COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

March 14, 1961

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

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MEMO TO: K. B. Johns
Director of Traffic

SUBJECT: A Method for the Design of Foundations
Supporting Highway Signs

The attached report by R. C. Deen outlines a method for determining the length of embedment and diameter of the required footing for signs. The structural design of the sign, the sign post or supports, and the attachment -- if any -- to the foundation are not covered in the analyses. Only soil or allied materials resistance to overturning has been considered.

This report has been prepared as a result of requests from the Traffic Division concerning the factors involved in sign foundation design. Please advise if we can be of any further help in this matter.

W. B. Drake
Associate Director of Research

WBD:dl
Enc.
cc: A. O. Neiser
R. L. Parker
W. B. Carrington

Commonwealth of Kentucky
Department of Highways

A METHOD FOR THE DESIGN OF FOUNDATIONS SUPPORTING HIGHWAY SIGNS

by

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Lexington, Kentucky
March, 1961

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INTRODUCTION

With the increased mileage of highways being built to high standards, the resulting high-speed travel requires that more and larger signs be installed to relay to the motoring public information they require. It would be desirable to have a method of design which will result in a foundation involving rather simple construction procedures. It was decided that a cylindrical, non-reinforced concrete foundation with an uniform diameter would be the most advantageous for construction purposes. It should be realized, however, that the most efficient shape theoretically is one that has increased diameters at the top and the bottom.

The resistance of a soil to the tilting forces induced in a sign foundation by forces acting on the sign are difficult to evaluate. However, there is a need for a method by which approximate analyses can be made so that the diameter and length of the cylindrical foundation can be determined. The errors in assumptions or solution must, of course, be kept on the side of safety.

THEORY

In Fig. 1, the forces acting on a highway sign and its foundation are illustrated. The net resistance of the soil to a tilting movement of the foundation can be expressed as the difference between its passive resistance and its active resistance (Fig. 2), or

$$R_t = R_p - R_a \tag{1}$$

where

R_t is the net resistance, and

R_p and R_a are the passive and active soil resistances, respectively.

Expressing the passive soil resistance as

$$R_p = \gamma z \tan^2 (45° + \frac{\phi}{2}) + 2c \tan (45° + \frac{\phi}{2}), \tag{2}$$

and the active soil resistance as

$$R_a = \gamma z \cot^2 (45° + \frac{\phi}{2}) - 2c \cot (45° + \frac{\phi}{2}), \tag{3}$$

Equation (1) becomes

$$R_t = \gamma z \left[\tan^2(45° + \frac{\phi}{2}) - \cot^2 (45° + \frac{\phi}{2})\right] + \\ + 2c \left[\tan (45° + \frac{\phi}{2}) + \cot (45° + \frac{\phi}{2})\right] \quad , \tag{4}$$

where

γ is the unit weight of the soil,

z is the depth coordinate,

ϕ is the angle of internal friction of the soil, and

c is the cohesion of the soil.

Equation (4) can be expressed in the form

$$R_t = a + bz \tag{5}$$

where

$$a = 2c \left[\tan (45° + \frac{\phi}{2}) + \cot (45° + \frac{\phi}{2})\right] \quad \text{and}$$

$$b = \gamma \left[\tan^2 (45° + \frac{\phi}{2}) - \cot^2 (45° + \frac{\phi}{2})\right] .$$

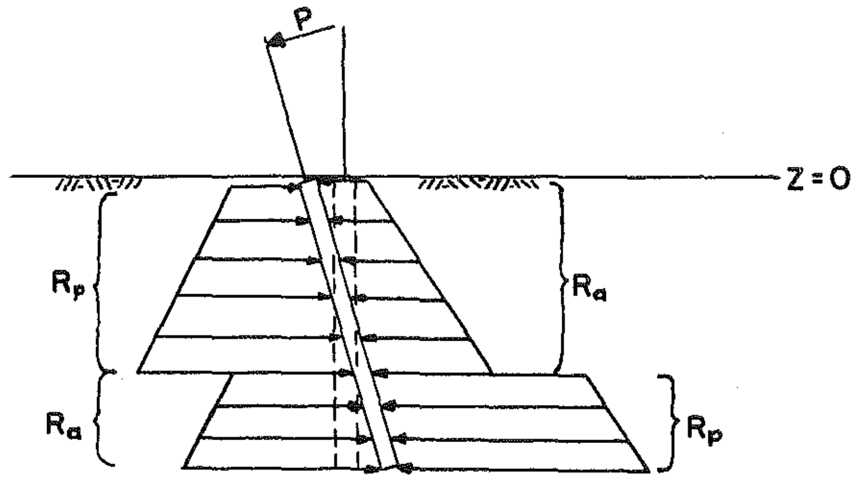

Fig. 1. Forces Acting on Sign and its Foundation

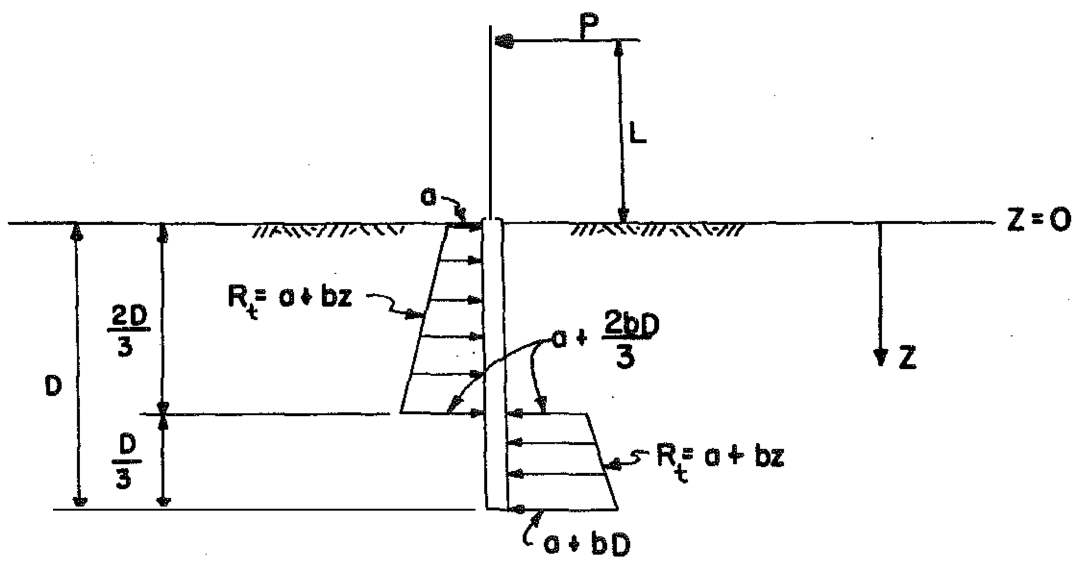

Fig. 2. Net Forces Acting on Sign and Foundation

It is noted that the coefficients a and b can be considered as properties of the soil.

In the analysis of moments in the foundations, it has been found that taking the "neutral axis" at a depth of 2D/3, where D is the depth of the foundation, results in errors that are on the safe side. It has also been observed in model studies of both granular and plastic soils that the neutral axis does occur at this depth of 2D/3.

Taking a summation of moments about the bottom of the foundation, it is found that

$$P(L + D) = (7aD^2W/18) + (13bD^3W/162), \qquad (6)$$

where

P is that portion of the force acting on the sign which is carried by the post and foundation in question,

L is the height above the ground line at which this force acts, and

W is the diameter of the cylindrical foundation.

To consider factors of safety other than one, Equation (6) becomes

$$P(L + D) = \left[(7aD^2W/18) + (13bD^3W/162)\right]/F, \qquad (7)$$

where

F is the factor of safety.

Rearranging Equation (7) in dimensionless form gives

$$FP/bL^3 = (7/18)(a/bL)(D/L)^2(W/L)(1/1 + \frac{D}{L}) + $$
$$+ (13/162)(D/L)^3(W/L)(1/1 + \frac{D}{L}). \qquad (8)$$

In the usual design problem, D, the depth of embedment of the foundation, and W, the diameter of the foundation, are the unknowns. From Equation (8) it is noted that it is not possible to obtain an explicit expression for D. The solution of Equation (8) is thus a trial and error procedure. Realizing that this trial and error procedure would be rather tedious and time consuming for the design engineer, a graphical solution has been prepared and presented in Figs. 3, 4, 5 and 6.

DESIGN PROCEDURE

In order to illustrate the use of the design curves, a foundation for a typical sign installation will be presented. Since the theory developed in this report pertains only to the design of the foundation for the sign, it will be assumed that the sign and its connection to the foundation have been properly and adequately designed.

For purposes of illustration, a design for the foundation for a sign loaded with a 1200 pound wind force at a height of 26 feet above the ground line will be obtained. The following information is known:

P = 1200 lb.	a = 4000 lb. /sq. ft.
L = 26 ft.	b = 42 lb. /cu. ft.
F = 2.0	

With this data, the following can be determined:

$$FP/bL^3 = 0.023$$

$$a/bL = 3.66.$$

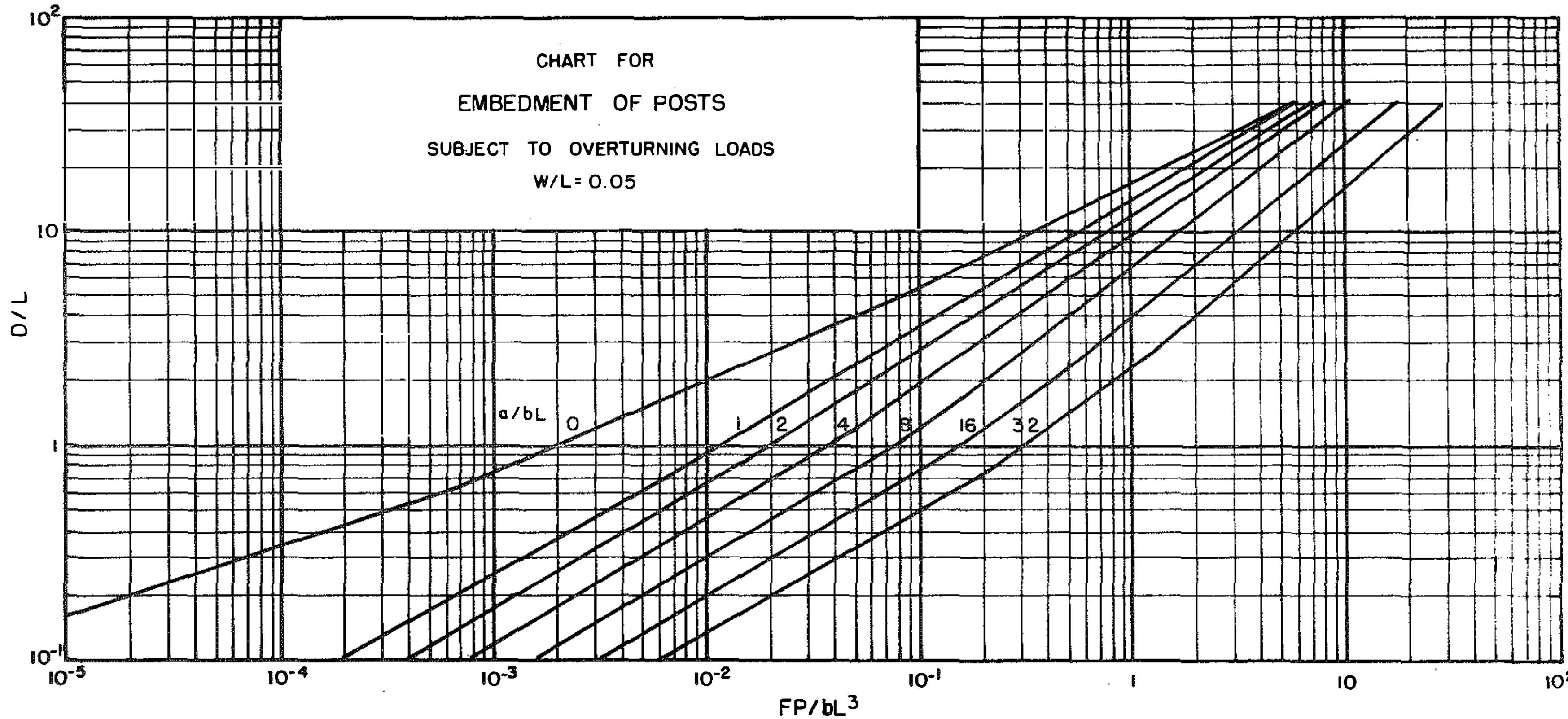

Fig. 3. Chart for Embedment of Posts Subject to Overturning Loads, W/L = 0.05

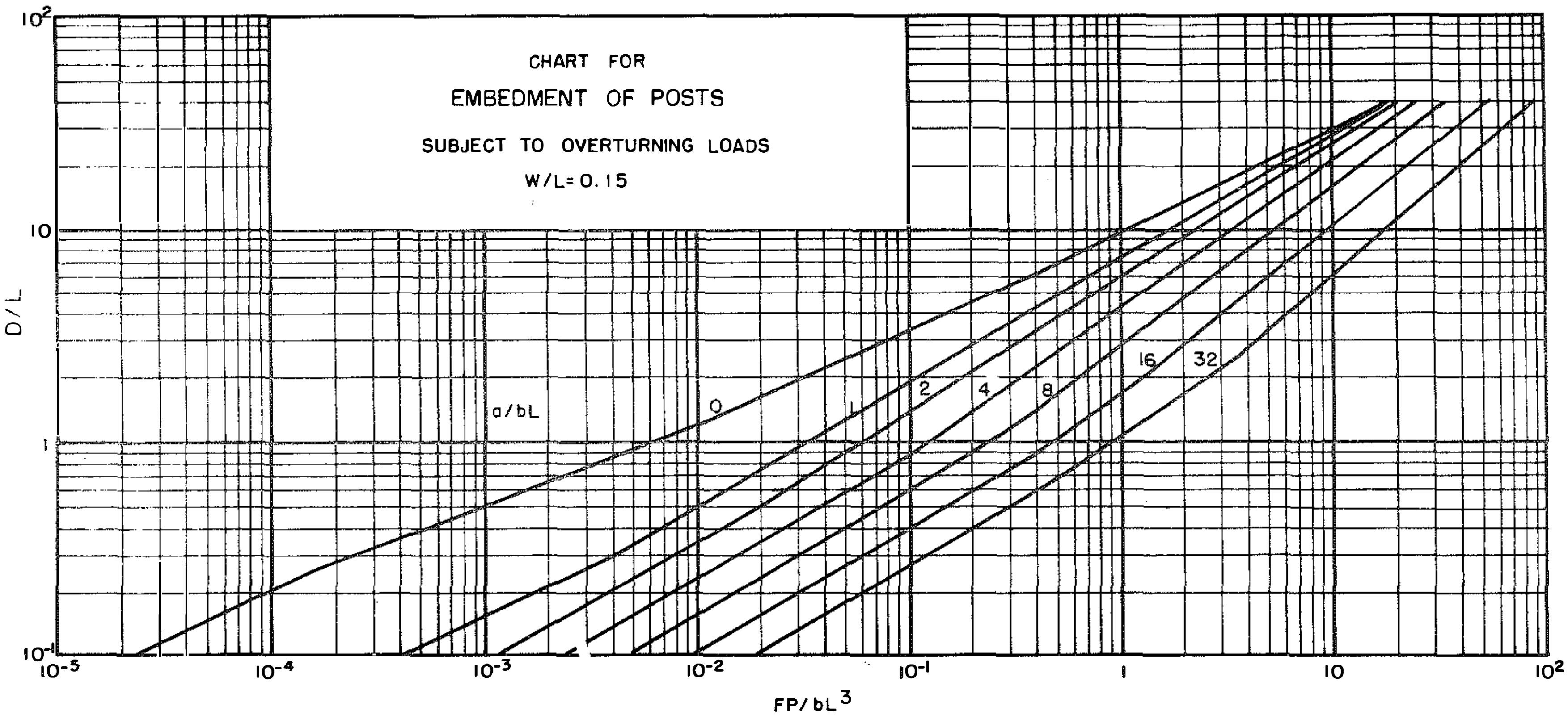

Fig. 4. Chart for Embedment of Posts Subject to Overturning Loads, $W/L = 0.15$

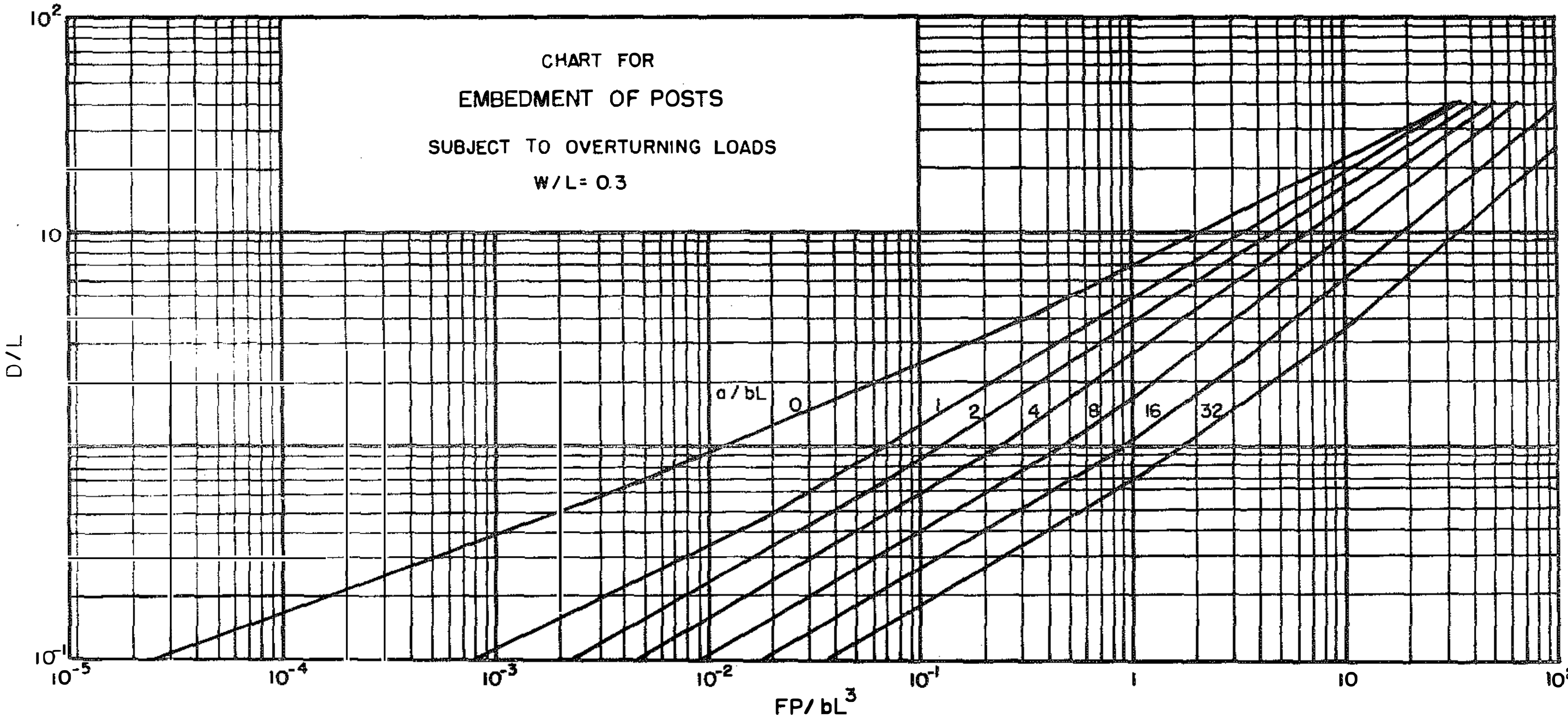

Fig. 5. Chart for Embedment of Posts Subject to Overturning Loads, W/L = 0.30

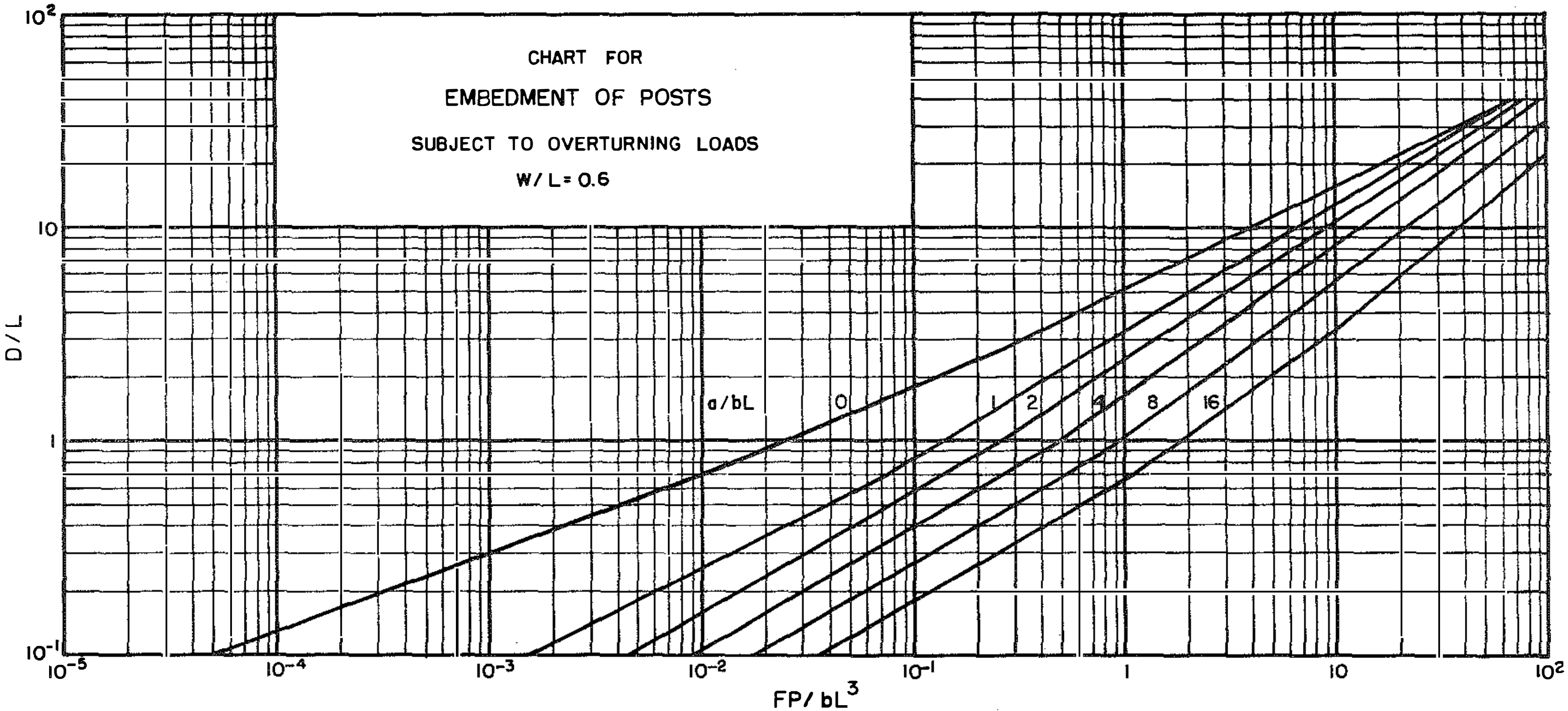

Fig. 6. Chart for Embedment of Posts Subject to Overturning Loads, W/L = 0.60

Referring to Figs. 3, 4, 5 and 6, the following values for D/L are obtained:

W/L	D/L
0.05	0.90
0.15	0.40
0.30	0.28
0.60	0.19

Plotting D/L against W/L the curve shown in Fig. 7 is obtained. Arbitrarily selected the diameter of the foundation as 2.5 feet, W/L is found to be 0.096. Entering Fig. 7 with this value for W/L, it is noted that D/L should be 0.56. Thus the depth of embedment of the foundation should be 14.5 feet if a 2.5-ft. diameter is used. If a 3-ft. diameter were used the depth of embedment would be reduced to 12 ft.

DISCUSSION

By using the design curves presented herein, and by following the procedure discussed above, the design of a foundation for a sign installation can be obtained in a matter of very few minutes. The method is very flexible in that a wide range of soil conditions can be considered, any factor of safety may be conveniently used, and a large range of loadings are taken into account. In the case of signs supported by two or more posts, the most critical foundation can be designed and this design used throughout, or each individual foundation can be designed.

It is necessary that the designer have a knowledge of soil conditions at the site in order to use this method. Table 1 lists typical values for the soil constants used in this analysis for several types of soils.

Certain factors which might affect the stability or resistance of a soil material as related to sign post foundations have been neglected. No consideration has been given to the resistance that is offered by skin friction. This could be a rather significant contribution in many situations. The soil also may be able to withstand short-time loads far in excess of the limits assumed. It has been suggested that impact factors as high as 2.0 or 2.5 may be used where small movements of the sign are not dangerous.

In the case that the sign foundation will penetrate two or more layers of different materials, special consideration must be given to the determination of the composite soil parameters a' and b'. In order to determine the values of a' and b' which will be used in the design of the foundation, first obtain a plot of the soil resistance, R_t, for the layered system as shown in Fig. 8. This relationship, which consists of a series of straight lines, between depth and soil resistance can be approximated by a single straight line. The values of a' and b' are then properties of this straight line.

Table 1. Typical Soil Constants

Type of Soil	Value of Cohesion, c (lb./sq.ft.)	Angle of Internal Friction, ϕ(°)	a (lb./sq.ft.)	b (lb./cu.ft.)
Silt	0	10	0	86
Sand, Loose	0	32	0	354
Dense	0	40	0	526
Gravel, Loose	0	45	0	679
Dense	0	60	0	1663
Rock Fill	0	60	0	1663
Clay, Soft	200	2	800	5
Medium	1000	6	4022	51
Stiff	2000	12	8179	104
Sand Clay	1000	34	4825	391
Silty Clay	100	14	4122	123
Silty Sand				
Loose	0	25	0	247
Dense	0	34	0	391

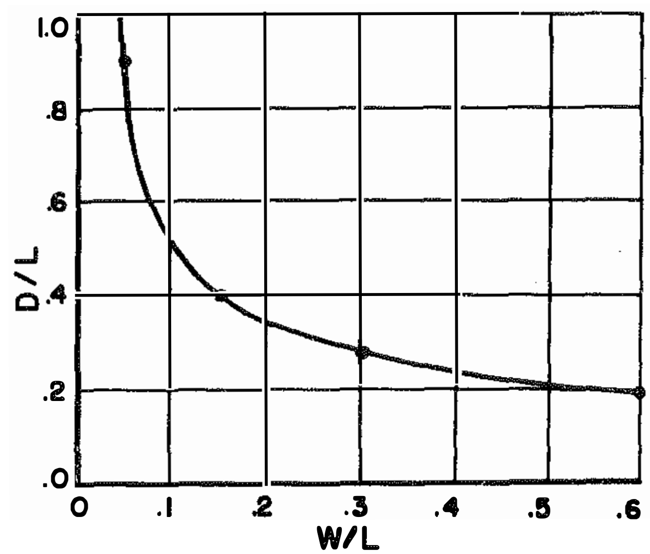

Fig. 7. Example of a Plot of D/L versus W/L

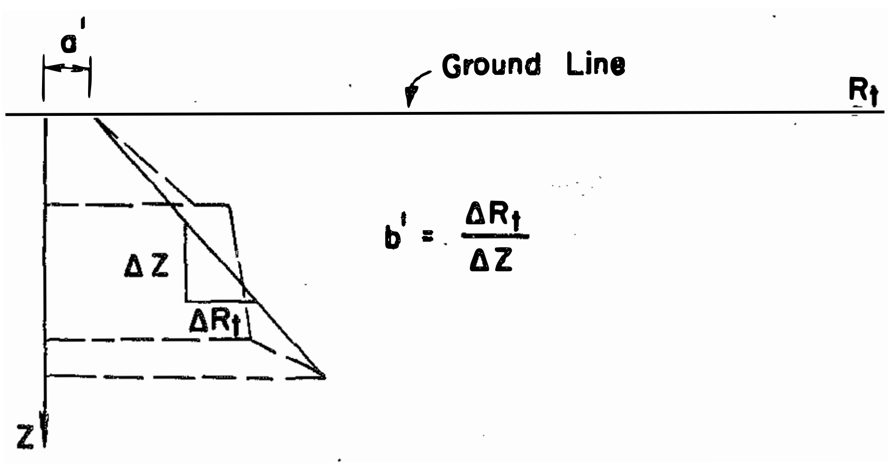

Fig. 8. Example of Method of Determining Composite Soil Parameters, a^1 and b^1.

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