Performance improvement of vertical anchor plates in sandy soil by using geogrid reinforcement

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Abstract. The stabilization of an anchoring system plays a significant role in geotechnical engineering structures. To develop a clear understanding of the vertical plate anchors behavior due to geogrid reinforced soil under various pullout load inclination ranging from (0, 25, 45, 60, and 90) degrees in Cohesionless soil, a series of total (34) tests were carried out. The soil has been investigated by using small-scale model tests. Geogrid with different width and heights placed (vertically or horizontally in front of the vertical anchor plate at different locations were used to reinforce a soil mass in front of square anchor plates. The studied parameters include reinforced soil mass width, soil mass height, the location of geogrid-reinforced soil mass, effect of water content increase, and the inclination angle of pullout load. The test results indicate that Geogrid reinforced mass in front of a vertical anchor plate significantly increases the stiffness of the soil and increases the pullout resistance of shallow anchor plates. According to test outcomes, critical situations also were stated and discussed.

1. Introduction

Ground anchors have become an essential component in modern construction techniques. A huge development plan is expected in Iraq, therefore, the use of ground anchors is expected to be used in supporting and preventing sudden failure of large structures such as bridges, tunnels. With the development of several special lightweight structures like radar towers and lattes transmission towers, it was essential to design and construct a special tension anchorage system, since wind loads may cause reactions more than the structures’ one-weight. Anchor plates could be applied for a wide diversity of uses, such as for stabilization of tunnels, aircraft moorings and to tie back resistance of retaining walls, sea walls, and pipelines. The capacity of anchor plates is mostly generated from the passive force forced by the soil in front of the anchor plate\textsuperscript{[1]} Tian, Y.A., Randolph, M.F. & Cassidy, M.J. 2015\textsuperscript{[1]}. Even with a perfect soil condition, there still will be some movement, which might threaten the stability of the anchoring system. The pullout capacity of the vertical anchor plate depends on soil condition in the construction site, if the plate has been placed in loose soil it will move, and the tension on the threaded cable will be lost and the structure will no longer be stabilized. The major concern is of this paper is to improve the soil placed in front of the vertical anchor plate to increase the pullout capacity. The placement of tensile reinforced soil mass significantly improves the bearing capacity and the soil stability at various pullout load angles.
2. Experimental setup
Figure 1 illustrates the experimental setup tank-loading system, having inside dimensions of \((1\times1\times1)\) m\(^3\) with a front door used to carefully observe any changes in the soil layers due to the pullout load. The internal walls of the tank have been coated to reduce friction between the tanks’ walls and the soil. The loading structure consists of 6 mm steel wire connected to a \((10\times10)\) cm\(^2\) in area and \((1)\) cm thickness rigid steel anchor plate passing through pulleys ending to a steel hanger. The anchor plate was placed in a 50 cm sand bed at a distance \((27)\) cm far away from the front of the tank. The steel pulleys were placed in a position to achieve the exact load angle. The two faces of the anchor plate were coated to minimize the friction effects. The load was transferred to the anchor plate by the steel wire which is connected to the midpoint of the anchor plate by a steel nut, and the two dial gauges were located in the opposite direction of the loading to measure the lateral displacement of the anchor. Four dial gauges were located at the surface of the soil at intervals \((-10, 0, +10, +30)\) cm to investigate the soil deformation at the surface. Figure 2 illustrates the clarification of the intended symbols.

![Figure 1. Schematic diagram of the model test set-up.](image1)

![Figure 2. Clarification of the intended symbols.](image2)
3. Materials properties
Locally available sand brought from the Al Najaf city in Iraq has been used in the experimental work. Physical and chemical test results are summarized in Table 1. According to the Unified soil classification system (ASTM D 422) [2], the sand can be classified as sand poorly graded (SP). The soil’s specific gravity was determined according to (ASTM D854) [3], which was found to be 2.65. According to (ASTM-D698) analysis, sands maximum and minimum dry density were found to be 19.95 and 14 kN/m$^3$ respectively. The shear strength parameters of the soil were determined in the laboratory using direct shear tests, (ASTM D3080) which were found (c = zero, $\Phi = 31$ degrees). The physical soil properties are summarized in Table 1.

| Soil property                          | Specifications          |
|----------------------------------------|-------------------------|
|                                        | ASTM D698 | ASTM D1556 | ASTM D3080 | BS 1377 (1975) |
| Maximum dry density (kN/m$^3$)         | 19.5       |            |            |                |
| Optimum moisture content (%)           | 10.5       |            |            |                |
| Field density (sand cone method) (kN/m$^3$) | 14        |            | 15.5       |                |
| Minimum unit weight (kN/m$^3$)         | 15.5       |            |            |                |
| Water content (%)                      | 2          |            |            |                |
| Cohesion (kN/m$^2$)                    | 0          |            |            |                |
| The angle of internal friction (deg.)  | 8.98       | 4.18       | 0.76       |                |
| Gypsum (%)                             |            |            |            |                |
| Sulfate (%)                            |            |            |            |                |
| Organic materials (%)                  |            |            |            |                |
| TDS                                    |            |            |            |                |
| Relative density (%)                   | 34%        |            |            |                |

4. Test procedure
A parametric study was conducted to investigate the soil improvement effect on the pullout resistance of a vertical plate anchor embedded at shallow depth (H/h = 4) with the use of a small-scale model test as illustrated in figure (1). A total of (34) tests were performed by placing two different volumes of geogrid reinforced soil mass ($0.4 \times 0.15 \times 0.1$ m$^3$ and $0.1 \times 0.15 \times 0.1$ m$^3$) in front of the anchor plate. , Netlon ltd British company manufactures geogrid used in all experiments. To ensure volume achievement of geogrid improved mass a (1) mm steel molds were used for forming the reinforced soil volumes.

A sand bed of (50) cm at field density was located on five equal layers each layer was (10) cm in height. The layers were compacted to the field density with 2% water content. Each successive layer was typically compacted uniformly until the desired height was reached by using a 5-kilogram steel plate of (0.2x0.3x 1) m3 connected to a steel handle in a grid pattern of (0.2x0.3) m2. When the anchor plate was placed in position at a constant depth of 0.4 m, a geogrid reinforced soil mass was located in front of the anchor, after which four other layers were placed above the anchor plate and compacted in the same way mentioned before to finally achieve 9 layers. A load was applied incrementally in a stress control manner by the addition weights at different load inclinations (0, 25, 45, 60, and 90) degrees. Every load has been maintained until the dial gauge reading keeps constant. After reaching a stabilized state of load-displacement, loading was continued. Vertical deformations, at the soil surface, was measured too by using four dial gauges located at the surface on small pins. , one was placed just above the anchor plate and the second was 10 cm before the anchor plate and two other dial gauges were placed at (10,30) cm away from the anchor plate. At each load stage, the horizontal displacement and vertical deformation at the top of the soil surface were noted. At the end of the test, the door of the steel tank
was open and the soil was carefully removed to observe the movement of soil layering to identify the failure zone. Fig. 3 clarifies the direction of geogrid placement in the experimental work.

![A-Vertical Geogrid vs B-Horizontal Geogrid](image)

**Figure 3.** Direction of geogrid placement.

### 5. Results and discussion

#### 4.1. Effect of the geogrid width at a horizontal pullout load

The influence of geogrid width on vertical anchor plate performance is depicted in figure 4. It is obvious that with increasing the geogrid reinforced soil width to B/b =4, significantly improved performance has been induced in which beyond that width improvement performance became less. As a result With increasing the width of geogrid from 1b to 4 b, the lateral displacement reduced about 62.5 %. As a result, a formalization of a semi, rigid mass in front of a vertical anchor plate redistributes, the stress over a larger number of ribs leading reduce the lateral displacement and enhance pullout capacity.

![Width Influence of Geogrid Improvement](image)

**Figure 4.** Width influence of Geogrid improvement.
4.2. Effect of the geogrid height at a horizontal pullout load

Figures 5, reflect the behavior of a vertical anchor plate improved by geogrid reinforced soil mass with two different improvement height conditions (H/h = 1 and 4). It seems that performance improvement with increasing the height up to H/h = 4, was found to be negligible. This is probably attributed to the stress concentration that, causes yielding is generated near to the vertical anchor plate area. The same results were reached by [4] which found that for (H/h >3), "there is no considerable effect of geogrid height. on the anchor plate's performance" Also, it was reached that, the height influence for geocell reinforcement located in front of the vertical anchor plate, for H/h>2.8 was found to be marginal [5]. However, it should be mentioned that although the height of improved mass did not affect the vertical anchor plate capacity, it was observed that the use of (H/h=4) reinforced soil mass has induced a stable behavior on the soil surface, this is attributed to the increase of rigidity of improved mass that enables the improved mass to stand against pullout load leading to a reduction in the vertical deformation (heave-settlement).

![Figure 5. Comparison between height influences.](image)

Figure 6, shows a comparison between vertical deformations due to the reduction of improved mass height at 1223 N load. It is of interest to note that the settlement-heave values at the soil surface with geogrid improvement have reduced to 80%, 70 %, respectively. Hence, it can be said that with the reduction of improved mass height the vertical deformation tends to be relatively much more

![Figure 6. Height influence on surface deformation.](image)
4.3. Influence of geogrid improved mass location at horizontal loading
Six series of model investigations were conducted to examine the influence of geogrid soil reinforced soil mass closeness to the anchor plate for both sizes of geogrid located at (X/b=0, 1 and 2) as seen in Figures 7 A and 7 B. It is clear that for B/b =4 widths, the increase in the performance improvement was significant at a distance of (X/b≥1) while with B/b =1 the best position for geogrid reinforced soil mass is at a distance of, (X/b ≤1). The same results were reached by [6]. He examined the placement of geogrid at distance "0.1H, 0.15H, 0.2H, 0.25H", he reached that the best location of geogrid was at a distance of 0.15H, from the loaded area.

![Figure 7. Distance improvement of Geogrid reinforced mass.](image)

4.4. Effect of geogrid direction at horizontal load
Figure 8 reflects the behavior of the vertical anchor plate when the geogrid is placed horizontally or vertically to the load-direction. The anchors capacity of the horizontal geogrid increased more than that for a vertical geogrid layer. It is of interest to note that the rupture surface is starting from the lower edge of the anchor and that the lower edge was exposed to a greater pressure than the higher edge therefore with the use of horizontal geogrid higher results were reached were. Similar results were reached by [7]. This is probably because of the higher concentration of generated stress due to the strong contact of the surrounded soil, which is more active at the lowest edge of the anchor plate, while at the upper edge, the soil mass falls into the space shaped behind the anchor, thereby relieving the contact between soil and the anchor plate. Besides that, a loose soil mass will reduce the passive pressure, as a result of which stress at the upper edge of the anchor plate reduces.
Figure 8. Direction of Geogrid influence.

4.5. Influence of a horizontal geogrid layer location
Figure 9. reflects the behavior of the vertical anchor plate due to a horizontally geogrid reinforced soil mass placed in front of it. It is obvious that as close as the improved soil mass to the vertical anchor plate (X/b <1), a higher resistance was obtained. In another word, the best location seems to be at a distance of b or attached to the anchor plate, this result confirms that the failure plane starts forming from the lower edge of the anchor plate and as the geogrid reinforced mass placed close to the anchor plate it probably intercepts the failure plane which starts forming from the lower edge of the anchor plate.

Figure 9. Distance improvement of Geogrid placed horizontally.

4.6. Width Influence of geogrid reinforced soil at 25-degree load angle
The influence of geogrid improved mass width on the performance of a vertical anchor plate at 25 degrees pullout load is depicted in figure 10. It is obvious that with the increase of width up to 4b the holding capacity of the anchor plate increased 50%. This is assigned to the significant increase of flexural rigidity of soil confinement and the load distribution over a wider area. With the reduction of
width, further, the improvement was much less. Hence, a \( B/b =1 \) width can be considered as a critical case.

![Graph](image)

**Figure 10.** Width influence on geogrid performance.

4.7 Width Influence of geogrid reinforced soil at 45 deg. load angle
Figure 11 reflects the effect of geogrid reinforced soil mass width \( (B/b=1 \text{ and } 4) \) on the vertical anchor plate performance. It obvious that the anchor plate's capacity increased significantly with the increase of improved mass width, it is expected that most of the rupturing soil mass to be intercepted. Besides that, the moment of inertia and rigidity of improved soil mass will increase. Moreover, the load will distribute over a larger area leading to enhance all the anchorage systems. As a result, the pullout capacity increased by increasing the width to \( 4b \) about 57%. The reduction of width reduced 22% of the anchor plate capacity.

![Graph](image)

**Figure 11.** Width influence on geogrid performance.

4.8 Width Influence of geogrid soil reinforced mass at 60 deg. load
The behavior of a vertical anchor plate subjected to a 60-degree pullout load angle and reinforced by two different soil masses \( (B/b =1 \text{ and } 4) \) is demonstrated in Figure 12. It can be observed that with
increasing the geogrid width to 4b a significant improvement has induced leading to a significant increase in anchor plate capacity. The holding capacity of a vertical anchor plate improved by larger soil mass carries 28% more load. In other words, the capacity of the vertical anchor plate was influence by the width of improved mass. This can be explained by the fact that with the increase of width the stress will distribute over a wider area leading to reduce load concentration, besides that the flexural rigidity and confinement of improved mass will increase and the improved mass will serve as a semi-rigid structure.

![Figure 12. Width influence on geogrid performance.](image)

4.9. Influence of water content of geogrid reinforced soil mass (B/b=4) at 60 deg. load

Figure 13 reflects the behavior of the vertical anchor improved by a geogrid reinforced soil mass having a width of (B/b=4) due to the increase of percent of water content added. It is clear that geogrid performance has reduced as the water content increased, this is probably due to the reduction of the friction coefficient between the Geogrid and soil, besides the change of interface frictional behavior due to water presence as the water content increased, as shown in figure (13).

![Figure 13. Influence of water content on geogrid performance.](image)
4.10 Width Influence of geogrid improved mass at a 90-degree load angle

Figure 14 illustrates the behavior of a vertical anchor plate pulled at a 90-degree load angle and improved by two different geogrid masses. The capacity of the anchor plate is not influenced by the width of improved mass placed in front of it. This might be due to the anchor plate's movement upwards. The capacity of the anchor plate is influenced by the friction generated between the anchor plate and the stiff improved mass placed in front of it.

![Graph showing pullout load vs. pullout displacement](image)

**Figure 14.** Width influence on geogrid performance.

4.11. Failure mechanism

After reviewing the literature, it is obvious that the rupture performance of vertical anchors has not been fully explained. Therefore, the load-carrying capacity of vertical anchor plates is estimated out of various assumed failure mechanisms, such as linear, bilinear, composite, logarithmic spiral, logarithmic spiral, and circular, although discrepancy continues to vary between the predictions and measurement.

There have been many studies assumed to study the failure technique related to the uplift of plate anchors in sand. From these investigations, several types of failure mechanisms have been recognized by [8]. The failure mechanism has coincided with that of Terzaghi's theory, which suggested that the anchor plate would fail through the ground without making a shear plane extending to the ground surface [9] and was similar to that of [10 and 11] theory. They reached that, the passive pressure was progressing in front of the plate anchor and the active pressure behind the plate. Besides, simulating the failure of the ground was extended to the maximum passive resistance, It was observed in the present work that the improved mass in front of the anchor plate intercepts the rupture plane and forces the plane to the unimproved soil zone lying ahead therefore, the size of the rupture surface significantly increased. Figure 15 clarifies the failure mechanism before and after soil improvement. The failure plane was close to the logarithmic linear and that. It was established that a large mass of soil was participating against soil failure. This is probably due to the dilatancy performance of soil which increases due to the increase of soil density leading to an increase in the angle of soil sliding mass. At the end of each test, the angle of the slip surface was carefully measured. It was found that for unimproved soil the slip angle was approximately 39.8 degrees. Figure 16 clarifies the slip angle of natural soil. For natural soil placed in the slip angle was increased. Similar results were reached by [5]. Figure 17 illiterates the Rupture surface for a shallow anchor plate.
4.12. Comparison with impervious work

So many researchers were concerned in considering the holding pullout capacity of a vertical anchor plate under horizontal loads. The experimental outcomes of the current work for cohesionless sandy soil without improvement were associated with many theories by using (Non-Dimensional pullout force coefficient) for horizontal pullout loading such as [12], proposed a method to estimate vertical anchor plates ultimate holding capacity by using Rankine lateral earth pressure. It was assumed that the passive pressure ($p_p$) and active pressure ($p_a$) to be generated in front of and behind the vertical anchor plate. Meyerhof [8], applied the passive and active coefficients to compute the ultimate capacity; Neely et al [13] investigated the vertical anchor plate holding capacity depending on the horizontal and vertical components of passive force that face the anchor plate. They assumed the rupture surface pattern is characterized by a line generated from the base of the anchor plate in association with a rupture zone comprising of Rankine and a logarithmic spiral. Basudhar and Singh [14] are rigorous in the theoretical sense since it does not need any expectations to be made related to the shape of possible failure shapes in the investigation of anchors [15]. Empirical equations have been developed for predicting the pullout capacity [16]. Hoshiya and Mandal [17] used a laboratory test to conduct the failure load of a vertical anchor plate. Table 4.1 illustrates a Comparison among the present
work values of non-dimensional pullout force coefficient with the values of the impervious work; it seems that the present work result showed a good matching with [10, 12, 13, 17 and 18]

### Table 10.1 Comparison with previous work [19]

| References                        | Mqy | γ  | Φ  | H /h |
|-----------------------------------|-----|----|----|------|
| Das and Seely [16]                | 74  | 15.92 | 34 | 5    |
| Rankin [12]                      | 34.3| 15.5 | 34 | 4    |
| Basudhar and Singh [14]          | 78.5| 16  | 38.5| 5    |
| Meyrhof [8]                      | 34.4| 15.5 | 31 | 4    |
| Hoshiya and Mandal [17]          | 62  | 14.12 | 29.5| 4    |
| Akinmusurn [18]                  | 60  | 15.55 | 35 | 4    |
| Dickin and Leung [20]            | 62.5| 16  | 41 | 5    |
| Neely et al [13]                 | 75  | 15.9 | 38.5| 5    |
| Experimental work                | 63  | 15.5 | 31 | 4    |
| Ovseen and storman [10]          | 66.7| 15.5 | 31 | 4    |

5. Conclusion

- Generally, the results of model tests have shown that the geogrid improved soil mass placed in front of a vertical anchor plate has a significant effect in increasing the pullout capacity.
- The lateral displacement of (geogrid) improved soil mass with B/b =4 placed in front of a vertical anchor plate when subjected to a horizontal load has increased the pullout capacity much more than the case of a soil mass with B/b = 1.
- A significant reduction in the vertical deformation was reached due to the increase of reinforced soil mass height.
- It can be noted that the reduction of the geogrid improved soil mass width to (1) b can be considered as a critical case since the capacity of the anchor plate increased only 9.5%.
- The anchor plate performance continues to intercept the majority of rupture surfaces even when the reinforced soil mass is placed at a distance of 2b.
- The anchors' capacity was influenced by the direction of geogrid placement, in which horizontal geogrid showed higher performance improvement.
- The load-deformation response of a vertical anchor plate display clear failure as the load angle increases, as a result, cracks showed at the soil surface.
- Geogrid is influenced by the percentage of water content added to the soil as the pullout capacity is reduced with the increase of water content.
- At a 90-degree load angle, the anchor plate capacity is not influenced by improved soil mass width.
- The failure plain was close to the logarithmic linear.

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