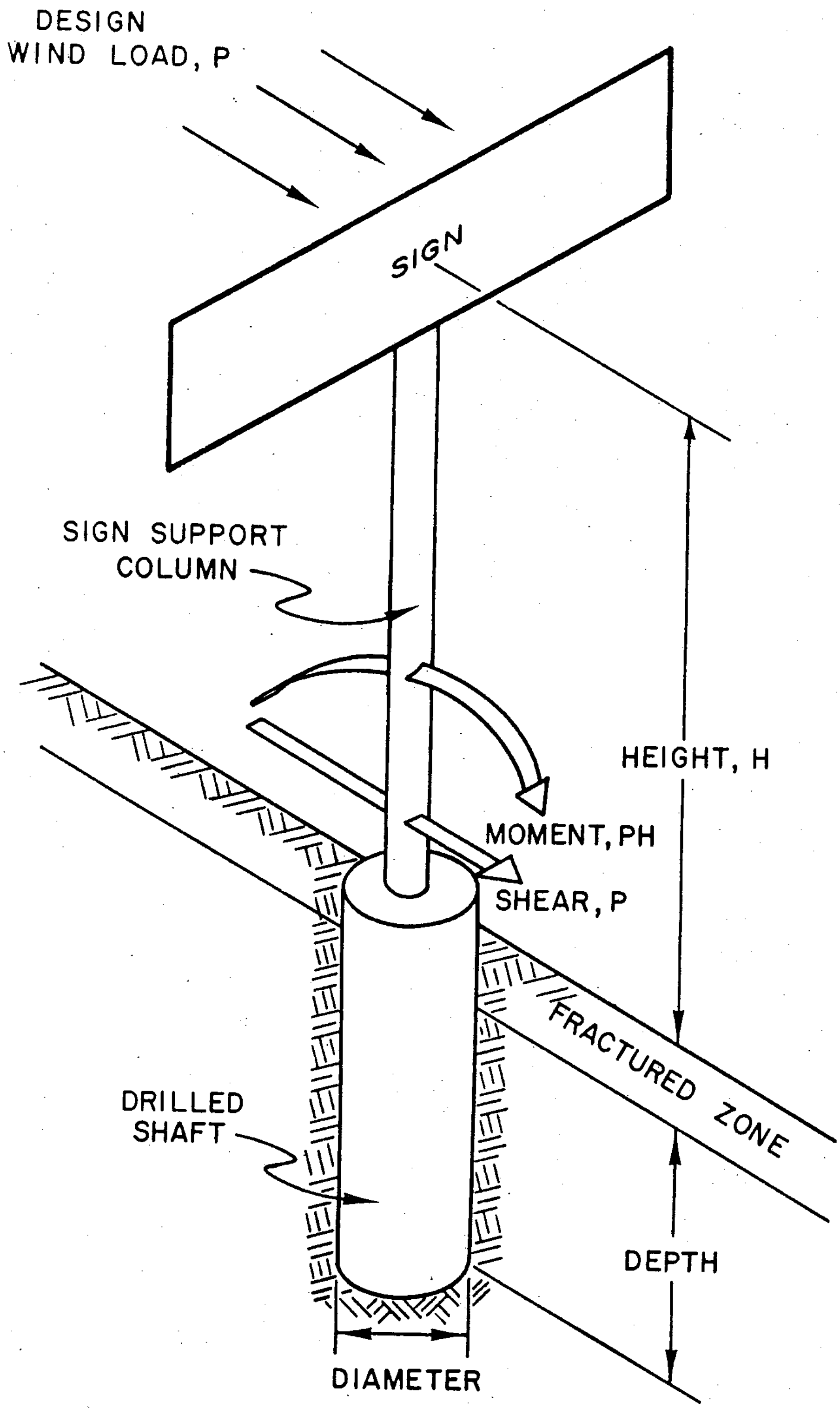


FIG. 1 AN ILLUSTRATION OF THE SIGN SUPPORT FOOTING DESIGN PROBLEM

Assumptions Used in Sizing Drilled Shafts

The development of the theory for predicting the ultimate load and moment which can be carried by a drilled shaft of diameter d and depth D was presented in Research Report 105-1, "Theory, Resistance of a Drilled Shaft Footing to Overturning Loads" and will not be repeated here. Several important assumptions were made in that report and they are repeated below:

1. The Drilled Shaft
   a. is a rigid cylinder
   b. has a maximum depth-to-diameter ratio of 6
   c. has a minimum depth-to-diameter ratio of 2

   Assumptions b and c will be discussed later in the section on Limitations of the Design Charts.
2. The Soil
   a. is at failure condition
   b. is uniform
   c. has strength characteristics of c, cohesive shear strength, and ϕ, angle of internal friction.
3. Limiting Equilibrium Condition
   a. drilled shaft is rigid
   b. soil is failed, c and ϕ are fully developed
   c. angle of tilt of the shaft is 5° from the vertical
4. Design Quantities
   a. specified: a height of load, H
   b. calculated: a maximum horizontal load, P and a maximum moment, PH. (See Figure 1)
   c. Factor of Safety in computed values of P and H is 1

The equations for P and PH are very involved and their determination requires the solution of two simultaneous cubic equations. Graphical solution of such equations would have been impossible to exhibit on nomographs or in any other manner suitable for routine design use if it had not been discovered that three simplifications could be made to the computed results. The first simplification came from recognizing that the curves of P versus H given in Research Report 105-3, "Design Procedure Compared to Full-Scale Tests of Drilled Shaft Footings," are very nearly hyperbolas which satisfy the equation

$$PH = \text{constant} \tag{1}$$

The second simplification made use of the approximate correlation between shear strength and the number of blows per foot of a Texas Highway Department penetrometer to give a "rough and ready" approximation of the soil shear strength parameters, c and ϕ.

The third simplification came from the decision to use only five typical soils as characteristic of all foundation materials. They can be described as clay, sand, soft clayey sand, medium sandy clay, and stiff sandy clay.

Each of the three simplifications will be discussed in detail below.

Constant Moment Approximation for the P-H Curve

Three curves are shown in Figure 2: one is a hyperbola passing through (P_1, H_1); another hyperbola passes through (P_2, H_2): and the third is a curve similar to the theoretically determined P-H curves. As H increases from H_1 to H_2, the product PH becomes larger. Physically, this means that the higher a sign is placed above the base of a footing,

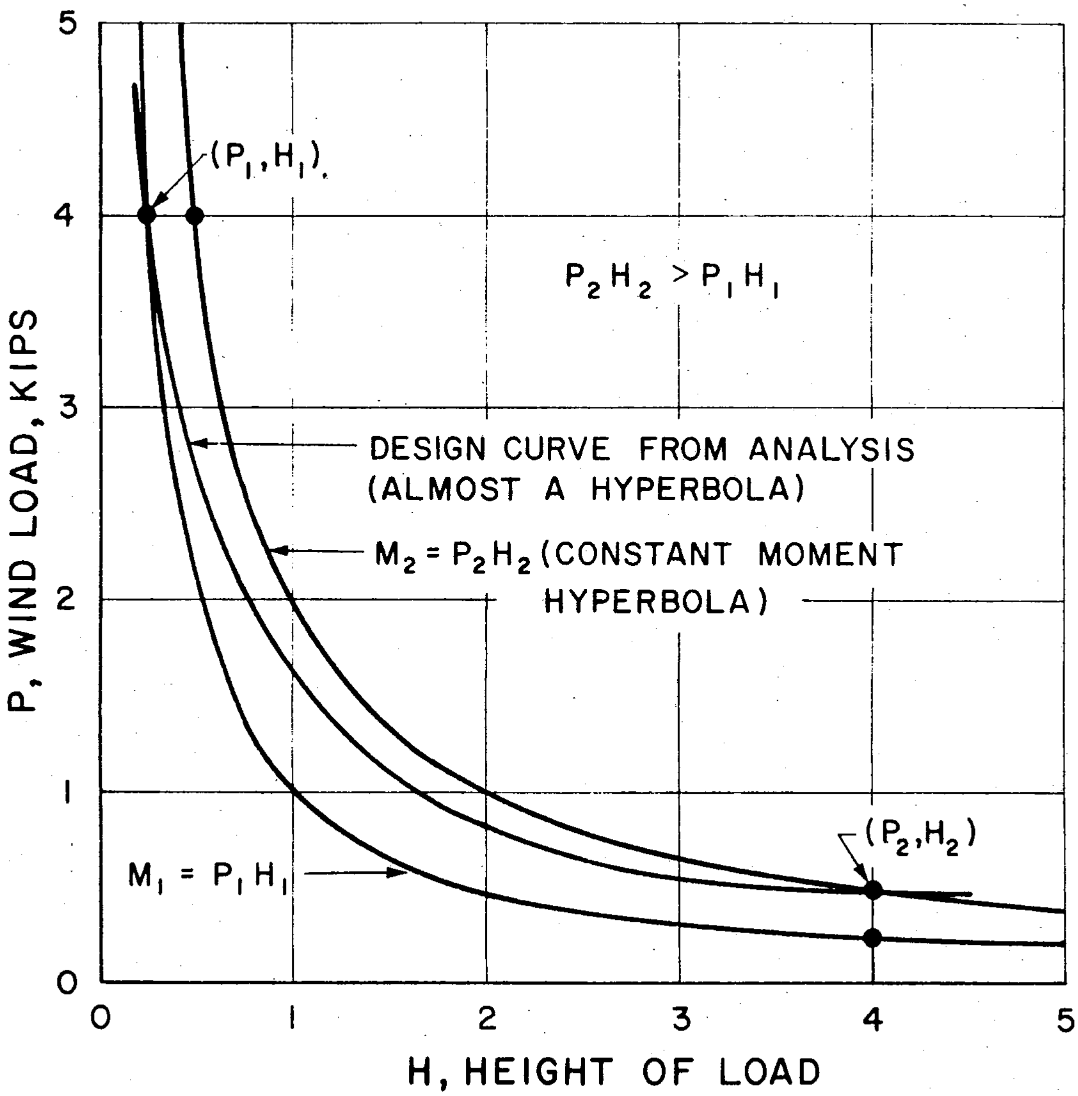


FIGURE 2. APPROXIMATION OF THE ANALYTICAL DESIGN CURVE BY A HYPERBOLA PASSING THROUGH A MINIMUM HEIGHT

the greater moment the footing can sustain. This is due to the fact that the shear P is smaller when H is large and does not weaken the soil in direct bearing as much as does the higher P at low height. The fact that greater moments can be carried as load heights increase is useful in design, particularly since the increase in moment is not more than about twelve percent with a one-hundred percent increase of height. If some minimum wind load height is determined and a design moment is found for that height then the drilled shaft will be able to carry at least that moment for all greater heights. As a general rule, a minimum load height of around ten feet was chosen except in the larger sized drilled shafts. The minimum sign heights used in developing the design charts in appendices A and B are given in Table 2. Footings designed for all wind load heights above these will have unknown factors of safety above 1.

Correlation Between N and Shear Strength

The Texas Highway Department Foundation Exploration and Design Manual, Figure 1, pg. 4-43 gives the following approximate correlations between one-half of shear strength and N, the number of blows per foot counted with the T. H. D. penetrometer.

$$1/2 \text{ shear strength (Tsf)} = \frac{N}{75} \text{ for } 0 < N < 30 \quad (2)$$

$$1/2 \text{ shear strength (Tsf)} = \frac{N}{77} \text{ for } 30 < N < 100 \quad (3)$$

More recent information by private communication with the Texas Highway Department contact representative indicates a change in this formula to the following:

$$1/2 \text{ shear strength (Tsf)} = \frac{N}{70} \text{ for all N.} \quad (4)$$

Table 2: Minimum Design Height of Wind Load, Ft.

Depth of Drilled Shaft, Ft.	Drilled Shaft Diameter, In. 12"	18"	24"	30"	36"	42"	48"
2	8	-	-	-	-	-	-
3	9	9	-	-	-	-	-
4	8	8	8	-	-	-	-
5	10	10	10	10	-	-	-
6	12	12	12	12	12	-	-
7	-	7	7	7	-	10	-
8	-	8	8	8	-	-	10
9	-	9	9	9	9	-	-
10	-	10	10	10	-	10	10
11	-	-	11	11	-	-	-
12	-	-	12	12	12	10	10
13	-	-	-	13	-	-	-
14	-	-	-	15	15	15	15
15	-	-	-	15	-	-	-
16	-	-	-	-	15	15	15
18	-	-	-	-	15	15	15
20	-	-	-	-	-	15	15
22	-	-	-	-	-	15	15
24	-	-	-	-	-	-	15

Equation 4 is the basis for the relations between c and ϕ used for design in this report. Reworking Eq. 4 to give shear strength in lbs./sq. ft. results in

$$N \text{ (blows/ft.)} = \frac{S \text{ (lb./sq.ft.)}}{57.1} \tag{5}$$

where S = the shear strength.

The relation between shear strength and normal pressure on the soil is

$$S = c + p \tan\phi \tag{6}$$

where p = normal pressure

c = cohesive shear strength, lb./sq. ft.

ϕ = the angle of internal friction, degrees.

If it is assumed that Eq. 5 holds for all soils, whether they are predominantly clay or sand, and if it is further assumed that normal pressure in a soil mass is the overburden pressure, then the following equations may be written:

For a clay,

$$c = 57.1\ N \tag{7}$$

For a sand,

$$S = \gamma z \tan\phi = 57.1N \tag{8}$$

where γ = the unit weight of the soil (lb./cu. ft.)

z = the depth below the surface, ft.

For a soil which has both c and ϕ,

$$S = c + \gamma z \tan\phi = 57.1\ N \tag{9}$$

The design curves in Appendices A and B were computed assuming a soil unit weight of 115 lb./cu. ft. It is apparent from that if THD penetrometer measurements are made at two points in a vertical profile, z_1 and z_2, Eq. 9 can be used to determine c and $\emptyset$, as follows:

$$S_1 = c + (115)z_1 \tan\emptyset = 57.1\ N_1 \tag{10a}$$

$$S_2 = c + (115)z_2 \tan\emptyset = 57.1\ N_2 \tag{10b}$$

$$\frac{S_1 - S_2}{115(z_1 - z_2)} = \tan\emptyset = \frac{57.1(N_1 - N_2)}{115(z_1 - z_2)} \tag{11}$$

Once $\emptyset$ is determined, c can be found from either of Eqs. 10. It is implied in these equations that the soil is uniform with depth. This is rarely the case but it will be safe for design purposes to use the weakest reasonable profile of THD penetrometer measurements in determining the approximate c and $\emptyset$ values for the soil. A graphical procedure has been devised to give c and $\emptyset$ values directly from a boring log of THD penetrometer readings versus depth. This graphical procedure will be demonstrated in Chapter 3 and the assumptions underlying it are as follows:

1. Uniform soil, c, and $\emptyset$, with depth
2. Constant unit weight, 115 lb./cu. ft.
3. Equation 9 is valid for all soils.

Reference is made to the discussion of other methods of determining soil shear strength parameters c and $\emptyset$ which is presented in Research Report 105-3, pp. 36-43. From that discussion, it will be seen that the graphical method of this report is a crude and approximate technique which is nevertheless useful and conservative if the designer always keeps in mind the warning that the weakest reasonable profile of THD cone penetrometer values should be used in determining c and $\emptyset$.

The Weakest Reasonable Profile

A designer with good engineering judgment will apply this rule automatically. Two specific examples of the use of this rule are described below. The designer should exclude all strength data collected in an unusually stiff stratum when the remainder of the soil above and below it is considerably weaker. Failure will occur in the weak material with the drilled shaft using the stiffer material much like a fulcrum. The fulcrum is crushed in bearing in the process. An example of this kind of profile is the Bryan Sandy Clay described in Research Report 105-3.

Another instance in which higher soil strength data should be excluded is common in coastal areas where a stiff crust of small thickness, perhaps 2 or 3 feet, overlies a weak cohesive clay. Failure will occur in the soft material and the stiff material will be crushed sideways. The failure load will be higher than would be predicted using the properties of the soft clay mainly because of the contribution of the overlying stiff material. This contribution could be predicted by more detailed analysis but such is probably not justified in practical design work. It would be more practical to use the weaker strength profile and accept the unknown contribution of the stiffer upper crust as a beneficial contribution to the factor of safety. An example of this kind of profile is the Galveston clay described in Research Report 105-3.

The Five Typical Soils

As mentioned previously, five typical soils were chosen and the design charts were based upon their minimum assumed properties. These five soils are expected to span the range of soils normally encountered in design.

Table 3 gives the soil description as well as the c and ϕ values used in computing the design moments, and the ranges of c and ϕ which that soil type are intended to encompass.

The soil types are given by Roman numerals I through V and these numbers correspond with the design charts assembled for that soil type. As an example, a soil with c = 1500 lb./sq. ft. and ϕ = 22 degrees would fall into Type III and the design charts used would assume a c of only 500 lb./sq. ft. Thus, any soil properties that fall <u>within</u> a soil type will contribute an added, but undetermined, factor of safety.

Table 3: Soil Properties for Design

		Soil Properties Used in Computing Design Curves		Ranges of Soil Properties	
Soil Type	Soil Description	C lb./sq. ft.	ϕ degrees	C lb./sq. ft.	ϕ degrees
I	Clay	0 - 5000	0	0 - 5000	0 - -
II	Sand	0	0 - 35	0 - 500	0 - 35
III	Soft Clayey Sand	500	0 - 35	500 - 2000	0 - 35
IV	Medium Sandy Clay	2000	0 - 15	2000 - 4000	0 - 15
V	Stiff Sandy Clay	4000	0 - 15	4000 - up	0 - 15

Limitations of Design Charts

Certain limitations have been imposed on the design charts in order to keep them within the range of behavior which satisfy the assumptions of the theory. These assumptions have been made with regard to the rigidity of the drilled shaft and the integrity of the resisting soil. The first consideration imposes a maximum limit on the depth-to-diameter ratio and the second imposes a minimum ratio.

Minimum D/d Ratio. Drilled Shaft design practice in the Texas Highway Department has recognized the existence of loose, friable soil near the surface as well as that kind of soil which changes volume, swells on wetting, and cracks on shrinking within the upper few feet of soil. Figure 1 illustrates this depth below the ground surface in which soil strength should be considered negligible because it is so undependable. Texas Highway Department design practice has taken this condition into account by specifying a minimum embedment of the footing. In the design charts of this report a minimum depth-to-diameter ratio of 2 has been established. The designer is wise always to make allowance for these upper, friable zones of fractured soil.

Maximum D/d Ratio. No really firm boundary can be drawn between what constitutes a rigid and a flexible drilled shaft. Pioneering work by Matlock and Reese (Ref. 5) on laterally loaded piles has indicated that the definition of rigidity is linked to the ratio of flexural stiffness, EI, and the soil "foundation" modulus, or coefficient of lateral subgrade reaction, k. If the soil stiffness is constant with depth, then the stiffness ratio is

$$T = \sqrt[4]{\frac{EI}{kd}} \tag{12}$$

where (13)

T = relative stiffness constant

and

I = moment of inertia of the drilled shaft.

Since the cross section of a drilled shaft is circular, the moment of inertia is

$$I = \frac{\pi d^4}{64} \tag{14}$$

which when substituted into Eq. 13 gives the following results:

$$T = d \sqrt[4]{\frac{\pi E}{64kd}} \tag{15}$$

The limiting range of rigid piles has been shown to be reached when

$$D \cong 2T \tag{16}$$

or

$$D \cong 2d \sqrt[4]{\frac{\pi E}{64kd}} \tag{17}$$

Approximate values of k range between 10 and 150 $lb./in.^3$, E is around 3×10^6 $lb/in.^2$ for concrete, and the diameters range between 12 and 48 inches. If these ranges are set into Eq. 17, then typical ranges for the maximum D/d ratio for rigid piles is

$$4.4 \leq D/d \leq 7.8 \text{ (Large shafts)} \tag{18}$$

$$6 \leq D/d \leq 12 \text{ (Small shafts)} \tag{19}$$

The numbers are approximate as is the assumption of uniform soil stiffness but they indicate the general range of validity of rigid shaft theory. A limited numerical study of the ways in which the design quantities for a flexible shaft will vary from those of a rigid shaft showed that the rigid shaft will impose higher pressures on the soil and will rotate through a greater angle at the top but the flexible shaft may experience slightly greater moments. The limiting value of depth-to-diameter ratio was chosen to be 6 on a fairly arbitrary basis as can be seen from the foregoing analysis. Yet it can be expected that drilled shafts with D/d ratios greater than this may experience trouble with design ultimate moments. Thus, the design curves in Appendix A should be extended only with due caution.

Accuracy of the Charts

Certain variations are to be expected in the design charts due to the fact that the system of choosing the minimum load heights was not uniform. Despite these inaccuracies, the depths of embedment read from the design charts will be within 1/2-foot of that which would be determined analytically for the given design conditions. The designer is advised to round the embedment depth determined to the next largest even foot.

Chapter III

USE OF DESIGN CHARTS

This chapter presents detailed instructions on the use of the design charts of Appendix A. There are 20 such charts corresponding to five different soil types used as foundations for each of 4 different sign support types which are abbreviated in the Texas Highway Department design standards as SMD-8, OBTM, OCS(B), and OSBT-I. SMD-8 is a standard designation for guidesigns mounted on breakaway posts. In order, the remaining three designations stand for

Overhead Balanced Tee Mount

Overhead Cantilver Support, Series B

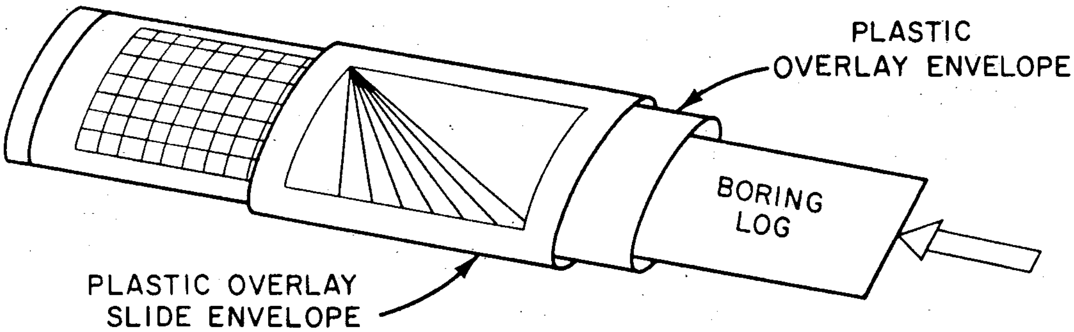
Overhead Sign Bridge Tower, Type I

This chapter is arranged in a numbered step-by-step manner which goes through all the steps required to complete a graphical design of a drilled shaft. There are 14 steps in all, the first seven of which lead to the proper choice of design chart. The remaining seven steps give the depth of embedment of a drilled shaft.

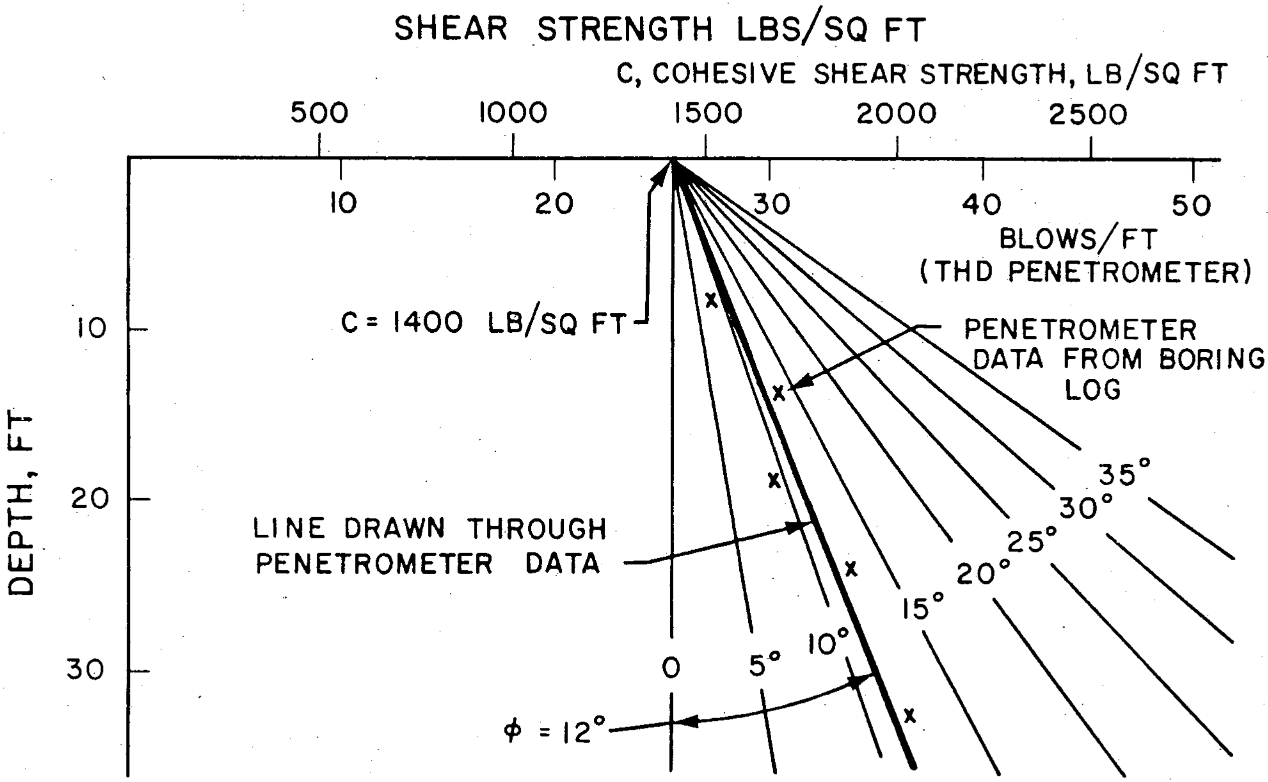
Selection of Proper Design Chart

1. Choose Column Size. Before entering the footing design charts choose the proper column size to support the sign. Charts or tables for selecting columns are available on sheets 16, 27, 49, 52, and 65 of Texas Highway Department Interstate Signing Standards.

2. Draw the Boring Log. Use a sheet of 8-1/2 x 11 inch graph paper with 10 divisions to the inch. Across the short direciton, make



a. INSERTION OF BORING LOG INTO OVERLAY ENVELOPE



b. SAMPLE READING OF C AND ϕ FROM THD PENETROMETER DATA

FIG. 3 USE OF OVERLAY ENVELOPES TO DETERMINE SOIL SHEAR STRENGTH C AND ϕ

the depth scale 10 feet to the inch. In the long direction, make the THD Penetrometer blow count scale 10 blows/ft. to the inch. Plot the blows/ft. versus depth and with a straight edge draw a line through the weakest reasonable profile.

3. Slip Boring Log into Plastic Overlay Envelope. See Figure 3a for an illustration of this. The boring log should be positioned properly so that the number of blows/ft. match the same marks on the overlay envelope.

4. Adjust Plastic Slide Envelope to Proper Position. The proper position is reached when the straight line drawn in Step 2 above passes through the zero point of the scale on the plastic slide envelope. Figure 3b illustrates how a typical boring log will look if Steps 2, 3, and 4 have been done properly.

5. Read Ø, the Angle of Internal Friction (degrees). If the straight line drawn in Step 2 falls between the slanted lines on the plastic slide envelope, estimate Ø (in degrees) by eye. In Figure 3b, Ø is about 12 degrees.

6. Read c, the Cohesive Shear Strength (lb./sq. ft). Under the arrow on the plastic slide, where the straight line of Step 2 crosses the top scale, read the cohesive shear strength (in lb./sq. ft.). In Figure 3b, c is about 1400 lb./sq. ft.

7. Choose the Proper Chart Number. Start at the bottom of the Chart Selection Table (Table 4) and move upward in Column 2 until a range of c is found which brackets the value of c found in Step 6. Then check the corresponding ranges of Ø in Column 3 to see if the value of Ø found in Step 5 is bracketed. If Ø is bracketed then the

proper chart number is found in Column 1. If the Ø determined in Step 5 is greater than the values in the range, use the highest value of Ø in the range for design. If Ø is zero, use Chart I. At times, when Ø is less than 5 or 10 degrees it may be desirable to use Chart I which uses the exact value of c found in Step 6 and assumes Ø to be zero.

Table 4: Design Chart Selection Table

Column 1	2	3	4
Chart No.	C Cohesive Shear Strength (lb./sq. ft.)	Ø Angle of Internal Friction (degrees)	Soil Description
I	0 - 5000	0	Clay
II	0 - 500	0 - 35	Sand
III	500 - 2000	0 - 35	Soft Clayey Sand
IV	2000 - 4000	0 - 15	Medium Sandy Clay
V	4000 - up	0 - 15	Stiff Sandy Clay

Use of the Design Chart

8. Use the Chart for the Proper Sign Support Type. The design charts are arranged by sign support type which was chosen in Step 1: SMD-8, OBTM, OCS(B), and OSBT-I. Make sure that the design chart you choose is for the proper sign support type.

9. Use the Chart for the Proper Soil Type. If you use Chart II, III, IV, or V, go to Step 10. If $\phi = 0$, go to Step 11.

10. Enter on the Horizontal Scale. Enter the chart with $\emptyset$ determined in Step 5. Then go to Step 12.

11. Enter on the Horizontal Scale. Enter the chart with c determined in Step 6. Now go to Step 12.

12. Go to the Proper Curve. Move upward to the curve for the sign support column chosen in Step 1. In some design charts you will not be able to find an embedment depth for the standard size of drilled shaft. In such a case, additional curves are provided for larger sized drilled shafts which must be used to get adequate embedment for the footing. Figure 4 shows this for the problem illustrated in Figure 3b for a 16 WF 36 L sign supporting column.

13. Read the Vertical Scale. Move horizontally to the left and find the design depth of the drilled shaft on the vertical scale. Round the embedment depth to the next largest even foot.

14. Finish the Design. Drilled shaft design is complete. If a non-standard diameter of drilled shaft is used, the shaft and the anchor bolts should be designed structurally to carry at least the sign support column design moment.

OSBT-I - CHART III

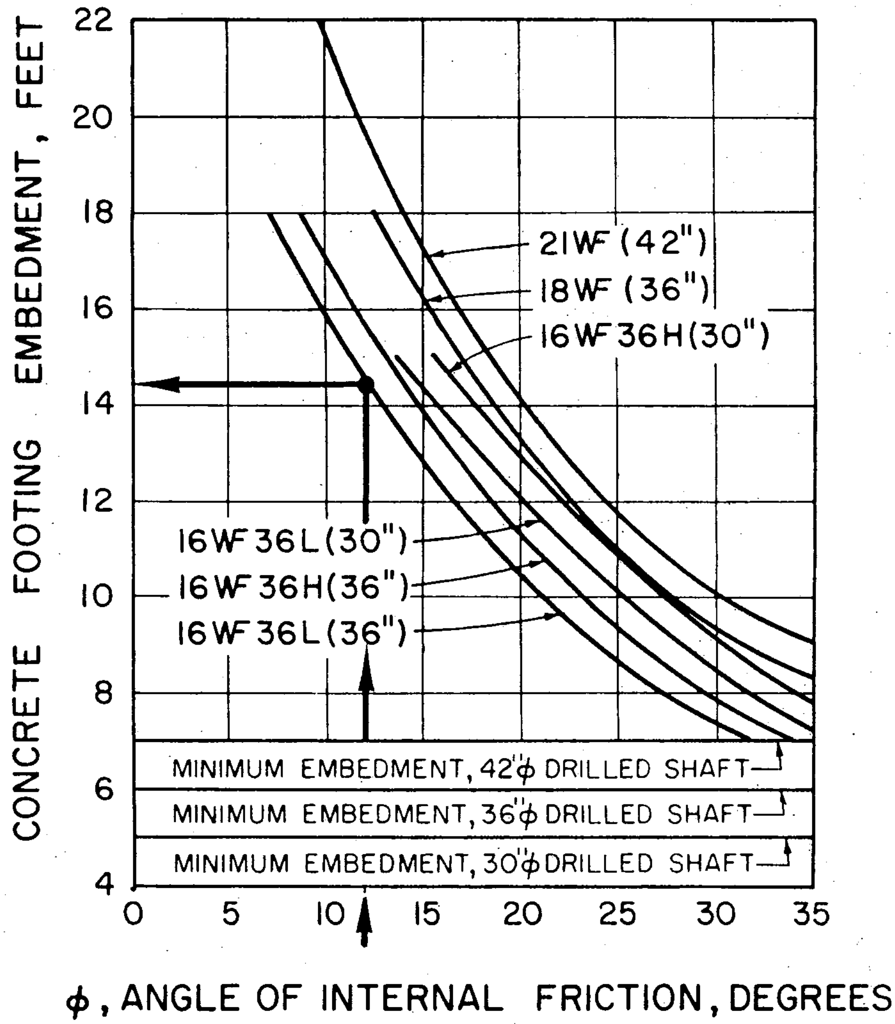


FIG. 4 METHOD OF READING EMBEDMENT DEPTH

Chapter IV

CONCLUSION

The design procedure and design charts presented in this report represent a simple design method that is consistent with current Texas Highway Department design and construction procedures for sign supports. The charts are an implementation for immediate use in design of the research done in Study 2-5-67-105, "Design of Footings for Minor Service Structures".

The appendices which follow contain the charts, the use of which has been explained in the body of this report.

Appendix A. This appendix has 21 figures consisting of 6 design charts for the SMD-8 sign support footings, and 5 design charts for each of the OBTM, OSBT-I, and OCS(B) sign support footings.

Appendix B. This appendix has 6 figures which present graphically the basic data from which the figures of Appendix A are drawn. One of these figures shows how another such design chart could be constructed from the basic data.

Appendix C. This appendix gives the masters for the plastic overlay envelope and the plastic overlay slide which permit THD penetrometer measurements to be converted into c and Ø.

The procedure of this report has been refined to allow design distinctions to be made between 5 different general soil types: clay, sand, soft clayey sand, medium sandy clay, and stiff sandy clay. Thus, by using the contents of this report, easily determined field data can be applied to the design of standard footings for minor service structures in an entirely graphical design procedure.

APPENDIX A

Design Charts

APPENDIX A

Design Charts

This appendix contains 21 design charts for four different sign support types as outlined in the table below. They are prepared on separate sheets so that they can be extracted and reproduced on design standard sheets.

Table IA

Design Chart Index

Sign Support Designation	Design Chart Numbers	Figures	Standard Footing Diameters (inches)	Column Sizes
SMD-8	I	5	18"	315.7, 417.7
	IIA	6	24"	6B8.5, 6B12,
	IIB	7	24"	6WF15.5, 8WF17,
	III	8	24"	8WF20, 10WF21,
	IV	9	24"	10WF25, 12WF27
	V	10		
	I	11		
	II	12		Round Columns
OBTM	III	13	30"	K, L, M
	IV	14		
	V	15		
	I	16		
	II	17	30"	16WF36L, 16WF36H
OSBT-I	III	18	36"	18 WF 50
	IV	19	42"	21 WF 62
	V	20		
	I	21		
OCS(B)	II	22		Round Columns
	III	23	36"	J, H, G
	IV	24		
	V	25		

SMD-8 — CHART I

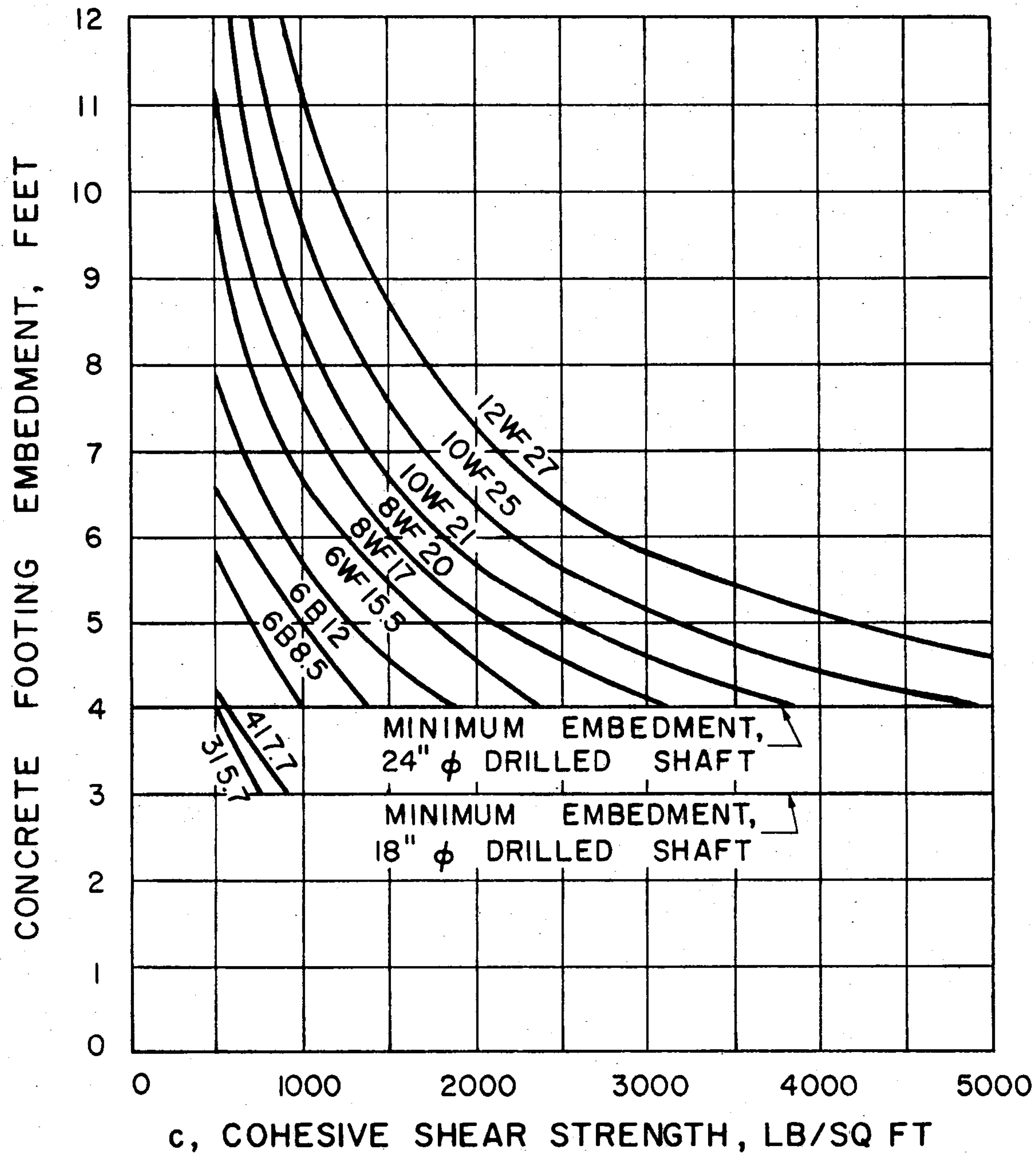


FIG. 5 $\phi = 0°$, C = VARIABLE, SMD-8 SIGN SUPPORT

SMD-8 — CHART IIA
(CURVES FOR NORMAL FOOTING SIZES)

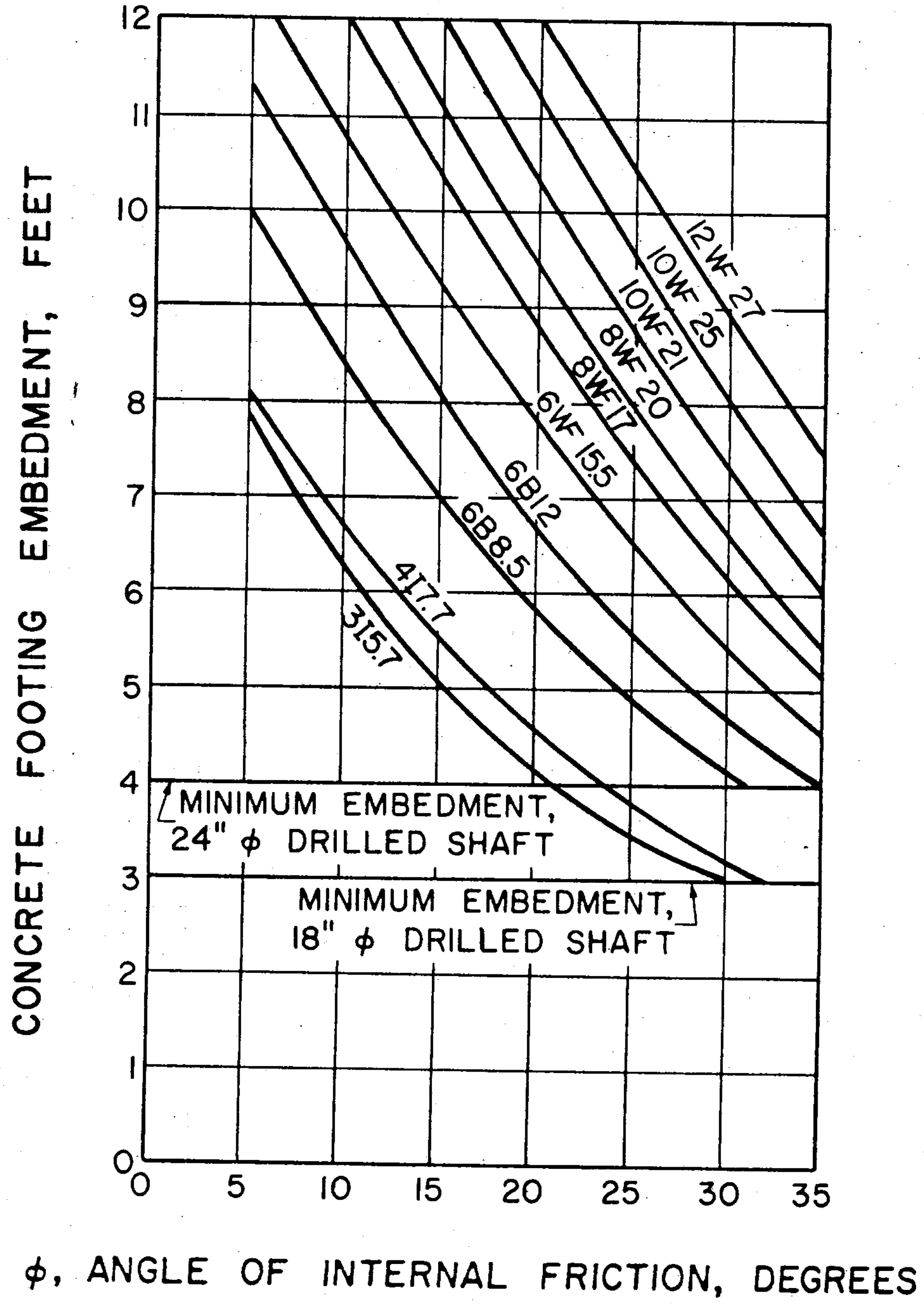


FIG. 6 c=0 LB/SQ FT,
φ=VARIABLE, SMD-8 SIGN SUPPORT

SMD-8 — CHART IIB
(CURVES FOR 30" ϕ DRILLED SHAFTS)

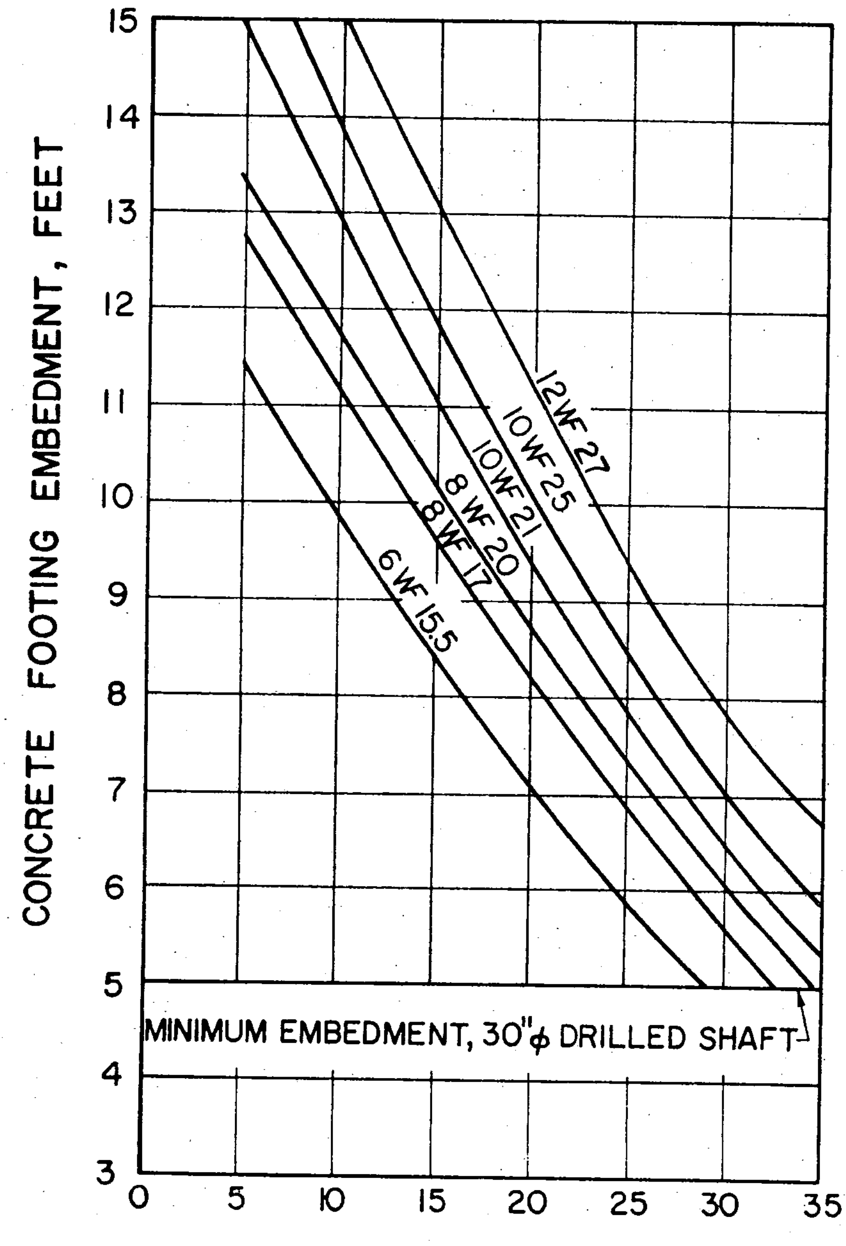


FIG. 7 c=0 LB/SQ FT,
ϕ=VARIABLE, SMD-8 SIGN SUPPORT

SMD-8 — CHART III

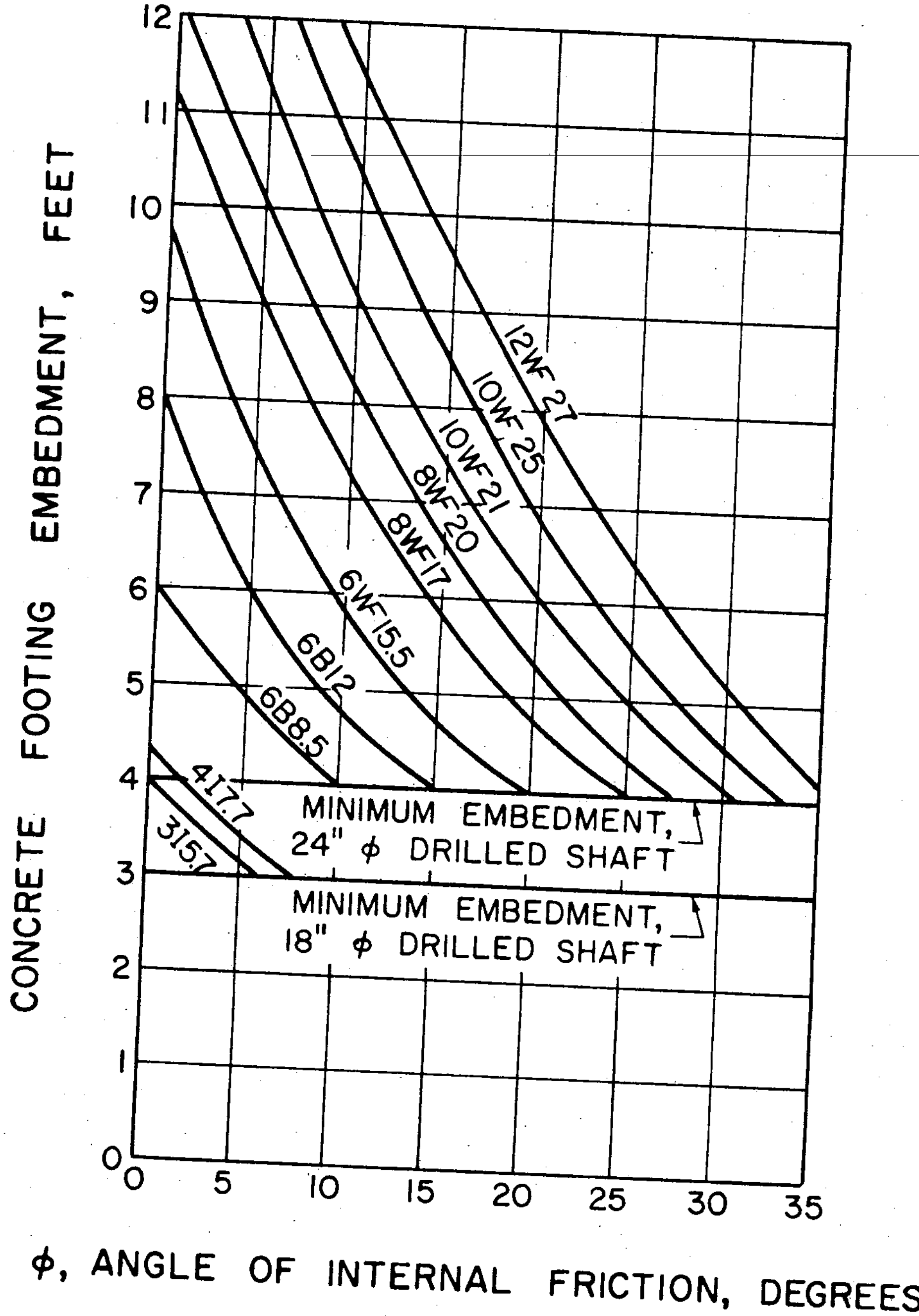


FIG. 8 c=500 LB/SQ FT,
ϕ=VARIABLE, SMD-8 SIGN SUPPORT

SMD-8 — CHART IV

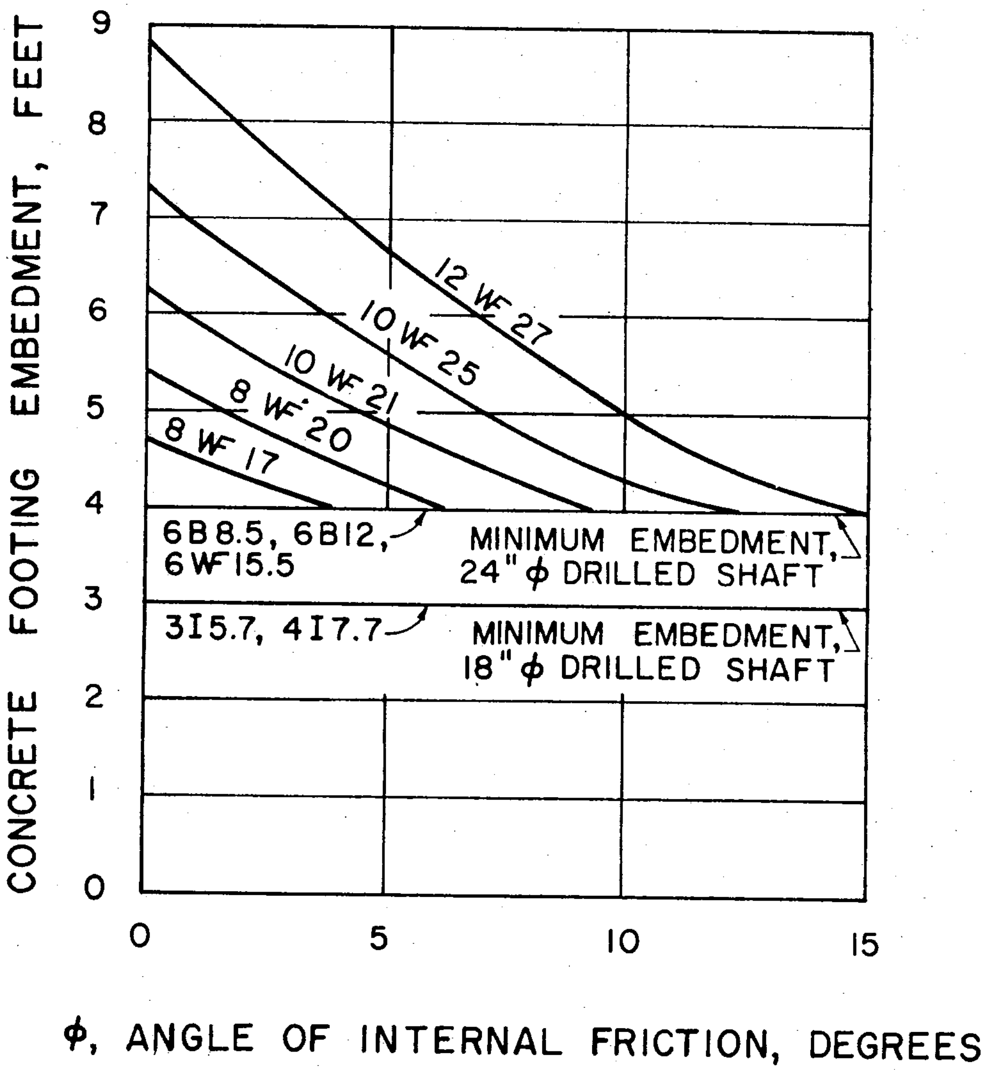


FIG. 9 c = 2000 LB/SQ FT,
ϕ = VARIABLE, SMD-8 SIGN SUPPORT

SMD-8 CHART V

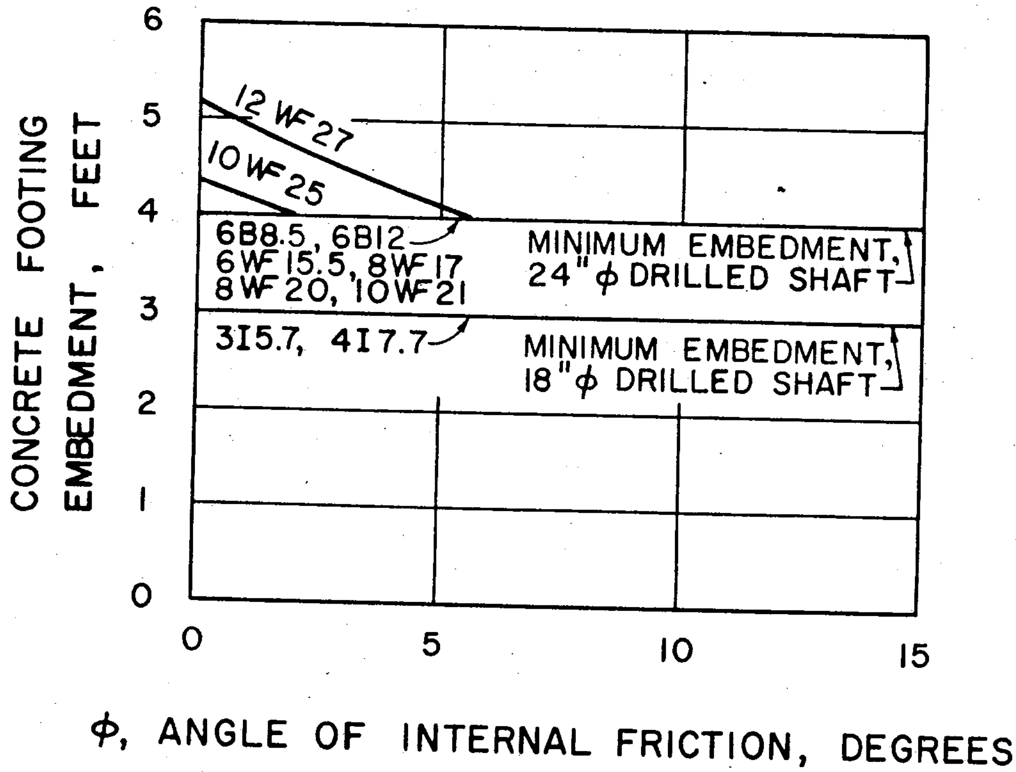


FIG. 10 c = 4000 LB/SQ FT,
φ = VARIABLE, SMD-8 SIGN SUPPORT

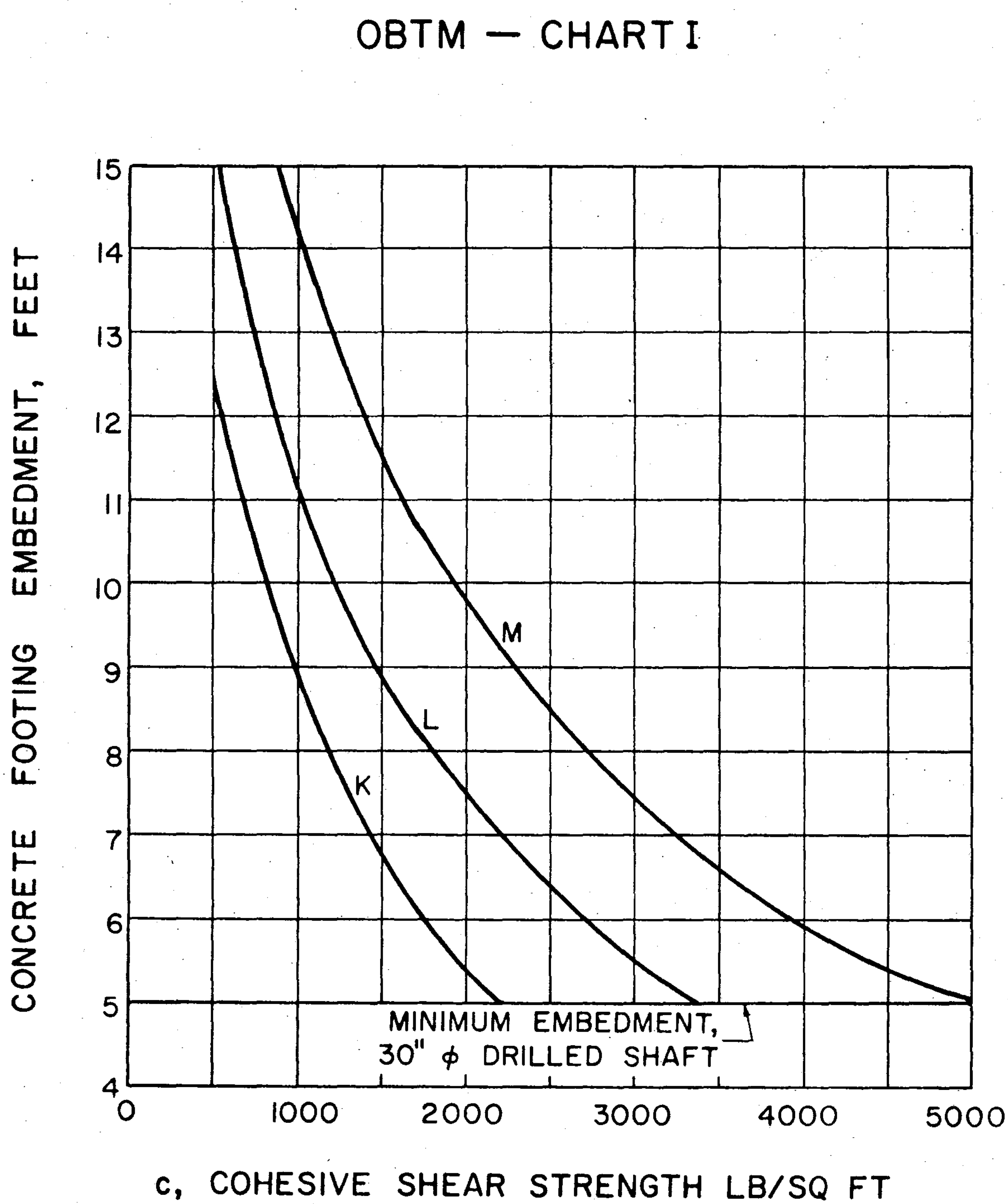


FIG. 11 $\phi = 0°$; c = VARIABLE, OBTM SIGN SUPPORT

OBTM — CHART II

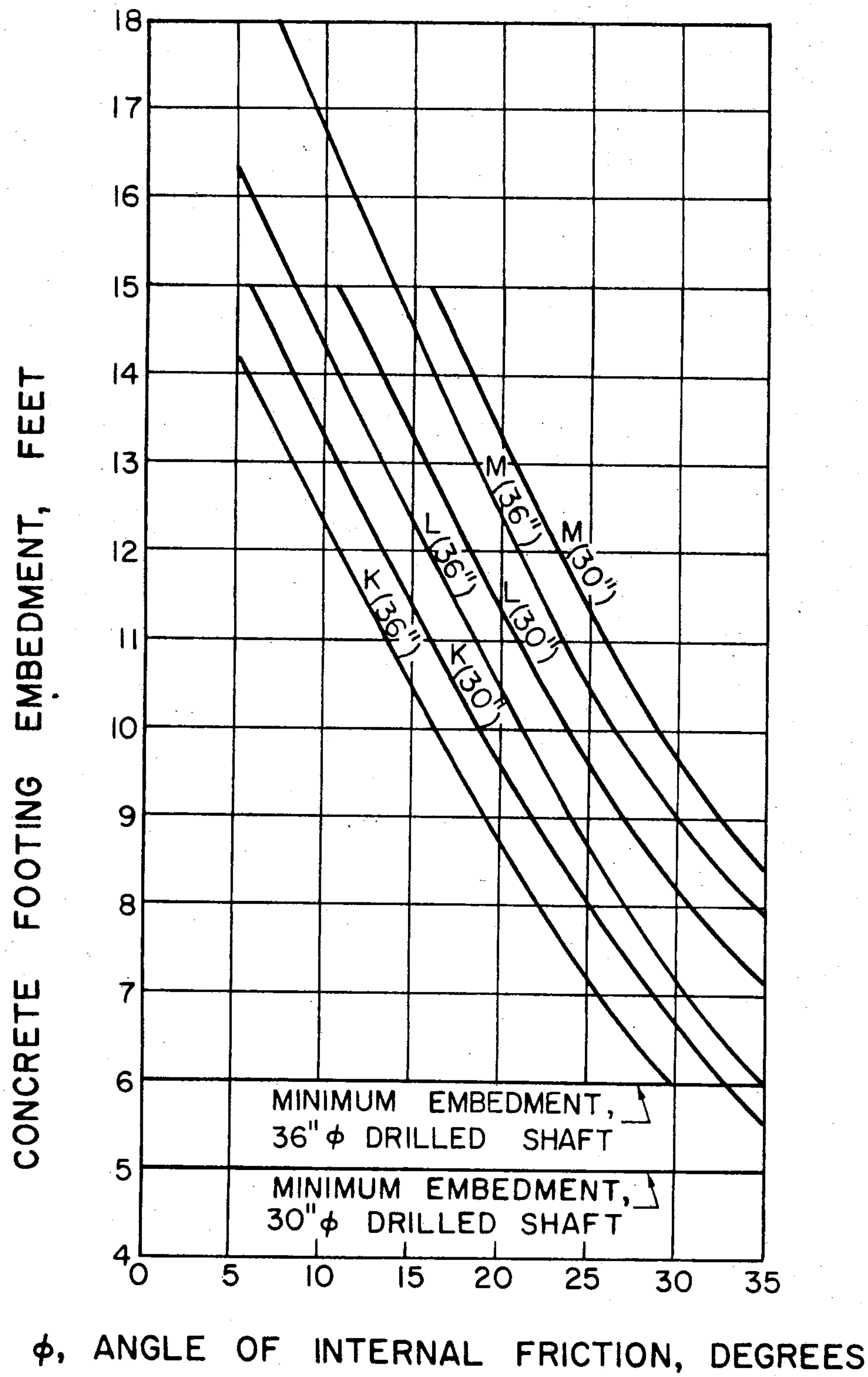


FIG. 12 c=0 LB/SQ FT,
ϕ = VARIABLE, OBTM SIGN SUPPORT

OBTM — CHART III

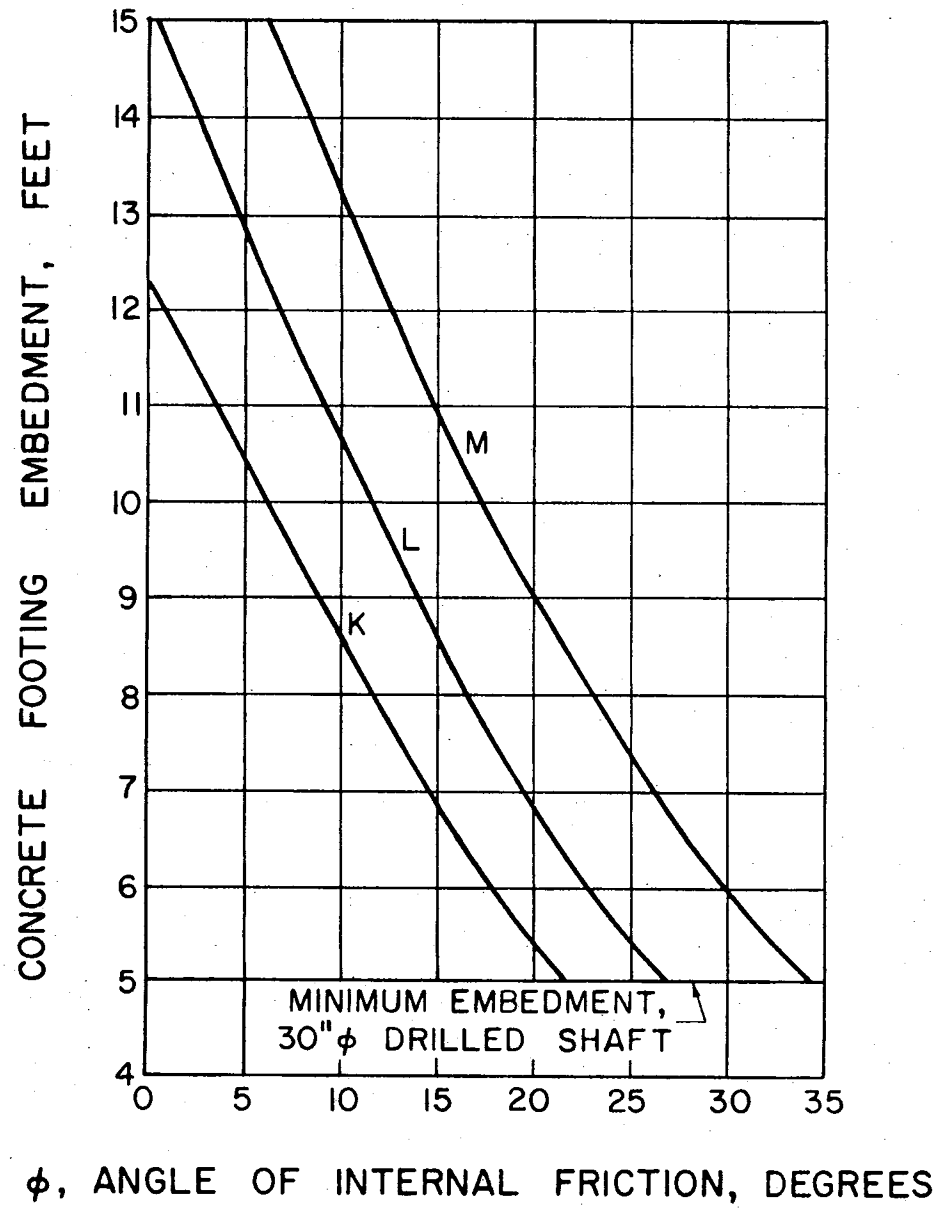


FIG. 13 c=500 LB/SQ FT,
ϕ=VARIABLE, OBTM SIGN SUPPORT

OBTM — CHART IV

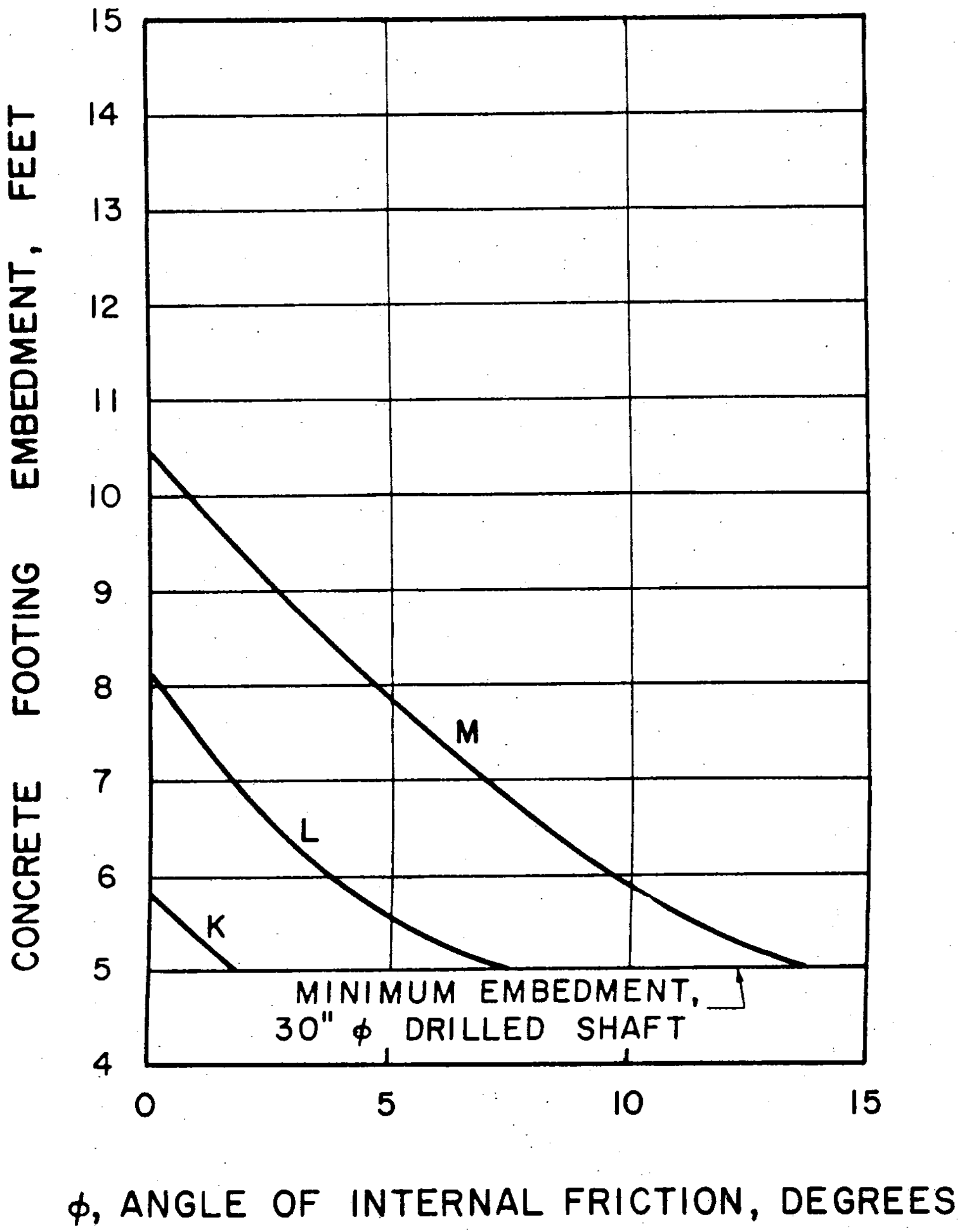


FIG. 14 c = 2000 LB/SQ FT,
φ = VARIABLE, OBTM SIGN SUPPORT

OBTM — CHART V

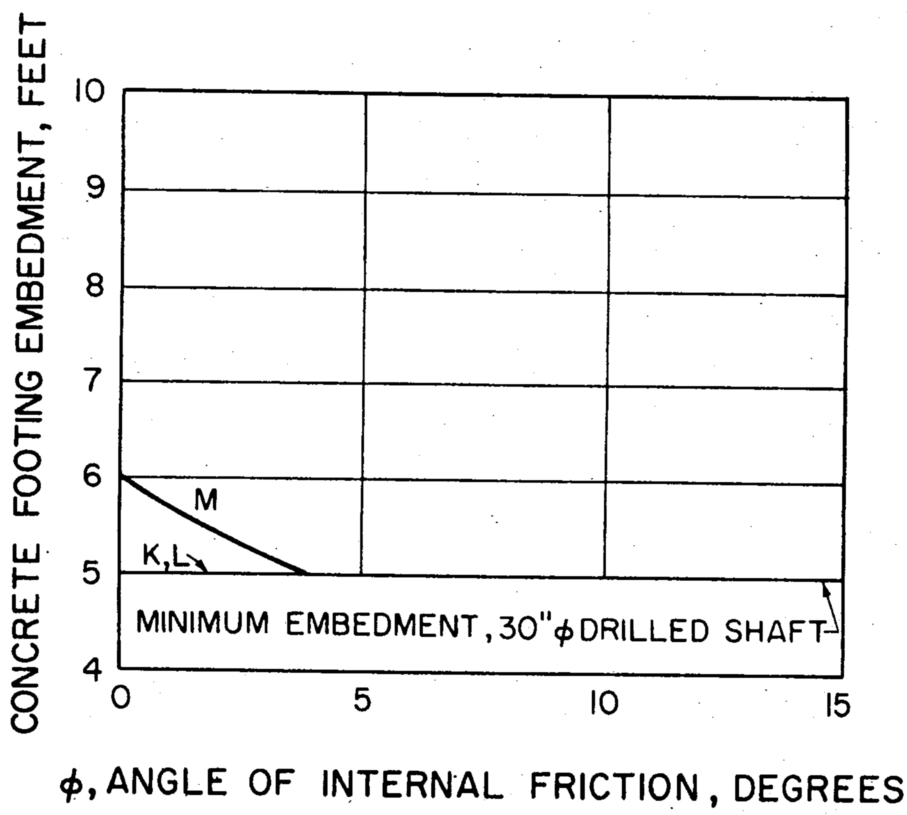


FIG. 15 c = 4000 LB/SQ FT,
ϕ = VARIABLE, OBTM SIGN SUPPORT

OSBT-I — CHART I

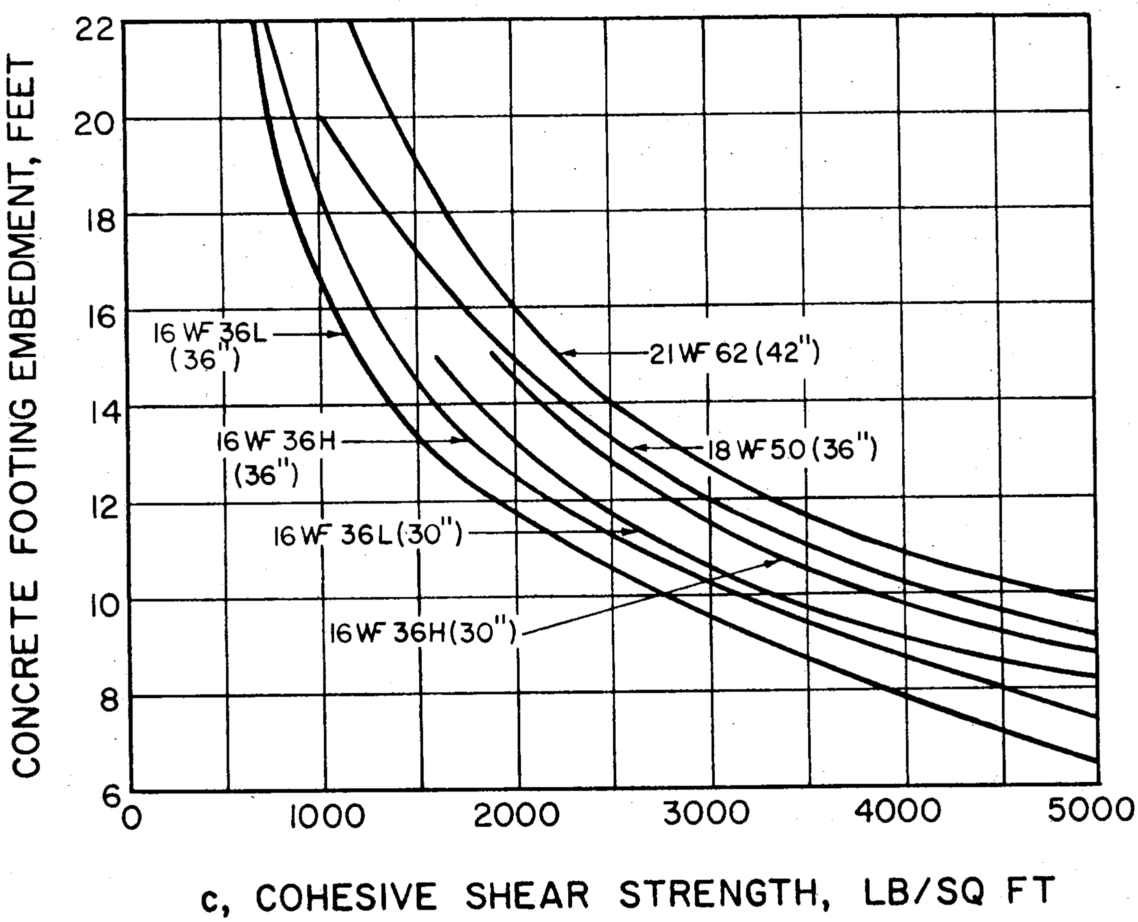


FIG. 16 $\phi = 0°$, c = VARIABLE, OSBT-I SIGN SUPPORT

OSBT-I— CHART II

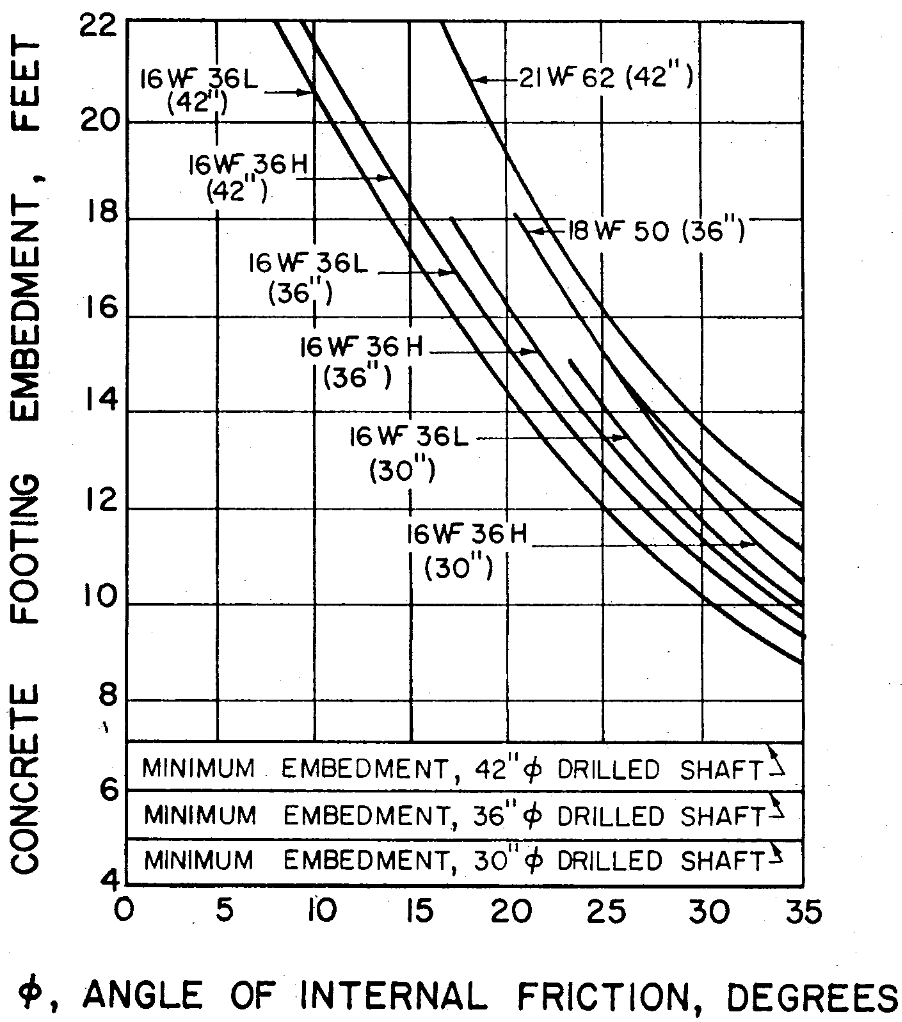


FIG. 17 c = 0 LB/SQ FT,
φ = VARIABLE, OSBT-I SIGN SUPPORT

OSBT-I - CHART III

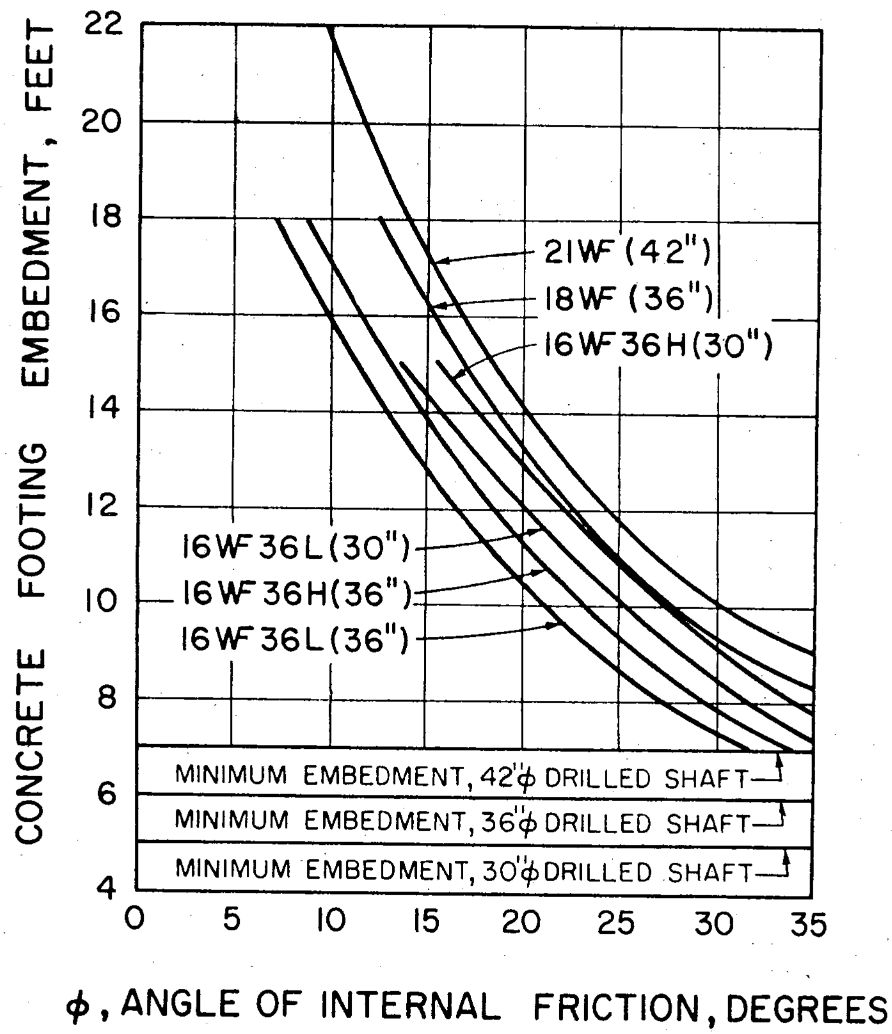


FIG. 18 c = 500 LB/SQ FT,
φ = VARIABLE, OSBT-I SIGN SUPPORT

OSBT-I — CHART IV

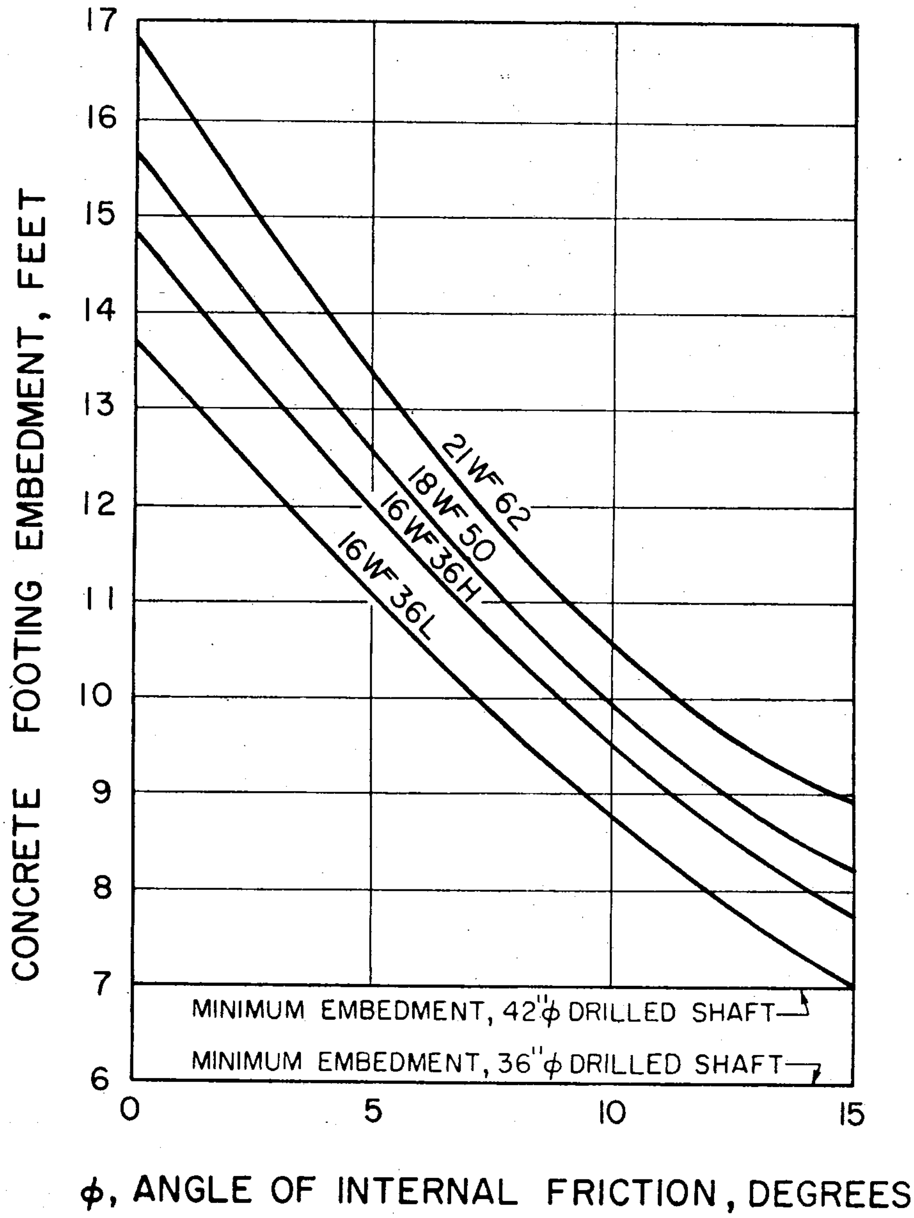


FIG. 19 c = 2000 LB/SQ FT,
φ = VARIABLE, OSBT-I SIGN SUPPORT

OSBT-I CHART V

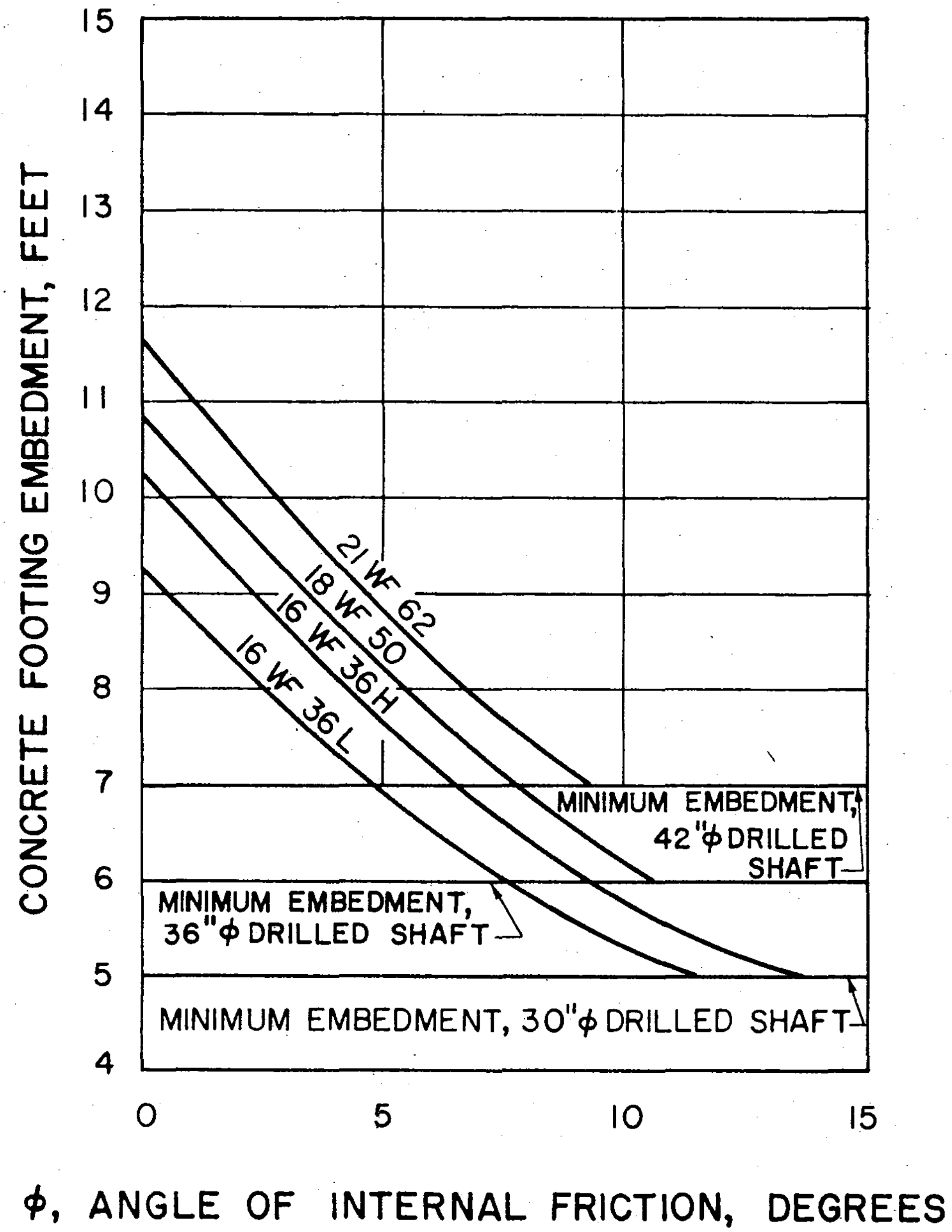


FIG. 20 c = 4000 LB/SQ FT,
φ = VARIABLE, OSBT-I SIGN SUPPORT

OCS(B) — CHART I

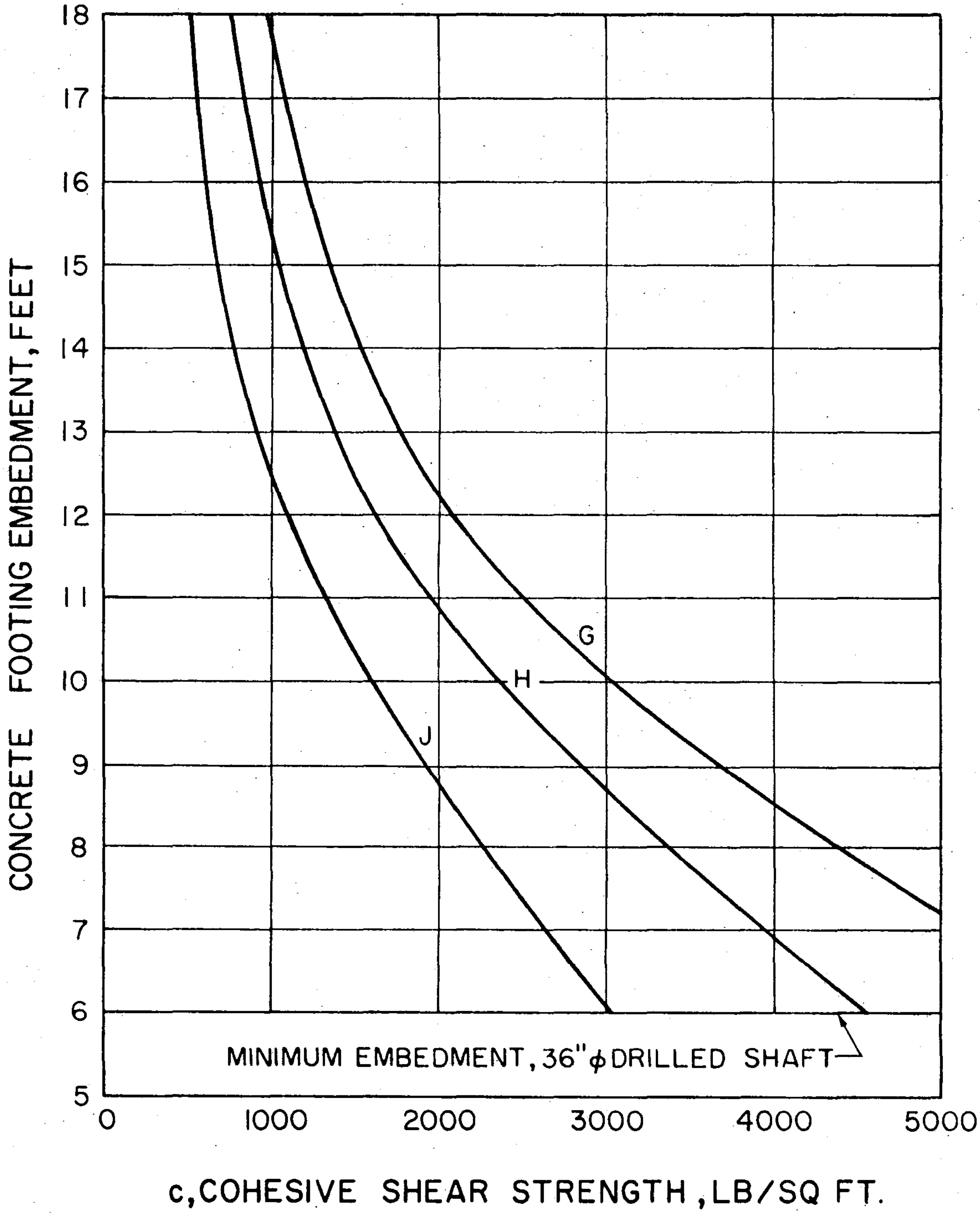


FIG. 21 $\phi = 0°$, c = VARIABLE, OCS (B) SIGN SUPPORT

OCS(B) — CHART II

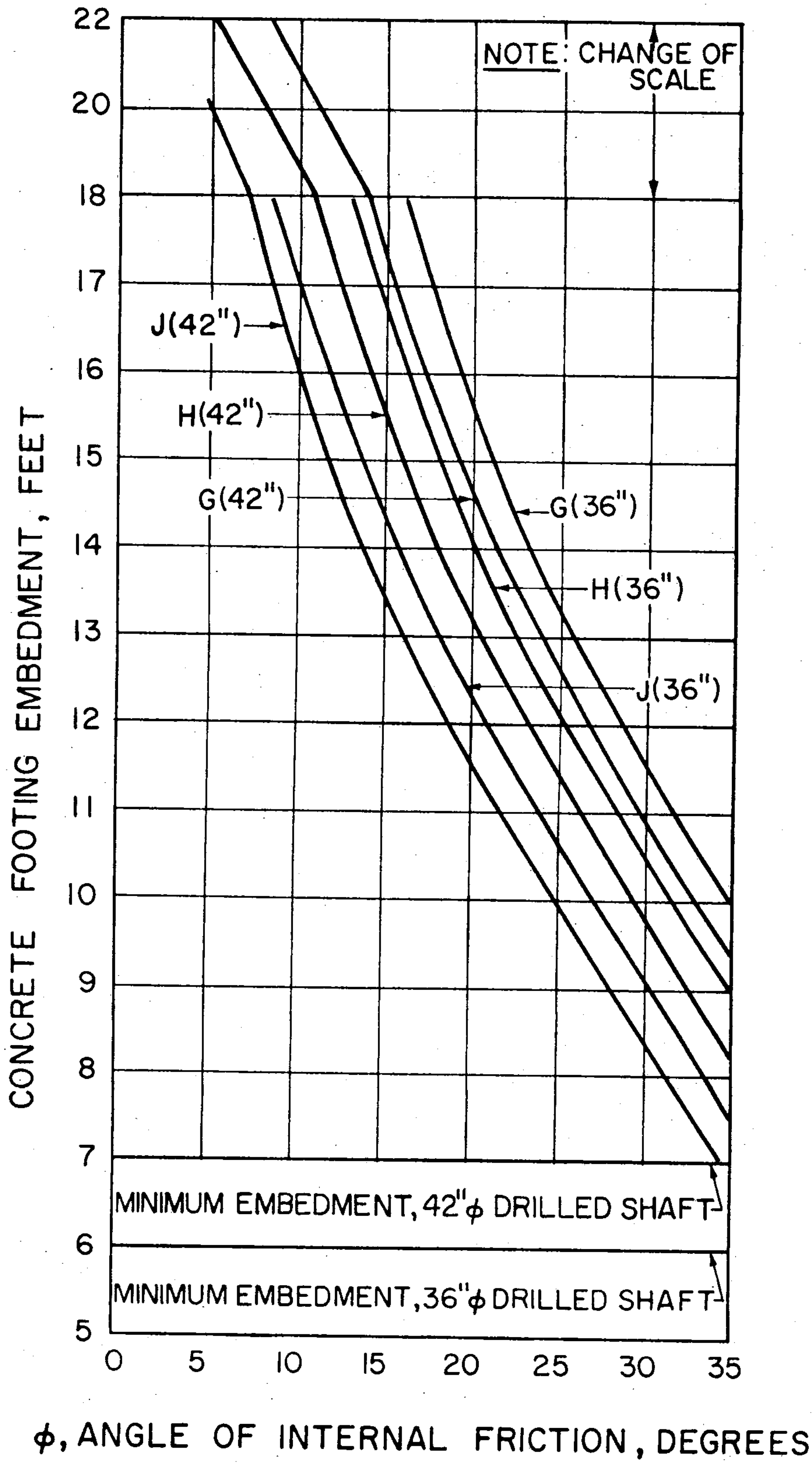


FIG. 22 c=0 LB/SQ FT,
ϕ = VARIABLE, OCS(B) SIGN SUPPORT

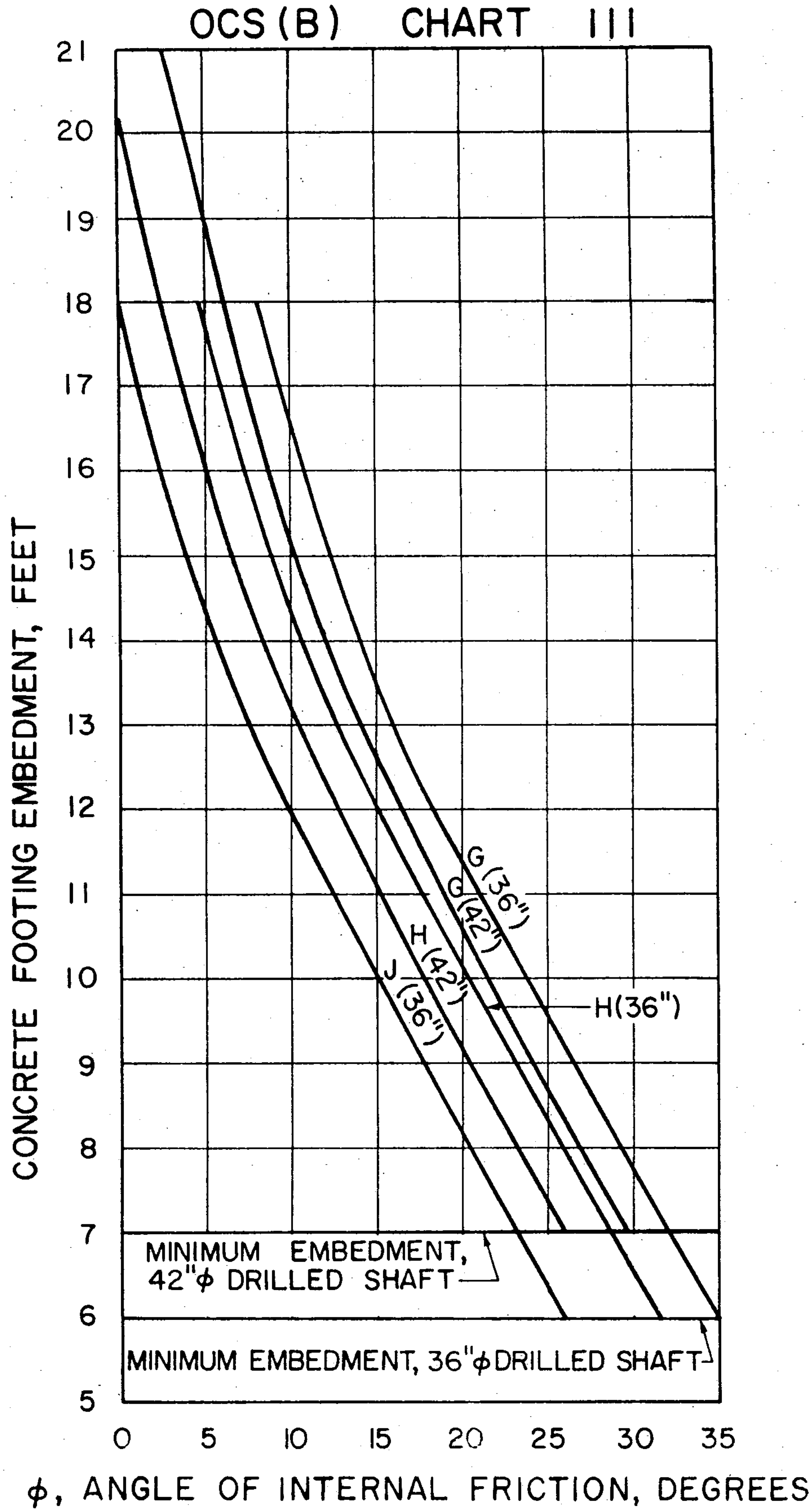


FIG. 23 c = 500 LB/SQ FT, ϕ = VARIABLE, OCS(B) SIGN SUPPORT

OCS(B) — CHART IV

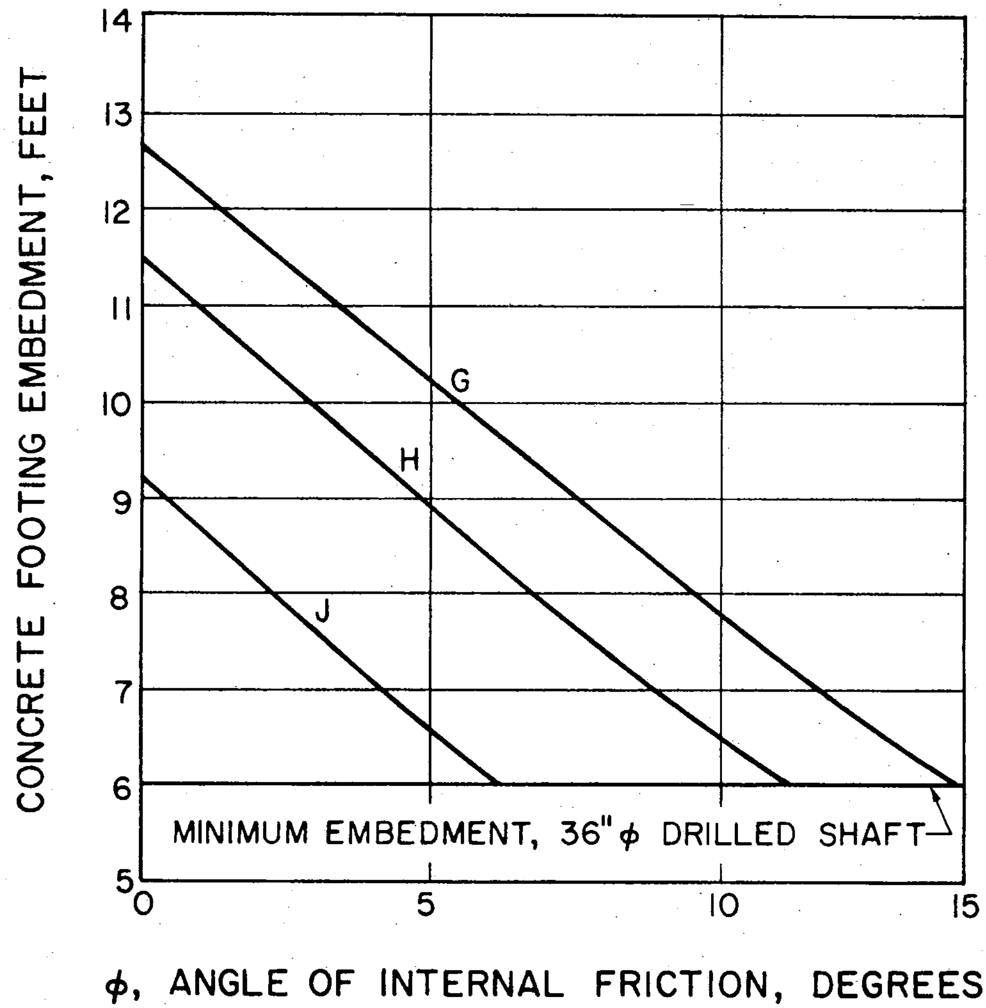


FIG. 24 c= 2000 LB/SQ FT,
φ=VARIABLE, OCS(B) SIGN SUPPORT

OCS(B) CHART V

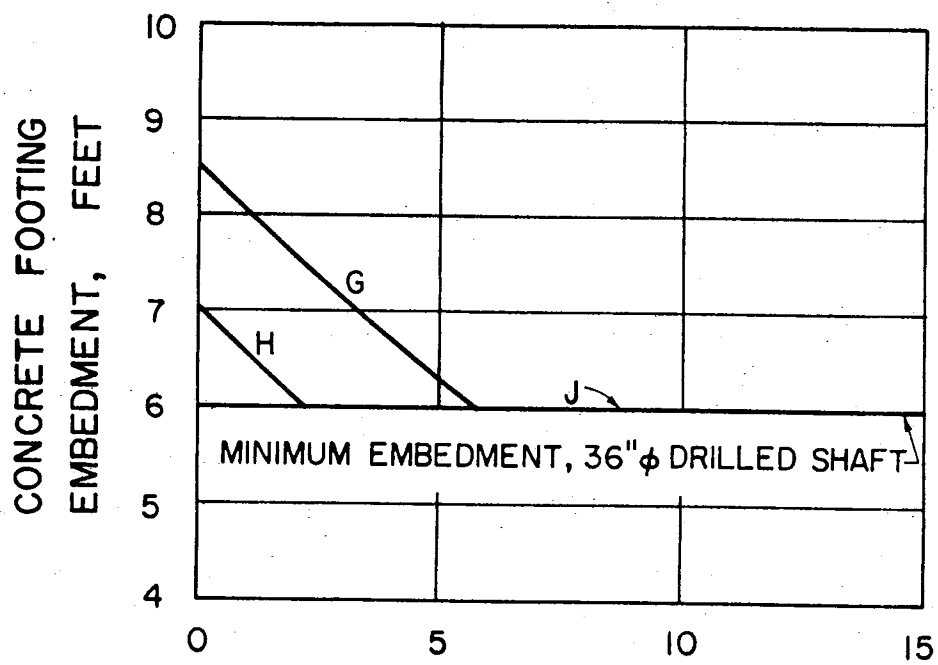


FIG. 25 c = 4000 LB/SQ FT,
ϕ = VARIABLE, OCS(B) SIGN SUPPORT

APPENDIX B

Basic Design Charts

APPENDIX B

Basic Design Charts

The design charts of Appendix A were derived from the "basic" design charts in this appendix. Figure 26 shows the procedure used to determine these charts.

Firstly, a sign support column is chosen and its design moment is drawn horizontally across the basic design chart. This horizontal line intersects the lines for different sizes of footing at certain levels of c (for Chart I) or $\emptyset$ (for Charts II through V) which can be read on the horizontal scale. Schematic design curves for a 3-foot diameter drilled shaft have been used to illustrate this principle in Figure 26.

Secondly, a graph is made by plotting the c or $\emptyset$ value read from the horizontal scale against the proper depth of embedment. The curve drawn through these points is the design curve for the sign support column originally chosen.

These basic design charts are included as a supplement to aid in the design of adequate footings for columns and anchorages which are not Texas Highway Department Standards but which are commercial equivalents that are normally permitted in contract specifications.

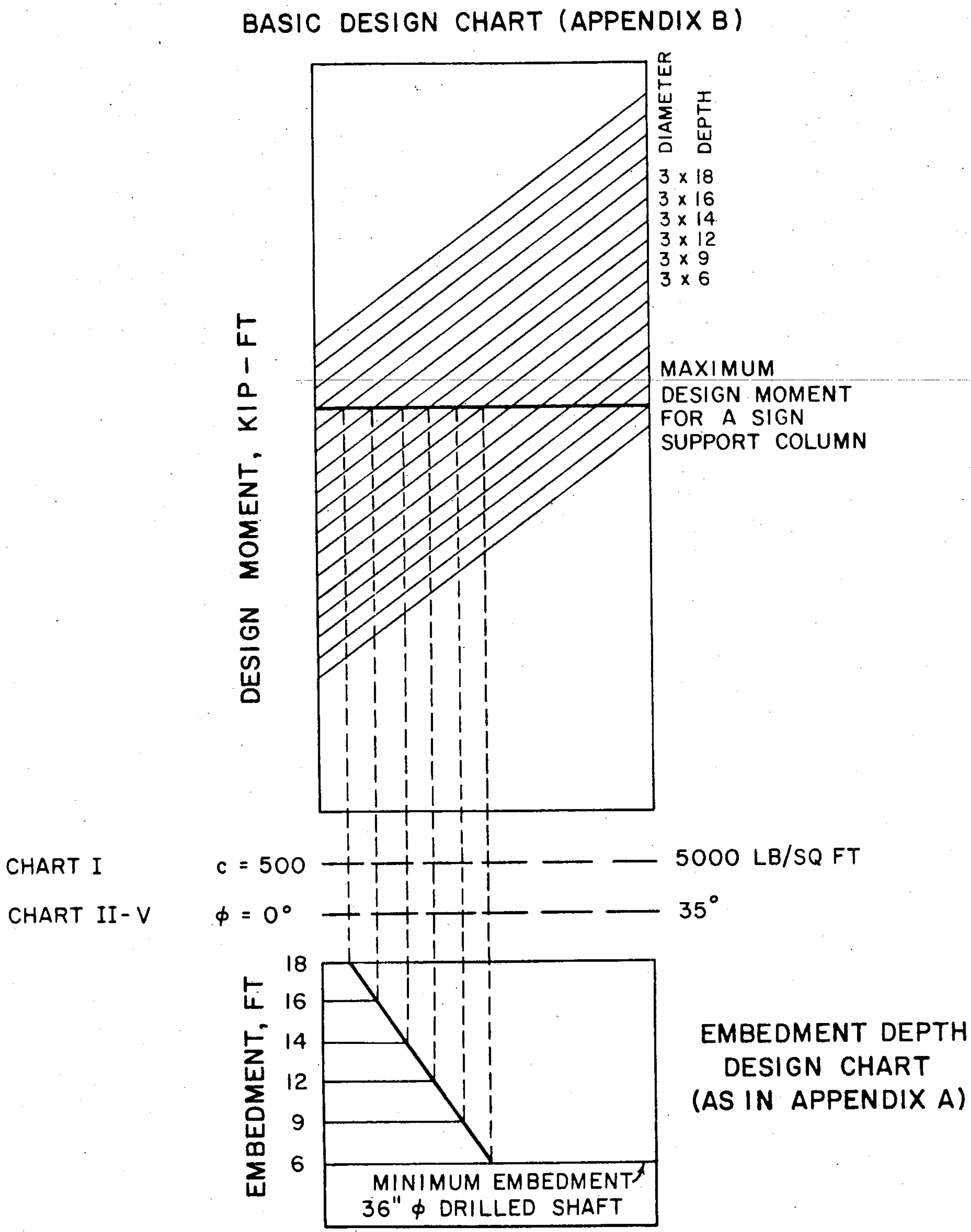


FIG. 26 USE OF BASIC DESIGN CHART TO CONSTRUCT AN EMBEDMENT DEPTH DESIGN CHART

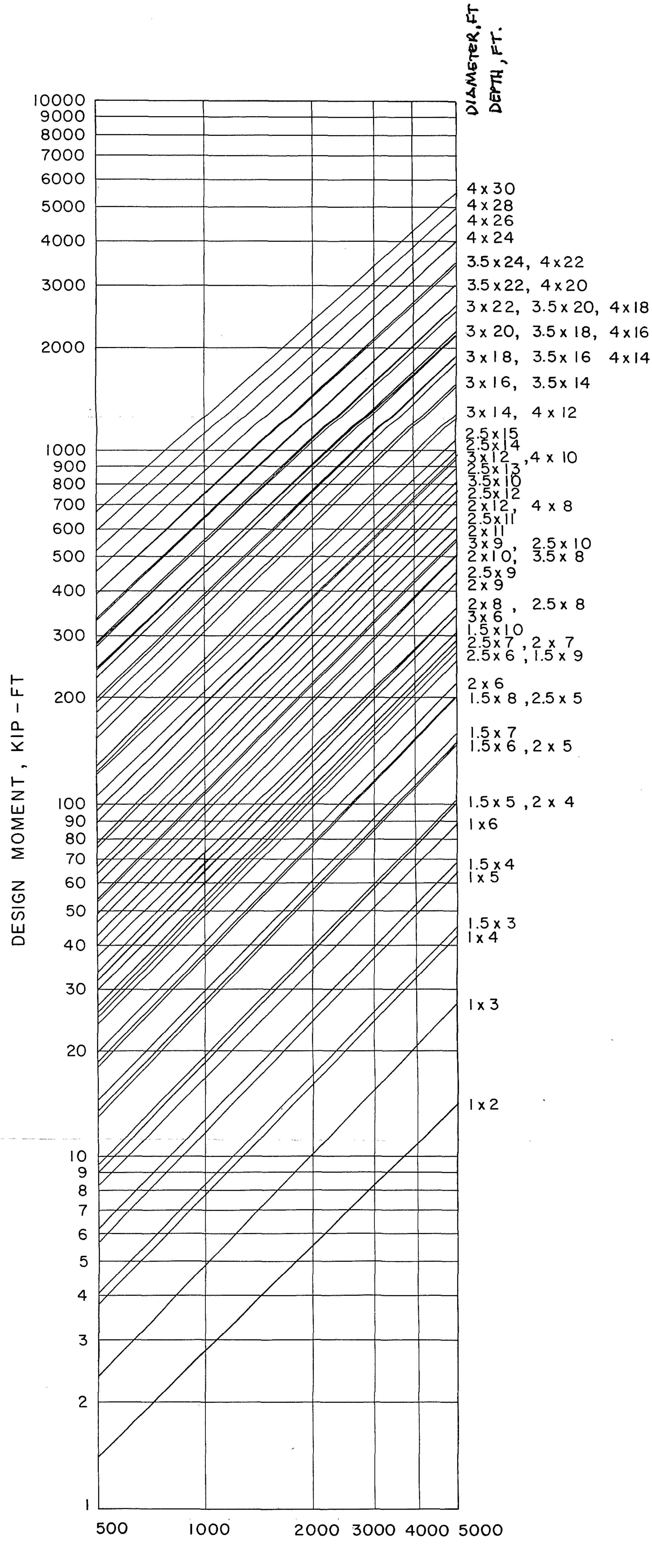
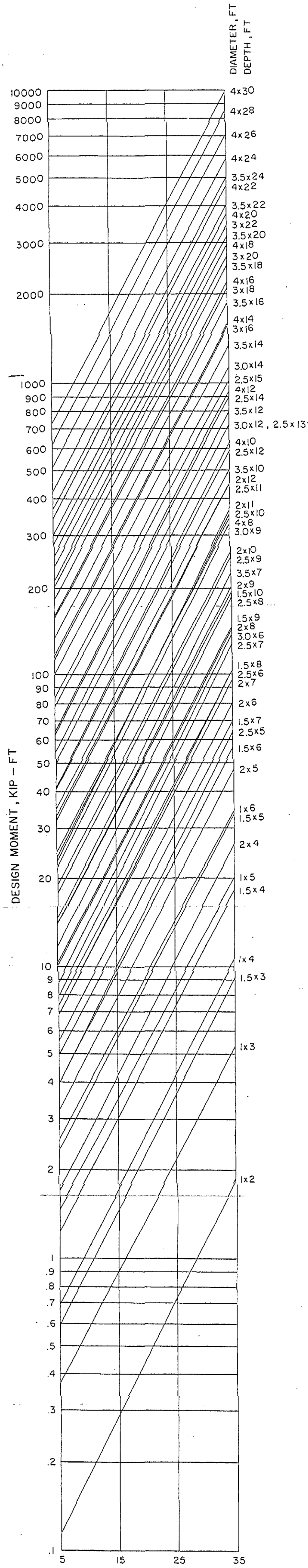


FIG. 27 BASIC DESIGN CHART I, $\phi = 0°$, C = VARIABLE



ϕ, ANGLE OF INTERNAL FRICTION, DEGREES

FIG. 28 BASIC DESIGN CHART II, c= 0 LB/SQ FT, ϕ =VARIABLE

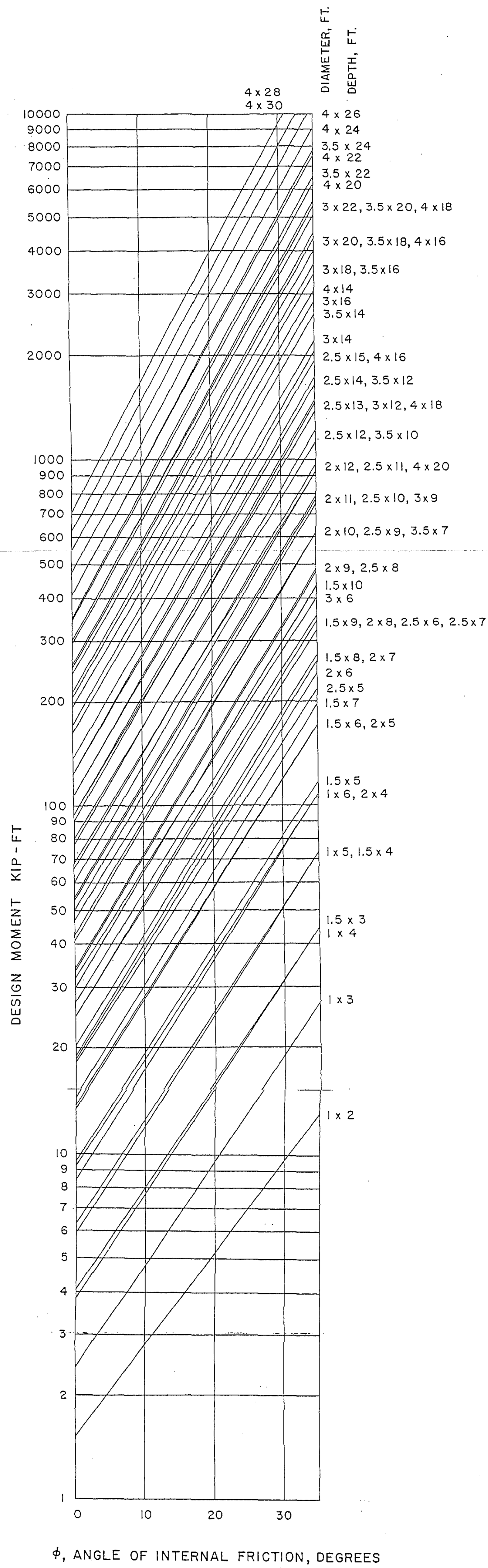


FIG. 29 BASIC DESIGN CHART III, $c = 500$ LB/SQ FT, ϕ = VARIABLE

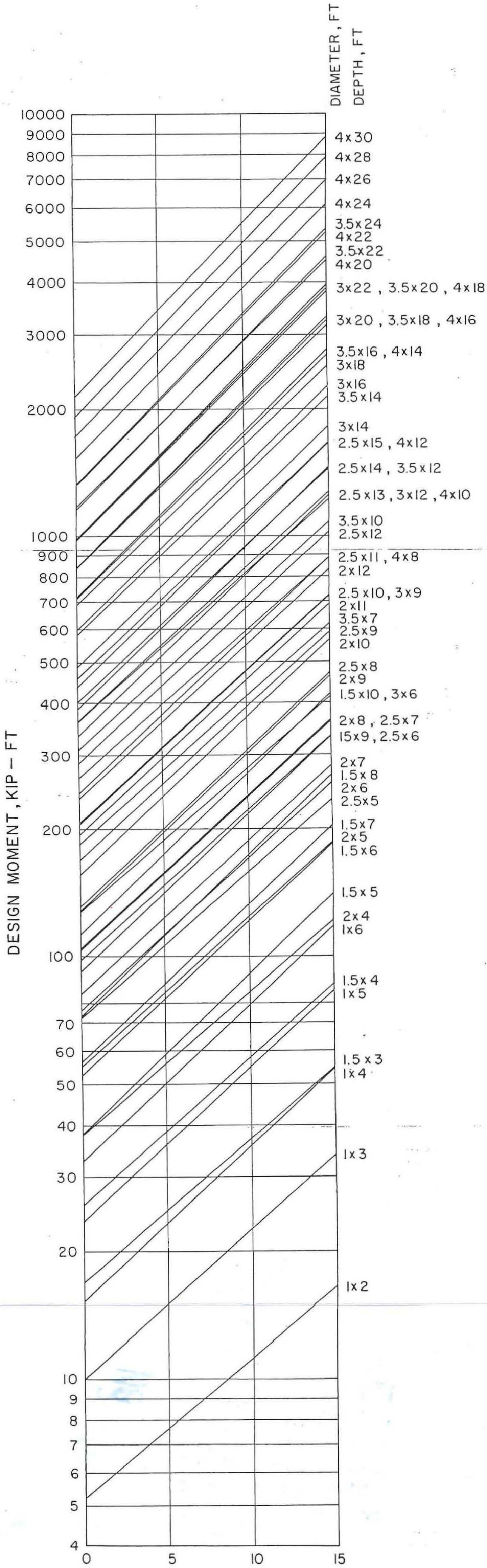


FIG. 30 BASIC DESIGN CHART IV, c = 2000 LB/SQ FT, ϕ = VARIABLE

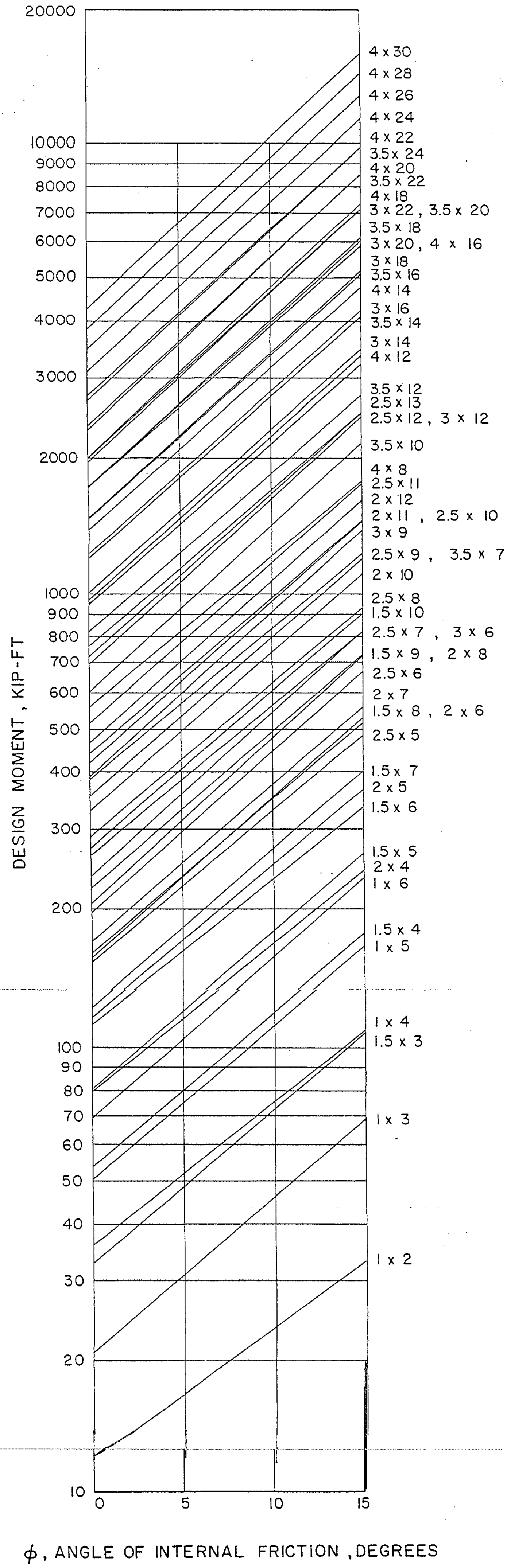


FIG. 31 BASIC DESIGN CHART V, C=4000 LB/SQ FT, ϕ=VARIABLE

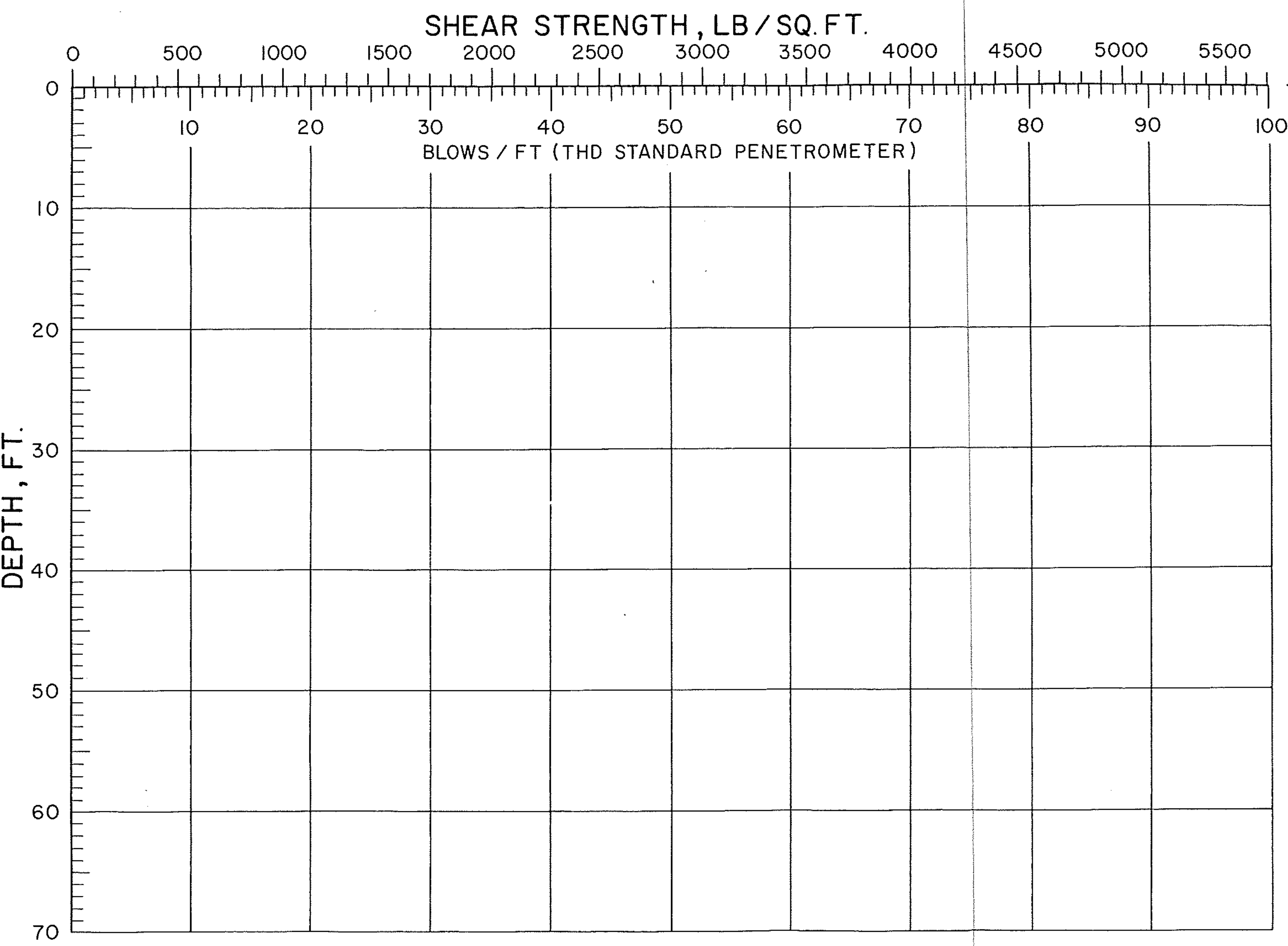
APPENDIX C

Overlay Envelopes

APPENDIX C

Overlay Envelopes

This appendix contains black line prints which can be extracted and used as masters for reproducing plastic overlay envelopes and overlay slides for determining c and ϕ from Texas Highway Department penetrometer data.



DESIGN CHART NO.	SOIL PROPERTIES		
	C, COHESIVE SHEAR STRENGTH, LB/SQ FT	ϕ, ANGLE OF INTERNAL FRICTION, DEGREES	SOIL DESCRIPTION
I	500-5000	0	CLAY
II	0-500	5-35	SAND
III	500-2000	0-35	SOFT CLAYEY SAND
IV	2000-4000	0-15	MEDIUM SANDY CLAY
V	4000-5000	0-15	STIFF SANDY CLAY

FIG. 32 MASTER FOR PLASTIC OVERLAY ENVELOPE

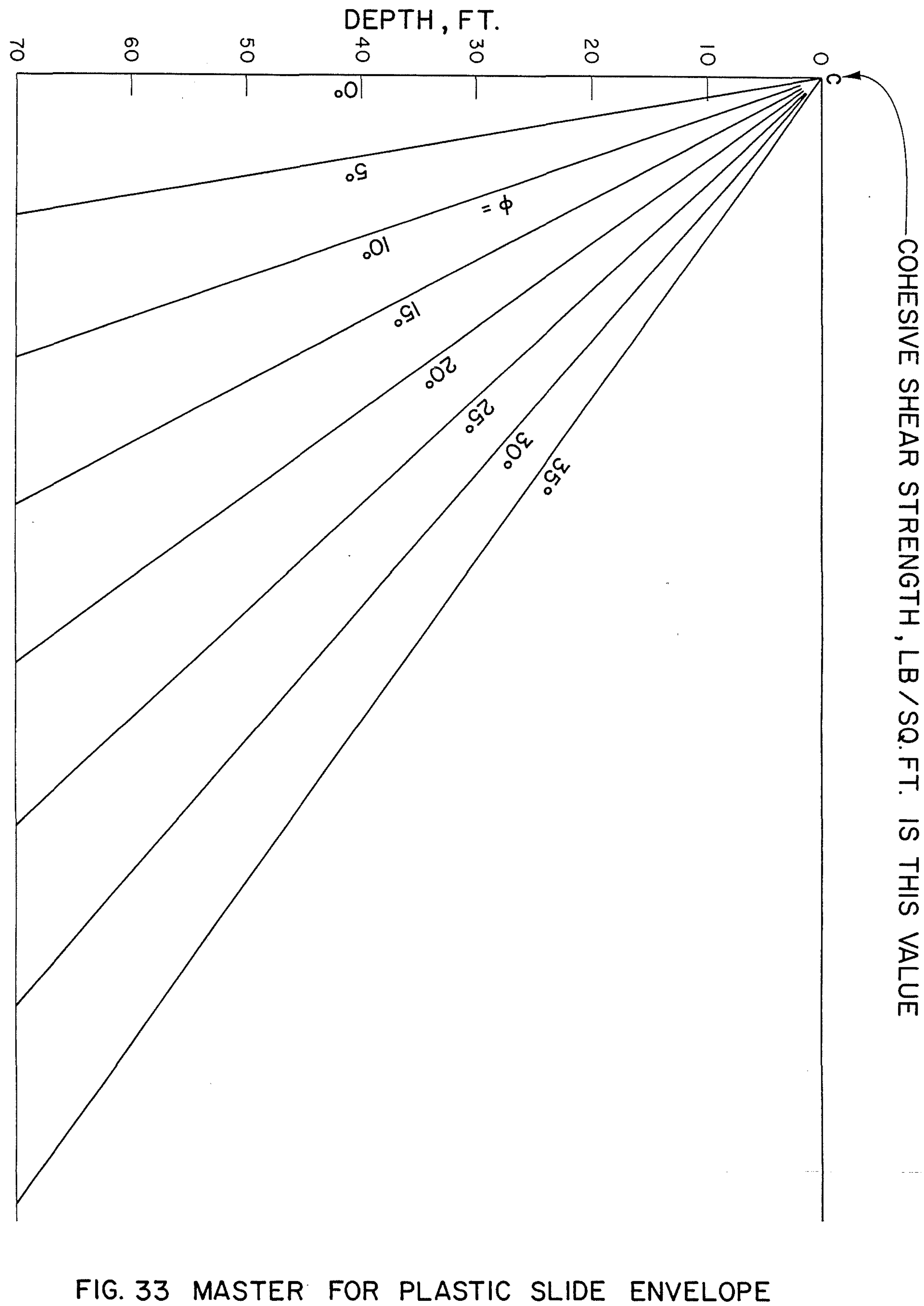


FIG. 33 MASTER FOR PLASTIC SLIDE ENVELOPE

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3. Ivey, Don L. (1968) "Theory, Resistance of a Drilled Shaft Footing to Overturning Loads," Research Report 105-1, Texas Transportation Institute, Texas A&M University.

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