Uplift Behavior of Plate Anchors in Cohesionless Soil

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ABSTRACT

In this study, the uplift behavior of plate anchors embedded in sand was investigated with a series of small scale laboratory pull-out tests. Model tests were performed in a test box with square and rectangular anchor plates. The effects of embedment and aspect ratio of anchor plates, and relative density of sand on uplift behaviour of plate anchors were investigated. Based on the test results, it can be concluded that the embedment and aspect ratio of anchor plates and relative density of sand are main parameters that affect the uplift capacity of anchor plates.

Key words: aspect ratio, rectangular anchors, uplift capacity, sand.

1 INTRODUCTION

Anchor plate is used to support the structures such as transmission tower or offshore platform that required high uplift resistance. Some also used to resist the lateral force for structure such as sheet pile wall. The plate anchor is various in shape, such as square, rectangular, circular and strip. However, square plate and rectangular plate are more often used in practical (Yau, 2006). In this study, the uplift behavior of square and rectangular anchors placed in different embedment ratio and relative density of sand is investigated with laboratory tests. Based on the test results, the embedment and aspect ratio of plate anchors and relative density of sand are main parameters that affect the behavior of plate anchors.

2 LITERATURE REVIEW

During the last thirty years, several theoretical and semi-empirical methods have been developed to predict the net ultimate uplifting load of continuous, circular and rectangular foundations embedded in sand. The ultimate uplift capacity of the foundation is the sum of two components: (a) the weight of the soil and the foundation in the failure zone and (b) the shearing resistance developed along the failure surface. Based on results of several model and field tests conducted in dense soil, Balla (1961) established that, for shallow circular foundation, the failure surface in soil make an angle and the angle α is equal to 45-ϕ/2. Existing literature, in general, Balla's theory is in good agreement with the uplift capacity of shallow foundations embedded in dense sand at an embedment ratio of $D_f/B \leq 5$. However for foundations located in loose and medium sand, the theory overestimates the ultimate uplift capacity. The main reason Balla's theory overestimates the ultimate uplift capacity for $D_f/B>$ about 5 even in dense sand because it is essentially deep foundation condition, and the failure surface does not extend to the ground surface.

Baker and Kondner (1966) confirmed Balla's major findings regarding the behavioural difference of deep and shallow anchors in dense sand. Sutherland (1965) presented results for the pull-out of 150mm horizontal anchors in loose and dense sand, as well as large diameter shafts in medium dense to dense sands. It was concluded that the mode of failure varied with sand density and that Balla's analytical approach may give reasonable results only in sands of intermediate density.

Das and Seeley (1975) reported uplift tests for the horizontal strip anchors (L/B ≤ 5) in dry cohesion less soils with a friction angle of ϕ=31° at a density of 14.8kN/m^3. For each aspect ratio (L/B), was found that the anchor capacity increases with the embedment ratio before reaching a constant value at the critical embedment depth. A similar investigation was conducted by Rowe (1978) in dry cohesion less soils with friction angles ϕ=31-33° and dry unit weight of γ=14.9kN/m^3. Polished steel plates were used for the anchors and the interface roughness was measured as δ=16.7°. Most tests were performed on the anchors with an aspect ratio L/B of 8.75. Rowe (1978) reported decreasing of the aspect ratio (L/D) leads to the increase of the anchor force (relative to L/B 8.75) of 10%, 25%, 35%, and 120% for L/B ratios of 1-5, respectively. Thus, the effect of the shape is significant for L/B ≤ 2 and is of little importance forL/B > 5. This suggests that the anchors with aspect ratios of L/B > 5 effectively behave as a continuous strip and can be compared with the methods which obtain the plane strain conditions.

In contrast to the observations of Das and Seeley (1975), Rowe (1978) did not observe a critical embedment depth and strip anchor capacity was found to be continually increasing with the embedment ratio over the range of H/B=1 to 8. Murray and Geddes (1987, 1989) performed extensive chamber testing programs who performed the uplift load tests on horizontal strip horizontal anchor plates in dense and medium dense cohesion less soils with ϕ=43.6° and respectively ϕ=36°. Anchors were typically 50.8mm in width or diameter and were tested at aspect ratios (L/B) of 1, 2, 5 and 10.

Dickin (1988) performed horizontal strip anchor plates with aspect ratios of L/B = 1-8 at embedment ratios H/B up to 8 in both loose and dense cohesion less soils. The few number of conventional gravity tests were also performed and compared to the centrifuge data. Dickin concluded that the direct extrapolation of the conventional chamber box test resulted at a field scale, would provide over-optimistic predictions of the ultimate force for strip horizontal anchor plates in the cohesion less soils. Dickin studied the influence of the anchor geometry, embedment depth and the soil density on the uplift capacity of one-meter prototype horizontal strip anchor plate, by objecting 25mm models to an acceleration of 40g in Liverpool centrifuge. It was found that for the strip anchors uplift resistance expressed as dimensionless break-out factor, increases significantly with the anchor embedment depth and soil density.

3 EXPERIMENTAL FACILITIES

3.1 Model Box

The experimental programme was performed using the facility in the Geotechnical Laboratory of the Civil Engineering Department of the University of Cukurova. The apparatus used for model testing consists of a tank, a loading system and measurement system. The facility and a typical model are shown in Figure 1a and 1b. Tests were conducted in a test box made of a steel frame with inside dimensions of 0.70×0.70m in plan and 0.70m in height. Two side walls of the box consist of fibreglass plate and the other sides consist of steel plate (Bildik and Laman, 2010).

Loading tests were carried out on model rigid anchors fabricated from mild steel. The model anchors were square and rectangular, had thickness of 10mm. The load is transferred to the footing through a pull rod as shown in Figure 1a.

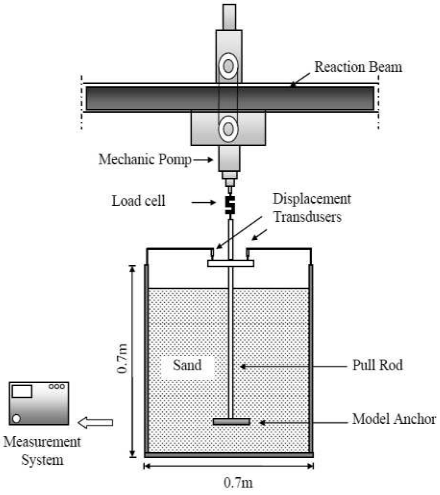

Figure 1a. Test set-up and loading system

Figure 1b. Test set-up and model box

3.2 Model Ground

Uniform, clean, fine sand obtained from the Çakıt River bed was used in this research. The sand was washed, dried, and sorted by particle size. The specific gravity of the soil particles was determined by the picnometer method. Three tests were carried out and the average value was obtained. The maximum and the minimum dry densities of the sand were measured. The particle size distribution was determined using the dry sieving method. Table 1 summarizes the general physical characteristics of the sand.

Table 1. Properties of sand.

Property	Unit	Value
Coarse sand fraction	(%)	0.00
Medium sand fraction	(%)	46.40
Fine sand fraction	(%)	53.60
D_{10}	mm	0.18
D_{30}	mm	0.30
D_{60}	mm	0.50
Uniformity coefficient, C_U	-	2.78
Coefficient of curvature, C_C	-	1.00
Specific gravity	kN/m^3	26.80
Maximum dry unit weight	kN/m^3	17.06
Minimum dry unit weight	kN/m^3	15.03
Classification (USCS)	-	SP

The sand bed was prepared up in layers 25 mm thick. Each layer was compacted by a hand-held vibratory compactor. After the compaction of each sand layer, the next lift height was controlled using scaled lines on the glass plates of the test pit. To maintain the consistency of in-place density throughout the test pit, the same compactive effort was applied on each layer. The difference in densities measured was found to be less than 1%. The compaction technique adopted in this study provided a uniform relative density of unit weights of 15.03kN/m^3 and 17.06kN/m^3.

3.3 Model Anchors

All model anchors were fabricated from 10mm thick mild steel plate. Tests were carried out on square and rectangular anchors (12.5x50mm, 25x50mm and 50x50mm). In the tests, the speed of the motor was adjusted to give anchor displacement rate of 0.96mm/min. The pullout displacement was transmitted to model anchor through the anchor rod, connected to loading arrangement..

4 TEST RESULTS

In this study, the main parameters investigated in the test program are the effects of the embedment and aspect ratio of plate anchors and relative density of sand on uplift capacity. The aspect ratios of the anchor are 1,2 and 4 and the embedment ratios of the anchor were varied from 1 to 8 in the tests.

4.1 The Effects of Embedment Ratio

In the tests, the effect of the embedment ratio of the uplift capacity was investigated. The uplift capacity of anchor plates were increased with embedment ratio. Typical plots for the uplift resistance-displacement behavior obtained from the experiment of the dense sand are shown in Figure 2 for rectangular anchors (12.5x50mm).

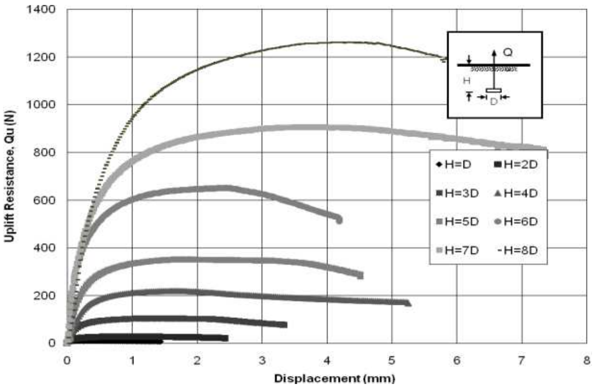

Figure 2. The effect of embedment ratio on uplift capacity ($L/B=4$, $\gamma_k=17.06kN/m^3$)

4.2 The Effects of Relative Density

In this study, the results are expressed in terms of break out factor (F_q) and breakout factor is calculated in the form $F_q=Q_u/\gamma*A*D_f$. Where A= area of the anchor plate, Q_u=uplift capacity, γ=unit weight of the sand and D_f=embedment distance of the anchor. In the study, excel used to fit the all curves. The relative density of loose sand is 35% ($\gamma=15.03kN/m^3$) and dense sand is 85% ($\gamma=17.06kN/m^3$).

The ultimate uplift capacity of the foundation is the sum of two components: (a) the weight of the soil and the foundation in the failure zone and (b) the shearing resistance developed along the failure surface (Balla, 1961). The weight of the soil increases with relative density and embedment ratio. In addition those, failure surface length increases with embedment ratio. Thus, the uplift capacity of anchors in sand is strongly influenced by their embedment ratio and by the relative density of the sand (Figure 3). The experimental results have shown that the breakout factor increases with embedment ratio. Relative density is the main parameter that affect the uplift capacity of anchor plates.

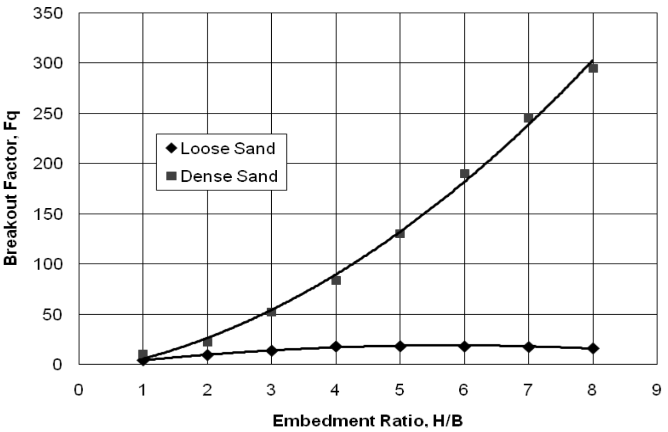

Figure 3. The effect of relative density on uplift capacity (L=50mm, B=12.5mm, L/B=4)

4.3 The Effects of Aspect Ratio

In the tests, the effects of the aspect ratio was investigated with different anchor plates (L/B=1, 2 and 4). The results have shown that breakout factors increase with increasing aspect ratio. The shape of the curve is convex in dense sand case (Figure 4) while it is concave in loose sand case (Figure 5). The following general equation was obtained from the curves given in Figure 4 and 5.

$$F_q=X\times(H/B)^2+Y\times(H/B)+Z$$

Equation has two coefficients and a constant. These parameters vary with relative density and aspect ratio. For the loose and dense sand conditions, coefficients and constant parameters are given in Table 2 and Table 3.

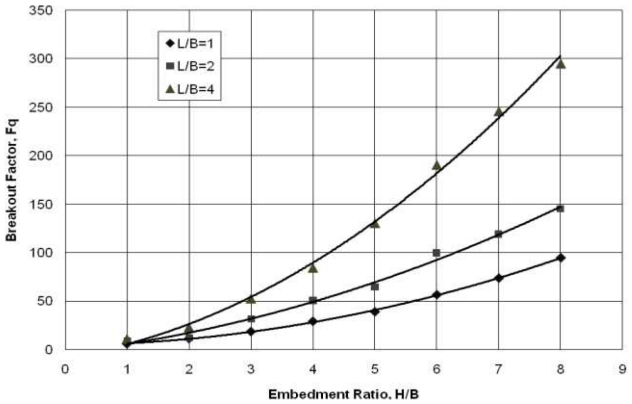

Figure 4. The effect of aspect ratio on uplift capacity in dense sand.

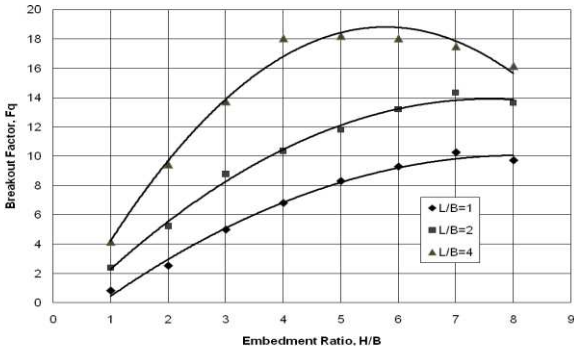

Figure 5. The effect of aspect ratio on uplift capacity in loose sand

Table 2. Coefficients and constant values for loose sand.

L/B	X	Y	Z	R^2
1	1.327	0.669	4.213	0.999
2	1.434	7.318	-2.901	0.993
4	3.619	9.804	-7.575	0.996

Table 3. Coefficients and constant values for dense sand.

L/B	X	Y	Z	R^2
1	-0.189	3.075	-2.431	0.992
2	-0.267	4.062	-1.500	0.993
4	-0.639	7.393	-2.54	0.985

5. CONCLUSION

Based on the laboratory investigations carried out on model anchors with three different geometry embedded at two different sand densities, the following main conclusions can be drawn:

- A general equation was obtained from the curves of breakout factor against embedment ratio for the loose and dense sand conditions.
- The aspect ratio and embedment ratio of anchor plates and relative density of sand are main parameters that affect the uplift capacity of anchor plates.
- The experimental results have shown that the breakout factor increases parabolically with embedment ratio in dense and loose sands. However the shape of the curve is convex in dense sand case while it is concave in loose sand case.
- Geometry of anchor plates has considerable effect on breakout factor considering the square or rectangular shaped geometry

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SYMBOLS

A : Area of anchor
B : Width of anchor
C_u : Uniformity coefficient
C_c : Coefficient of curvature
D : Diameter of anchor
D_f : Embedment depth of anchor
D_f/B : Embedment ratio of anchor
$(D_f/B)_{cr}$: Critical embedment ratio of anchor
L : Length of anchor
Q_u : Uplift capacity of anchor
α : Angle of failure surface
ϕ : Soil friction angle
γ : Unit weight of soil

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