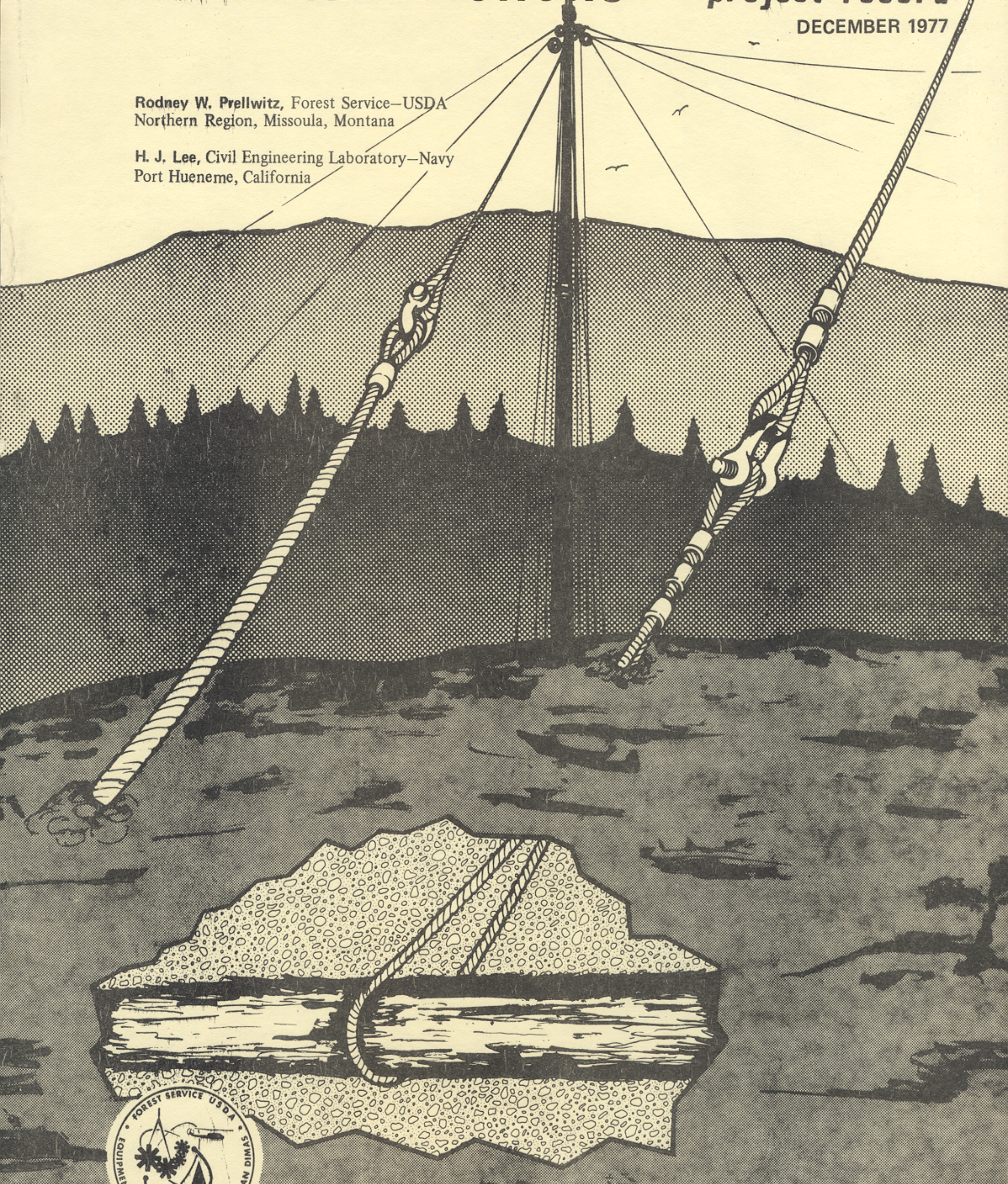
DEADMAN ANCHORS

project record

DECEMBER 1977

Rodney W. Prellwitz, Forest Service–USDA
Northern Region, Missoula, Montana

H. J. Lee, Civil Engineering Laboratory–Navy
Port Hueneme, California



Forest Service–U. S. Department of Agriculture
Equipment Development Center, San Dimas, California 91773

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DECEMBER 1977

February 1974 Report—

DESIGNING DEADMAN (SOIL) ANCHORS FOR SKYLINE LOGGING

by

Rodney W. Prellwitz, Soils Engineer
Northern Region—Engineering
Forest Service—U.S. Department of Agriculture
Missoula, Montana

June 1977 Technical Memoranda—

ASSESSMENT OF THE PRELLWITZ-FOREST SERVICE METHOD OF DEADMAN ANCHOR DESIGN

and

COMPARISON OF THE PRELLWITZ-FOREST SERVICE METHOD OF DEADMAN ANCHOR DESIGN WITH OTHER METHODS AND TESTS

by

H. J. Lee, Civil Engineering Laboratory
Department of the Navy
Naval Construction Battalion Center
Port Hueneme, California

Compiled by—

FOREST SERVICE—U. S. DEPARTMENT OF AGRICULTURE
EQUIPMENT DEVELOPMENT CENTER
SAN DIMAS, CALIFORNIA

for—

ED&T Project No. 2640

Substitute Anchors for Aerial Cable Transport Systems

7724 1204

PREFACE

Logging operators have long used large, old-growth stumps to anchor high-lead cable logging towers. However, loggers are now working in areas that are either extensively cut over or are lightly timbered, second-growth stands. Thus, few (if any) large stumps are available for anchors. Then too, more skyline logging systems are in use, putting more of a load demand on stump anchor systems. Consequently, when adequate stump anchors are not available substitutes must be provided.

The Forest Service's San Dimas Equipment Development Center (SDEDC) has been working on ED&T project No. 2640 to develop and field test substitute anchor systems for use with cable logging systems. This document has been compiled by SDEDC as that part of the effort that dealt with the possibility of using deadman anchors as substitutes for stumps. It consists of a report by the Forest Service's Rodney W. Prellwitz on the design of deadman anchors for skyline logging plus two technical memoranda by H. J. Lee of the Navy's Civil Engineering Laboratory (CEL) that review and comment on the Forest Service report. The Prellwitz report explains how deadman anchor failures can occur and provides verification for the problems presented in the author's "Deadman Anchoring Guide" that is appended to the Forest Service report. The two CEL tech memos provide an excellent state-of-the-art evaluation of Prellwitz's work on deadman anchors.

Presently, SDEDC is following through on ED&T project No. 2640 by looking into plate anchors and picketts as possible substitute anchors and investigating early warning systems to detect impending failure of cable logging tower anchors.

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By

Rodney W. Prellwitz, Soils Engineer
Materials Investigations
Northern Region, Division of Engineering
Forest Service, U.S. Department of Agriculture
Missoula, Montana

INTRODUCTION

Searching for a proper way to introduce this topic, I came across the following statement which says it much better than I ever could. This statement was used by Charles Campbell of the Pacific Northwest Forest and Range Experiment Station to introduce his paper[1/] "Mechanics of Skyline Anchoring" at the Skyline Logging Symposium in 1969:

> "Good anchoring cannot be overemphasized in planning a skyline operation. In the past, there have been many instances where carriages and other equipment have been damaged or destroyed because of anchor failures. Presently, the only way to estimate how much an anchor will hold is by experience - usually gained the hard way. Three types of anchors are commonly used: stumps, deadman anchors, and rock bolts. Stumps are, of course, the most common, and this paper is limited to a discussion of stump anchors. Deadman anchors and rock bolts require a high degree of engineering for correct installation and cannot be adequately dealt with within the time allotted for this paper."

Even though Mr. Campbell made those statements in 1969, much of what he said then still applies today. I would like to take up where he left off and discuss deadman anchoring and demonstrate that the load-carrying capacity of a deadman anchor can be safely predicted and show how this can now be done without a high degree of engineering computations by using chart solutions.

DEADMAN ANCHOR DESIGN METHODS

Stump anchors are generally more economical than deadman anchors, but where stumps are too small or nonexistent, deadman soil anchors may be the only anchoring alternative. The anchor usually consists of one or more logs of a given length and diameter buried under controlled conditions of location, depth, and compaction. The cover sheet of the "Deadman Anchoring Guide" illustrates a cross section of a typical installation. The load-carrying capacity of such an installation can be predicted if all of the variables are properly accounted for. Even though a degree of engineering computations are normally required to predict the design load for a deadman anchor, the "Deadman Anchoring Guide," which I am introducing reduces these computations to the use of three relatively uncomplicated charts. These three charts are based on sound soils and structural engineering design principles selected from the references cited. Engineering computations for the two Design Examples given in the "Deadman Anchoring Guide" are included in the Appendix to illustrate the technical basis on which the charts are based.

MODES OF ANCHOR FAILURE

In order to understand the need for evaluating certain variables such as log length (L), log diameter (d), soil characteristics, and burial, it is important to first look at the possible ways in which a log deadman anchor might fail if excessive tension or pull (P) is applied to the cable. Figure No. 1 illustrates the three modes of failure: flexure, shear, and pullout.

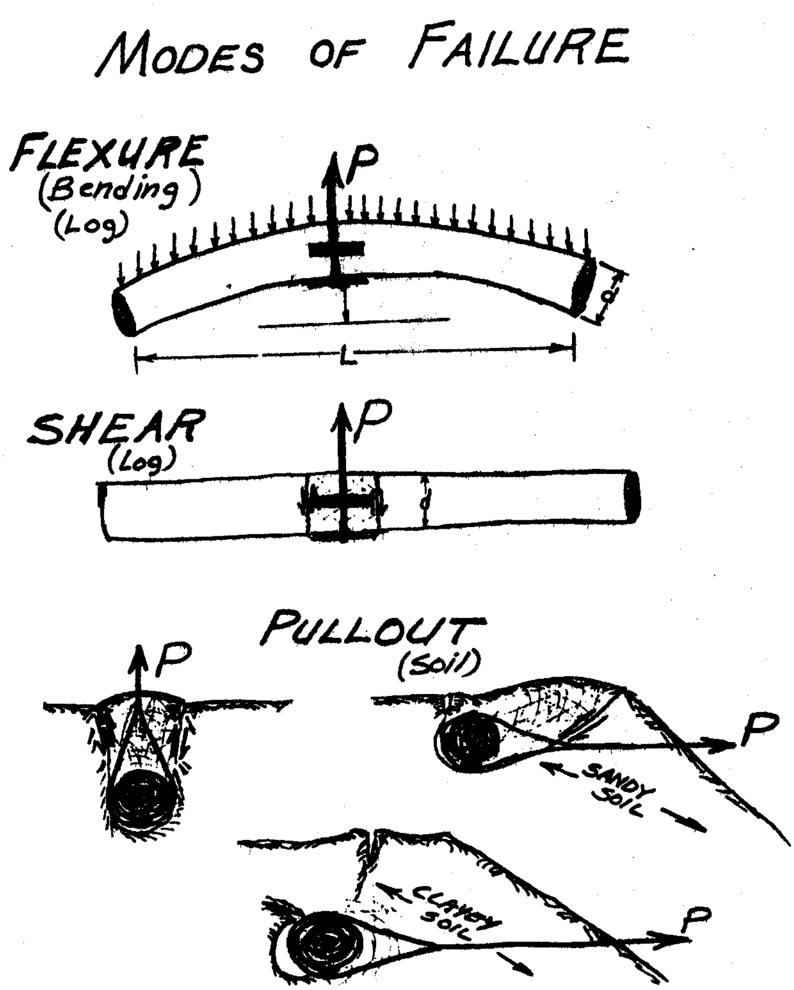


Figure No. 1 - Three modes of failure which must be prevented in the design of a log deadman anchor.

A. Flexure (Bending). The type of engineering computations necessary to prevent failure by flexure are much like those used to prevent excessive fiber stress in the design of a timber beam or floor joist for a structure. However, instead of being simply supported at the ends or at fixed points which is common in beams, the support in a soil anchor is continuous over the entire length of log. A maximum log length (L) for a given log diameter (d) must be established to prevent excessive flexure stress. The ability to withstand flexure stress varies with the timber specie. The charts are applicable to logs from species such as firs, ponderosa pine, larch, and lodgepole pine and do not apply to such low strength and density species as cedar and spruce.

B. Shear. Shear is the second mode of structural failure of the log itself. It can be compared to the failure of a metal pin or rivet supported on both ends which must be sheared along two planes to fail. A minimum log diameter (d) must be selected to prevent shear failure. In addition, bearing plates should be used between the cable and the log to develop the maximum shear strength of the log. As with flexure, the maximum shear stress also varies with specie, and the charts are applicable only to those species indicated.

C. Pullout. Pullout unlike flexure and shear is not a failure of the log, but a failure in the ability of the soil in which the anchor is located in withstanding the applied pull. In addition to controlling log length (L) and diameter(d) several other variables enter into designing to prevent a pullout failure. These include soil strength characteristics, direction of pull and burial.

1. Soil Strength Characteristics. Just as different species of timber have different shear strengths, the shear strength of soil varies with soil type. The picture is further complicated in that clay soil has entirely different strength characteristics from that of the granular soils commonly referred to as gravel, sand, and silt. The direction of load application and burial conditions also affects the soils ability to withstand pullout.

   Without resorting to a technical explanation, I'll attempt to illustrate by idealized diagrams that portion of soil which will react to resist the pullout of a deadman. Consider the difference between two log anchors with horizontal pulls as shown in Figure No. 1. One is located in a sandy (granular) soil and one in a clayey soil. The ability of both of these to withstand the applied horizontal pull (P) is due to the passive resistance of the soil. In the sandy soil, it is dependent on the weight of the overlying soil and angle of internal friction (Ø) to prevent a shear failure along a plane as illustrated. However, the clayey soil develops its passive resistance somewhat from the weight of the overlying soil but largely from the shear strength parameter of cohesion (C), which is independent of weight. Pullout failure from a horizontal pull for a clayey soil may be more in the form of plastic flow around the anchor rather than displacement of a soil wedge as in the sand. On the other extreme, the vertical pull in either sand or clay develops much less if any shear strength, and in common practice, the strength in the vertical direction is conservatively limited to the combined weight of the log and the overlying soil.

Other factors, which can drastically reduce soil shear strength, are high organic content and saturation. Highly organic soil commonly called topsoil, peat, and muck has low density and low shear strength and should be avoided. Ponding water or locations of high water table should also be avoided. For example, saturation of a sandy soil can reduce the size of the resistive strength about half that of the unsaturated soil.

2. Direction of Pull. Figure No. 2 further illustrates the effect of variations in pull direction on the "pullout" strength of a sandy soil. In each case, the log has the same dimensions and is buried similarily in the same sandy soil. The amount of "pullout" resistance for the various pull directions is relatively compared to the size of the soil wedge in resistance as shown. The vertical pull is shown to have the least resistance for burial at the illustrated depth, and the downward ($-\theta$) pull is shown to have the greatest resistance even though the log dimensions and burial conditions are the same in each case.

3. Burial. Figure No. 3 illustrates in a similar manner (using the size of the soil wedge in resistance for comparison) the effects of variations in burial on the ability of a sandy soil to prevent a pullout failure from a horizontal pull. This situation is one that you would encounter in installing a deadman in a spur road. The first illustration shows development of the full resistance wedge for a depth of twice the diameter by burying the log at least four times the diameter in from the edge of the slope. The second illustration shows the reduction in size of the resistance wedge when the depth of burial is decreased to a depth equal to the diameter. The third illustration shows that the full passive wedge cannot be developed when the depth of burial is reduced from four times to two times the diameter in from the shoulder.

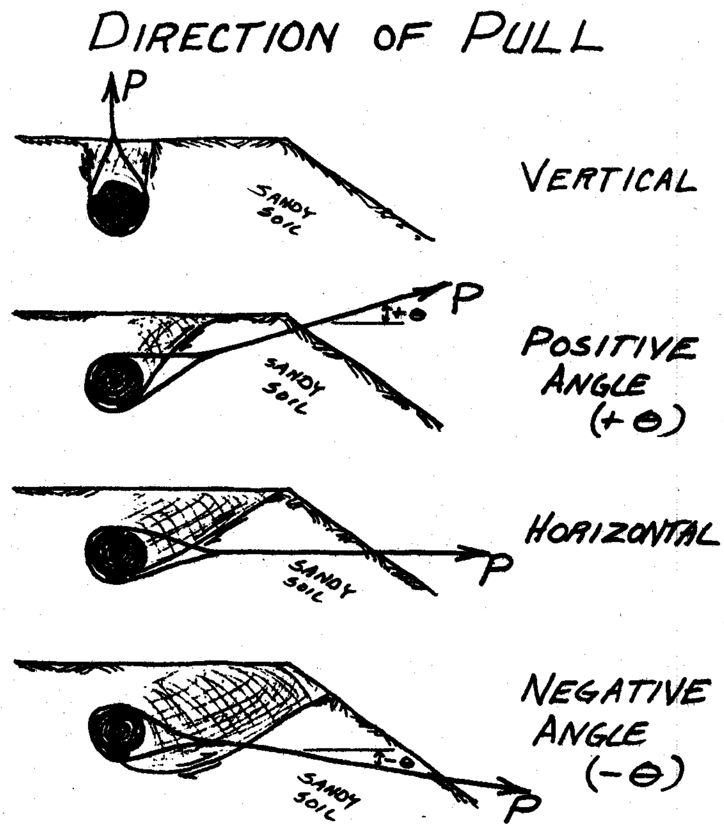


Figure No. 2 - Effects of pull direction on resistance of a sandy soil (size of soil wedge in resistance).

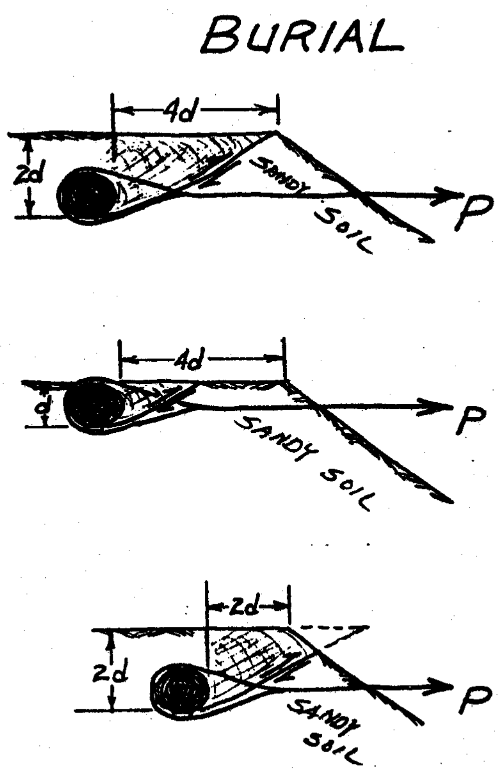


Figure No. 3 - Effects of burial variations (depth and location) on resistance of a sandy soil (size of soil wedge in resistance.

DEADMAN ANCHORING GUIDE

In order to take these variables into account in the design of a deadman anchor in such a way that the minimum amount of calculations are necessary, I've developed the charts and sample problems of the "Deadman Anchoring Guide." The "Deadman Anchoring Guide" is included as a part of the soon-to-be-published "Cable Logging Systems Handbook." Stump anchors and rock bolt anchors are also covered in the "Handbook." The "Deadman Anchoring Guide" only is included in the Appendix of this paper.

Sheet No. 1 of the "Guide" gives the following recommended procedure for deadman design: (1) The line tension or pull (P) in units of kips (1,000 pounds) is determined according to procedures found elsewhere in the "Handbook." (2) The minimum cable diameter is then selected to correspond to this tension (P). (3) From a profile of the skyline layout, the angle of pull on the deadman is determined. (4) Chart No. 1 of the "Guide" gives the correction factor which must be applied to (P) in order to correct for this pull direction. This chart will also be useful in the event there is latitude for change of deadman location to result in a more efficient design. (5) This corrected (P) can then be used with Chart No. 2A (for granular soils) or Chart No. 2B (for clayey soils), and the estimated soil strength to determine the required log dimensions directly. Maximum log dimensions are controlled on Charts 2A and 2B to prevent flexure and shear failure. Estimating the soil strength will be the most difficult part of the procedure. Field estimating procedures are shown on the charts. These are empirical estimating procedures from Sowers and Sowers,[6] a soil mechanics text and, if used conservatively, should give satisfactory results. The Forest Service has Materials (Soils) Engineers like me, who work with the actual soil strength parameters (γ, ϕ, and C) in the design of cut and fill slopes, structure foundations, and retaining walls; and we can assist in estimating soil strength if you have difficulty in this area. (6) After the proper log dimensions are obtained, Chart No. 3 is used to determine the minimum burial requirements to make the solutions of Chart No. 1 and 2A or 2B valid. These are <u>minimum</u> requirements. Deeper burial and burial further inslope is advisable to increase the safety margin if this can be done safely and within economic limitations. (7) "Suggestions for Deadman Installation" are given on Sheet No. 1 of the "Guide." Items such as the selection of log species, the control of excavation, and backfill techniques, and the use of bearing plates to develop full shear strength are summarized here to aid in the proper installation of soil anchors.

DESIGN EXAMPLES

Sheets 2 through 4 of the "Guide" illustrate the use of the charts in the solution of two design examples.

Deadman Design Example No. 1 illustrates the selection of a single 30-inch middiameter by 26-foot long log to withstand a skyline tension (P) of 30 kips pulling downward at 10 percent. In this example, the designer determined the soil to be a "firm" gravel and chose a spur road burial location with minimum trench depth of 5 feet, and trench located at least 10 feet back from original groundline are shown.

Deadman Design Example No. 2 illustrates a deadman design for a skyline tension (P) of 57 kips with the pull direction upward at 25 percent. At the anchor location, the ground slopes downward at 30 percent in the direction of pull. The designer determined the soil to be a "soft" to "firm" clay, and from Chart No. 2B, a single log of 48-inches middiameter and 38-foot length is determined. In this example, 24-inch middiameter logs are the largest available for use as deadman anchors so it becomes necessary to go to a multiple anchor system. The example shows that four 24-inch middiameter by 20-foot long logs are required to replace the one 48-inch by 38-foot log. Two acceptable alternate methods of rigging this multiple system are illustrated. To simplify the solution, the tension (P) in each line was set equal to one-fourth of the skyline tension. This shortcut approximation may or may not result in significant error. Refer to Figure No. 4 for an explanation.

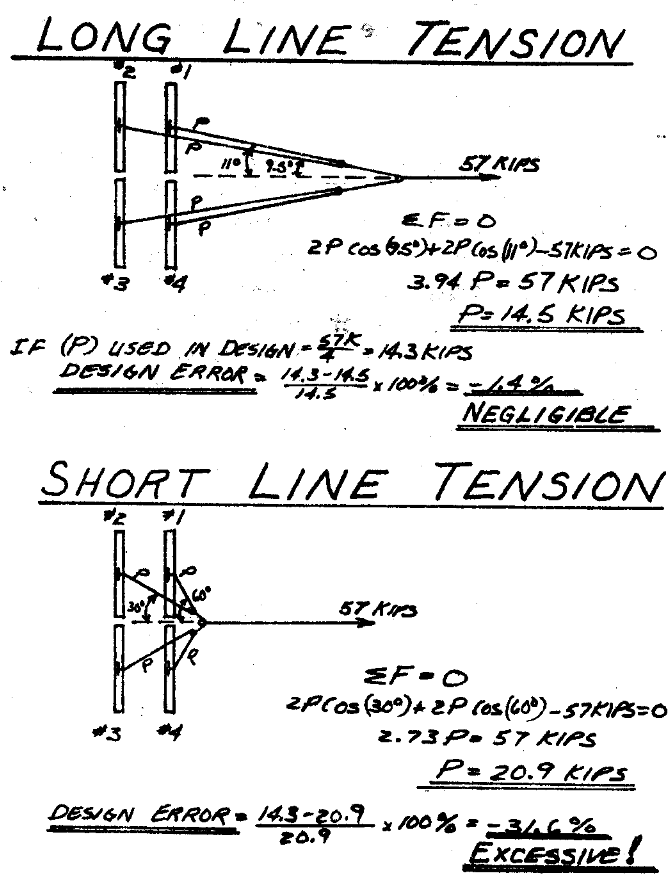


Figure No. 4 - Effects of variations in anchor line length in a multiple anchor system on the individual line tension (P).

If long lines are used so that the extreme angle from straight pull is small, then the error is negligible. As illustrated in Sample Problem No. 2, the tension in each line is determined to be 14.5 kips rather than the 14.3 kips used in the design resulting in a percent error of only 1.4 percent which is negligible. You will note that for the long line illustration the extreme angle from straight pull is approximately 11 degrees. On the other hand, if short lines had been used as illustrated on the bottom of Figure No. 4 such that the extreme angle from straight pull is increased to 60 degrees, then the actual tension in each line is determined to be 20.9 kips. When compared to the 14.3 kips used in the design, the system is found to be underdesigned by 31.6 percent, which is excessive and could result in failure.

Normally, these large angles from straight pull can be avoided simply by using longer lines. If it is not possible to avoid using short lines, the tension should be computed as illustrated in Figure No. 4, and deadman designed to withstand the computed tension. Generally, if the extreme pull angle is less than 15 degrees, it can be ignored.

This type of multiple anchor problem will be encountered more often in anchoring to stumps. The section on "Stump Anchors" in the "Cable Logging Systems Handbook" is tailored to prevent these common errors made in laying out multiple anchors. I wanted to illustrate here how the same mechanics apply to multiple soil anchoring systems.

CONCLUSIONS

The design charts I've introduced with this paper are not intended to replace engineering judgment but only the time-consuming drudgery of extensive mathematical computations. I hope that through their use, the designer can let the charts do the tedious work and spend his time and judgment in the proper selection and placement of the anchor systems. The designer unfamiliar with soil mechanics should not hesitate in seeking help from a materials (soil) engineer in identifying and categorizing the soil. This part of the procedure will present the most difficulty and result in the largest single source of error if not properly handled.

LIST OF REFERENCES

1. Campbell, Charles O., "Mechanics of Skyline Anchoring," Proceedings of Skyline Logging Symposium, Oregon State University, 1969.

2. Leonards, G. A., "Foundation Engineering," McGraw-Hill, 1962, pages 462 to 469.

3. Hough, B, K., "Basic Soils Engineering," Ronald Press, 1969, pages 458 to 464.

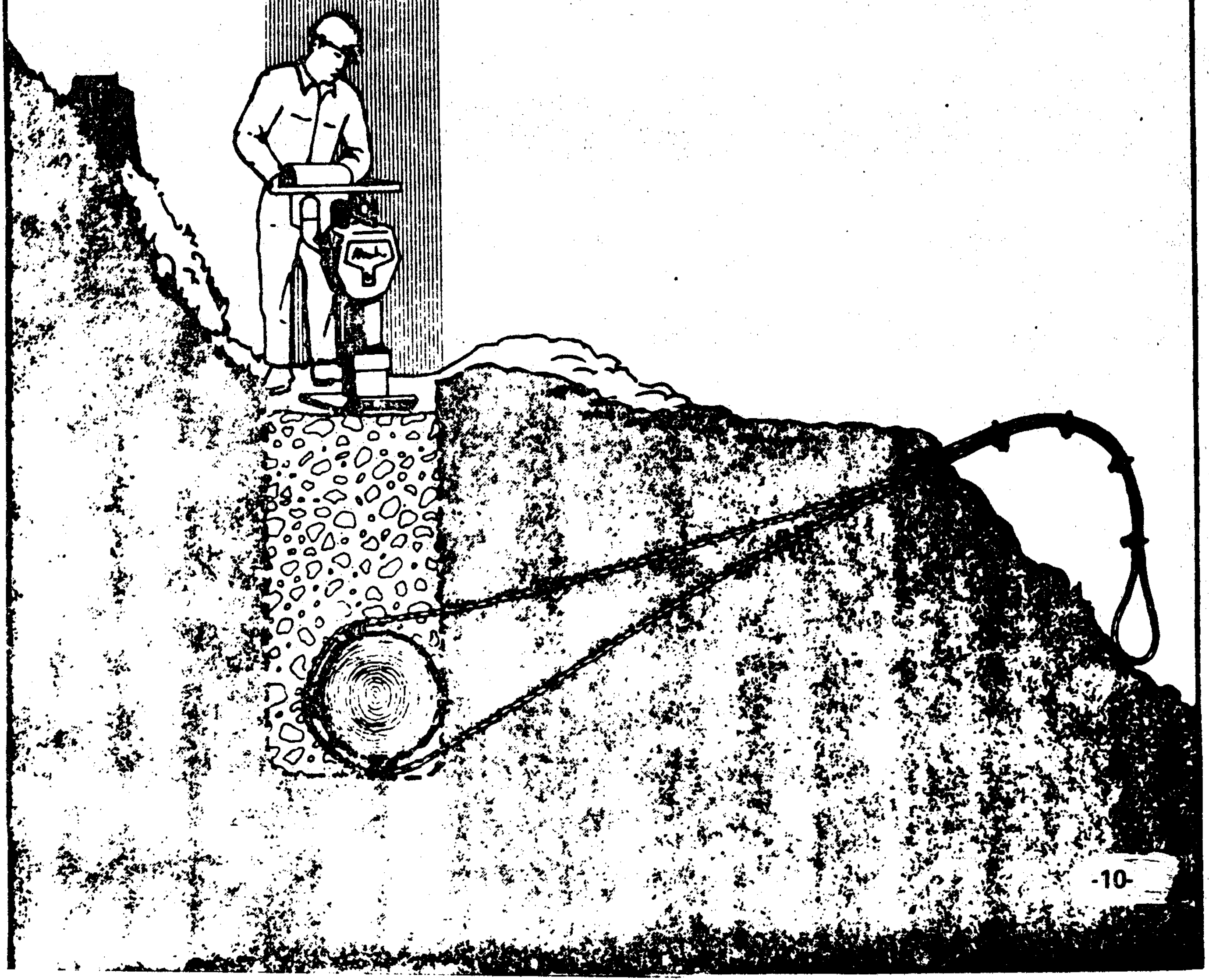
4. NAVFAC CM-7, "Design Manual-Soil Mechanics, Foundations, and Earth Structures," Department of the Navy, 1971, pages 1-7, 11-10, 11-14 to 11-17.

5. Scofield, W. F. and O'Brien, W. H., "Modern Timber Engineering," Southern Pine Association, 1963, pages 83 to 88.

6. Sowers, G. B. and Sowers, G. F., "Introductory Soil Mechanics and Foundations," MacMillan Co., 1961, pages 108 to 359.

Deadman Anchoring Guide

by Rodney Prellwitz



GUIDE FOR DESIGNING DEADMAN ANCHORS

1. Determine skyline tension (P) from worksheet.

2. Select cable size (for Extra - Improved plow steel cable with a safety factor of 3):

Safe Working Load (P)	Cable Diameter
13.7 kips	5/8-inch
19.6	3/4
26.5	7/8
34.5	1
43.3	1-1/8
53.3	1¼
64.0	1-3/8
76.0	1½

3. Determine angle of pull on deadman (chord slope from horizontal).

4. From Chart No. 1 - Determine correction factor to be applied to the working load (P).

   Corrected (P) = working load (P) x correction factor.

5. Using corrected (P) and known soil conditions at deadman location, determine log diameter and length from Chart No. 2A or 2B.

6. From Chart No. 3, determine necessary depth of burial.

7. Refer to "Suggestions for Deadman Installation" for burial recommendations.

SUGGESTIONS FOR DEADMAN INSTALLATION

1. Select deadman log from species such as firs, Ponderosa pine, larch, lodgepole pine. Avoid cedar, spruce, and other species of low strength and density.

2. Excavate trench at right angle to pull. Excavate wall in the direction of pull as vertical as possible.

3. Use a minimum of three bearing plates between the cable and log to prevent cutting. Refer to State Safety Code for fastening requirements.

4. Excavate for the cable exit to prevent bending in cable and vertical lifting of deadman.

5. Use good backfilling techniques same as for culvert installation; i.e., layer placement and tamp with mechanical compactor.

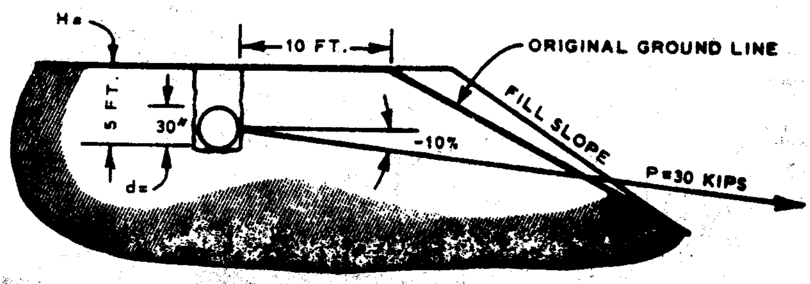
DEADMAN DESIGN EXAMPLE NO. 1

1. (P) from skyline worksheet = 30 kips.
   Ex. - Improved plow steel cable diameter required = 1 inch.

2. Burial is to be in spur road with downward pull (-θ) at 10%. Using Chart No. 1: Corrected (P) = 30 kips x 0.98 = 29 kips.

3. Soil in spur road is a "firm" gravel. From Chart No. 2A, select a 30-inch diameter log - 26 feet long.

4. From Chart No. 3, minimum trench depth = 2 x (30") = 5 feet. Locate trench at least 4 x (30") = 10 feet back from original ground line.



DEADMAN DESIGN EXAMPLE NO. 2

1. (P) from skyline worksheet = 57 kips. Ex. - Improved plow steel cable diameter required = 1 3/8-inch.

2. Pull is upward (+θ) at 25%. Ground slopes downward - 30%. Using Chart No. 1, Corrected (P) = 57 kips x 1.5 = 85 kips.

3. Soil is a "soft" to "firm" clay. From Chart No. 2B: Select a 48-inch diameter - 38 feet long.

4. There are no 48-inch diameter logs in the area, but there are 24-inch diameter logs available. How many 24-inch diameter deadmen are required, how long should they be, and how should they be placed?

5. From Chart No. 2B, select a 24-inch diameter log - 18 feet long, and for "soft" to "firm" clay find: maximum corrected (P) = 20 kips.

6. Using Chart No. 1, if 25% is used as the approximate positive angle of pull (+θ), maximum working load (P) per deadman =

$$\frac{20 \text{ kips}}{\text{Correction factor for } +25\%} = \frac{20 \text{ kips}}{1.5} = 13 \text{ kips}$$

   Minimum number of 24" x 18' deadmen required $= \frac{57 \text{ kips}}{13 \text{ kips}} = 4.4$

   Use four deadmen and resize length of 24-inch log:

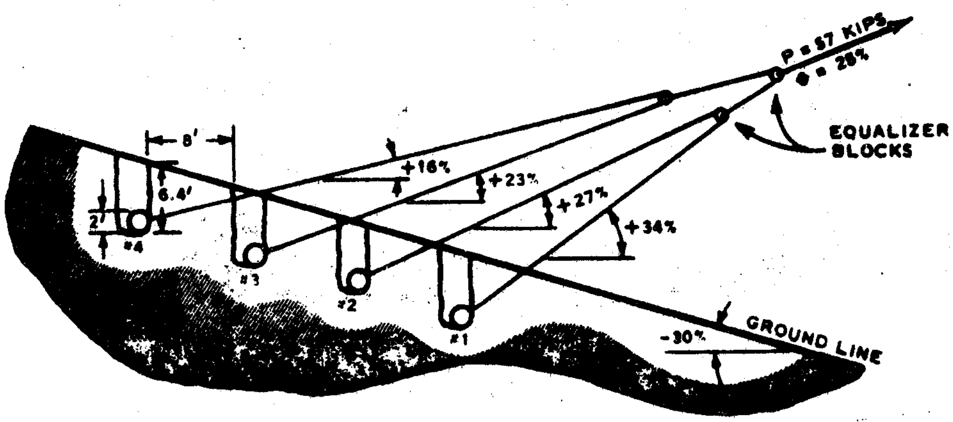
   Corrected (P) per deadman $= \frac{57 \text{ kips}}{4} \times 1.5 = 21.5$ kips

   From Chart No. 2B, select a 24-inch diameter - 20 feet long.

7. Trial design using four 24-inch deadmen placed as shown in sketch. Since burial is on 30% sideslope, from Chart 3A or 3B: **minimum trench** depth = 3.2d = 3.2(24") = <u>6.4 feet</u>.

   Minimum horizontal distance of undisturbed soil between **deadman** trenches = 4d = 4(24") = <u>8.0 feet</u>.

8. Distribute load as uniformly as possible to the four deadmen through the use of equalizer blocks.



Deadman #1: $P_1 = \frac{21.5 \text{ kips}}{1.8} = 11.9$ kips
(θ = +34%)

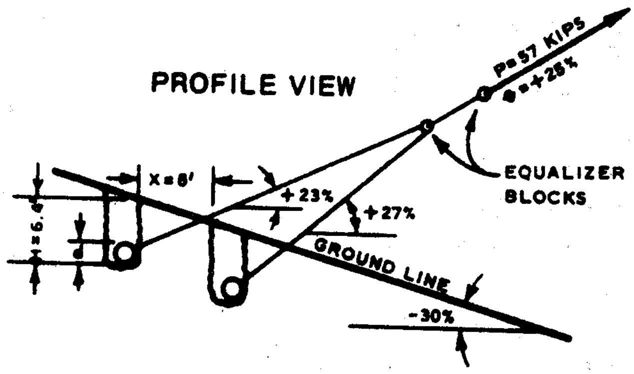
Deadman #2: $P_2 = \frac{21.5 \text{ kips}}{1.5} = 14.3$ kips
(θ = +27%)

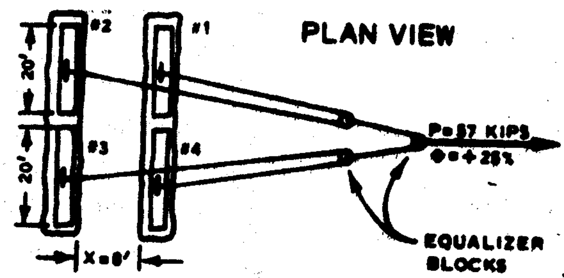
Deadman #3: $P_3 = \frac{21.5 \text{ kips}}{1.4} = 15.4$ kips
(θ = +23%)

Deadman #4: $P_4 = \frac{21.5 \text{ kips}}{1.2} = 17.9$ kips
(θ = +16%)

59 kips - o.k.

9. Test another possible design:





Deadman #1: $P_1 = \frac{21.5 \text{ kips}}{1.5} = 14.3$ kips
(θ = +27%)

Deadman #2: $P_2 = \frac{21.5 \text{ kips}}{1.4} = 15.4$ kips
(θ = +23%)

$P_2 + P_2 = 29.7$ kips
$P_3 + P_4 = \times 2$

59 kips - o.k.

CHART NO. 1 CORRECTION FOR PULL DIRECTION

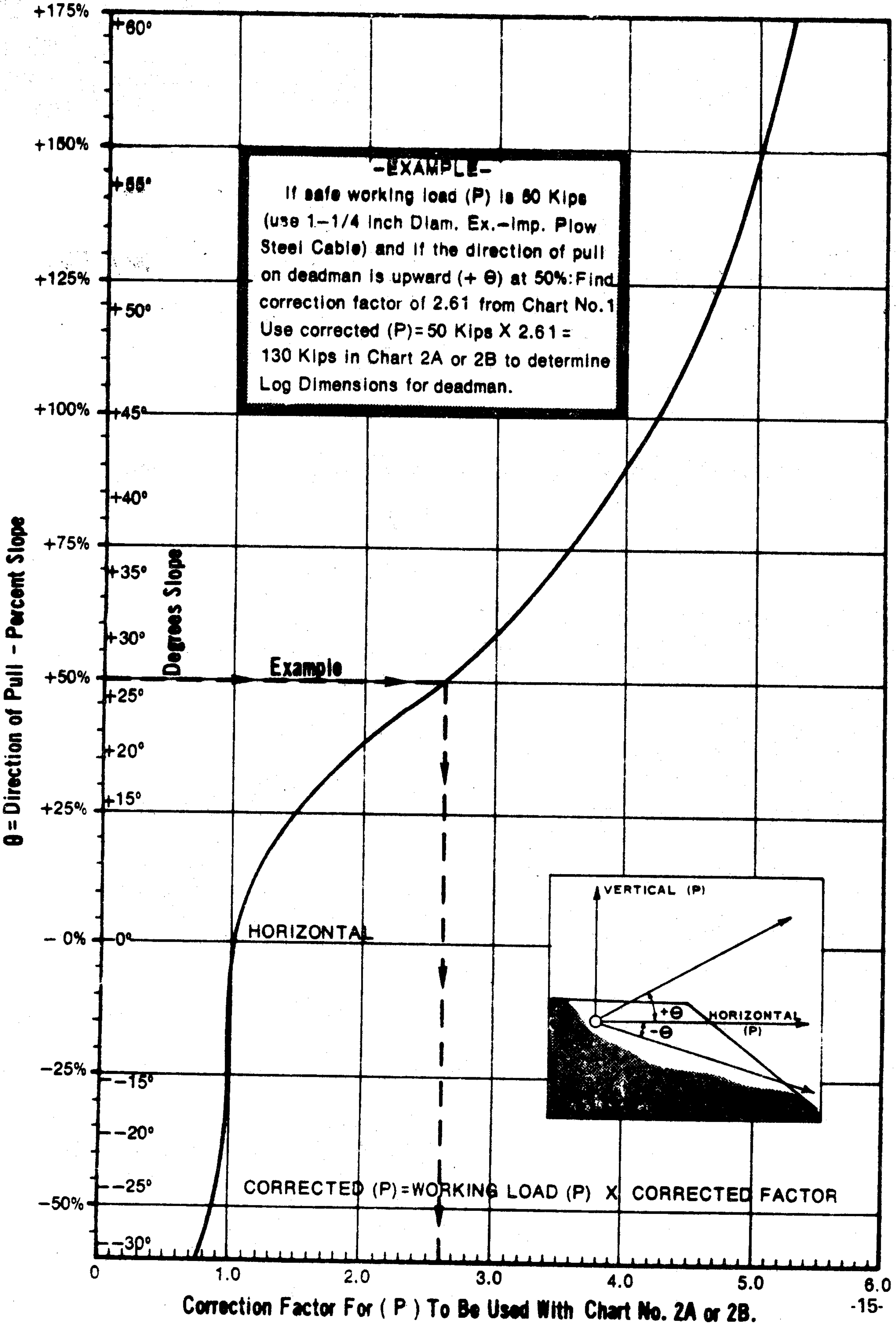
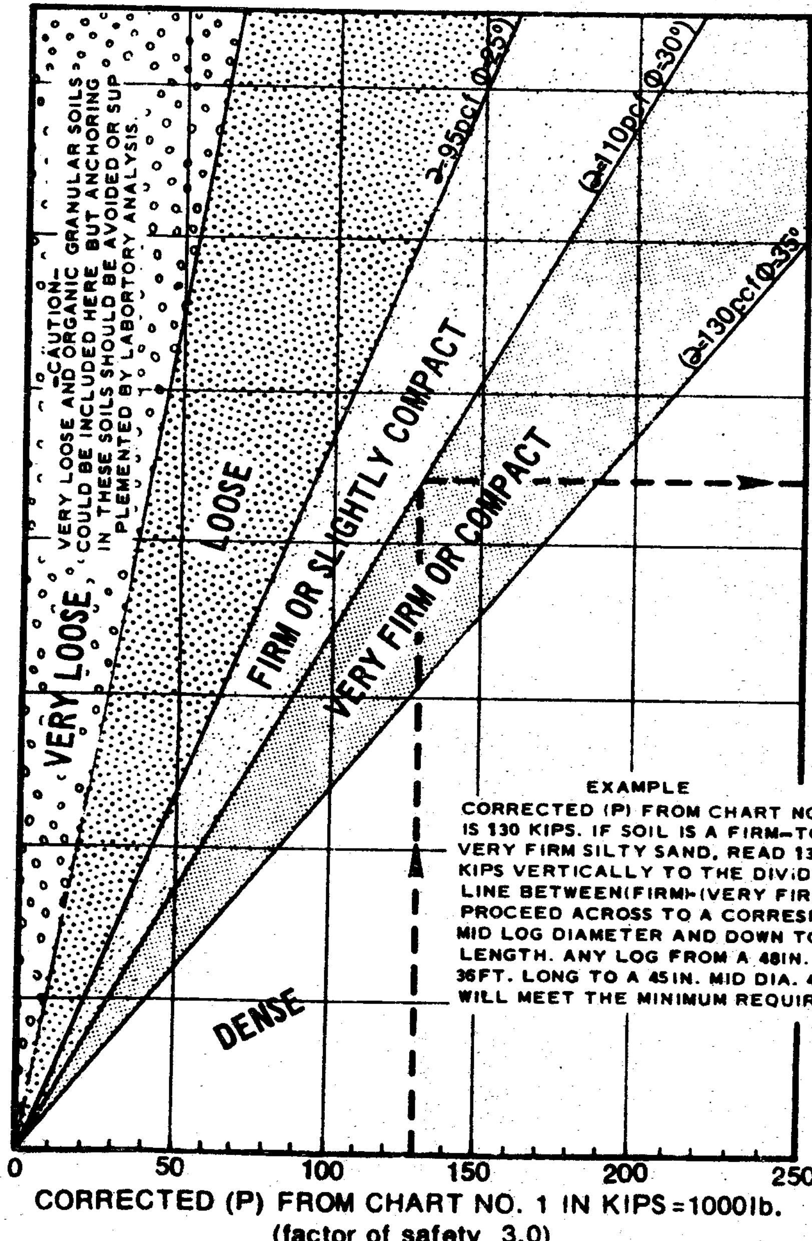


CHART NO. 2A GRANULAR SOILS – (P) CORRECTED V.S. DEADMAN LOG DIMENSIONS

(For use with Inorganic Silt, Sand and Gravel above the watertable)



EXAMPLE

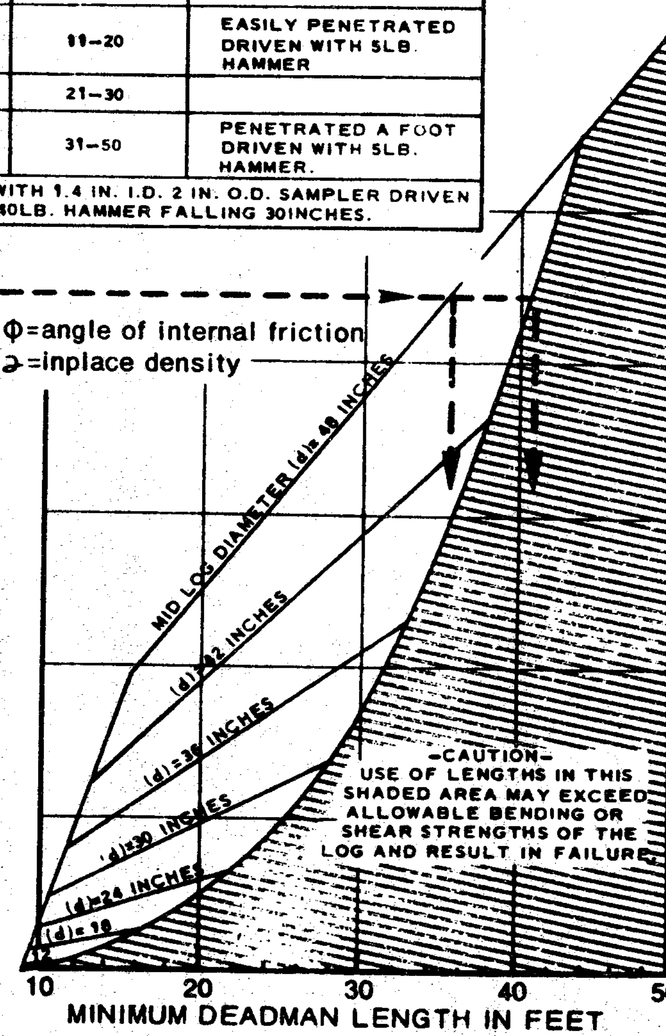
CORRECTED (P) FROM CHART NO.1 IS 130 KIPS. IF SOIL IS A FIRM-TO-VERY FIRM SILTY SAND, READ 130 KIPS VERTICALLY TO THE DIVIDING LINE BETWEEN(FIRM)-(VERY FIRM) PROCEED ACROSS TO A CORRESPONDING MID LOG DIAMETER AND DOWN TO IT'S LENGTH. ANY LOG FROM A 48IN. MID DIA. 36FT. LONG TO A 45IN. MID DIA. 41FT. LONG WILL MEET THE MINIMUM REQUIREMENTS.

SOIL DENSITY	STANDARD * PENETRATION RESISTANCE	FIELD ESTIMATE [1] USING 1/2IN. REBAR
VERY LOOSE	0–4	EASILY PENETRATED PUSHED BY HAND
LOOSE	5–10	
FIRM	11–20	EASILY PENETRATED DRIVEN WITH 5LB. HAMMER
VERY FIRM	21–30	
DENSE	31–50	PENETRATED A FOOT DRIVEN WITH 5LB. HAMMER.

* MEASURED WITH 1.4 IN. I.D. 2 IN. O.D. SAMPLER DRIVEN 1 FT. BY 140LB. HAMMER FALLING 30INCHES.

EXAMPLE

Φ=angle of internal friction
ə=inplace density



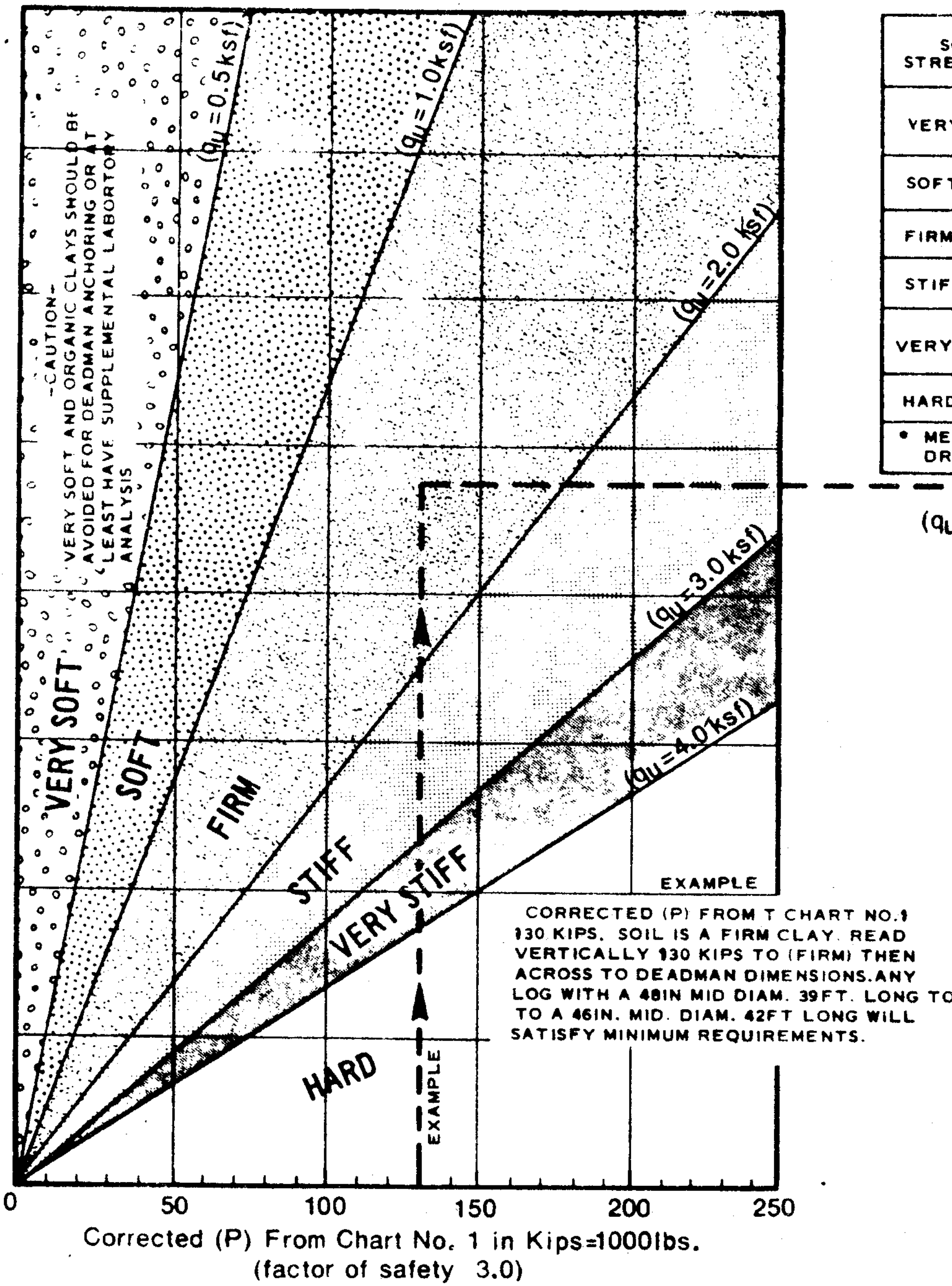
[1] SOWERS G.B. AND SOWERS G.F. (INTRODUCTORY SOIL MECHANICS AND FOUNDATIONS) MACHILLAN CO. 1961 P 108 & 359.

CHART NO. 2B CLAYEY SOILS (P) CORRECTED V.S. DEADMAN LOG DIMENSIONS

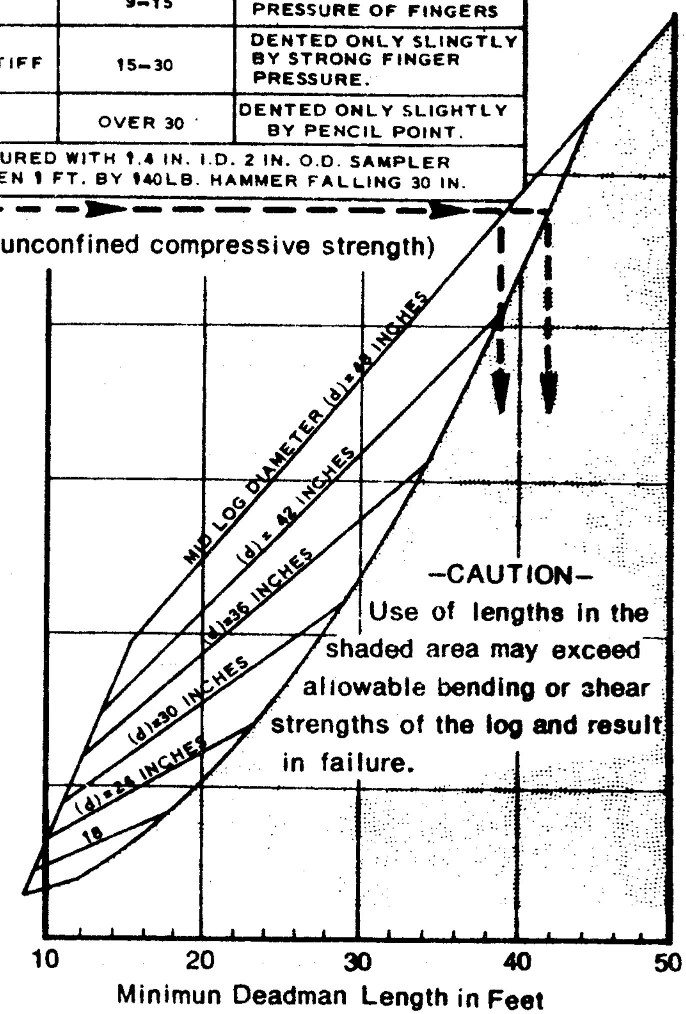
(For use with Inorganic Clays above the watertable)

SOIL STRENGTH	STANDARD* PENETRATION RESISTANCE	FIELD ESTIMATE [1]
VERY SOFT	0–1	SQUEEZES BETWEEN FINGERS WHEN FIST IS CLOSED.
SOFT	2–4	EASILY MOLDED BY FINGERS.
FIRM	5–8	MOLDED BY STRONG PRESSURE OF FINGER.
STIFF	9–15	DENTED BY STRONG PRESSURE OF FINGERS
VERY STIFF	15–30	DENTED ONLY SLINGTLY BY STRONG FINGER PRESSURE.
HARD	OVER 30	DENTED ONLY SLIGHTLY BY PENCIL POINT.

* MEASURED WITH 1.4 IN. I.D. 2 IN. O.D. SAMPLER DRIVEN 1 FT. BY 140LB. HAMMER FALLING 30 IN.



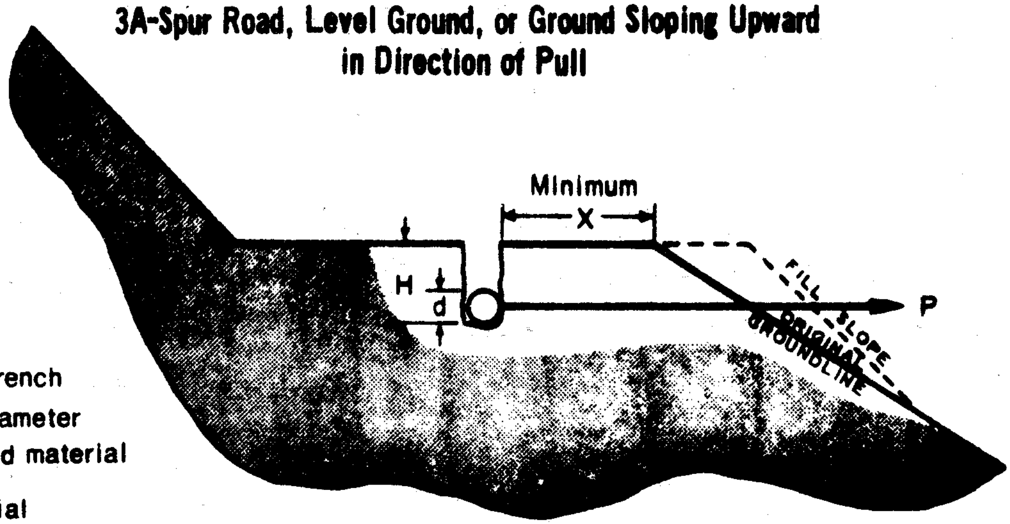
(qu=unconfined compressive strength)



[1] SOWERS G.B. AND SOWERS G.F. (INTRODUCTORY SOIL MECHANICS AND FOUNDATIONS) MACMILLAN CO. 1961, P. 108 & 359.

CHART NO. 3 DEADMAN BURIAL

3A-Spur Road, Level Ground, or Ground Sloping Upward in Direction of Pull

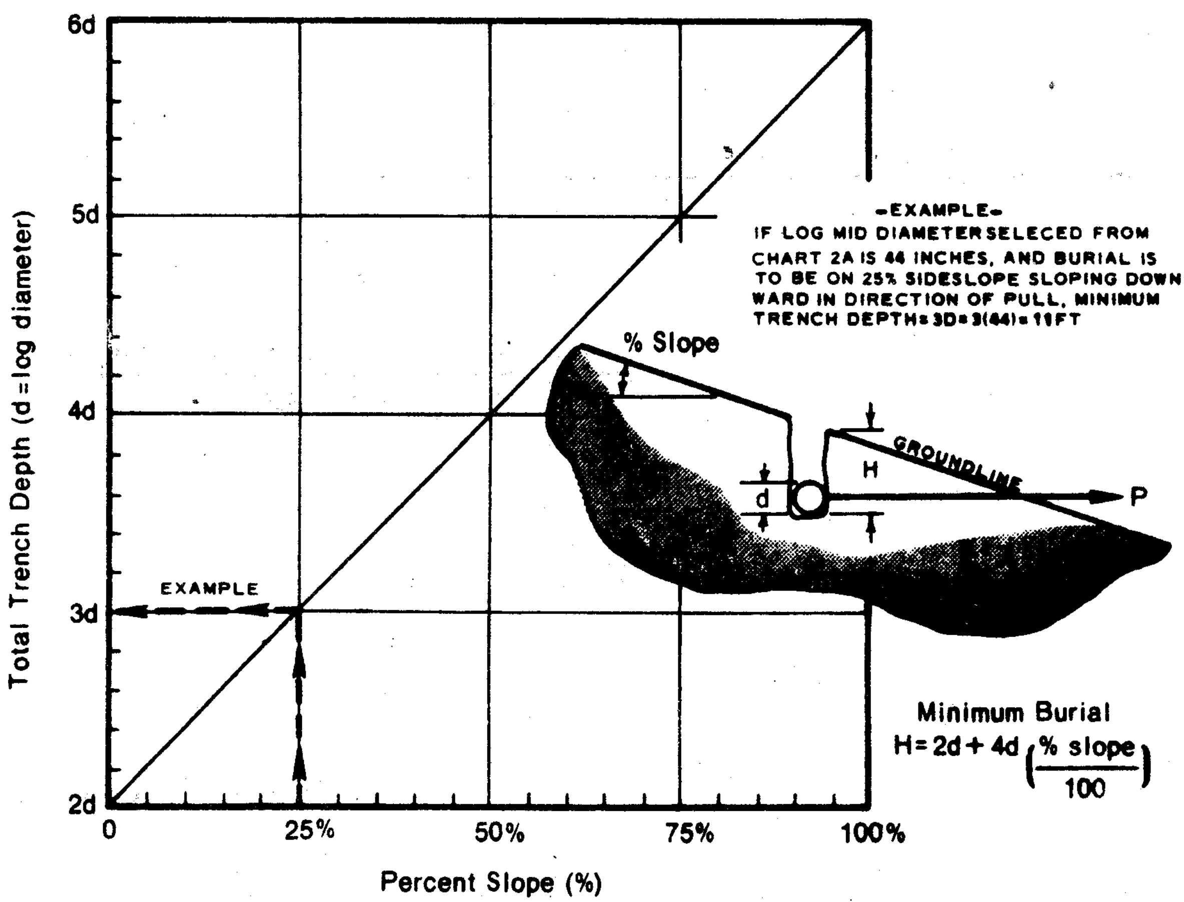


LEGEND

H = depth of trench
d = mid log diameter
X = undisturbed material

Minimum Burial
H = 2d
X = 4d

3B-Ground Sloping Downward in Pull Direction



Minimum Burial

$$H = 2d + 4d\left(\frac{\%\ slope}{100}\right)$$

COMPUTATION SHEET

"DEADMAN ANCHORING GUIDE"

Subject: Verification of Chart Solution for Sample Problem No. 1

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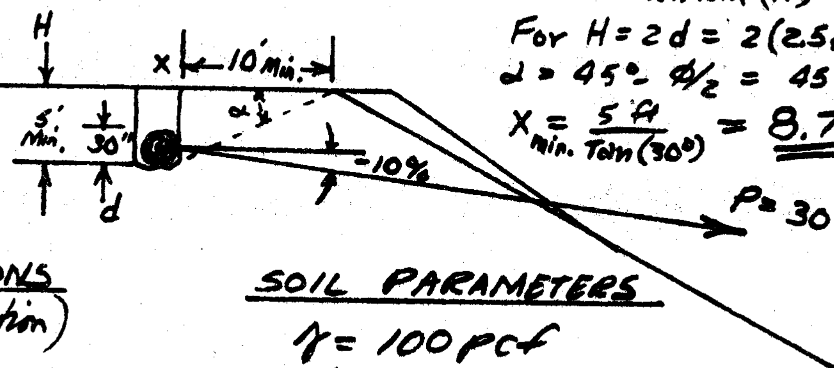
PROBLEM:

Determine the Factor of Safety against: (1) Flexure failure, (2) Shear Failure, and (3) Pullout Failure of the deadman in Sample Problem No. 1.

BURIAL (H & X)
(By Chart Solution)
H = 5 ft.
X = 10 ft.



MINIMUM (X)

For $H = 2d = 2(2.5ft) = 5ft.$

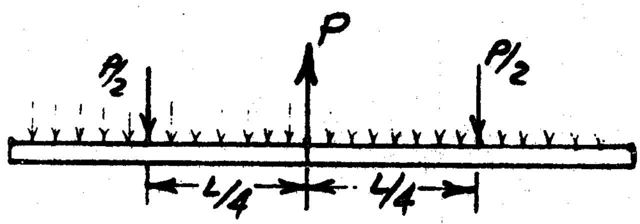
$\alpha = 45° - \phi/2 = 45° - 15° = 30°$

$X_{min.} = \frac{5 ft}{Tan(30°)} = \underline{8.7 ft.}$ (10 ft OK)

LOG DIMENSIONS
(By Chart Solution)
d = 30 inches
L = 26 ft.

SOIL PARAMETERS
$\gamma = 100 pcf$
$\phi = 30°$
$c = 0$

(1) FLEXURE



$$f = \frac{Mn}{I}$$

$$f = \frac{(P/2)(L/4)(d/2)}{\frac{\pi d^4}{64}} = \frac{4PL}{\pi d^3}$$

$$f = \frac{4(30k)(26ft)}{\pi (2.5ft)^3} = 63.6 KIPS$$

Allowable (f) for Pine, Fir, Larch [5/] ≅ 1,500 psi ≅ 216 ksf

$$\text{Factor of Safety} = \frac{216 Ksf}{63.6 Ksf} \cong \underline{3.4} > 3.0 \quad \underline{OK}$$

which verifies the chart solution for FLEXURE

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COMPUTATION SHEET

SHEET 2 OF 3

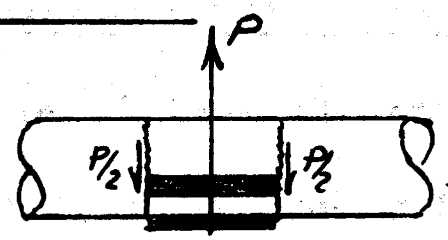
MADE BY

CHECKED BY (INITIAL AND DATE)

Subject:

Sample Problem No. 1 (continued)

(2) SHEAR



$$S_s = \frac{4}{3}\frac{V}{A}$$

$$S_s = \frac{4}{3}\frac{(P/2)}{\left(\frac{\pi d^2}{4}\right)} = \frac{8P}{3\pi d^2}$$

$$S_s = \frac{8(30k)}{3\pi(2.5ft)^2} = 4.1\ Ksf$$

Allowable (S_s) ⊥ to grain for Pine, Fir, Larch[5] ≅ 90psi ≅ 13 Ksf

Factor of Safety $= \frac{13\ Ksf}{4.1\ Ksf} \cong \underline{3.2} > 3.0$ OK

Which verifies the chart Solution for SHEAR

(3) PULLOUT

If Pull were Horizontal:

$$E_p = \frac{\gamma H^2}{2} K_p \quad \text{where } K_p = \frac{1+\sin\phi}{1-\sin\phi}$$ Leonards[2]

when $\phi = 30°$ $K_p = 3.00$

$$E_p = \frac{(100pcf)(5ft)^2}{2} \times 3.00 = 3{,}750\ lb/ft.$$

for (L) = 26 ft.

$$P_{max} = (3750\ lb/ft)(26ft) = 97{,}500\ lb. = \underline{97.5\ KIPS}$$

which would have a Factor of Safety $= \frac{97.5\ Kips}{30\ Kips} \cong \underline{3.2}$

But Pull is Downward @ 10% = 5.7° Angle:

from Leonards[5], If direction were $-\phi/2 = -15°$; $K_p = 3.70$

It may be valid to make a linear interpolation between $K_p = 3.00$ for $\measuredangle = 0°$ and $K_p = 3.70$ for $\measuredangle = 15°$ to arrive at a (K_p) value for $\measuredangle = 5.7°$. Function may not vary linearly for these small angles. A better assumption is that the interpolation can be made based on the cosine of the angle and in that manner be related to the horizontal component:

Angle	Cosine	K_p
± 0°	1.000	3.00
− 5.7°	0.995	$K_{p(5.7°)}$
− 15°	0.966	3.70

$$K_{p(5.7°)} = 3.00 + \left(\frac{1.000 - 0.995}{1.000 - 0.966}\right)(3.70 - 3.00) \cong \underline{3.10}$$

$$E_p = \frac{(100\,pcf)(5\,ft.)^2}{2} \times 3.10 = 3{,}875\ \text{lb/ft.}$$

for (L) = 26 ft,

$$P_{max.} = (3875\ \text{lb/ft})(26\ \text{ft.}) = 100{,}750\ \text{lb.} = \underline{100.8\ \text{KIPS}}$$

$$\text{Factor of Safety} = \frac{100.8\ K}{30\ K} \cong \underline{3.4} > 3.0 \quad \underline{OK}$$

which verifies the chart solution for PULLOUT

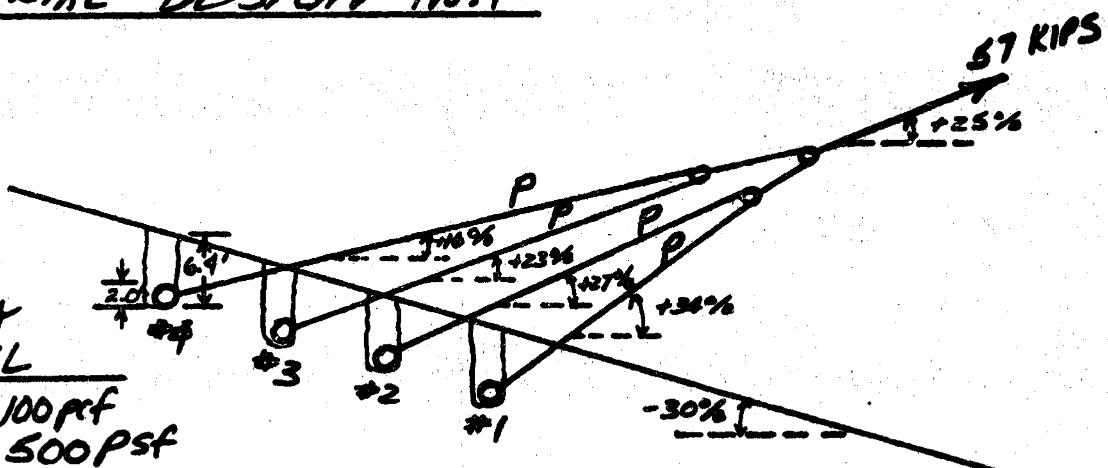
"DEADMAN ANCHORING GUIDE"

Subject: Verification of Chart Solution for Sample Problem No. 2

PROBLEM:

Determine the Factor of Safety against: (1) Flexure failure, (2) Shear Failure, and (3) Pullout Failure of the two trial designs in Sample Problem No. 2

TRIAL DESIGN No. 1



Determine (P)

$$\alpha_{\#1} \text{ \& } \alpha_{\#4} = \frac{34\% - 16\%}{2} = 9\% = 5.1^\circ$$

$$\alpha_{\#2} \text{ \& } \alpha_{\#3} = \frac{27\% - 23\%}{2} = 2\% = 1.1^\circ$$

$$\Sigma F = 0$$

$$2P\cos(5.1^\circ) + 2P\cos(1.1^\circ) = 57 \text{ KIPS}$$

$$P = 14.3 \text{ KIPS}$$

Since (P) same for all anchors check the design for Anchor No. 1 and all others will be even safer since No. 1 has the extreme pull angle (θ) = 34%

$$\theta = +34\% = 18.8^\circ$$

TRIAL DESIGN No. 1 (Continued)

(1) FLEXURE F.S.
(True for all Anchors in the system) (See Sample Prob. #1 for Background)

$$F.S. = \frac{216\ ksf}{\frac{4PL}{\pi d^3}} = \frac{(216\ ksf)\ \pi (2.0 ft)^3}{4\ (14.3k)(20\ ft.)} = \underline{\underline{4.7}} > 3.0\ \underline{\underline{OK}}$$

(2) SHEAR F.S.
(Also true for all Anchors in the system)

$$F.S. = \frac{13.0\ ksf}{8P/3\pi d^2} = \frac{(13\ ksf)(3\pi)(2.0 ft)^2}{8\ (14.3k)} = \underline{\underline{4.3}} > 3.0\ \underline{\underline{OK}}$$

(3) PULLOUT F.S. (Based on VERTICAL Component)
(Anchor No. 1 only)

$$F.S. = \frac{\text{Log Weight} + \text{Overlying Soil Weight}}{P_V} = \frac{\left(\pi \frac{d^2 L}{4}\right)\gamma_{log} + (H_s d L)\gamma_{soil}}{P \sin\theta}$$

$$F.S. = \frac{\left[\frac{\pi (2.0 ft.)^2 (20 ft.)}{4}\right](40 pcf) + \left(\frac{6.4 ft. - 2.0 ft.}{2}\right)(2.0 ft.)(20 ft.)(100 pcf)}{14.3\ KIPS \times 1{,}000\ lb/KIP \times \sin(18.8°)}$$

$$\underline{\underline{F.S. = 2.5}}$$

This is less than the Design Standard = 3.0; however, since this is the least (F.S.) for the four anchors in the system, an (F.S.) between 2.0 and 3.0 is acceptable. The designer may if he wishes to balance the system, either bury Anchor No. 1 deeper [increase (H_s) in the above equation] or lengthen (L) within the limits for FLEXURE.

Subject: Sample Problem No. 2

TRIAL DESIGN No. 1 (Continued)

(3) PULLOUT F.S. (Based on HORIZONTAL Component)

$$F.S. = \frac{3.4\ C d L}{P_H}$$

Leonards [2], P. 468
Hough [3] ; DM-7 [4]

$$F.S. = \frac{3.4 (500 psf)(2 ft.)(20 ft.)}{14.3 \text{ KIPS} \times 1,000 \frac{lb}{kip} \times \cos(18.8°)} = \underline{\underline{5.0 > 3.0}}\ \underline{\underline{OK}}$$

DISCUSSION - TRIAL DESIGN No. 1

the solution is shown to be controlled by PULLOUT due to the vertical component (P_V) which must be compensated for by: weight of anchor + weight of overlying soil.
A F.S. ≐ 2.5 was determined on Sheet No. 2

this can also be shown from the results of the chart solution. Knowing that the charts are based on a F.S. = 3.0 :
By chart solution (P_1) was determined to be 11.9 KIPS

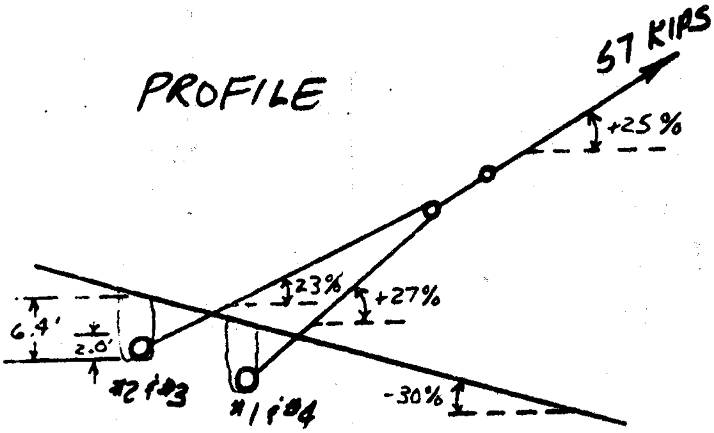
then $P_1 (max.) = 11.9K \times 3.0 = \underline{35.7 \text{ KIPS}}$

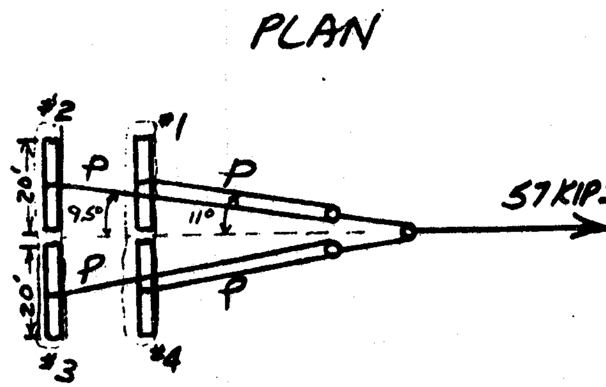
the individual anchor cable tension (P) used in the chart solution was $\frac{57 \text{ KIPS}}{4} = \underline{\underline{14.3 \text{ KIPS}}}$

For (P_1) you would estimate an actual F.S. :

$$F.S. = \frac{35.7K}{14.3K} \cong \underline{\underline{2.5}}$$ which verifies the chart solution.

TRIAL DESIGN No. 2





CLAY SOIL

$\gamma = 100$ pcf

$c = 500$ psf

$\phi = 0$

Determine (P)

$$\text{Profile } \measuredangle = \frac{27\% - 23\%}{2} = 2\% = 1.1^\circ$$

$$\text{Plan } \measuredangle_{\#1 \,\&\, \#4} = 11^\circ$$

$$\measuredangle_{\#2 \,\&\, \#3} = 9.5^\circ$$

$$\alpha_{\#1 \,\&\, \#4} = \tan^{-1}\sqrt{\tan^2(1.1^\circ) + \tan^2(11^\circ)} = \underline{\underline{11.1^\circ}}$$

$$\alpha_{\#2 \,\&\, \#3} = \tan^{-1}\sqrt{\tan^2(1.1^\circ) + \tan^2(9.5^\circ)} = \underline{\underline{9.6^\circ}}$$

$$\Sigma F = 0$$

$$2P\cos(9.6^\circ) + 2P\cos(11.1^\circ) = 57 \text{ KIPS}$$

$$\underline{P = 14.5 \text{ KIPS}}$$

TRIAL DESIGN No. 2 (Continued)

Since (P) is approx. the same as for TRIAL DESIGN No. 1; F.S. FLEXURE ≅ F.S. SHEAR ≅ 4.5 as found for DESIGN No. 1.

PULLOUT F.S. (Based on VERTICAL Component)

Anchors #1 & #4

$$F.S. = \frac{(\pi d^2 L/4)\gamma_{log} + (H_S d L)\gamma_{soil}}{P \sin\theta} \quad \text{where } \theta = 27\% = \underline{\underline{15.1^\circ}}$$

$$F.S. = \frac{\left(\frac{\pi (2)^2 20}{4}\right)(40) + \left(\frac{6.4-2.0}{2}\right)(2)(20)(100)}{14.5 \text{ KIPS} \times 1000 \text{ lb/KIP} \times \sin(15.1^\circ)} = \underline{\underline{3.0}} \geq 3.0 \quad \underline{\underline{OK}}$$

PULLOUT F.S. (Based on HORIZONTAL Component)

Anchors #1 & #4

$$F.S. = \frac{3.4(500 \text{ psf})(2)(20)}{14.5 \text{ KIPS} \times 1000 \text{ lb/KIP} \times \cos(15.1^\circ)} = \underline{\underline{4.9}} > 3.0 \quad \underline{\underline{OK}}$$

COMPARISON TO CHART SOLUTION

Least F.S. (PULLOUT - VERTICAL) = $\underline{\underline{3.0 \text{ (above)}}}$

From chart solution P_1 = $\underline{\underline{14.3 \text{ KIPS}}}$

Using F.S. = 3.0 $P_{1(max)} = (14.3 \text{ KIPS})(3.0) = \underline{\underline{42.9 \text{ KIPS}}}$

(P) used in Chart Solution $= \frac{57 \text{ KIPS}}{4} = \underline{14.3 \text{ KIPS}}$

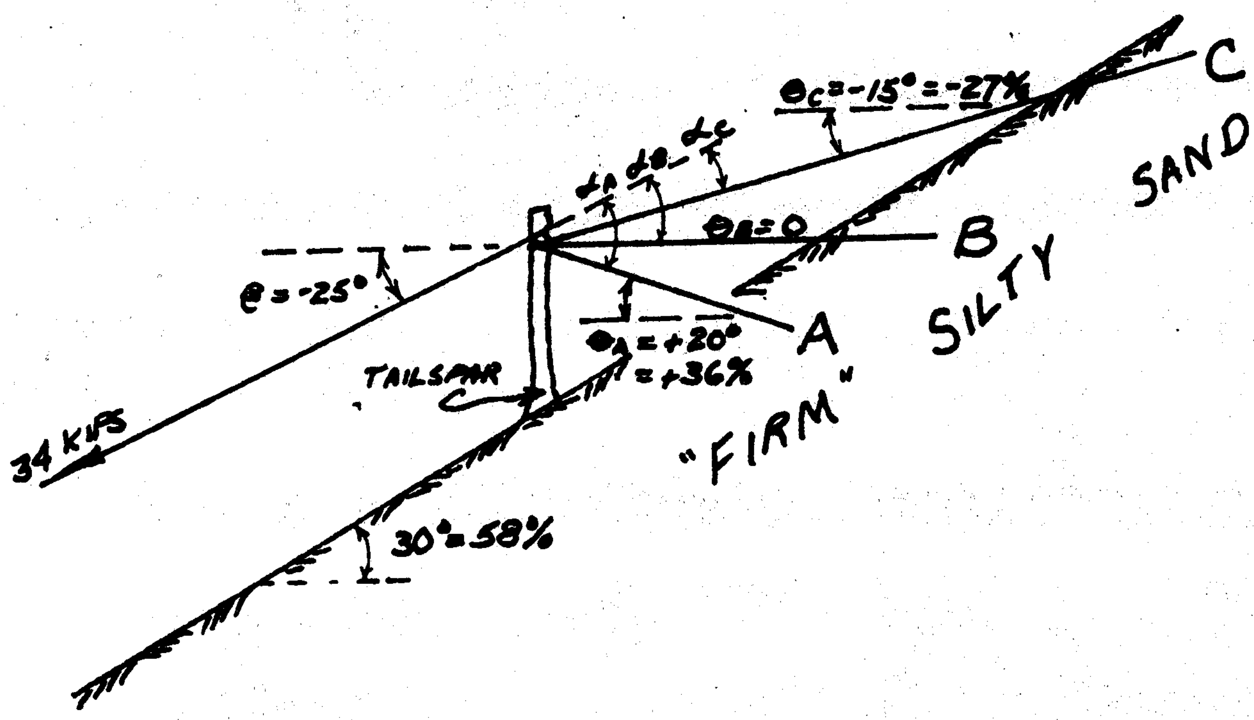
for P_1 actual $F.S. = \frac{42.9 \text{ KIPS}}{14.3 \text{ KIPS}} = \underline{\underline{3.0}}$ which verifies the chart solution.

SAMPLE PROBLEM NO. 3:

1. For the illustrated problem, at which location A, B, or C would you judge a deadman with the least dimensions (d and L) could be installed to withstand the cable tension?

2. To verify your judgment, determine the required deadman dimensions at each location.

3. For the location selected, complete the design by determining the minimum burial depth.



SUGGESTED PROCEDURE

1. Determine the angle (α) between the pull direction on the tailspar and the pull direction on the anchor for each location. If this were a stump rather than a tailspar, it would carry as much as two-thirds of the load[1/]; however, since the tailspar will flex with load, assume that it will carry no load and determine the anchor line tension to each location using: $P = \frac{34 \text{ kips}}{\cos \alpha}$

2. Using Chart No. 1 and the pull angles (θ) from horizontal at each location, correct P for use with Chart No. 2A.

SAMPLE PROBLEM NO. 3 (continued):

3. Using Chart No. 2A and the midrange scale of "firm" (to correspond to the soil description), determine the log dimensions required at each location.

4. Select the location with the least dimensions and complete the design for burial requirements using Chart No. 3.

SOLUTIONS:

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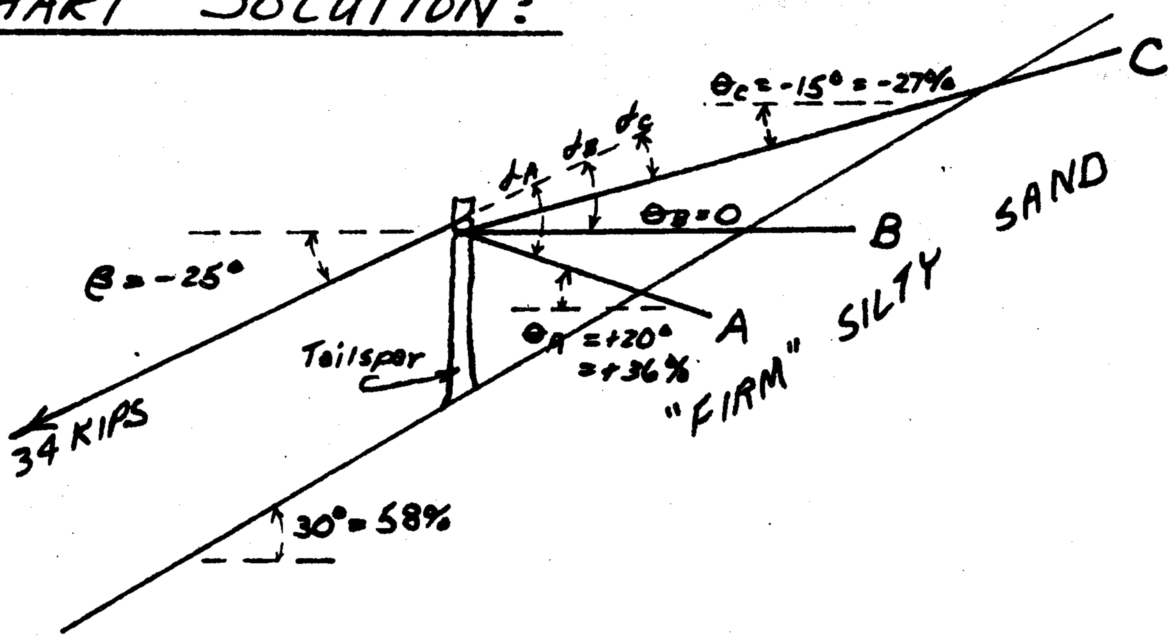
COMPUTATION SHEET

SHEET 1 OF 2
MADE BY Prellwitz 2/74
CHECKED BY (INITIAL AND DATE)

Subject: SAMPLE PROBLEM No. 3

CHART SOLUTION:



LOCATION (A)	LOCATION (B)	LOCATION (C)
$\alpha_A = -\theta + \theta_A$	$\alpha_B = -\theta + \theta_B$	$\alpha_C = -\theta + \theta_C$
$\alpha_A = +25° + 20°$	$\alpha_B = +25° + 0$	$\alpha_C = +25° - 15°$
$\alpha_A = 45°$	$\alpha_B = 25°$	$\alpha_C = 10°$
$P_A = \frac{34\ KIPS}{\cos(45°)}$	$P_B = \frac{34\ KIPS}{\cos(25°)}$	$P_C = \frac{34\ KIPS}{\cos(10°)}$
$P_A = 48.1$ KIPS	$P_B = 37.5$ KIPS	$P_C = 34.5$ KIPS

Using chart No. 1

Corrected(P_A) = (48.1K)(1.9) = 91.2 KIPS	Corrected(P_B) = (37.5K)(1.0) = 37.5 KIPS	Corrected(P_C) = (34.5K)(0.96) = 33.1 KIPS

Using Chart No. 2A

d_A = 44 in.	d_B = 32 in.	d_C = 30 in.
L_A = 35 ft.	L_B = 28 ft.	L_C = 27 ft.

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COMPUTATION SHEET

SHEET 2 OF 2

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Subject: PROBLEM No. 3 (Continued)

Location (C) would require the least log dimensions.

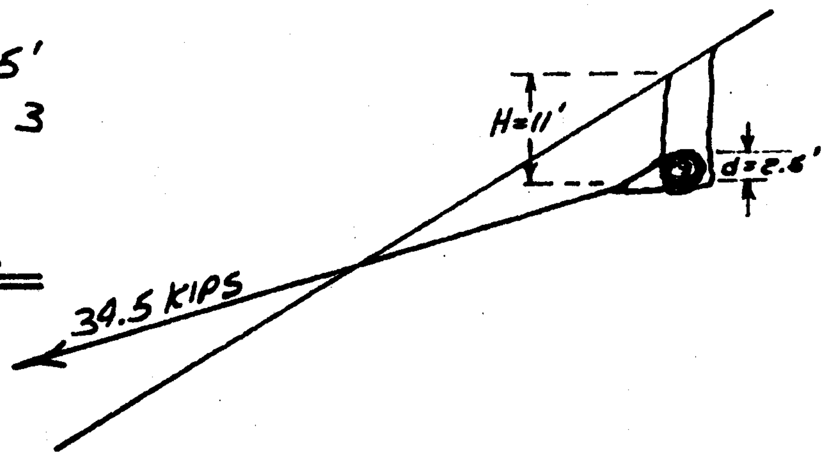
Minimum burial requirements on 58% slope for log w/ d = 30 in. and L = 27 ft. :

$d = 30'' = 2.5'$

from Chart No. 3

$H_{min.} = 4.4\,d$

$H_{min.} = 11$ ft.



If spur road is constructed - Minimum burial requirements:

$H_{min.} = 2d = 5$ ft.

$X_{min.} = 4d = 10$ ft.

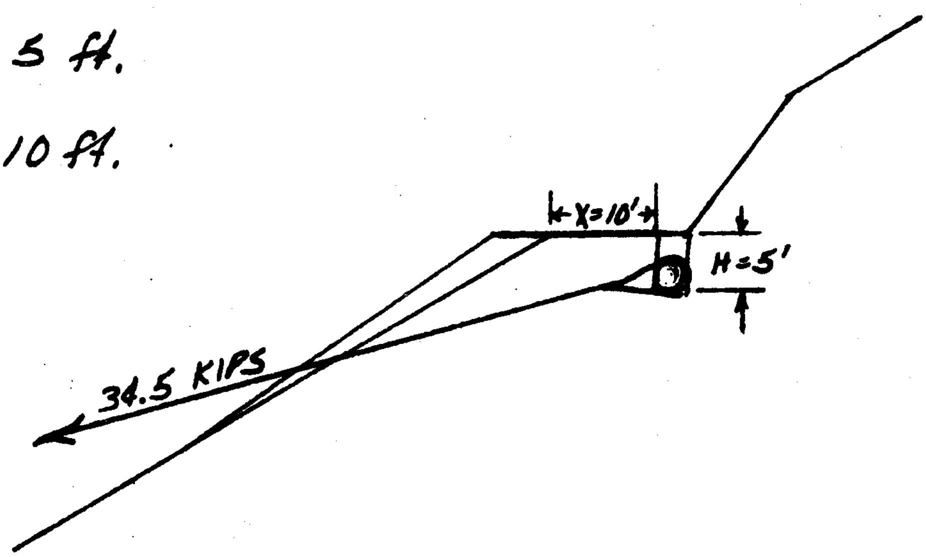


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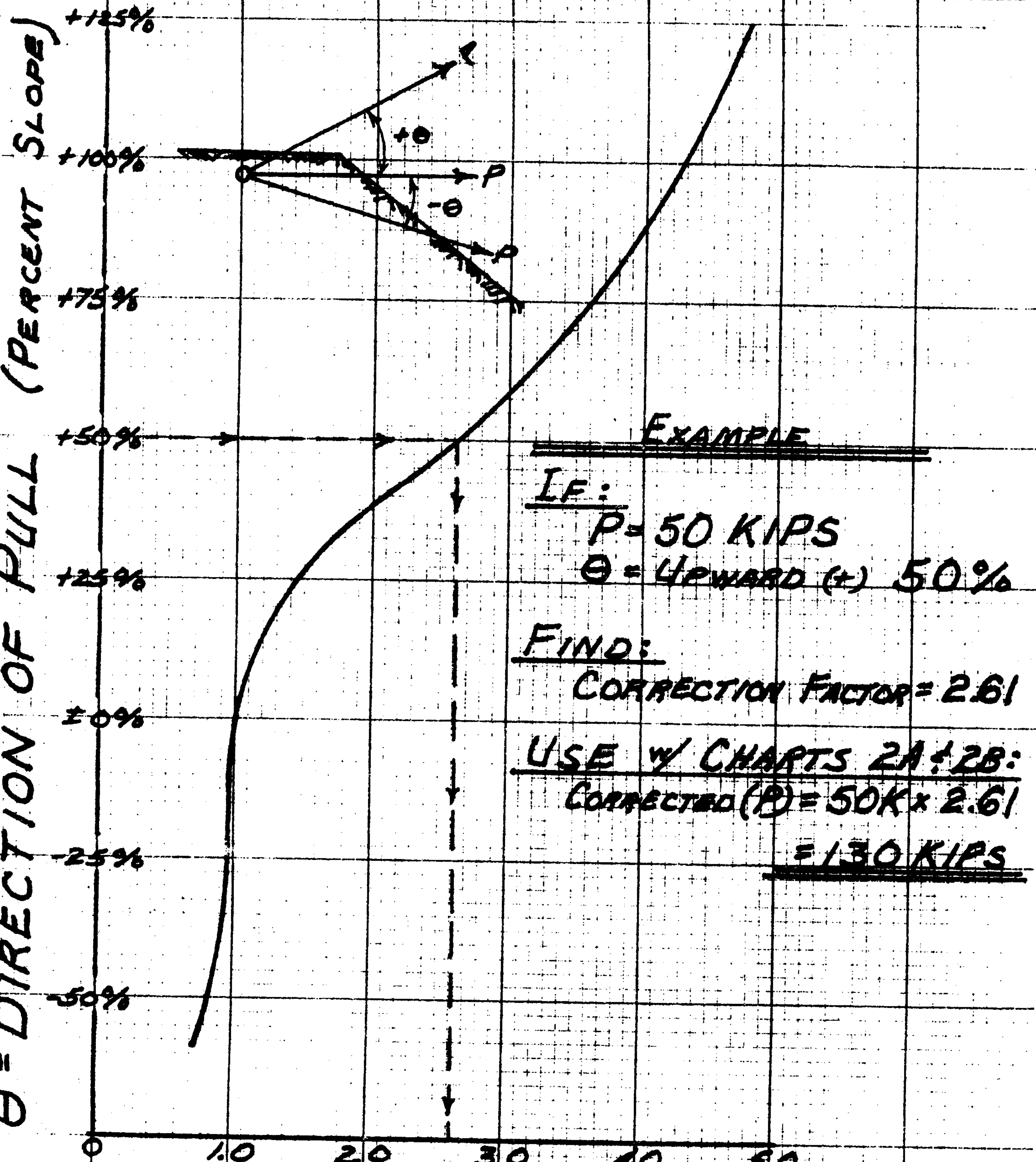
CHART NO. 1

CORRECTION FOR PULL DIRECTION



CORRECTION FACTOR FOR (P)

(TO BE USED WITH CHARTS NO. 2A & 2B)

CHART NO. 2A - GRANULAR SOILS - (GRAVEL, SAND, SILT - INORGANIC & ABOVE WATER TABLE)

CORRECTED (P) V.S. DEADMAN LOG DIMENSIONS

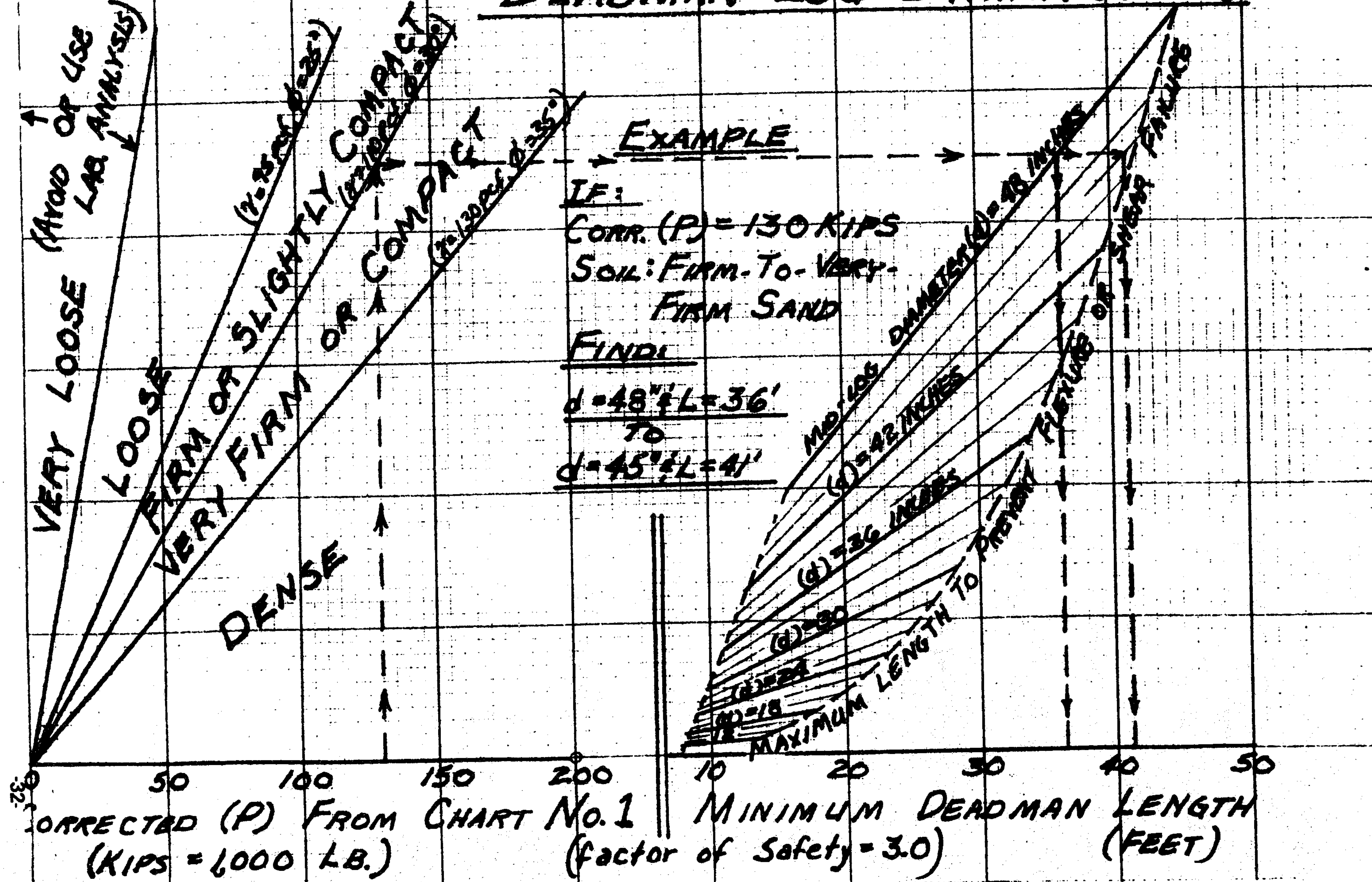
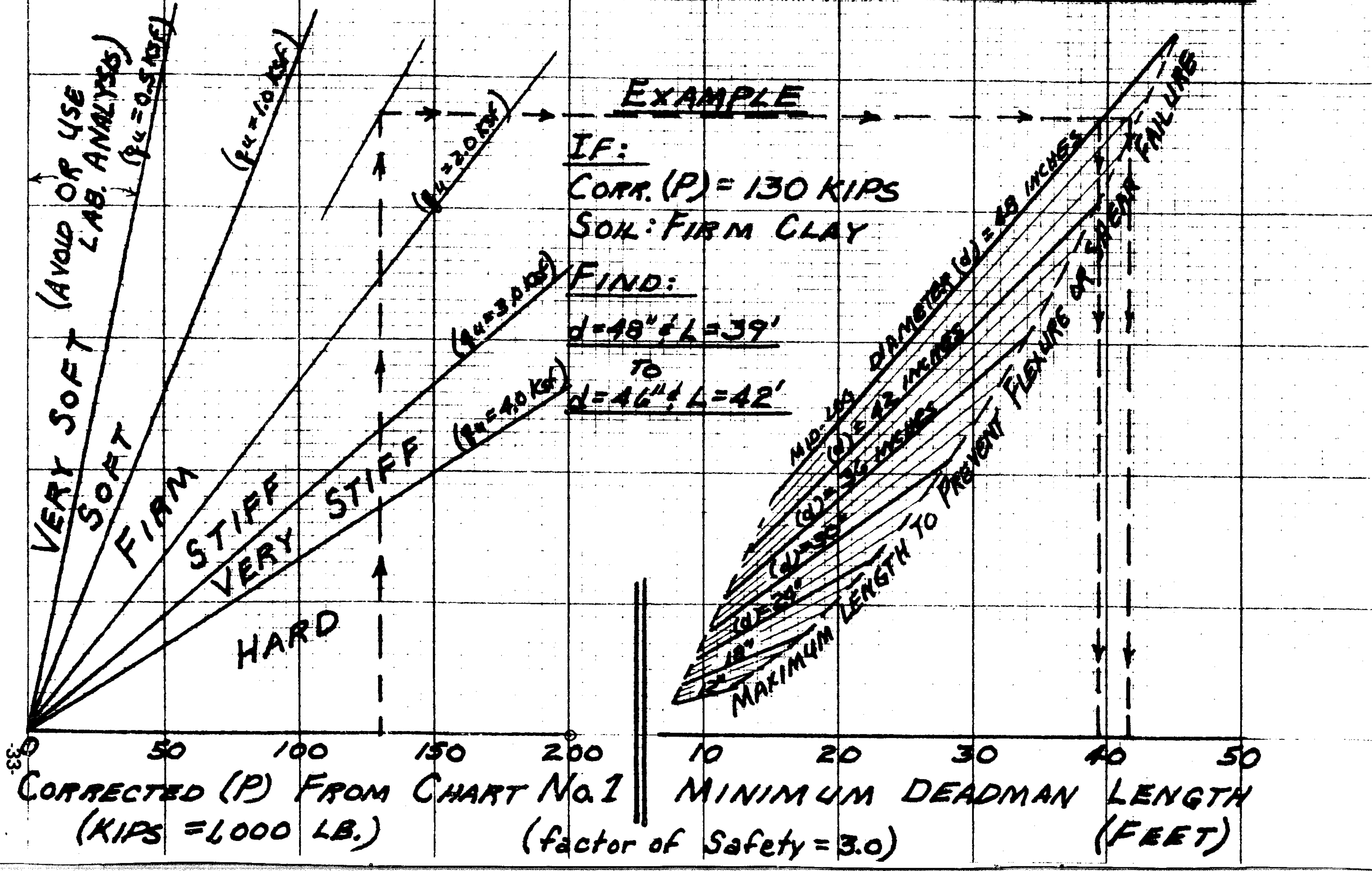
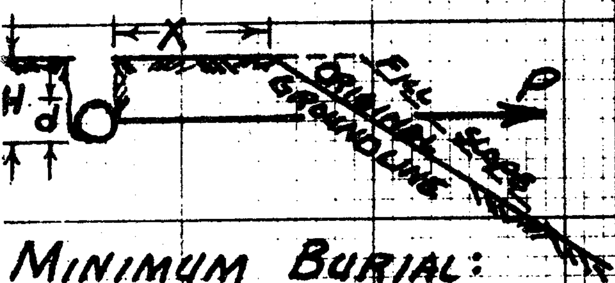


CHART NO. 2B - CLAY SOIL - (INORGANIC & ABOVE WATERTABLE)
CORRECTED (P) V.S. DEADMAN LOG DIMENSIONS



MINIMUM BURIAL REQUIREMENTS

SPUR ROAD LEVEL GROUND, OR UPWARD GROUND SLOPE (IN PULL DIRECTION)

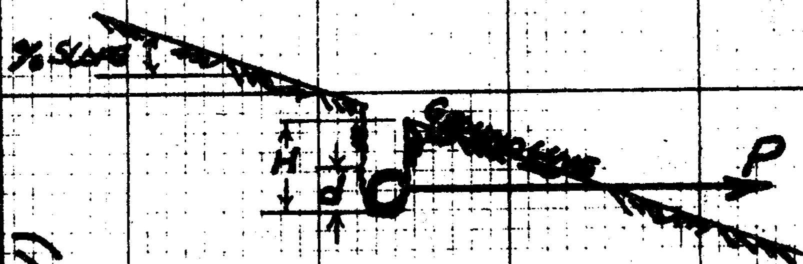


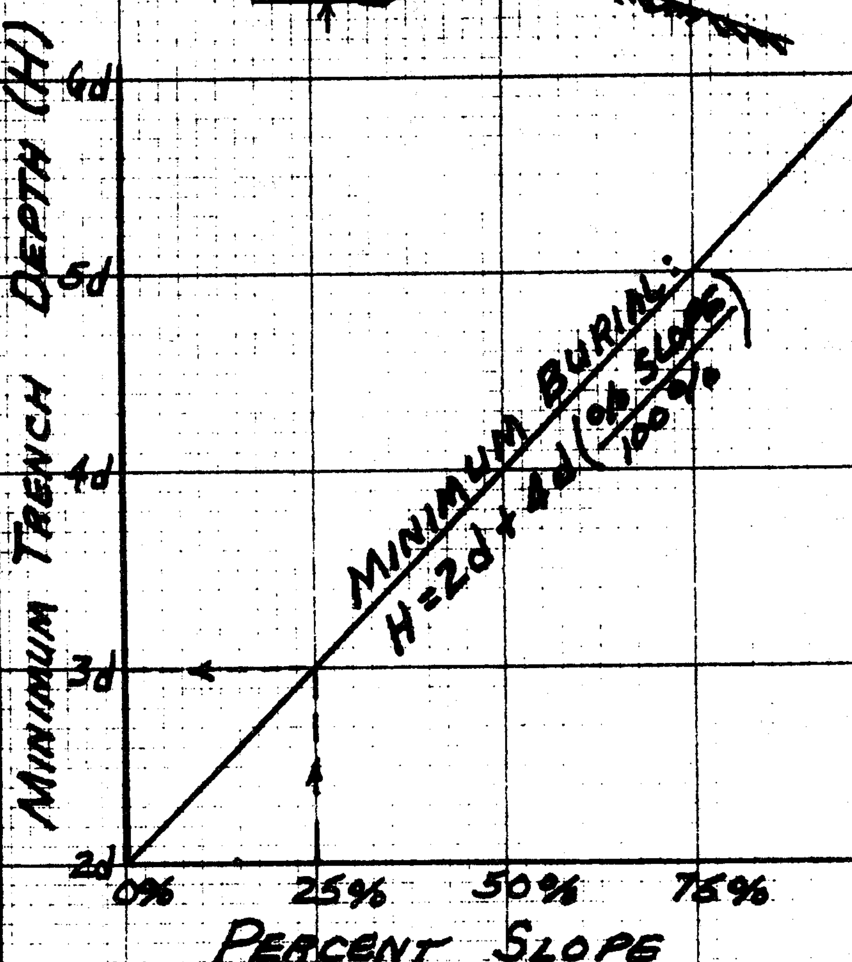
MINIMUM BURIAL:

$H = 2d$

$X = 4d$

DOWNWARD GROUND SLOPE (IN PULL DIRECTION)





LEGEND

H = MINIMUM TRENCH DEPTH

d = MID-LOG DIAMETER

X = MINIMUM HORIZONTAL INSLOPE DISTANCE (UNDISTURBED)

EXAMPLES

IF:
d = 48" (FROM CHART #2A OR 2B)

AND LOCATION IS:

SPUR ROAD:	25% DOWNWARD SLOPE (USING CHART)
$H_{(MIN)} = 2d = 2(\frac{48}{12}) = \underline{8\ FT.}$	$H_{(MIN)} = 3d = 3(\frac{48}{12})$
$X_{(MIN)} = 4d = 4(\frac{48}{12}) = \underline{16\ FT.}$	$= \underline{12\ FT.}$

TM no. M-42-77-5

TECHNICAL MEMORANDUM

title: Assessment of the Prellwitz-Forest Service Method of Deadman Anchor Design

author: H. J. Lee

date: June 1977

sponsor: U.S. Department of Agriculture - Forest Service

program nos:

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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INTRODUCTION

This is the first of two reports dealing with deadman anchors for logging system operations. In this report, a method developed by Forest Service Soil Specialist, Rodney Prellwitz (4, 5, 6, 7), is analyzed and assessed as to its technical validity. In the second report (1), the Prellwitz method of deadman anchor design is compared with other methods of design and measured model and field test data.

DEFINITION OF PROBLEM

The problem of interest is the case of a log buried in a vertical trench and loaded through its midpoint in a direction perpendicular to its length. The direction of loading may have virtually any angle relative to horizontal. The trench may be cut in a slope, on flat ground, or on a flat section near the top of a slope. The applied load and loading angle are known, and it is necessary to select the log length and diameter and trench depth so that the anchorage will not pullout.

THE PRELLWITZ METHOD

The method of design, as described in references 6 and 7, has the advantage of being a simple "cookbook" approach. Once the angle of pull (chord slope from horizontal) and skyline tension are known, one proceeds through a series of nomographs to obtain log diameter and length. The nomagraphs are identified as Charts 1, 2A, 2B, and 3. Chart 1 is entered first with the pull angle and is used to obtain a load correction factor. The factor is slightly less than one, if the load angle is downward relative to horizontal, and becomes much greater than one as the load angle moves upward. The factor is multiplied by the working load to give a corrected load. The corrected load is essentially an equivalent horizontal load. This load is then entered in Chart 2A (granular soil) or Chart 2B (cohesive soil). A rough soil classification is entered next and a diameter-length combination is obtained. Logs that are too long relative to their diameter to withstand bending or shear are excluded. Chart 3 yields minimum trench depth as a function of slope configuration. For a horizontal surface, the trench depth must be at least twice the log diameter.

To assess the validity of this method, it is necessary to go into Prellwitz's working papers (4, 5). In reference 4, Prellwitz divides the problem into five sections:

(a) Design for horizontal load and horizontal soil surface (granular soils);

(b) Effects of burial on sloping ground;

(c) Effects of load inclination;

(d) Selection of log dimensions;

(e) Design for cohesive soils.

Each of these will be considered separately below. Only soil mechanics aspects are discussed; the design of logs to resist shear and bending is not considered.

Horizontal Load and Soil Surface (granular soils)

Prellwitz refers to two basic soils texts: Teng (8) and Leonards (2). Teng provides the equation:

$$P = \frac{\gamma\,(K_p - K_a)\,H^2 L}{2}$$

where, P = Anchor capacity (lbs)

γ = soil unit weight (pcf)

K_p = coefficient of passive earth pressure

K_a = coefficient of active earth pressure

H = depth to base of anchor

L = anchor length

K_p and K_a are related to the angle of internal friction of the soil, ϕ, and the angle of friction between soil and anchor, δ. For a typical medium silty sand ($\phi = 30^o$, $\delta = 15^o$, $\gamma = 110$ pcf), K_p is 5.0 and K_a is 0.3. Therefore:

$$P = .26\ H^2L \quad \text{kips/ft}^3$$

This relation is based on earth pressure theory alone.

Leonards provides the relation:

$$P = \frac{\gamma K_p\ H^2L}{2}$$

with the other terms the same as before, but with a special K_p given on a figure. For most realistic values of embedment, Leonards' K_p is 3.2.

Therefore, by Leonards for γ = 110 pcf:

$$P = .18\ H^2L \quad \text{kips/ft}^3$$

This relation is based on experiments.

Since Leonard's equation is more conservative than Teng's and since it is based on experiments rather than theory alone, it appears reasonable to use it rather than Teng's. This is Prellwitz's recommendation.

A problem with Leonard's equation is that it gives no soil property dependence. It is an empirical equation based on model tests on one particular soil (a sand with $\phi = 32.5^{o}$). Prellwitz overcomes this problem by noting that Leonards provides another parameter K_p for the passive resistance of retaining walls. For a sand with a typical friction angle of 30^{o} but an untypical δ of 0^{o}, the retaining wall $K_p = 3.0$. Since this is close to the 3.2 Leonards gives for his deadman anchor K_p, Prellwitz assumes that he can use the variation in the retaining wall K_p to indicate how the deadman anchor K_p varies. Prellwitz simply uses the retaining wall K_p's for $\phi = 25^{o}$, 30^{o}, and 35^{o} and $\delta = 0$ to construct his design curves. This appears to be a good use of engineering judgment in overcoming what is really an incomplete design method.

Prellwitz applies two other modifications to Leonards' equation. First, he applies a factor of safety of 3 to the allowable load. This seems somewhat excessive (the Navy Design Manual DM-7 recommends 1.5), but is perhaps reasonable for the rough conditions that might be encountered. Next, he sets H = 2d, where d is the log diameter. This effectively changes the equation and design charts from dependence on total embedment depth to dependence on anchor size. There are at least two problems in doing this. First, it makes it appear that the diameter of the anchor is the most important parameter. This is in conflict with both Teng and Leonards who show embedment depth as the only geometric parameter in their equations. Second, the design curves do not show how much of an increase in capacity one can obtain by placing the deadman deeper, doubling the depth quadruples the capacity of the same log.

Since Prellwitz requires that deadmen always be buried by at least 2d, these problems can never lead to an unsafe condition. They do remove flexibility, however, and potentially lead to a highly overconservative design.

Effects of Burial on Sloping Ground

Prellwitz assumes that the surface of failure generated in the soil at pullout rises from the bottom of the anchor at an angle to the horizontal of $(45 - \phi/2)$. He also assumes the surface is a plane. These assumptions are in keeping with classic passive earth pressure theory. For anchors on slopes, he assumes the same failure surface configuration and develops criteria for anchor burial such that the length of the failure surface remains constant.

In most cases, this approach is conservative. As shown in Prellwitz's Chart 3B, as the slope becomes steeper, the anchor must be embedded deeper to maintain the same failure surface length. Neglecting the influence of stresses generated by the slope itself, the anchor holding capacity will increase roughly with the square of the embedment depth. For low slopes, the factor of safety against pullout will actually increase with slope angle using the Prellwitz design technique. However, as the slope angle increases to relatively high values, especially as it approaches the soil's angle of repose, the stresses generated by the slope itself become very significant. Additional loads generated by the anchor, even if they are relatively small in themselves, would easily fail the soil. Prellwitz does not consider this problem at all, and this could be a serious flaw on the unconservative side. A complete analysis of the slope-anchor interaction problem is beyond the scope of this report, but is something that should be conducted in the future.

Effects of Direction of Load

Prellwitz considers the effect of non-horizontal loading in a variety of different ways in reference 4. His first approach (identified as IIIA in reference 4) is an incorrect application of Leonards' work. However, since this approach is not used in the final design curves, and since the reasons for its being incorrect are somewhat involved, it will not be discussed here.

The next approach (IIIB and IIIC) is used for the design curves. Prellwitz uses the Navy Manual DM-7 (3) criterion which states that the vertical component of load should not exceed the weight of the anchor. No additional factor of safety needs to be applied. He then formulates a ratio of the total line load that is tolerable, using this criterion, to the horizontal capacity using Leonards' equation and a typical sand ($\phi = 30^{o}$). The inverse of this ratio is identified as the pull direction correction factor and is plotted versus pull angle in Chart No. 1 of reference 6. The true line load is multiplied by this factor and then treated as if it were a horizontal load. That is, Chart 2A is entered with actual soil properties and this "equivalent horizontal Load," and the log diameter and length are determined.

A problem with this approach occurs for near horizontal loading. The vertical component of line pull is very low in this situation and a strict application of the DM-7 criterion would lead to unsafe design. Prellwitz overcomes this by forcing the correction factor curve to pass through 1.0 for horizontal loading rather than the 0.0 that would occur in the criterion were rigorously applied. The curve is apparently drawn free hand from this point up to a load inclination of about 25^{o} where it intersects the curve developed from the DM-7 criterion. In checking the curve of Chart No. 1 versus the calculations of reference 1, a discrepancy factor of 1.16 was observed. The values on the chart were too low (unconservative) by this amount.

As will be seen in the next report (1), this approach is not unreasonable in comparison with more recent research. it becomes increasingly conservative as the load angle approaches vertical, but this is primarily because DM-7 is highly overconservative for these cases. In general, the approach is safe and easy to use.

The approach is not particularly rational, however, and the true factor of safety is unknown. For near vertical loading, the true safety factor appears to approach 10 (see next report) and this is wasteful. (The unconservative factor of 1.16 discussed above is clearly negligible.) Also, the approach introduces soil properties in an obtuse way. The DM-7 criterion does not mention the soil; it simply states the anchor weight should counterbalance the vertical load component. Prellwitz includes soil properties by dividing the line load allowable by DM-7 by a horizontal load calculated from typical soil properties. This ratio is then multiplied by a horizontal load calculated for the properties of the design soil. The soil properties more or less cancel out. The field engineer is left to believe that the soil properties are playing a larger role than they really are.

The DM-7 criterion itself is the most questionable. Recent research at CEL and elsewhere indicates that the vertical holding capacity of embedded anchors is always higher, usually by a significant amount, than the weight of the anchor.

Cohesive Soils

Prellwitz applies another relation given by Leonards (2) to the analysis of horizontally loaded anchors in cohesive soils. The relation is:

$$P = 3.4\ c\ d\ L$$

where, c = soil shear strength

He again includes a factor of safety of 3 (which may be somewhat excessive, as discussed previously) and plots the relation in Chart 2B. This approach is in keeping with present soil mechanics concepts.

For non-horizontal loading, Prellwitz suggests applying Chart No. 1 again. This is an unusual application since Chart 1 was derived from the DM-7 criterion and a typical sand. It yields very conservative designs.

Soil Properties

The typical soil properties given in Charts 2A and 2B appear reasonable for rapid design. The classifications are rough but easily understandable to the person in the field.

Other Items of Importance

Water Table. All calculations are based on the water table being below the anchor. It should be recognized that if the water table rises above the anchor, the holding capacity will be reduced drastically (by at least a factor of 2).

Saturation. Many cohesive soils have an artificially high strength because they are dry . When they become satruated after heavy rains they may lose much of their strength. Cohesive soil properties should be selected for the wettest state possible during the use of the anchor rather than for the state during installation. A procedure for estimating properties of wet soil given the properties of dry soil needs to be developed.

Another problem with saturation has to do with pore pressures. Loading a saturated soil with an anchor generates negative pore water pressures that dissipate with time. This often causes further softening of the soil. A way to check on this problem is to use Chart 2A and assume the saturated cohesive soil behaves as a loose sand (γ = 95 pcf, ϕ = 25^{o}). If this yields a more conservative design than the one based on Chart 2B, it should be used.

GENERAL COMMENTS

In most ways, the Prellwitz method yields designs that range from moderately conservative to overconservative. Some conservatism is in order since only rough soil properties are used; however, the level of conservatism varies to such an extent (depending on the angle of loading) that a good deal of waste is involved. The situation is particularly acute for near vertical loading.

For anchors on steep slopes, it appears that this design method is unsafe. Further analysis is required to determine the critical slope angle at which unsafe conditions being to occur.

It is somewhat unfortunate that the design charts consider only the case of embedment to twice the log diameter. With cohesionless soils, considerable increases in holding capacity would result from burying smaller logs deeper.

Water table and moisture conditions should be considered. If there is a possibility of the water table rising above the anchor, an additional factor of safety (perhaps 2.0) should be used. Cohesive soil properties should be estimated for wet rather than dry conditions. A means to obtain wet properties given dry properties is needed.

Even with the above reservations, it appears that Prellwitz method is basically sound. It is safe for most situations and is set up in a very easy to use manner.

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no. M-42-77-6

CIVIL ENGINEERING LABORATORY
CEL
PORT HUENEME, CALIF.

TECHNICAL MEMORANDUM

title: Comparison of the Prellwitz-Forest Service Method of Deadman Anchor Design with Other Methods and Tests

author: H. J. Lee

date: June 1977

sponsor: U.S. Department of Agriculture - Forest Service

program nos:

CIVIL ENGINEERING LABORATORY

NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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INTRODUCTION

This is the second of two reports dealing with deadman anchors for logging system operations. In the first report (3), a method developed by Forest Service Soil Specialist, Rodney Prellwitz (7, 8), was analyzed and assessed as to its technical validity. One of the principal findings was that the Prellwitz method is often overconservative, particularly for anchors that are loaded nearly vertically. A few cases in which the Prellwitz method might be unconservative were identified.

This report presents a comparison of the Prellwitz method with other design methods and recent test data. All of the situations considered are those for which the Prellwitz method yields a conservative or overconservative design. One of the main purposes of this report is to indicate the actual factors of safety inherent in the Prellwitz method.

OTHER WORK CONSIDERED

It would be impossible to consider all of the applicable research that has been conducted in the limited time available. Instead, this author has selected a limited set of reports which he considers to be the best available and most suitable for comparison with Prellwitz's reports. The research considered is by Meyerhof (5), Neely and others (6), Vesic (10), Das (2), Smith (9), and Beard and Lee (1).

FORM OF COMPARISON FOR COHESIONLESS SOILS

Prellwitz uses a procedure by Leonards (4) for predicting the capacity of deadmen in sands under horizontal loads. It is based on the equation:

$$P = \frac{K_p \gamma H^2 L}{2} \qquad (1)$$

where, P = Pullout load

K_p = Coefficient of passive earth pressure

$= \frac{1 + \sin\phi}{1 - \sin\phi}$

ϕ = Soil friction angle

γ = Soil unit weight

H = Embedment depth of bottom on anchor

L = Anchor length

The influence of loading angle is considered by a load factor plotted in Chart 1 of reference 8. This factor is strictly a function of angle of load inclination (relative to horizontal), θ. The load, P, calculated above is divided by the load factor to yield the predicted holding capacity. Prellwitz also applies a factor of safety of 3.0 that will be considered in a later section.

All of the other methods for cohesionless sediments can be formulated in a manner similar to Equation (1), i.e., a K multiplied by $\gamma H^2 L/2$. For the Prellwitz method, the K (identified as K_F) is equal to K_p divided by the Chart 1 load factor.

The parameter K plotted versus inclination angle, θ, is a good way of comparing methods. For the Prellwitz method, this is a family of curves for different values of ϕ. For some of the other methods, the height of the anchor, h (or log diameter for this problem), enters into the problem as well and slightly different types of plots need to be constructed.

COMPARISON FOR COHESIONLESS SEDIMENTS

Plots of the Prellwitz method are provided in Figure 1 as curves of

K_F versus θ for $\phi = 25^o$, 30^o, and 35^o.

Meyerhof Method

Meyerhof (5) suggests an equation similar to (1) to which is added the weight of soil over the anchor times sin θ. To facilitate this comparison the weight term will be ignored presently and considered later in the discussion.

The Meyerhof K factor is identified as K_m and plotted in Figure 1 as a family of curves for $\phi = 25^o$, 30^o, and 35^o. The Meyerhof curves are based on theory that agrees fairly well with model and field tests. Meyerhof specifies that the data are applicable only to shallow anchors. He defines these for loose sands as those with a ratio $H/h \leq 4$. This should include virtually all Forest Service applications.

Neely and Others

Neely considers only anchors that are loaded horizontally. He develops a theoretical solution that is somewhat more involved than Meyerhof's, and presents the results as a K factor that is a function of h/H as well as ϕ. The theory checks nicely with field and model test data. These results are presented in Figure 2 which contains plots of K_N (Neely K factor) versus friction angle, ϕ. Individual plots correspond to different values of h/H. Curves from Meyerhof and Prellwitz for horizontally loaded anchors are included for comparison.

Smith

An extensive set of large scale field tests was conducted by Smith (9) at CEL. These results were used by Neely and others. It was found that these test results matched Neely's theory well.

Das

Das (2) performed model tests on horizontally loaded square and circular anchors and found that his results compared well with the general theoretical relations of Neely and others.

Vesic

Vesic (10) provides a theoretical evaluation of the vertical anchor pullout problem. The results compare fairly well with model tests.

Figure 3 presents Vesic's theoretical curves for a K factor (identified as K_V) as a function of ϕ and $\frac{h}{H}$. The curves of Prellwitz and Meyerhof for vertically loaded anchors are included as well for comparison.

Beard and Lee

The CEL recommendation (1) for vertical holding capacity in sand has been to use Vesic's curves for shallow anchors. Currently ongoing research may slightly modify the recommended curves.

Discussion

As may be seen from Figures 1, 2, and 3, the Prellwitz method agrees very well with the Meyerhof method for inclination angles less than about 30^o. At greater angles the methods differ by about a factor of 2 with Prellwitz being more conservative.

In Figure 2 (horizontal loading), it may be seen that the Meyerhof method becomes increasingly conservative relative to the Neely method as the relative depth of embedment is decreased. For the typical H/h of 2 used by the Forest Service, the Meyerhof and Prellwitz methods imply a factor of safety of 1.75 relative to Neely's method. Neely's approach is the most advanced and agrees best with model and field tests (including CEL's).

In Figure 3 (vertical loading), it may be seen that the Prellwitz method is very conservative relative to Vesic and Meyerhof. It differs from Vesic (H/h = 2) by a factor of over 4 and from Meyerhof by a factor of 2. Also, an additional weight term is included in the Meyerhof method that was not considered in this comparison. If included, it would make the Prellwitz method appear even more conservative relative to Meyerhof for vertical loading.

It should be recalled that Prellwitz utilized a factor of safety of 3 which has not been considered to this point. The actual Prellwitz design loads, therefore, have a factor of safety of from 3 to 5 for horizontal loading and from 6 to 12 for vertical loading as compared with the work of other researchers. This seems excessive, at least for vertical loading.

FORM OF COMPARISON FOR COHESIVE SOILS

Prellwitz uses another procedure from Leonards (4) for predicting the horizontal capacity of deadmen in cohesive soils. It is based on the equation

$$P = F\,h\,L\,c$$

where, F = load coefficient (function of H/h)

c = undrained shear strength of soil

for H/h = 2 (typical Forest Service case), F is equal to 3.4.

For inclined loads, Prellwitz uses the same load inclination factor as for sands. The other methods can be compared with Prellwitz by comparing their load coefficients, F (often called N_c in the literature).

COMPARISON FOR COHESIVE SEDIMENTS

A plot of the Prellwitz F (identified as F_F) versus inclination angle, θ, is given in Figure 4.

Meyerhof

Meyerhof (5) presents theoretical and experimental data for the load factor F as a function of θ and H/h. These data are shown as F_m in Figure 4. Meyerhof also gives conservative recommended design values shown as F_{mr} in Figure 4.

Beard and Lee

CEL has not developed design values for long strip anchors. Values shown as F_c in Figure 4 are for vertically loaded square or circular anchors in saturated marine clays.

Discussion

As may be seen from Figure 4, Prellwitz gives values that exceed Meyerhof's recommended values by almost a factor of 2 for horizontal loading and which are exceeded by Meyerhof by a factor of 2 for vertical loading.

When Prellwitz's recommended safety factor of 3 is inserted, it is seen that Prellwitz is safe by a factor of 1.5 (horizontal) to 6 (vertical) relative to Meyerhof's recommendations. The CEL data are not really applicable since marine sediments do not typically develop tension cracks when loaded and the data are for circles and squares rather than strips.

Because of the tension crack problem it may be reasonable to use safety factors as high as Prellwitz does. The recommended factors for vertical loading may still be somewhat excessive, however.

SUMMARY

For the situations considered (horizontal soil surface, cohesive or cohesionless soil, relatively shallow embedment), the Prellwitz method always yields design values that are conservative relative to methods of other investigators. The level of conservatism varies from factors of 3 to 5 for horizontal loading in sand to 6 to 12 for vertical loading in sand, and from 1.5 for horizontal loading in clay to 6 for vertical loading in clay. Some of these factors seem excessive and overconservative, although most are reasonable.

In the first report (3), a few cases were considered in which the Prellwitz method may be unconservative. These are: (1) anchors on steep slopes; (2) situations where the water table might rise above the anchor; and (3) situations where cohesive soil properties might change with saturation brought on by heavy rains. Approaches for handling the second two items were given in the first report. The first item is complex and no clear answer is available. CEL is currently investigating anchors on slopes and new data may be available in the future.

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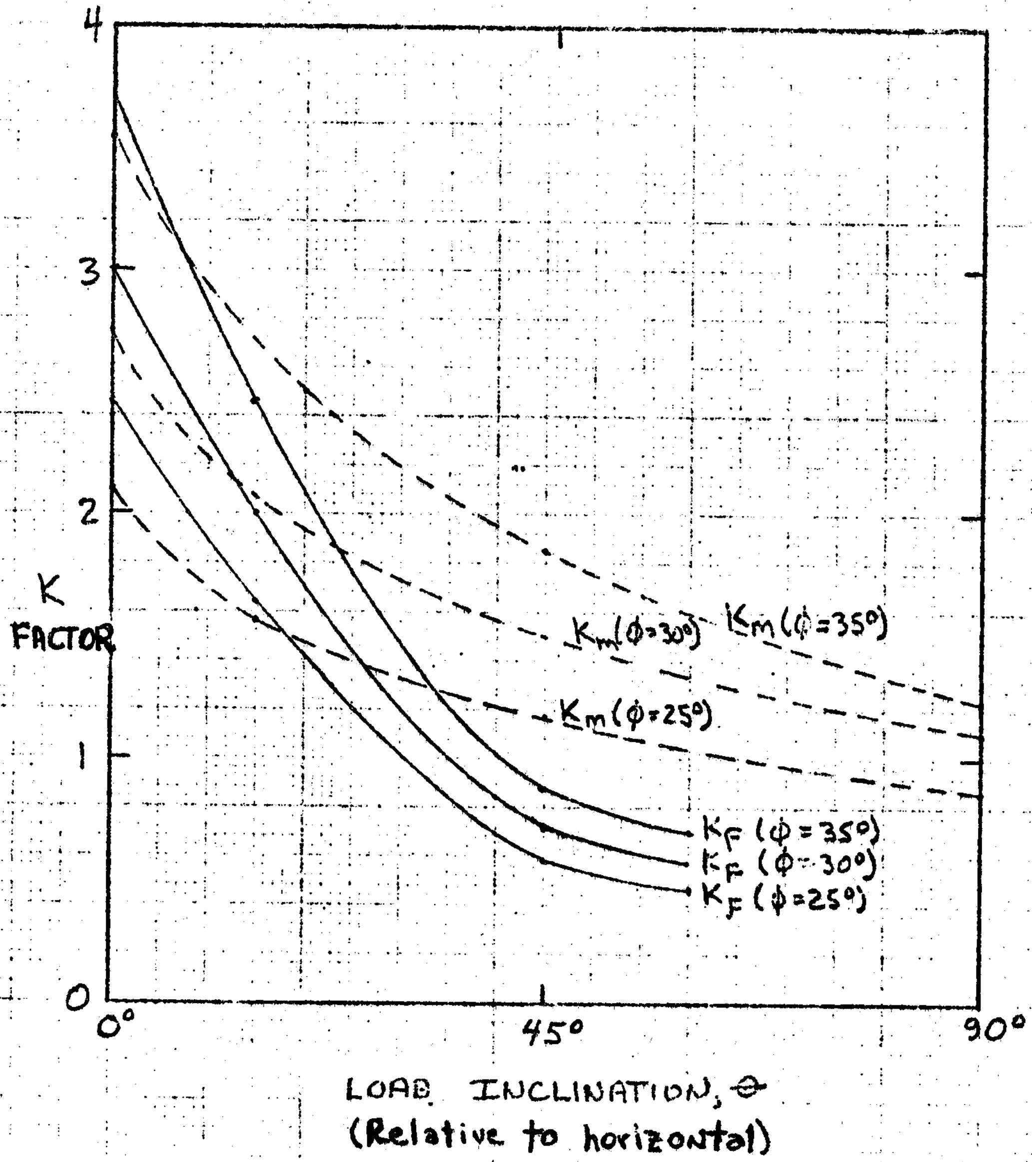

Figure 1. Comparison of Prellwitz (K_F) and Meyerhoff (K_M) methods as a function of load inclination for cohesionless soils.

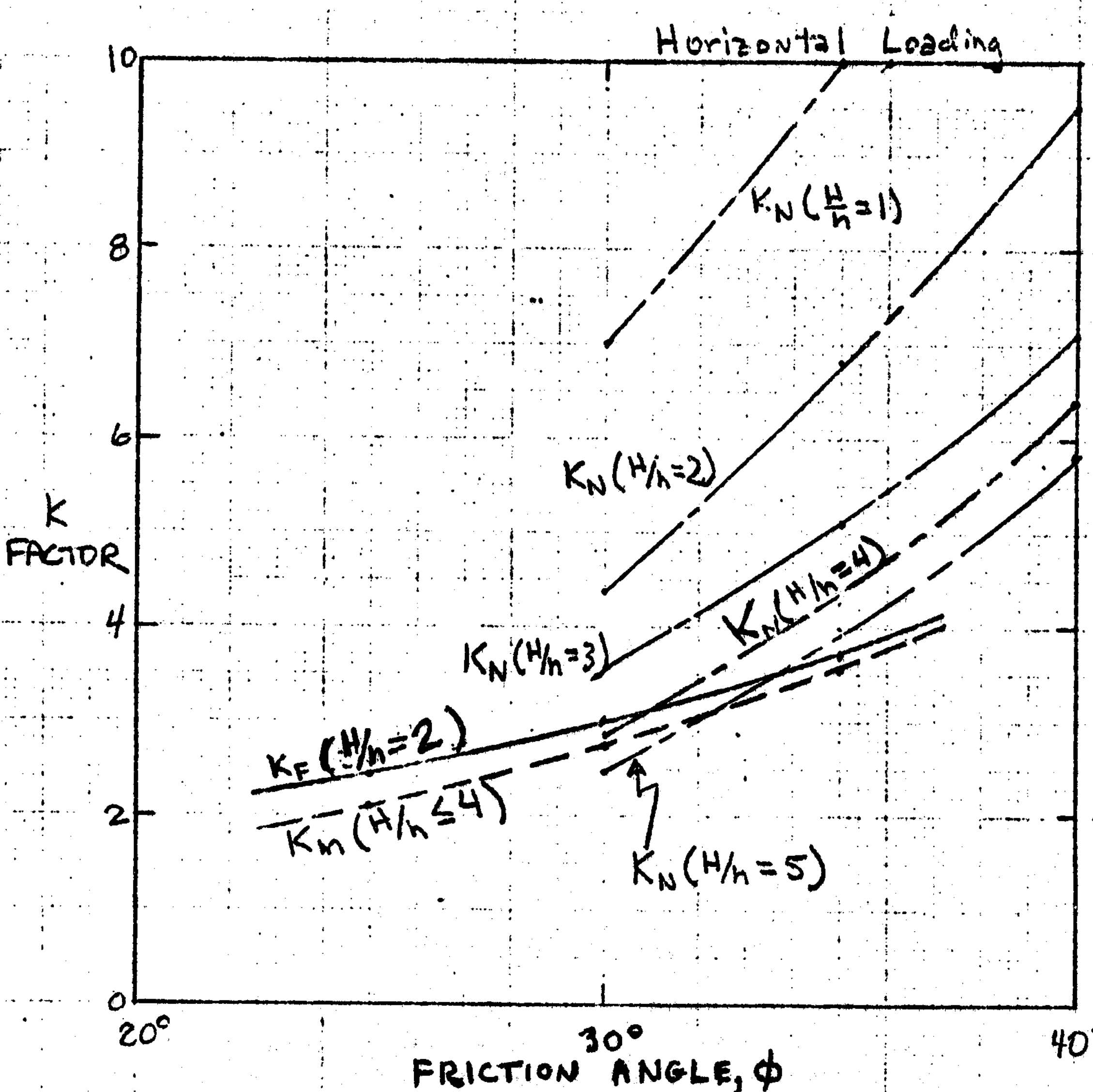

Figure 2. Comparison of Prellwitz (K_F), Meyerhoff (K_M), and Neely (K_N) methods for horizontal loading of cohesionless soils.

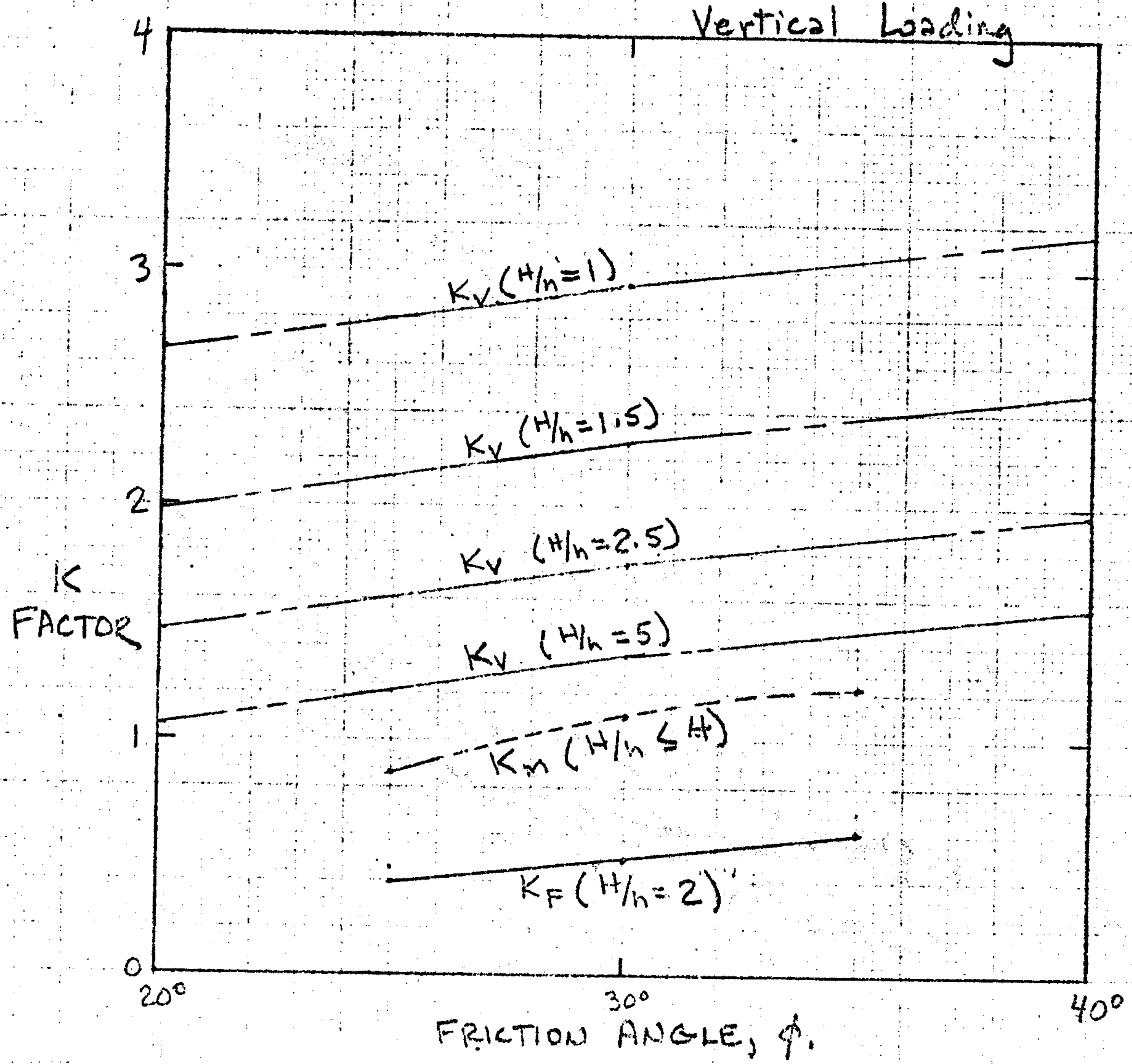

Figure 3. Comparison of Prellwitz (K_F), Meyerhoff (K_M), and Vesic (K_V) methods for vertical loading of cohesionless soils.

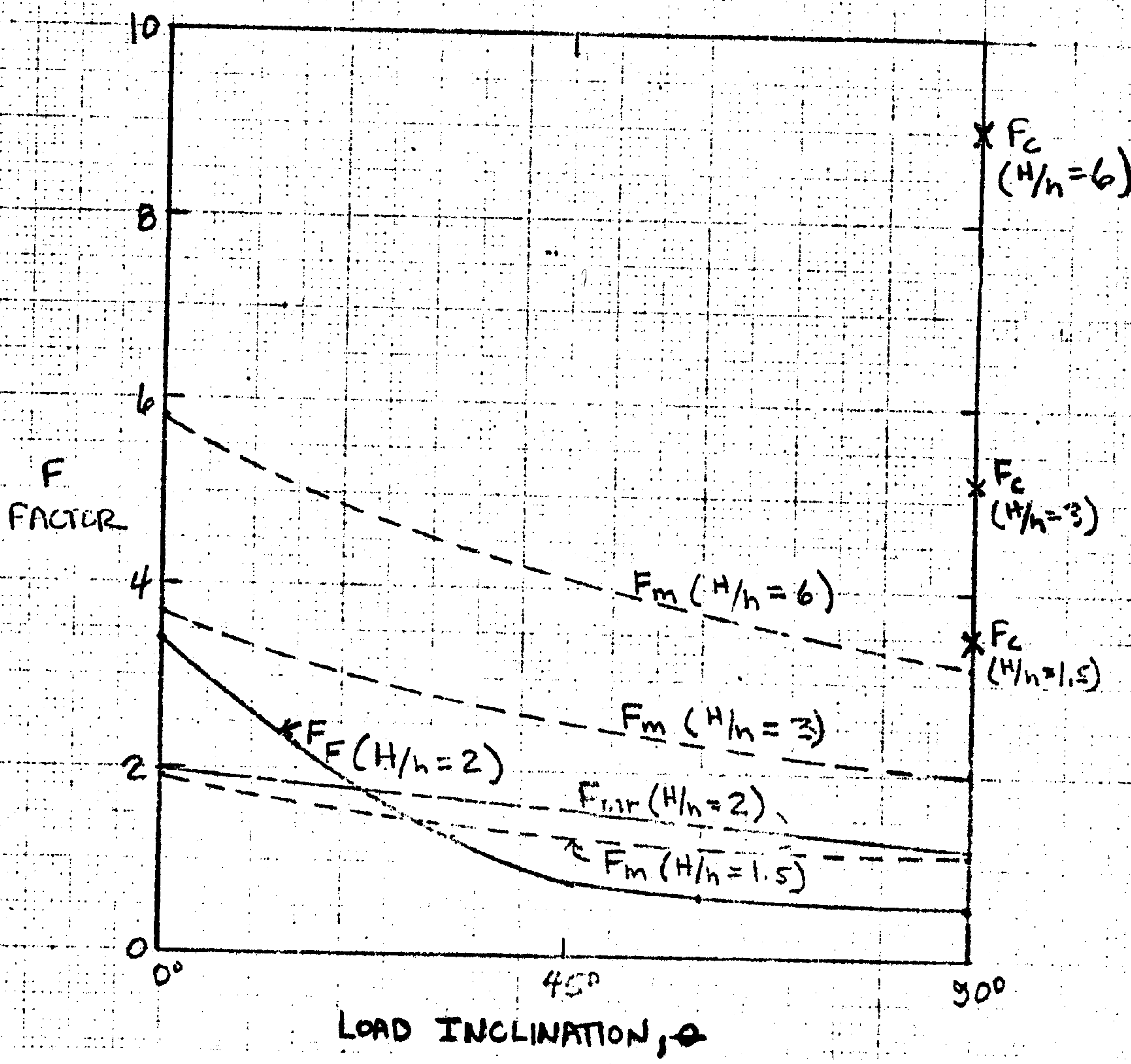

Figure 4. Comparison of Prellwitz (F_P), Meyerhoff theory (F_M), recommended Meyerhoff factors (F_{MR}), and CEL (F_C) methods for cohesive soils.