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Short Communication

Pullout-Displacement of Shallow Vertical Anchor Plates

by

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Introduction

Displacement of anchor plates under pullout forces becomes of paramount importance when design requirements limit such displacement. Only limited studies *e.g.* Neely *et al.* (1973), Das *et al.* (1975) and Ranjan *et al.* (1977) have reported results pertaining to load-displacement behaviour of these anchors. However, there is a great need to generalize load displacement characteristics for these anchors.

Trautman and Kulhawy, (1988) have presented a mathematical formula utilizing a rectangular hyperbola to represent the load displacement curves for horizontal anchor plates subjected to vertical pullout. The purpose of this paper is to examine Trautman and Kulhawy's approach for the case of vertical anchor plates in sand subjected to horizontal pull. In this study the available test data in the literature as well as the present test results on model vertical anchor plates in sand have also been presented. Test set-up and procedure of the present investigation has been reported by Hanna *et al* (1988).

Theoretical Development

The ultimate pullout load of vertical anchor plates in sand under horizontal pull depends on the height of anchor plate h, depth of embedment H, (Fig. 1) shape of anchor plate *i.e.* strip, square etc. surface roughness and rigidity of the anchor plate, relative density of the sand, and the moisture content of sand. The load-displacement characteristics of these anchors vary for shallow ($H/h < 5$), transition ($H/h = 5$ to 8) and deep anchors $H/h > 8$ (Ranjan, 1974). Neely *et al.* (1973) presented experimental data of a model test to show the effect of the width of the plate B,

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the height of the plate h, and the depth of embedment H. The experimental data are given in Fig. 2. Das *et al.* (1975) and Ranjan *et al.* (1977) plotted experimental data in the form of $\bar{P}$ $(=P/Pu)$, and $\bar{\Delta}$ $(=\Delta/\Delta u)$ where is the applied horizontal pullout load to the plate corresponding to a displacement, Δ, and Pu is the ultimate pullout load corresponding to a total displacement at failure, Δu. Utilising non-dimensional plot, Das *et al.* (1975) fitted a rectangular hyperbola and proposed the following equation:

$$\frac{P}{P_u} = \frac{\Delta/\Delta_u}{[0.15+0.85\ (\Delta/\Delta_u)]} \tag{1}$$

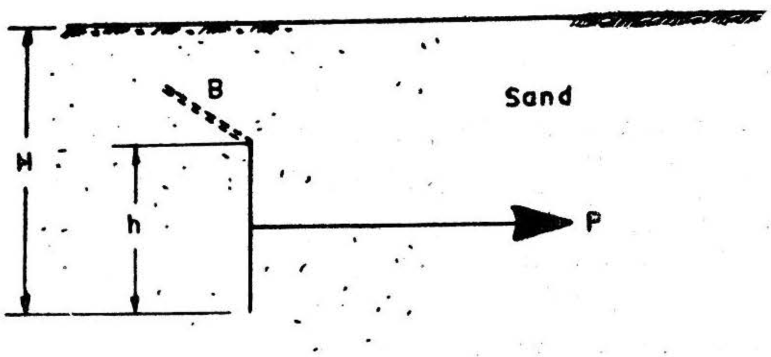

FIGURE 1 Vertical anchor plate subjected to horizontal pull

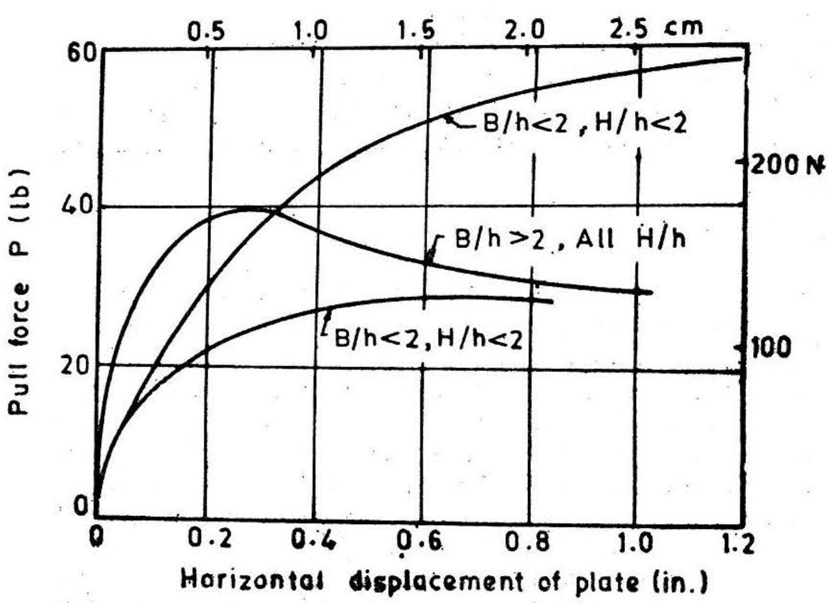

FIGURE 2 Typical load-displacement curves of Model anchor Plates (After Neely *et. al.*, 1973)

Das (1987) suggested that the ultimate load, P_u be obtained from the available theories in the literature and Δ_u, from the charts given by Neely *et al.* 1973 and shown in Fig. 3. The estimate of anchor pullout capacity, *P*, at any given displacement, Δ, can be then calculated from Eq. 1. The failure displacements of strip anchors ($B/h \geqslant 8$) are not known precisely. Also, Das has pointed out that the estimated value of *P* is only approximate, since the value of Δu may vary from the one shown in Fig. 3.

The behaviour of shallow anchors ($H/h<5$) is significantly different than that of deep anchors (Ranjan, 1974). Further, Neely *et al.* (1973) while plotting the variation of displacement at failure with width/height ratio and embedment ratio (Fig. 3) stated that a clear pattern emerges, showing that the displacement is greatest for deep square plates, and least for long plates at the surface. In the later case, the length of the plate is relatively unimportant. However, no attempts has been made to identify

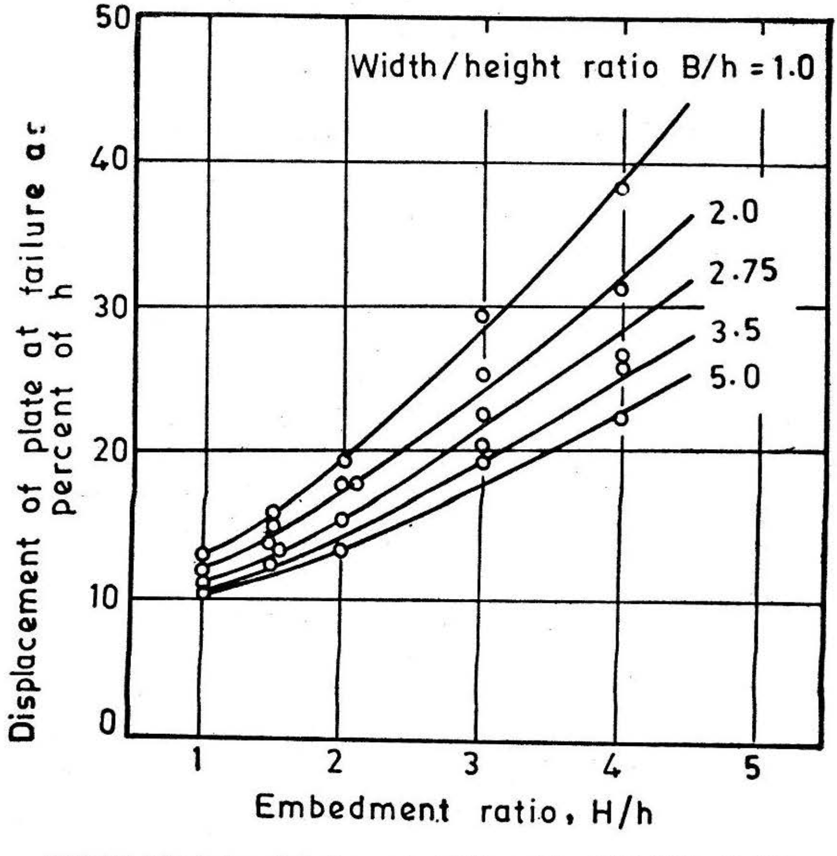

FIGURE 3 Variation of displacement at failure with width/height ratio B/h and embedment ratio H/h
(After Neely *et al.*, 1973)

the displacement at failure in the case of strip/long anchors. Accordingly to identify the displacement at failure the experimental data (Ranjan *et al.* 1977, Hanna *et al.* 1988) of shallow strip anchors has been plotted in non-dimensional form of P/P_u versus Δ/h in Figs. 4 to 6 in loose sand ($D_R = 50\%$), medium dense sand ($D_R = 65\%$) and dense sand ($D_R = 70\%$) respectively. These figures indicate that variation in displacement ratio at 50% failure load in different relative densities of sand is not much. However, the displacement ratio at failure is higher in loose sand ($\Delta/h = 0.5$) as compared to that in dense sand ($\Delta/h = 0.4$). This is in order.

The average plot (Figs. 4 to 6) can be approximated by a rectangular hyperbola of the form:

$$Y = \frac{X}{a+bX} \tag{2}$$

in which Y = normalized load, P/Pu; and X = dimensionless displacement, Δ/h and a and b are constants. Setting Y equal to 0.5 and 1, equation 2 can be solved to obtain the solutions of a and b.

$$a = \frac{X_1 X_2}{(X_2 - X_1)} \tag{3}$$

$$\text{and } b = \frac{X_2 - 2X_1}{(X_2 - X_1)} \tag{4}$$

where X_1 and X_2 are dimensionless displacements at 50% and 100% of the failure load respectively. Though the values of X_1 and X_2 should be obtained separately for different states of sand, yet adopting the average values of X_1 and X_2 as 0.06 and 0.40 respectively the following relationship is obtained.

$$\left(\frac{P}{P_u}\right) = \frac{(\Delta/h)}{0.0706+0.82\,(\Delta/h)} \tag{5}$$

or solving for Δ/h

$$\left(\frac{\Delta}{h}\right) = \frac{0.0706\left(\frac{P}{P_u}\right)}{1-0.82\left(\frac{P}{P_u}\right)} \tag{6}$$

Thus, knowing the load ratio P/Pu the horizontal displacement of the shallow anchor plates can be easily determined from Eq. 6.

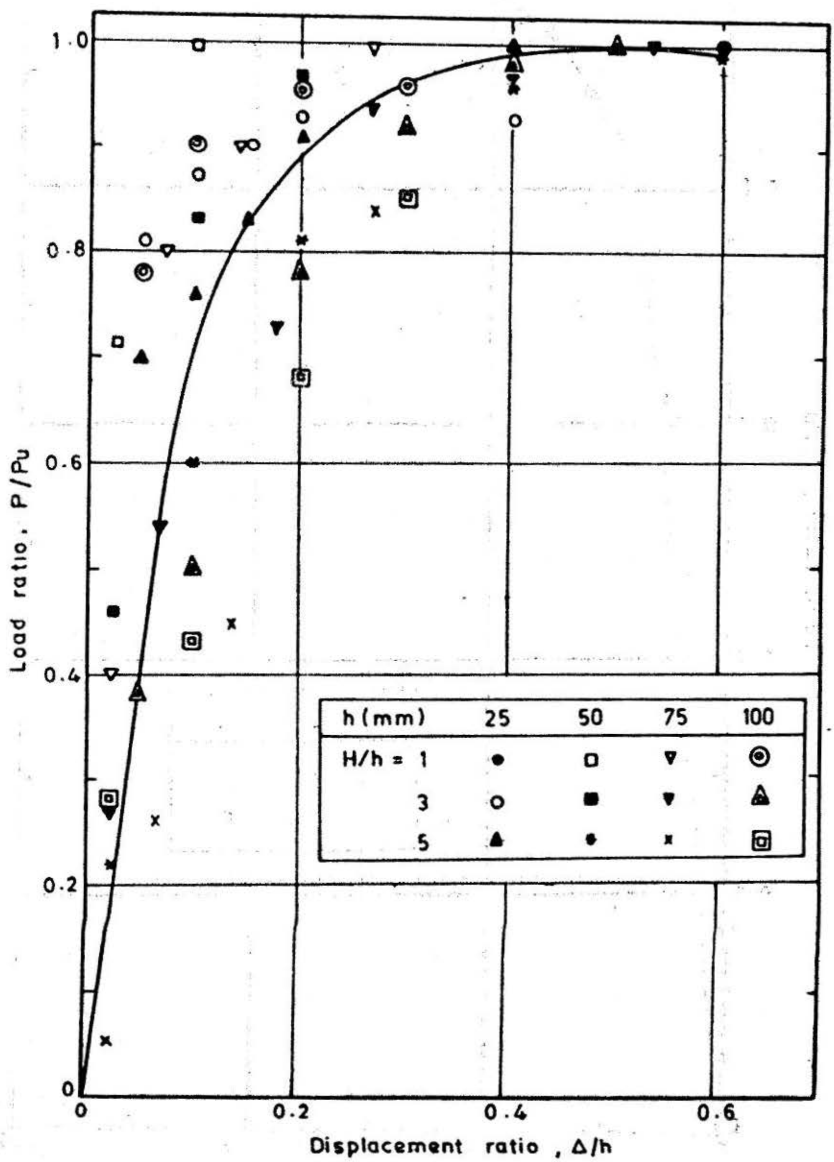

FIGURE 4 Load ratio, P/P_u versus displacement ratio Δ/h from model tests on shallow strip anchors in dry loose sand (Relative density 50%)

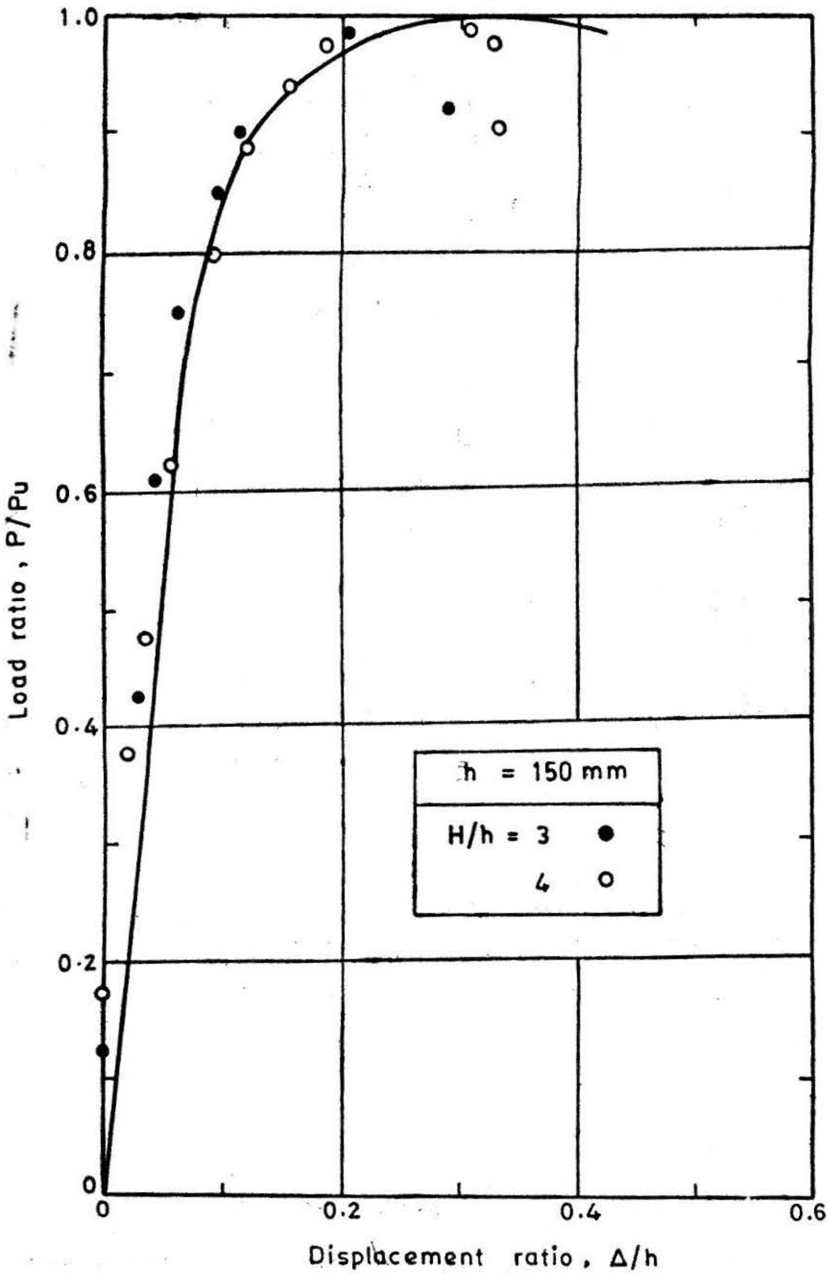

FIGURE 5 Load ratio, P/P_u versus displacement ratio, Δ/h from model tests on shallow strip anchors in dry medium dense sand (Relative density (5%)

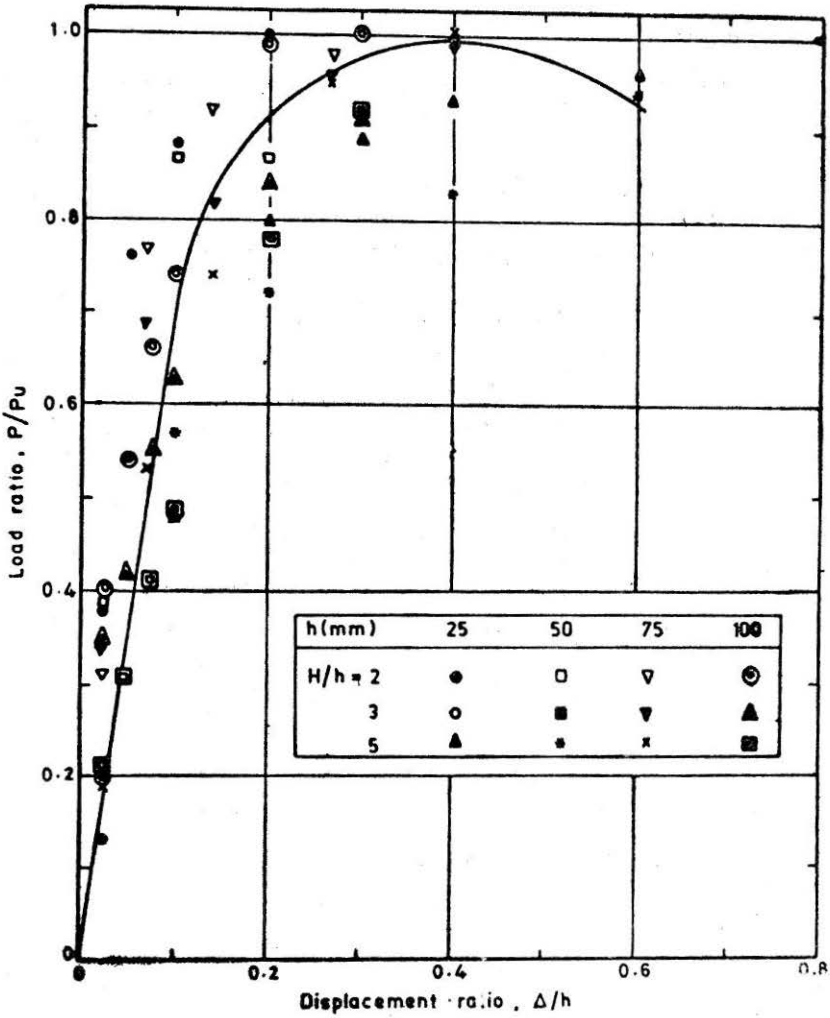

FIGURE 6 Load ratio, P/P_u versus displacement ratio Δ/h from model tests on shallow strip anchors in dry dense sand (Relative density 70%)

Summary and Conclusions

A generalized load-displacement curve for shallow vertical anchor plates subjected to horizontal pullout load has been presented. The proposed relationship is based on limited test data available on shallow vertical anchor plates under horizontal pull in sand. Field data are needed to support this relationship.

Acknowledgements

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Notations

a — constant

B — width of the anchor plate

b — constant

D_R — relative density

h — height of the anchor plate

H — depth of Embedment

Δ — displacement

Δ_u — displacement at failure

P — pullout load

P_u — ultimate pullout load

X_1 — dimensionless displacement at 50 % of the ultimate pullout load

X_2 — dimensionless displacement at failure load

Y — normalized load