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Experimental Study on Uplift Capacity of an Inclined Square Plate Anchor

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***Abstract:*-- Anchors are the soil anchoring method for resist the tension forces and uplift forces subjected to structure such as transmission towers, buried pipe lines, retaining walls, tents etc. There are three types of plate anchors are mainly used based on their load application- vertical, horizontal and inclined plate anchors. So many studies are done for the determination of uplift capacities of vertical and horizontal plate anchors. Only few studies are carried out for the determination of uplift capacity of inclined plate anchors. The uplift resistance of inclined plate anchors in layered soil is not yet studied. The present laboratory study was done to determine the uplift capacity of an inclined square plate anchor of size 75mm in layered cohesionless soil. The effect of angle of inclination (α), density of sand and thickness of loose layer (HL) were investigated through the small scale model test. The different layer of sand is prepared with locally available sand at 30% and 70% relative densities corresponding to the thickness of layer.**

Index Terms:- Inclined Plate Anchor, Retaining wall, Uplift capacity, Relative density.

I. INTRODUCTION

Anchors are mainly used at the foundation of transmission towers, aircraft moorings, buried pipe lines, utility poles, tents, retaining walls, sea walls etc. These are used for the structures where they subjected to pullout, uplift, tension loads, overturning moments etc. The use of plate anchors improves the stability and safety of the structures for above loads. For the purpose of soil anchoring we use different anchors such as helical anchors, grouted anchors, plate anchors, pile anchors, different shaped anchors etc. according to their load transfer.

Anchors are made up of light weight structural elements with timber sheets, steel plates, fiber reinforced polymer etc. These methods are the most applicable ones used for the structures like transmission towers tents, and structures which are subjected to uplift loads. The arrangement of plate anchors depends upon the direction of load coming through it. According to the direction of load the plate anchors are classified into horizontal, vertical and inclined plate anchors. In the present study, the uplift capacity of inclined plate anchor is done. Plate anchors can also be classified based on the shape of the anchor plates. According to that it can be circular, strip, square and rectangular shapes.

Deep anchors provide more pullout capacity, but the cost of construction and difficult of excavation increases. So we can provide shallow depth anchors as an alternative to overcome this problem.

Hanna A et al. 2014 has been investigated the effect of dialatancy, plate flexibility and shape factor on pullout capacity of inclined plate anchor in a medium cohesionless soil. Uplift capacity of inclined strip plate anchor was studied by Merifield R. S. et al. 2005 (Lower and upper bound analysis in purely cohesive soil) and Hambleton J.P. (Block set mechanism in sand). Uplift capacity of circular and strip horizontal plate anchors were investigated in two layered sand (Paramitta B et al. and Bouazza et al.).

The present study consist of the determination of uplift capacity of inclined square plate anchor. Inclined plate anchors are the combination of vertical and horizontal plate anchors. They can resist both horizontal and vertical pullout capacities. Most of the experimental, numerical and theoretical studies were done for the determination of pullout capacities of the vertical and horizontal anchor plate. Only few studies were done for pullout capacity of inclined plate anchors and most of them are numerical studies.

In this study the pullout capacity of inclined square plate anchor has been investigated. The study was related to the effect of angle of inclination (α), density (loose or dense) and thickness of loose layer (HL).

II. MATERIALS USED

Locally available dry sand was used for conducting the model pull out tests. The specific gravity of the sand was found to be 2.57. The sand have effective mean particle size (D10) of 0.17 and uniformity coefficient (Cu) of 3.64 and coefficient of curvature (Cc) of 0.97. The sand is classified as poorly graded sand (SP) as per IS classification system. The physical properties of sand are given in Table I. The particle size distribution curve of the sand is shown in Figure 3.

The plate anchor used in this study is rigid steel square plates of size 75mm x 75mm and 8mm thickness welded together with steel rods of 6mm diameter as shown in Figure 2. A hole is provided at the top of the steel rod to connect the pulley wire.

Fig. 1 Sand

Fig. 2 Square Plate Anchor

A. Properties of sand

Table I. Index properties of sand

Parameters	Value
Specific Gravity	2.57
Effective Particle Size, D_{10}(mm)	0.17
D_{30}(mm)	0.32
D_{60}(mm)	0.62
Uniformity coefficient, C_u	3.64
Coefficient of curvature, C_c	0.97
Gradation of sand	SP
Maximum dry density(g/cc)	1.7
Minimum dry density(g/cc)	1.46
Sand density (30% RD)(g/cc)	1.52
Sand density (70% RD)(g/cc)	1.62
Angle of internal friction(30%RD)(degree)	35
Angle of internal friction(70%RD)(degree)	40

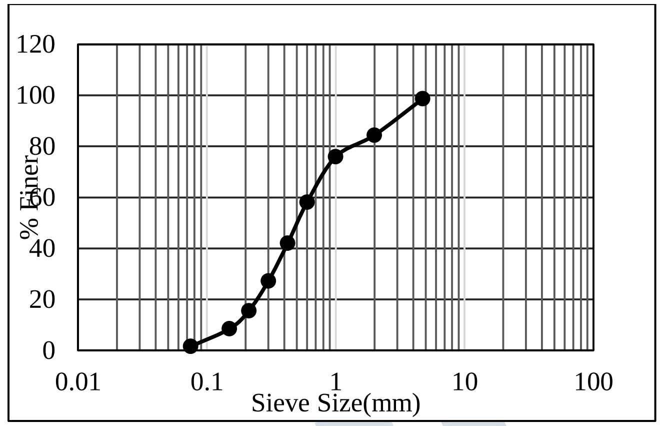

Fig. 3 Particle size distribution of sand

III. EXPERIMENTAL PROGRAMME

The sand is prepared in a tank of size 1000mm x1000mm x 850mm as shown in Figure 4. Weighed sand is filled layer by layer in the tank uniformly and is levelled and compacted to acquire desired density (γd = 1.52 g/cc and 1.62g/cc) corresponding to the tests by using tamping rod. Sand was filled up to 700mm with dense condition (γd =1.62g/cc). Then plate anchor is placed over it inclined at an angle 30˚ with the vertical by the help of set up arranged at the side of tank. After filling the sand above the plate anchor with required density and thickness, the setup is removed. Then the cable is connected through the hole provided at the top of the shaft of plate anchor and passed over a pulley arranged on the test set up as shown in Figure. 5 and connected to a hanging system for application of load. Gradually increased load of 2kg is applied to the hanging system. The corresponding movement of plate anchor embedded in to the sand is noted by using dial gauge with 25mm maximum capacity and of sensitivity 0.01. The load is applied up to the failure condition.

The constant parameters used in the study are size of the anchor plate (B) 75mm, embedment ratio (H/B) of 2. The variable considering in a series of tests are angle of inclination (α), density (loose or dense) and thickness of loose layer (HL). Pullout tests were conducted for the above conditions.

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Fig. 4 Test Tank

Fig. 5 Pullout loading arrangement

IV. RESULTS AND DISCUSSIONS

In the present study the pullout capacity of square plate anchor is studied. The study included the effect of angle of inclination (α), density of sand bed and the thickness of upper loose layer (HL/H) on the pullout capacity of square plate anchor of size 75mm (B) embedded at a depth of 2B. The following graphs shows the results from the pullout test corresponding to the above parameters.

A. Effect of angle of inclination on the uplift capacity of the plate anchor

Figure 6, Figure 7 and Figure 8 shows the pullout load versus anchor displacement curve in different thickness of loose layer conditions. From the graph we can observe that the ultimate uplift capacity of plate anchor increases as the angle of inclination at a particular embedment depth in different thickness of loose sand layer condition. The pullout capacity improves 30% as from the angle of inclination moves from 30˚to 60˚. The reason behind the increase in uplift capacity of plate anchor is due to the extent of failure surface as the angle of inclination increases. It will take time to reach at the ground surface (top surface of the tank).

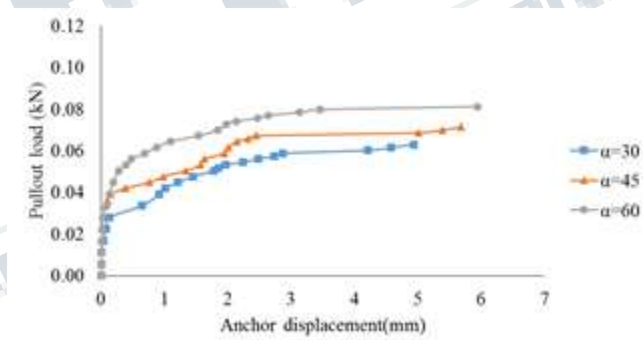

Fig. 6 Pullout load - Axial displacement curve for $H_L/H=1$ at different angle of inclination

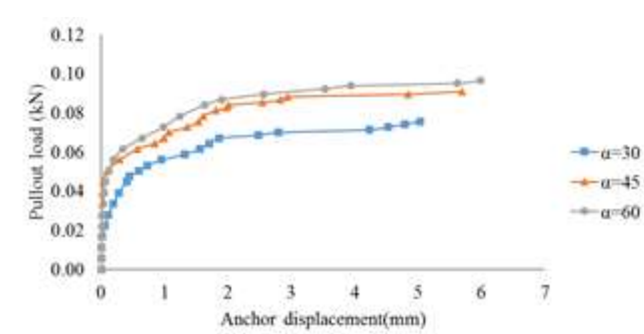

Fig. 7 Pullout load - Axial displacement curve for $H_L/H=1/2$ at different angle of inclination

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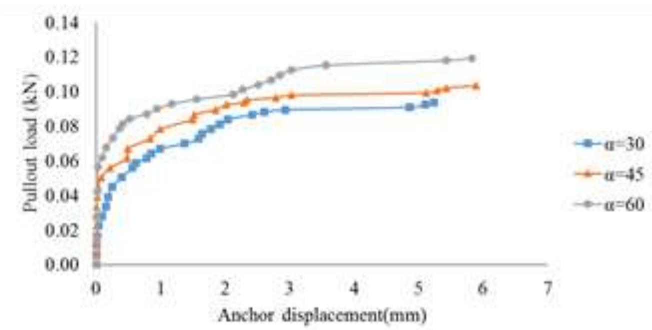

Fig. 8 Pullout load - Axial displacement curve for HL/H=0 at different angle of inclination

B. Effect of density on the uplift capacity of the plate anchor

Figure 9 shows the comparison of pullout capacity versus density of soil at different angle of inclination. The results shows that the pullout capacity of anchor plate is higher for the dense sand condition the percentage of increase is about 50%.

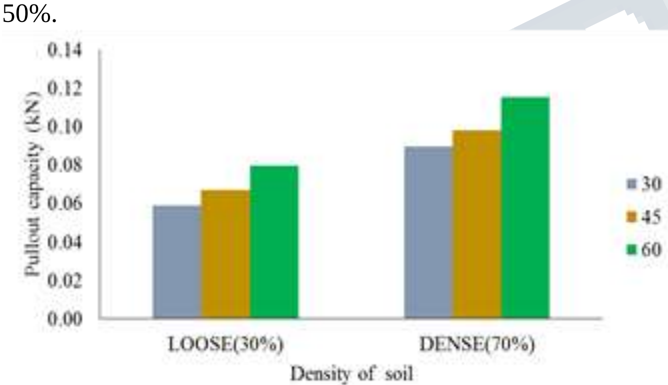

Fig. 9 Comparison of Pullout capacity with density of soil at different angle of inclination

C. Effect of thickness of loose soil layer on the uplift capacity of the plate anchor

Figure 10, Figure 11 and Figure 12 shows variation of the pullout capacity due to the change in thickness of upper loose layer of the sand at 30, 45 and 60˚respectively. Corresponding anchor displacements are also represented in the graphs. As the thickness of loose layer is decreases uplift capacity increases. So the maximum capacity is obtained at HL/H=0 (i.e., fully dense or no loose layer).

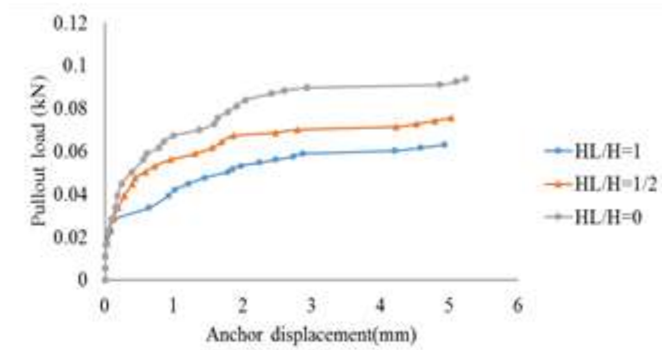

Fig. 10 Pullout load - Axial displacement curve for the 30˚inclination at different thickness of loose layer

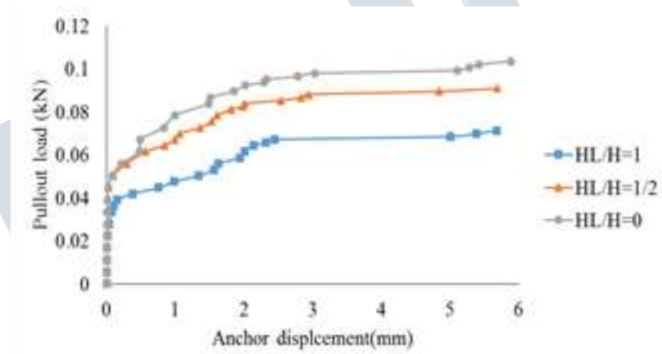

Fig. 11 Pullout load - Axial displacement curve for 45˚inclination at different thickness of loose layer

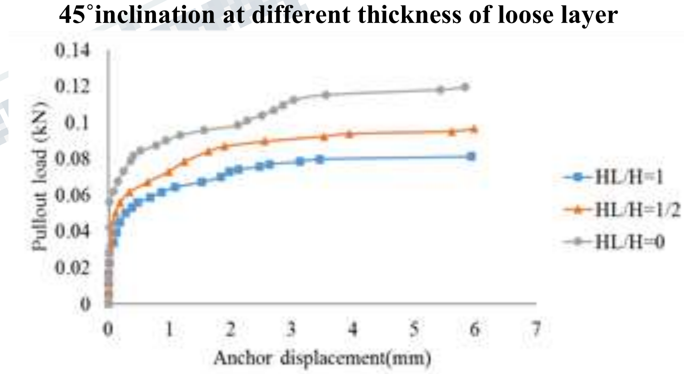

Fig. 12 Pullout load - Axial displacement curve for 60˚inclination at different thickness of loose layer

CONCLUSIONS

The present study conducted to estimate the uplift capacity of inclined plate anchor embedded in shallow depth. The study included the tests showing the effect of angle of inclination, density of soil medium and the thickness of loose layer above the anchor at a 2B embedment depth on the uplift capacity of inclined plate anchor.

- Pullout capacity of square plate anchor increases as the angle of inclination of plate from the vertical increases.
- The uplift capacity improves 30% from the angle of inclination moves 30˚to 60˚
- The reason behind this is as the angle of inclination increases the area of plate anchor embedment increases. The soil above the plate anchor increases and it will prevent the sudden pullout of the anchor plate from the soil.
- The decrease in thickness of loose layer improves the pullout capacity about 50% from loose to dense condition
- The uplift capacity of inclined plate anchor in dense sand medium is greater than that of the loose condition.
- The thickness of loose layer above the center of plate anchor influences the pullout capacity of the anchor plate.
- As the thickness of loose layer decreases the uplift capacity increases.
- The pullout capacity is maximum when the sand bed is fully dense condition.

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