Investigating the Pull-out Capacity of a Horizontal Plate Anchor Embedded in Sandy Soil

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Abstract. Anchor systems have been widely used recently due to its importance in increasing the stability of structures subjected to uplift forces and overturning moments. Accordingly, it is vital to investigate the parameters that might affect anchor systems' operational performance and structural behavior. The current study investigates the characteristics and parameters that might affect the uplift capacity of a horizontal anchor plate embedded in cohesionless soil. The sample of soil was brought from Al-Najaf province (Iraq). The parameters included are; plate embedding depth, the soil's effective dimension above the plate, and soil improvement by compaction. The model setup includes forming a steel container with dimensions (70 x 70 x 70) cm and a circular steel plate of 10 cm diameter. Three embedding depth ratios were chosen; these are 0.1, 0.2, and 0.3 of the total soil sample depth. Three effective soil diameters were chosen as percentages of the plate diameter; these are 1.0%, 1.5%, and 3%. According to the ASTM specification, several physical and chemical tests were carried out on the soil sample to determine its classification and needed engineering characteristics. The laboratory test results revealed that for both treated and untreated soil samples, the ultimate uplift capacity of the anchor plate increases with increasing the embedded depth of the anchor plate; for example, at improvement ratio (D/d=3.0), the ratio (P/Po = 1.05,1.28 and 1.6) for depth ratio (h/T=0.1,0.2, and 0.3) respectively. The values of the pull-out capacity of the anchor plate are increased with increasing the improvement area above the anchor plate; for example, at depth ratio (h/T=0.3), the values P/Po = 1.05,1.28 and 1.6 for D/d=1,1.5 and 3.0) respectively. Finally, the compaction technique can effectively improve the behavior of the anchor plate.

Keywords. Uplift capacity, Horizontal anchor plate, Cohesionless soil, Embedded depth, Improvement area.

1. Introduction

Many structures such as transmission towers, seawalls, buried pipelines, retaining walls, and tunnels are usually subjected to overturning moments and forces of a pull-out that may threaten their stability. The use of anchor systems is considered an effective technique to enhance foundation stability performance, as demonstrated in Figure 1 (Niroumand and Kassim, 2016, [1]). Thus, the use of anchor plate systems has been recently increased, and hence there has been increasing academic efforts to investigate their operational performance and the design parameters that might affect that performance. Anchor plates can be installed in horizontal, vertical, and inclined directions according to the direction of applied uplift loads. They are also made of several materials such as timber sheets, steel plates, cast, and precast concrete slabs. In general, anchors work like other foundation systems in that they earn their strength from the dead load of the soil mass surrounding them and from the shear
resistance developed along with the anchor. It is essential to mention that anchor plates installation does not require heavy machinery (Choudhary and Dash., 2013, [2]).

![Anchor plates](image)

**Figure 1.** Buried pipelines (Niroumand and Kassim, 2016, [1]).

The current study investigates the characteristics and operational performance of a horizontal plate anchor system model embedded in cohesionless soil. Parameters such as embedding length, effective soil diameter above the anchor plate, and compaction effect have been examined. The soil sample has been taken from the Al-Najaf Sea region in the Province of Al-Najaf in Iraq. Types of anchors and anchoring systems are being used widely all over the world. In Iraq, however, anchor foundations are of limited use, and thus there is a lack of relevant studies. Previous studies have shown that the anchor system's structural behavior and the shape of the surface of failure might greatly influence the failure loads and the load-deformation relationship. Figure 2 exhibits a distinct failure surface for a horizontal anchor plate (Niroumand and Kassim, 2016, [1]).

![Failure surface of the horizontal anchor plate](image)

**Figure 2.** Failure surface of the horizontal anchor plate.

Several theories and approaches have been produced to model the shape of the failure surface of anchor plates and hence computing their uplift capacity more realistically (Das and Shukla, 2013, [3]). Some of these theories were based on laboratory works, whereas the others were based on field tests. The most common ones are the soil cone method (Mors, 1959, [4]), Downs and Chieurzzi (1966), [5], Balla’s Theory (1961), [6], Vesic’s approach (1971), [7], Meyerhof and Adams (1968), [8], and Saedy’s Theory (1987), [9]. Accordingly, based on these theories, lots of studies have been devoted to examining the factors that might influence the analysis of anchor plate systems and their uplift capacity. Typical examples of such parameters include the type and shape of the anchor, type, and
characteristics of soil, and the method adopted to analyze the anchor plate system. Following are a brief of only the studies that include investigating horizontal plates in cohesionless soils. In Bangladesh, Ali (2001), [10], studied the uplift behavior of horizontal anchor plates in sands. The experimental part included carrying out a series of anchor pull-out tests in the laboratory. From the test results, it has been observed that anchor plates' load-displacement behavior is consistent with most of the similar investigations. Variations of breakout factor and displacement with embedment ratio also qualitatively satisfy most of the theoretical observations. El Sawwaf and Nazir (2006), [11] investigated the effect of soil reinforcement on pull-out resistance of an existing vertical anchor plate in the sand. They adopted an empirical research methodology with small-scale model tests in which steel rods have been used as model piles. Steel rods of various diameters and lengths were installed vertically or with an inclination angle. The results confirmed the viability of such soil reinforcement in modifying soil strength besides the pull-out capacity of the anchor plates. The uplift response of strip anchors in cohesionless soil was also estimated by Dickin and Laman (2007), [12]. They confirmed that there is a positive proportional relationship between break out factors (highest resistances) and both sand packing and anchor embedment ratio. According to the PLAXIS modeling, the uplift performance at pre-peak conditions of strip anchors in the sand can be modeled acceptably using the Hardening Soil Model.

Niroumand et al. (2010), [13] performed an experimental study of horizontal square anchor plates in cohesionless soil. They reviewed the results of several previous studies that tackled the pull-out capacity of square-shape anchor plates buried in the sand. A group of ten anchor plates of horizontal alignment, square shape, and various geometries and configurations was reviewed. Horizontal anchor plates have been found to participate in maximizing soil stiffness effectively. Depending on the reported results, several installing techniques and threshold values have been suggested. Any increase in the sand angle of friction or any increment in the embedment length may effectively raise the anchor’s uplift resistance.

Liu et al. (2013), [14], studied experimentally the pull-out capacity of a strip plate anchor installed in three sand soil samples (loose, medium-dense, and dense). The model plate anchor was with varying width (5 to 40) cm and with the depth of embedment ranges from one plate width to 12 times plate width. The three densities of the dry sands were 1.65 g/cm$^3$, 1.73 g/cm$^3$, 1.85 g/cm$^3$ (i.e., relative density, as 30%, 55%, 80%) with three angles of friction, $\phi$, 34°, 38°, and 43°, respectively. The analysis results showed how the load-displacement curves for loose sand are dissimilar from medium and dense sand. In the case of loose soil, there is a fast growth to reach the maximum uplift resistance and then starts going down steadily until the uplift strength attains its steady state. Niroumand et al. (2013), [15] explored the influence of soil reinforcement on the uplift response of a symmetrical anchor plate embedded in the sand. In this part of their research series regarding the performance of anchors under pull-out forces, Niroumand et al. (2013), [15] interrogated the uplift capacity of symmetrical anchor plates. The effect of reinforcing the soil with geogrid and grid fixed reinforced (GFR) has been examined. The scale model's design parameters included sand relative density, anchor embedment length, and the influential characteristics of geogrid and GFR reinforcement, such as the number of layers, size, and the nearness of the layer to the anchor plate. Choudhary and Dash (2013), [2] estimated the uplift behavior of horizontal plate anchors embedded in geocell-reinforced sand. Their empirical study explored the potential increase in the pull-out capacity for plate anchors buried in sand soil improved by using geocell reinforcement. The test results proved the evident impact of geocell reinforcement in maximizing the uplift resistance ability of plate anchors; in numbers, about 1.7 times higher than the case with no soil reinforcement. Johnson and Sandeep (2016), [16] estimated the ground improvement by using a granular pile anchor foundation. The tests showed that as the relative density for a 5cm pile was improved from 50 to 70%, a 35% rise in the anchor, uplift capacity was achieved. Similar behavior was obtained for pile’s diameter; as the pile’s diameter increases, an enhancement in granular pile anchor’s uplift capacity was gained. The same rise in the percentage of pull resistance (35%) was gained when the pile’s diameter increased from 3cm to 5cm at a soil relative density of about 70%. Finally, the results confirmed that when the pile is encased, the greatest enhancement of just over 13% in the ultimate uplift capacity was obtained for a 3cm pile. Giampa (2017), [17] performed an experimental study of plate anchor-soil interaction in the sand to develop a
novel anchor. As water depth increases, floating substructures would be the adequate means for installing wind turbines inside the sea. As a result, a good anchoring system becomes necessary. Choudhary et al. (2018), [18] examined the pull-out behavior of vertical plate anchor in granular soil. Their recent work examined the pull-out capacity of plate anchor with vertical alignment embedded in cohesionless soil. According to their results, plate anchors' failure displacement and load-carrying capacity depend largely on design parameters such as soil density and embedment depth. If the anchor is embedded at a shallow distance from the surface, the failure would be obvious, and its plane may reach the ground surface. In contrast, when the anchor is installed further far from the surface, the soil would experience constrained plastic deformation resulting in a localized failure around the vertical plate anchor. Their analysis results showed that the critical embedment ranged between (7h) when the soil is dense and (5h) when the soil with medium density or loose, where h represents the anchor plate height. A mathematical model has been created to estimate the load-carrying capacity of vertical plate anchors subjected to pull-out loading conditions. Rahimi et al. (2018), [19] inspected the impacts of using geocell to reinforce and improve the soil on anchor plates' pull-out capacity. The experimental tests needed for examining uplift resistance were performed in a test pit of almost full-scale. The experimental results revealed that the residual and peak anchor pull-out resistance capacities were greatest when using the geocell layer. Choudhary et al. (2019), [20] investigated the uplift capacity of horizontal anchor plates in geocell reinforced sand. Based on the results of the series of model tests, the unreinforced anchor plate endures an evident failure at a displacement of almost 3% of its width, while the presence of geocell in line with a layer of geotextile right under the geocell mattress remarkably strengthens the anchor’s uplift resistance by nearly 4.5 times larger than that of unreinforced sand and might withstand anchor displacement of higher than 60%. A very recent study was carried out by Srinivasan et al. (2020), [21] whereby the researchers have investigated the interaction effect regarding circular plate anchors that are closely spaced and installed at shallow depth in sandy soil that is layered and homogenous. A group of large-scale model tests was carried out. The field findings illustrated that group anchors with the effect of interaction endure larger displacement in line with a major decline in the uplift resistance at closer spacing. As with the case of individual anchors, the pull-out resistance of a group of interacted anchors rises as the embedment depth rises.

2. Experimental work
Several design parameters have been investigated to examine the pull-out capacity of horizontal plate anchor in sandy soil. These are anchor plate depth, anchor plate diameter, and soil characteristics. In the developed laboratory model, the anchor was embedded in three different depths represented as ratios of the plate depth from ground surface level (h) to the total soil thickness (T); these depths are h/T (depth of plate to a thickness of soil) = 0.1, 0.2 and 0.3. Three soil improvement diameters were tested, which are equal to 1.0, 1.5, and 3.0 of the anchor plate’s diameter. The uplift capacity was computed for the original and treated soil; the compaction was adopted as the soil improvement technique. The treated soil was placed into a steel box model as a cylindrical column above the anchor plate.

2.1. Soil properties
The soil used in the model tests was sandy soil from the Al-Najaf sea region in Al-Najaf province at a depth of 0.25 m below ground surface level. The site characteristics of Al-Najaf soil were determined to be used in the laboratory model tests. These characteristics include the physical and chemical properties of the soil and steel properties of the anchor plate. For the physical tests, the sieve analysis was performed according to the ASTM D422 on Al-Najaf sandy soil, and the results are listed in Table (1). The soil was classified as poorly graded sandy soil.

| $D_{10}$ | $D_{30}$ | $D_{60}$ | $C_u$ | $C_c$ | Soil Classification     |
|---------|---------|---------|------|------|-------------------------|
| 0.19    | 0.28    | 0.6     | 3.16 | 0.69 | SP (Poorly Graded Sandy Soil) |
Table 2 represents the values of the tests carried out on the soil sample in line with their corresponding standard specifications.

| Soil property                        | Specification | ASTM D698 | ASTM D1556 | ASTM D3080 | BS 1377 (1975) |
|--------------------------------------|---------------|-----------|-------------|-------------|----------------|
| Maximum dry density (kN/m³)          |               | 16.5      |             |             |                |
| Optimum moisture content (%)         |               | 10        |             |             |                |
| Field density (sand cone method) (kN/m³) |           |           | 15.51       |             |                |
| Water content (%)                    |               | 2         |             |             |                |
| Cohesion (kN/m²)                     |               | 0         |             |             |                |
| The angle of internal friction (deg.)|               | 31        |             |             |                |
| Gypsum (%)                           |               | 6         |             |             |                |
| Sulfate (%)                          |               | 2.8       |             |             |                |
| Organic materials (%)                |               | 5.7       |             |             |                |
| Electric conductivity                |               | 7.1       |             |             |                |
| PH                                   |               | 6.9       |             |             |                |

2.2. Model set up

The test container was made from a steel plate. The shape of the container was a cube with dimensions (70 x 70 x 70) cm. Figure (3) exhibits the steel box and the anchor plate model of the foundation, a circular steel plate of 10 cm in diameter. Three different steel cylinders were used to create the treated soil samples above the anchor plate; these are 10, 15, and 30 cm. The treated soil was spread inside the cylinder into many layers until reaching the ground surface level. The compacted (treated) soil was formed with unit weight and water content similar to those in the situ, unit weight of (15.5 kN/m3), and natural water content of (2%). The anchor plate was placed at three depths (6, 12, and 18 cm), then the compaction process continued until reaching the bed of the soil level. The soil sample dimensions for each model are 60 cm in height and 70 cm in both width and length.

![Figure 3. Steel cylinder.](image)

Figure (4) shows the two electronic dial gauges with a sensitivity of (0.01) mm installed to measure the upward displacement that occurred due to the uplift load. The container is provided with a steel arm used to support the steel wire required to generate the uplift load through two pulleys by a certain deadweight (see Figures 4 and 5). For each load increment, the deadweight was maintained for five minutes to allow displacement readings to stabilize with no movement. Anchor plate was embedded into the soil to constant depths (h/T= 0.1, 0.2, and 0.3). Figure (6) shows a schematic illustration for the model setup.
Figure 4. Fixed two dial gauges.

Figure 5. Experimental set-up.

Figure 6. Schematic of anchor plate set up.
3. Experimental results

3.1. Model tests for natural soil (Untreated Soil)

Figure (7) represents the circular anchor plate's load-displacement behavior with different embedment ratios (h/T); 0.1, 0.2, and 0.3. Each curve shows the effect of the incremental loads applied on the plate's displacement values before reaching its capacity. The embedment depth of the plate can affect the pull-out response as well as the shape of the failure surface. For the model test with shallow depth of the anchor plate (h/T=0.1), the uplift load reached its capacity at the lowest load application among all the three cases (90 N) (Displacement small compared with h/T = 0.2 and 0.3). The plate at an embedment depth of 0.2 has a different response to the load application but eventually reached failure at a load of 137 N. The test with a depth ratio of 0.3 required the highest load application (215 N) to reach failure.

![Figure 7](image)

**Figure 7.** Applied load versus displacement for untreated soil.

Figure (8) depicts images of the untreated soil tests at the failure state. The failure state can be noted in any model test. The significant loss of shear strength and continuous upward displacement of the ground surface increase with no further increase in uplift load increment. Only one crack was generated on the soil's ground surface as a circle shape with diameter equals the anchor diameter, and the failure wedge shape is similar to a cylindrical shape for model tests with shallow anchor plate ≤0.2. When the h/T=0.3, the diameter of the circular crack on the ground surface level is greater than that of the diameter plate, the failure wedge shape is like a truncated cone. The results of the present experimental work in terms of the pull-out capacity of anchor plate of model test with depth h/T=0.3 for the untreated soil were compared with many common theories such as Mors (1959), [4], Balla (1961), [6], Ireland (1963), [22], Vesic (1965), [7], Downs and Chieurizzi (1966), [5], Meyerhof and Adams (1968), [8], Veesaert and Clemence (1977), [23], and Saeedy (1987), [9]. The comparison showed reasonably good matching with Mors (1959), [4], and Veesaert and Clemence (1977), [23]. The discrepancy might due to the different terminology used in defining the stress at failure and soil type.

3.2. Load-displacement relationships for the treated soil

3.2.1. Model tests with shallow depth ratio (h/T =0.1). The effect of the compacted soil area on the ultimate uplift resistance of the circular anchor plate is presented in Figure (9).
Figure 8. Failure mode of anchor plate for untreated soil.

Figure 9. Results of model tests for depth ratio (h/T=0.1) at various treated area ratio (D/d) and with untreated soil condition.

The figure illustrates the variation of uplift applied load versus upward displacement at different values of the treated soil diameter to the diameter of anchor plate ratios (D/d=1.0, 1.5, and 3.0). No effect of compaction method can be observed when the improvement areas (D/d ≤1.5) due to small improvement areas, no effect of compaction can be observed, but when the ratio of the D/d equals 3.0, the performance improvement of the anchor plate can be noted. Figure (10) illustrates the photo images of model tests at failure load ultimate uplift resistance of the pile. The failure occurs when the incremental loading cannot be maintained, but with this sharp increase in displacements at the failure load, a sudden collapse of the anchor – soil treated system may occur. Also, many cracks can be noted on the ground surface level in all directions.
3.2.2. Model tests with intermediate depth ratio ($\frac{h}{T}=0.2$). In this section, the uplift load – upward displacement curves for all three treated model tests ($D/d = 1, 1.5$, and $3.0$) in addition to the untreated model test are similar to that of the curves in the previous section. In other words, the negative effect of compaction the values of the uplift capacity of the treated model test are lower than that of untreated model test improvement techniques with low ($D/d \leq 1.5$) can be observed when the embedded depth of the anchor plate is near from the ground surface level ($h/T \leq 0.2$), but it becomes as a positive for $D/d$ equals $3.0$ as shown in Figure (11). For example, at working uplift load of $80N$, the upward displacements are $0.02, 0.0$ from figure (11), $0.052, 1.1$, and $1.4$ for model tests with ($D/d=3, 1, 1.5$ and untreated case) respectively. The modes of failure are presented in Figure (12). Sudden damage may occur during the application of the uplift load increments for all model tests. The final bed of the soil surface level is puff up, and the disturbance and destroy around the bars of the anchor plate.

3.2.3. Model tests with deep depth ratio ($\frac{h}{T}=0.3$). The pull-out load is applied on the horizontal anchor plate incrementally. Figure (13) shows a typical relationship between the pull-out load and the corresponding upward displacement of a deep, circular anchor plate ($h/T=0.3$). In this case, the compaction method with any area ($D/d$) is very effective in increasing the ultimate uplift capacity and decreasing the anchor plate's displacements. This is due to rearrange the soil particles and reduce the void ratio. As ($D/d$) ratio increases, the effect of the compaction improvement on the behavior of the anchor plate increases. When the uplift load reached failure, the anchor plate penetrates the ground surface level with the development of cracks around the bar of the anchor plate, as shown in Figure (14).

3.3. Effect of the embedded ratio of the anchor plate with different areas of treated soil
For three series of model tests for horizontal anchor plates with pulling loading, the effect of plate depth can be named as shallow, intermediate, and deep anchor plates. Figures (15-17) demonstrate the combined effect of the anchor depth ($h/T$) and the area of the improvement soil by compaction technique above the anchor plate ($D/d$) on the anchor performance. With increasing the embedment ratio ($h/T$) at any value of ($D/d$), the uplift capacity of the anchor plate increases.

**Figure 10.** Images of the model tests at failure state at ($h/T=0.1$) with various treated area ratio ($D/d$).
Figure 11. Results of model tests for depth ratio (h/T=0.2) at various treated area ratio (D/d) with untreated soil condition.

a. \( \frac{D}{d} = 1.0 \)

b. \( \frac{D}{d} = 1.5 \)

c. \( \frac{D}{d} = 3.0 \)

Figure 12. Images of the failure wedges at (h/T=0.2) with various treated area ratio (D/d)

Figure 13. Results of model tests for depth ratio (h/T=0.3) at various treated area ratio (D/d) with untreated soil condition.
Figure 14. Deformations of model tests at (h/T=0.3) with various treated area ratio (D/d).

Figure 15. Uplift load versus displacement for different embedded ratio (h/T) at (D/d=1).

Figure 16. Uplift load versus displacement for different embedded ratio (h/T) at (D/d=1.5).
3.4. Anchored Plate Pull-out Capacity for treated soil

The maximum failure point is considered as the pull-out capacity of the anchor plate. The effect of compaction is represented as the ratio of pull out capacity of anchor plate for treated soil to that of untreated soil \( \frac{P}{P_0} \). Figure (18) illustrates the variation of the ratio \( \frac{P}{P_0} \) with the ratio of the diameter treated soil to anchor plate diameter \( \frac{D}{d} \). The figure shows that the ratio \( \frac{P}{P_0} \) increases due to the increased area treated of soil above the anchor plate when the plate depth \( \frac{h}{T} = 0.1, 0.2, \) and 0.3).

Figure 17. Uplift load versus displacement for different embedded ratio \( \frac{h}{T} \) at \( \frac{D}{d} = 3.0 \).

Figure 18. Effect of diameter of treated soil by compaction on pull out capacity of anchor plate.

The relationship between the ratio \( \frac{P}{P_0} \) and the anchor plate depth \( \frac{h}{T} \) is presented in Figure (19). When the region of treated soil is greater than the plate diameter condition, the peak value of the ratio \( \frac{P}{P_0} \) can be noted at \( \frac{h}{T} = 0.1 \) and 0.3, while for \( \frac{h}{T} = 0.2 \) condition, the minimum magnitude of \( \frac{P}{P_0} \) can be observed. With increasing the \( \frac{h}{T} \) ratio, the \( \frac{P}{P_0} \) value increases when the treated soil's diameter is equal to that of the plate.
Figure 19. Effect of plate depth and diameter soil treated by compaction on the pull-out capacity of the anchor plate.

Figures (18) and (19) are represented as a mathematical equation (1) using regression analysis by MS-Statistica. Figure (20) shows the relationship between predicted and observed (P/Po) values. The (R2) coefficient is equal to 0.97.

\[
\frac{P}{P_o} = C_1 \left( \frac{h}{T} \right)^{C_2} + C_4 \left( \frac{h}{T} \right)^{C_3} \exp \left( \frac{D}{\pi} \right) - C_1
\]  

(1)

Where the values of the coefficients are as the following:

\[C_1=426.1, \quad C_2=-0.00048, \quad C_3=5.5, \quad C_4=0.00935, \quad C_5=0.6405\]

Figure 20. Relationship between predicted and observed (P/Po).
4. Conclusions

Based on the obtained findings, the following main conclusions can be drawn:

1- Generally, the increase in the ratio of the compacted soil diameter to the anchor plate diameter (D/d) can effectively improve the performance of the anchor plate.
2- For all the treated and untreated soil model tests, the anchor plate's ultimate uplift capacity increases with increasing the embedded depth of the anchor plate.
3- For the untreated soil tests and during the applied load, only one crack was generated at the soil's ground surface as a circle shape with diameter equals the anchor’s diameter. The failure wedge shape is cylindrical for the tested model with a shallow anchor plate ≤0.2.
4- A failure state for the untreated model with anchor depth h/T=0.3, the circular crack diameter on the ground surface level is greater than that of the diameter plate. The failure wedge shape is like a truncated cone.
5- The reverse effect of compaction improvement techniques with (D/d ≤ 1.5) can be observed when the embedded depth of the anchor plate is near the ground surface level (h/T ≤ 0.2), but it becomes with positive effect for (D/d=3.0).
6- For compacted soil, the wedge failure is a truncated cone, the top area equals the improvement area, and the bottom area equals the anchor plate. Also, many cracks can be noted on the ground surface level in all directions.
7- At a deep anchor plate (h/T=0.3), the compaction technique effectively increases the ultimate uplift capacity and decreases the displacements of the anchor plate.
8- The ultimate uplift capacity of the anchor plate increases with increasing the embedded depth of the anchor plate; for example, at improvement ratio (D/d=3.0), the ratio (P/Po = 1.05,1.28 and 1.6) for depth ratio (h/T=0.1,0.2, and 0.3), respectively.

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