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Behaviour of Enlarged Base Piles in Sand under Oblique Pullout Loads

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Introduction

Pile foundations are generally used to support and transfer heavy compressive loads from super structure to deeper load bearing-strata. Increasing need of construction of structures like transmission towers, mooring systems for ocean surface and submerged platforms, tall chimneys, jetty structures and underground tanks which transmit not only heavy compressive loads but also considerable amount of uplift and oblique pulling forces to the foundations led to the development of footing which can anchor the structures to the load bearing stratum. Sometimes piles are used as anchorage for guyed structures and they must be capable of resisting oblique pull. It has been observed that the behaviour of a vertical pile, with or without enlargement at the base under axial as well as non-axial pulling load, depends on the deformation characteristics of soil and pile. The failure mechanism involved is also complicated.

Studies are available on straight-shafted and enlarged base piles mostly in sand, under axial pulling loads (Meyerhof and Adams, 1968; Vesic, 1971; Sharma et al., 1978; Chandraprakash, 1980; Chattopadhyay and Pise, 1986a, 1986b; Rao and Kumar, 1994; Sharma and Pise, 1994). A few investigations are available on the ultimate lateral resistance of straight shafted piles (Broms, 1964; Meyerhof, 1973; Chattopadhyay and Pise, 1986d). However, limited information is available on laterally loaded enlarged base piles. Also limited investigations are available

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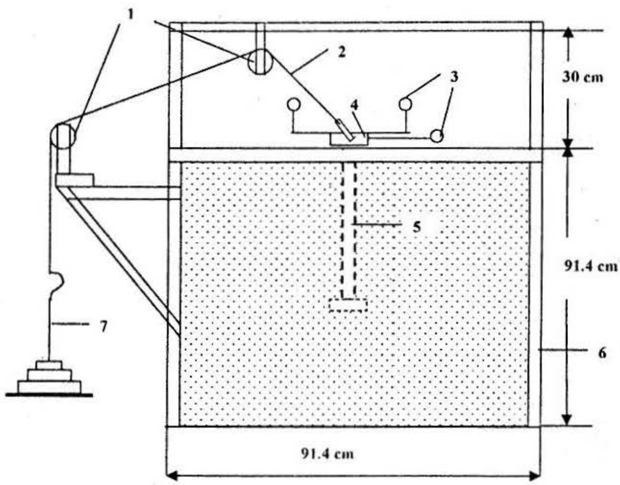

(1) PULLEYS
(2) NONEXTENSIBLE WIRE ROPE
(3) DIAL GAUGES
(4) PILE CAP
(5) MODEL ANCHOR PILE
(6) TEST TANK
(7) LOADING PAN

FIGURE 1 : Schematic Diagram of Experimental Set up

on the behaviour of piles under oblique pulling loads (Yoshimi, 1964; Das et al., 1976; Ismael, 1989). A few authors (Broms, 1965; Meyerhof, 1973; Poulos and Davis, 1980; Chattopadhyay and Pise, 1986c) have proposed analytical methods to predict the ultimate oblique resistance of piles.

Scope of Study

The soil-pile interaction behaviour depends on various parameters such as embedment length and diameter of pile shaft, diameter of the base, roughness of the pile surface, properties of the surrounding soil and the type of loading. Laboratory investigation has been carried out here to study the effect of such parameters on the load-displacement response and ultimate resistance of vertical piles embedded in sand subjected to oblique pullout loads. It is believed that the experimental data generated will add to the better understanding of soil-pile interaction phenomenon.

Experimental Set up

Model Test Tank

Tests were conducted in a steel tank of size 914 mm × 762 mm × 914 mm deep (Fig.1).

Foundation Medium

Uniformly graded "Ennore sand" obtained from Chennai (Tamil Nadu, India), was used as foundation medium. The specific gravity and uniformity coefficient of the material were 2.66 and 1.1 respectively. The limiting void ratios were $e_{min} = 0.56$ and $e_{max} = 0.92$ corresponding to maximum and minimum dry densities 17 kN/m^3 and 14 kN/m^3 respectively. The placement densities during the laboratory testing were 15.5 kN/m^3 for medium dense packing (R.D. $\approx$ 50%) and 16.0 kN/m^3 for dense packing (R.D $\cong$ 70%). The angles of shearing resistance for medium-dense and dense sand were 36° and 40° respectively.

Model Piles

Aluminium tubes of outer diameter, d = 19.05 mm and wall thickness 1.2 mm were used as model piles. The enlargement of the diameter at the base of the pile was provided by means of circular aluminium plates of thickness 10 mm and diameters, B = 19.05 mm, B = 38.1 mm and B = 57.15 mm corresponding to B/d ratio of 1, 2 and 3. A thread and nut arrangement was made at the bottom of the shaft to fasten the shaft and the base plate firmly. All the piles were coated with fine fraction of Ennore sand passing 425 micron IS-sieve and retained on 300 micron IS-sieve to make the pile surface rough. The adhesive sand coating increased the shaft diameter to 20 mm. The model piles were of two embedment lengths, 254 mm (short pile, L/d = 12.7) and 762 mm (long piles, L/d = 38.1) where L is the embedment length of pile. The pile-soil friction angles, δ for medium-dense and dense packings were 30° and 36° respectively. The piles had removable mild steel pile cap with welded adjustable 'S' hook at the top in order to apply inclined pulling loads at the desired inclination with the vertical axis of the pile.

Test Procedure

Figure 1 shows the schematic view of the experimental assembly. In general, the experimental procedure is similar to the one described elsewhere (Patra and Pise, 2001). The pile cap along with the pile in position is supported in the model empty tank. Sand was poured manually in the tank by rainfall technique. Oblique pulling loads were applied by the wire rope at inclinations of 0°, 15°, 30°, 45°, 60° and 90° with the axis of the vertical pile at the pile top through a double pulley frictionless arrangement (Fig.1). The enlarged base pile with loading is shown in Fig.2. Flexible steel wire was attached to the 'S' hook at the top of the pile cap. The arrangement was made with precision to avoid eccentricity in the application of loading. The wire rope was taken over the first adjustable pulley which was fitted with nut and bolt to the top solid steel channel near the pile head and then over

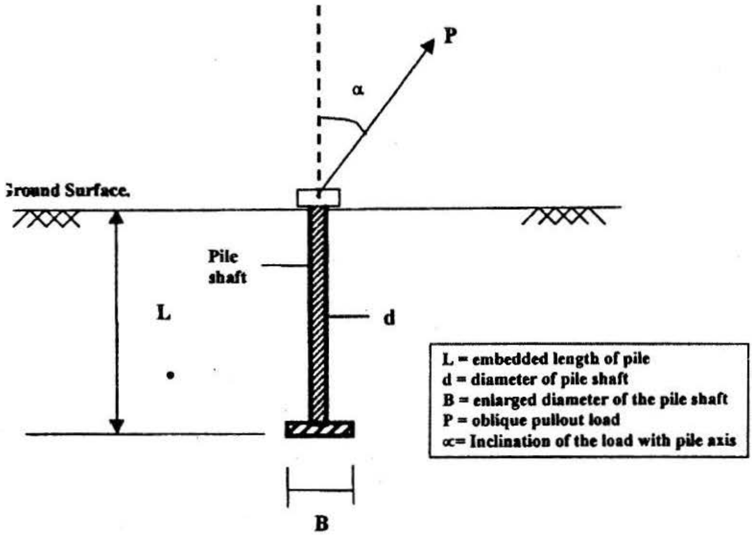

FIGURE 2 : Enlarged Base Pile with Loading

the second pulley and finally to the loading pan. Dead weights were put in the pan for loading in stages. Mechanical dial gauges with magnetic bases having sensitivity of 0.01 mm were used for recording displacements. Two dial gauges were placed equidistant from the axis of the pile cap top. The axial displacement and rotation of the pile cap were determined from their readings. Another dial gauge was placed on the vertical face of the pile cap, along the direction of loading, to record lateral displacement.

Experimental Results

Oblique Pull – Displacement diagrams

Typical "oblique pull versus axial-displacement" and "oblique pull versus lateral displacement" diagrams are given in Fig.3. It is observed that at a particular lateral movement of the pile the pull out load decreases with an increase in the inclination of the load.

Ultimate Oblique-Pulling Resistance of Pile

The ultimate oblique pull from the oblique pull axial-displacement response has been determined by the method suggested by Meyerhof (1973). It is taken as the load corresponding to the point where the load-displacement curve sharply changes its curvature.

The ultimate oblique pull from the oblique-pull versus lateral-

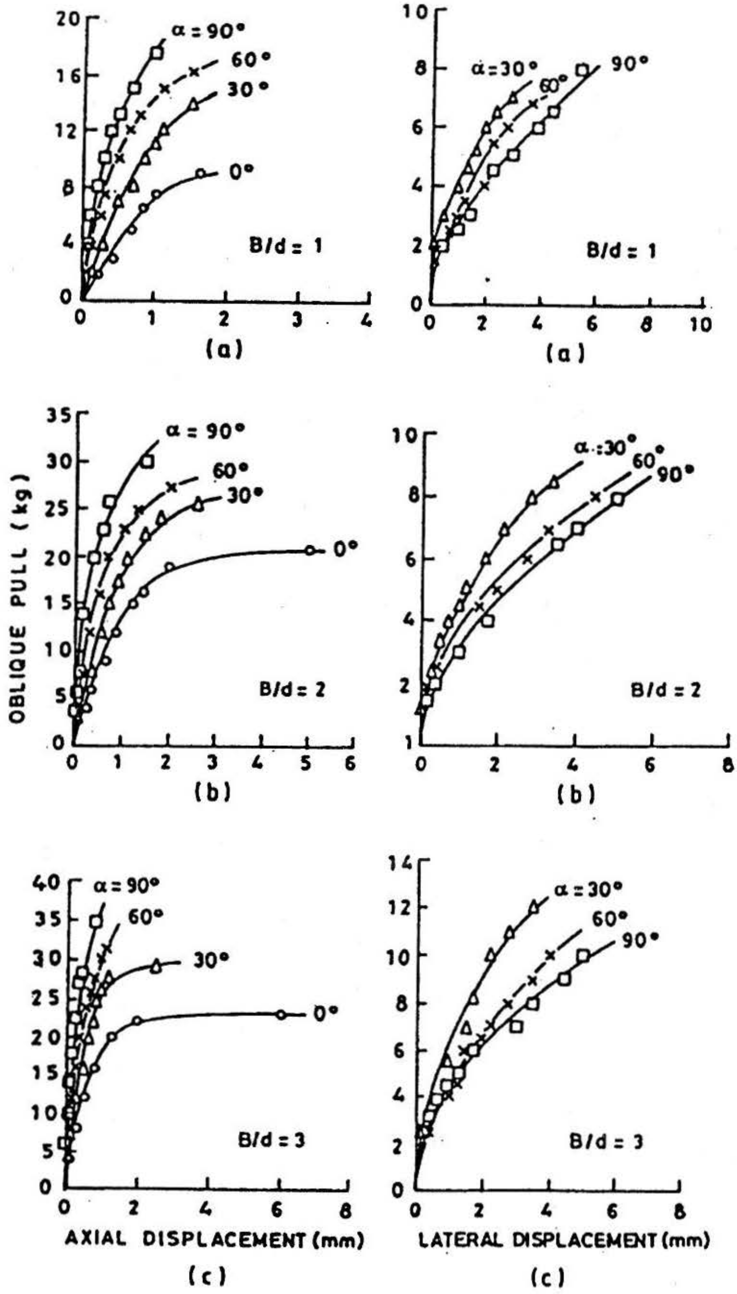

FIGURE 3 : Oblique Pull versus Displacementss

displacement diagram has been evaluated by the approach suggested by Chattopadhyay and Pise (1986d). In case of failure due to excessive normal displacement, it is taken from the log load versus log normal displacement diagram (LL-Method) as the load corresponding to lateral displacement equal to the diameter of the pile (Chattopadhyay and Pise, 1986d).

From the overall consideration of failure (axial or bending), the ultimate oblique pulling resistance of the pile is taken as the least value of the two ultimate loads thus obtained.

Discussion of the Results

Effect of L/d *Ratio*

Typical diagrams showing effect of L/d ratio on ultimate pull are given in Figs.4(a) to 4(d). It is observed that ultimate oblique pull, increases with increase in L/d, B/d and density of sand. Long piles offer more resistance than short piles. The increase in ultimate pull is more significant for dense condition of soil.

Effect of B/d *Ratio*

Typical diagrams showing the effect of B/d ratio are given in Figs.5(a) to 5(d). It is observed that the ultimate oblique pull increases with increase in B/d, L/d and density of sand. For short piles, the enlargement of base increases the ultimate oblique pull by about 15% to 18% compared to the straight-shafted piles. However, the increase is more for long piles and it is about 45% to 60%.

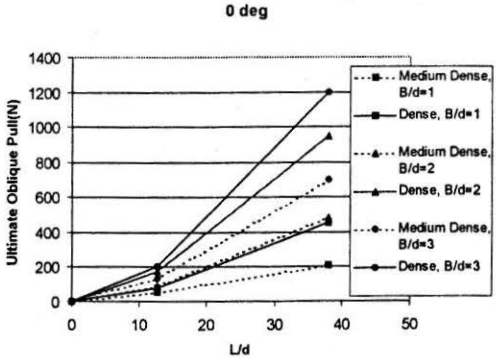

FIGURE 4(a) : Ultimate Oblique Pull versus L/d **(α = 0°)**

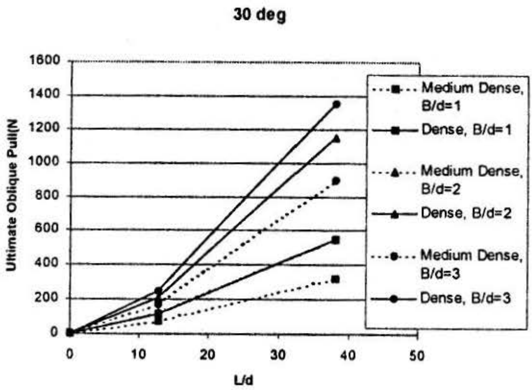

FIGURE 4(b) : Ultimate Oblique Pull versus L/d (α = 30°)

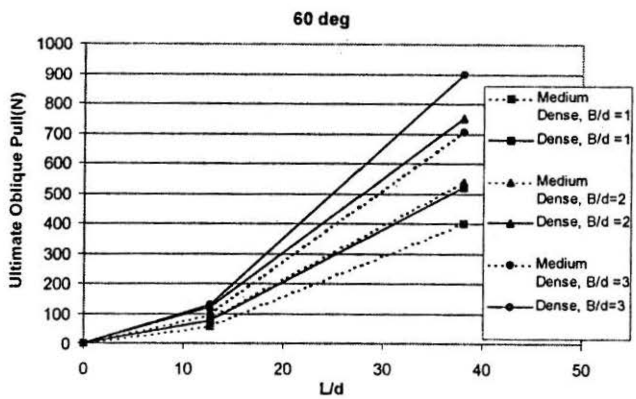

FIGURE 4(c) : Ultimate Oblique Pull versus L/d (α = 60°)

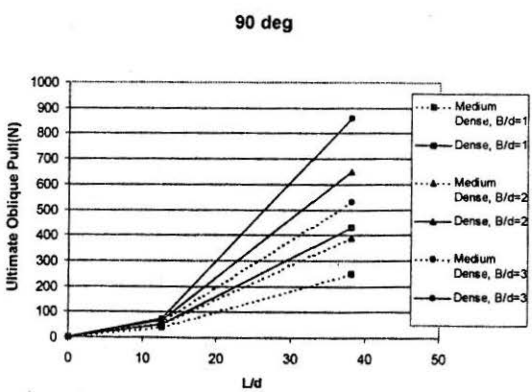

FIGURE 4(d) : Ultimate Oblique Pull versus L/d (α = 90°)

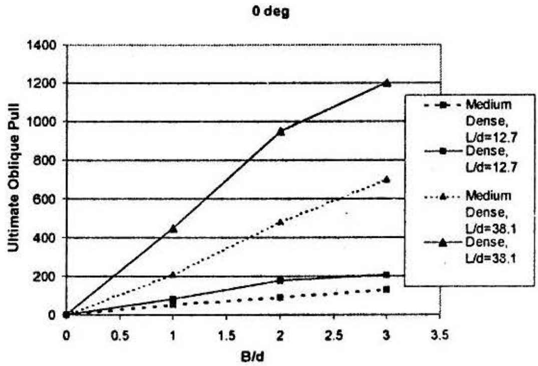

FIGURE 5(a) : Ultimate Oblique Pull versus B/d **(*α* = 0°)**

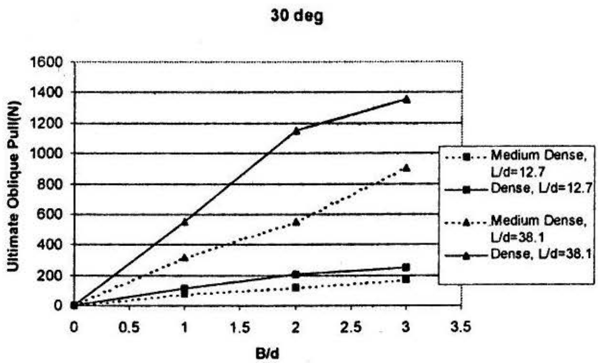

FIGURE 5(b) : Ultimate Oblique Pull versus B/d **(*α* = 30°)**

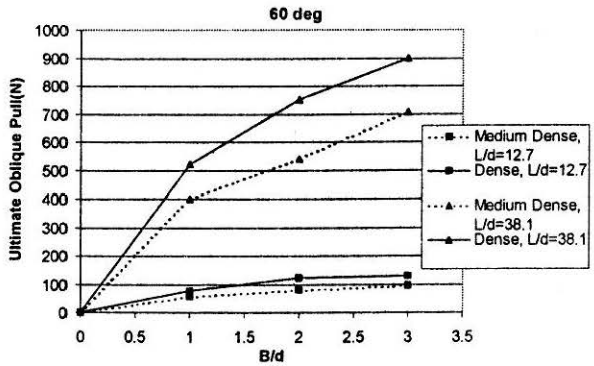

FIGURE 5(c) : Ultimate Oblique Pull versus B/d **(*α* = 60°)**

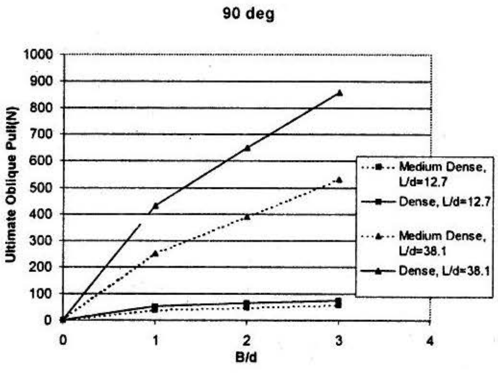

FIGURE 5(d) : Ultimate Oblique Pull versus B/d (α = 90°)

Effect of Inclination of Load, α

At all the conditions of testing the variations of ultimate oblique pull with inclination of load, α (Figs.6a to 6f) are similar. It is observed that the ultimate oblique pulling resistance increases with increase in inclination of load 'α' for $\alpha \leq \alpha_{cr}$ and after attaining the maximum value at a particular load-inclination (termed as critical angle, α_{cr}), it decreases with increase in 'α'. The critical angle depends on the length of a pile and soil density. For short piles (L/d = 12.7) the critical angle is 30° and is independent of the relative base enlargement and density of sand. For long piles (L/d = 38.1) the critical angle depends on the base enlargement and also on the density of sand. The values of these critical angles, α_{cr}, are as follows:

α_{cr} = 60° for B/d = 1 in medium-dense sand,

α_{cr} = 45° for B/d = 1 in dense sand,

α_{cr} = 45° for B/d = 2 in medium-dense sand,

α_{cr} = 30° for B/d = 2 in dense sand, and

α_{cr} = 30° for B/d = 3 in both sand densities.

Conclusions

The behaviour of anchor pile under oblique pullout loads depends on the embedment length/diameter ratio, L/d, base enlargement ratio, B/d, inclination of the load, α, and density of the foundation medium. The ultimate resistance increases with increase in L/d, B/d ratio and initial

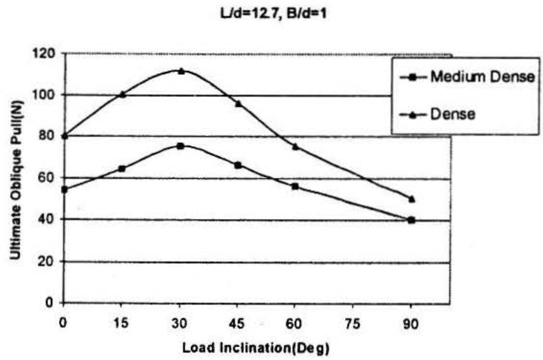

FIGURE 6(a) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 12.7, B/d = 1)

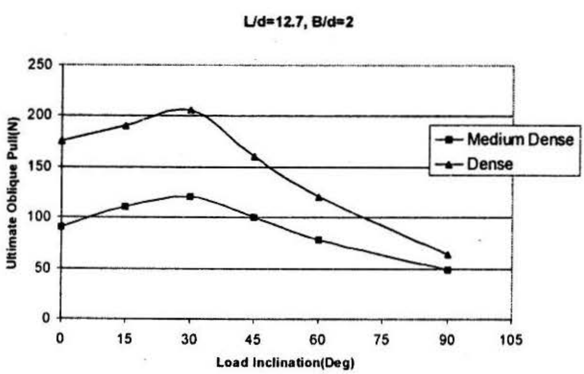

FIGURE 6(b) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 12.7, B/d = 2)

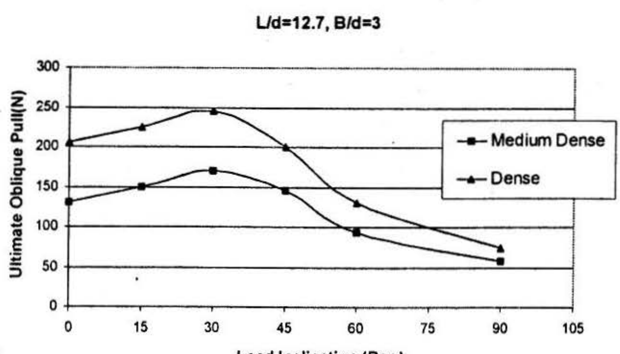

FIGURE 6(c) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 12.7, B/d = 3)

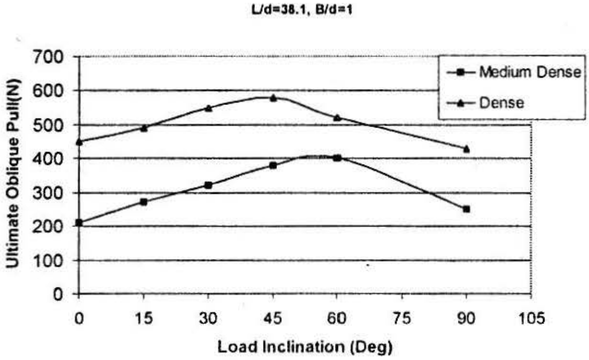

FIGURE 6(d) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 38.1, B/d = 1)

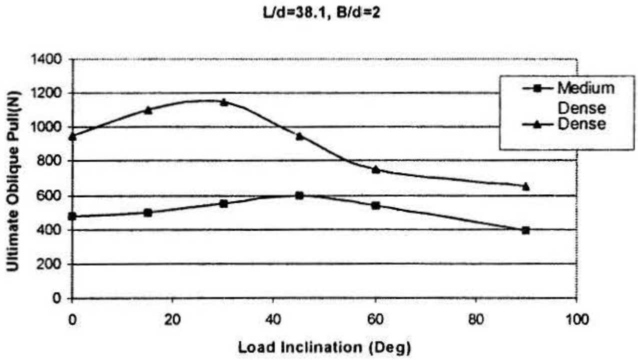

FIGURE 6(e) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 38.1, B/d = 2)

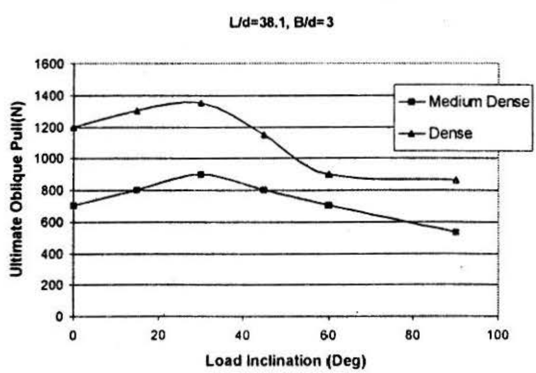

FIGURE 6(f) : Ultimate Oblique Pull versus Inclination of Load, α (L/d = 38.1, B/d = 3)

placement density of sand. There is a critical inclination, acr, of the load at which the pile attains maximum ultimate oblique resistance. The critical angle, acr, depends on L/d, B/d ratios and sand density.

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Notations

B	=	Enlarged diameter of the pile shaft
L	=	Embedded length of a pile
d	=	Diameter of the pile shaft
P	=	Oblique pullout load
α	=	Inclination of the load with pile axis
α_{cr}	=	critical angle, α