Influence of Water on Anchor Plate Behavior in Sandy Soil with and Without Improvement

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Abstract. Plate anchors are one of the most common types of ground anchors used in foundation systems, as they transfer loads from the foundation to the soil to prevent overturning the foundation and overcome the forces that could threaten the integrity of the structure. The present work concerns the study of the combined effects among the behavior of the anchor plate in sandy soil with and without water presence as a static state at a different head level (h=15, 30, and 40 cm) above the base of the anchor plate and for two states of the soil with improvement by geogrid at various location and without improvement. The soil sample was brought from AL-Nidaa district in the city of AL-Najaf (Iraq). The highest value of the ultimate uplift capacity is observed when the geogrid layer is adjacent to the anchor plate for dry and submerged cases of the soil. The negative effect of the presence of the geogrid layer appears when the water table level rises above the ground surface level.

Keywords: Sandy soil; uplift capacity; anchor plate; geogrid layer.

1. INTRODUCTION

Anchor plates are the most useful of soil anchors. They are lightweight elements that transmit forces from the structure to the ground to resist pullout forces and overturn determinations. Anchor resistance is improved by shear strength and dead weight of soil above an anchor [1]. They are also economical and efficient elements that support the structure against overturning and pullout loads. The plate anchor is one type of anchor that is the most commonly used to resist great uplift forces when tall structures such as transmission towers, chimneys, wind turbines, utility poles, etc. are performed [2] where the governing is the horizontal force coming the wind, earthquake, seepage, etc. The use of anchors is suitable in many applications when the weight of a structure is light or less than the external, which may cause uplift displacement or overturning movement. Then, using anchors gives an advantage to increase the structure's resistance and, therefore, its stability [3]. Additionally, anchors are used to tie down structures where they provide resistance when hydrostatic or overturning loading because uplift forces, also for structures subjected to sliding, overturning, and earthquake loading can provide additional resistance [1]. Published information presented in the literature about the influence of water on the behavior of the anchor plate subjected to pullout forces is generally few. In this study, the influence of a few parameters is presented, such as: (the use of geogrid layer improvement or not, the location of the geogrid layer, and the presence of water at different levels where all these parameters combined were not studied in a previous experimental study. There are many experimental and numerical researches to investigate the performance of plate anchors under the influence of pullout loads.

Rahman [4] studied the effect of the groundwater table on the pullout capacity of a vertical plate anchor is placed in frictional soil. The research adopted the numerical approach by taking advantage of the finite element program PLAXIS-2D to discover the decrease in the pullout resistance of the vertical anchor plate when it is submerged in water. In addition, the study investigated the effect of an embedment ratio on the capacity of an anchor where it chose two embedment ratios (H/B=3 and H/B=5) where H: is the distance between the bottom of the anchor and the ground surface B: is the width of the anchor. The effect of the internal friction angle was considered, which represents soil resistance by using different values of (Ø = 20°, 30°, 40°). The results of this study were verified where by it had good agreement with the results of Merifield and Sloan (2006) and Kumar and Sahoo (2012). The study demonstrated that the pullout capacity of an anchor was affected significantly by the groundwater, as it lost almost 40 % of its capacity.

Sakib [5] analyzed the effect of fluctuation of phreatic level on the pullout capacity by using the finite element method (FEM) in PLAXIS 3D. The methodology involved repeating several embedment depth ratios and phreatic levels and recording load versus displacement. The numerical results revealed that the ultimate pull resistance of the vertical anchor plate loses 50% of its resistance in the case of dry soil when the phreatic surface rises to the ground surface. At the same time, no effect appears and gives the maximum ultimate pull capacity when the water surface is close to the bottom of the anchor plate.

Choudhary [6] carried out an experimental model test on groups of horizontal square anchor plates in sand soil reinforced using an improved geogrid layer. The dimensions of the model tank are (1.5m *1.5m) and 1m in height. All tests were carried out with a fixed embedment depth ratio (H/B= 4) where H: embedment depth of anchor plate and B: width of anchor plate. The models were divided into two groups. The first includes an unreinforced anchor plate, and it contains a group with two anchor plates and a square group in two rows (four anchor plates), while the second group contains anchor plates reinforced using geogrid. In this group, various factors were studied affecting the behavior of the anchor group, including the size of geogrid reinforcement (1 m*5.4 m), (3 m*7.4 m), (5 m*9.4 m) and (7 m*11.4 m), as well as tests were conducted with a different number of layers of the geogrid (0, 1, 2, and 3) layers.

The mentioned factors in this group were studied on an isolated anchor plate consisting of two anchor plates and a square group with four anchor plates. The results of model tests were compared with numerical analysis using FLAC ^{3D}, which is the three-dimensional finite-difference. The simulation shows good agreement for the groups of anchor plates in unreinforced and reinforced soil masses. The conclusions of this study: 1) In the group of unreinforced soil, it was proved to be (3.4*B) the optimum spacing between two anchor plates where B: is the width of the anchor plate. 2) It was observed that the unreinforced anchor plates appear a clear failure at a displacement of about 5% of their width, while reinforcement with geogrid anchor displacements can continue more than 45%. In addition, the pullout load of the groups two-fold increases that of the unreinforced case. 3) The study demonstrated that b/B = 5 and l/B = 9.4 are the optimum width and length ratio, giving the best performance improvement of groups of two anchor plates where b and l are the width and length of geogrid, respectively. 4) Using one layer of geogrid reinforcement improves the ultimate pullout load capacity of the groups of anchor plates. Any increase in the number of layers has little effect on the performance of the group. 5) The performance improvement was observed to be ultimate for single anchor plates, and then it started to decrease with increasing number of plates (groups of anchor plates = 2×1 and 2×2).

The study deals with the change in the behavior of the anchor plate when the water oscillation can occur due to temperature change, dewatering, etc. This is an actual problem in Al-Najaf soil site after the implemented construction of an anchor.

2. EXPERIMENTAL WORK

A small-scale laboratory model is used to explain the effect of water on the uplift capacity and deformations of the anchor plate embedded into treated and untreated sandy soil. The steel anchor plate of 10 cm in diameter is placed at a certain depth (D/d=3) where D: is the constant anchor plate depth of 30 cm and d: is the diameter of circular plate anchor= 10 cm. Ilampruthi [7] proved that for a specific embedment depth, the non-dimensional (breakout factor) remains almost constant for anchor sizes greater than 10 cm. Therefore, the anchor diameter of this size was chosen in this study. Figure 1 illustrates the steel box with (70x70x70) cm interior dimensions. One side of the container can be opened (door) to select the shape and pattern of the failure lines generated from the anchor plate to the soil surface (failure wedge). The uplift anchor load was applied through a flexible wire with two pulleys to ensure the dead load was vertical.

Figure 1: Photograph of the model test setup.

2.1 Soil Used

A sandy soil was brought from AL- Nidaa district in the city of AL-Najaf. The sandy soil is classed as a poorly graded sand (SP) according to the Unified soil classification system ASTM D2487 [8] after calculating the values of (D_{10}, D_{30}, and D_{60}) from the results of the sieve analysis test ASTM D422 [9] depending upon table1. According to ASTM D854 [10], the specific gravity was 2.57. The maximum dry density and optimum water content of sand were found to be 17.422 kN/m^3 and 12.5%, respectively, ASTM-D698 [11], while according to ASTM D4254 [12] the minimum dry density was 13.077 kN/m^3. Direct shear tests ASTM D3080 [13] are performed in the laboratory; the values of the shear strength parameters are c = 18.46 kN/m^2, ϕ=40.57 degrees for dry case, and it becomes c = 12.5 kN/m^2, ϕ=35.51 degrees for submerged case. In addition, the natural water content was 2.35%, according to ASTM D2216 [14]. Table 1 summarizes the findings of physical and chemical tests. The chemical tests were conducted according to British Standards [15].

The soil used is compacted into a steel container in [12] layers with a height of 5 cm by using a steel tamping hammer weighing 5.67 kg and evenly distributed. Six layers are compacted as bed soil, and the other six are compacted above the circular anchor plate of 10 cm in diameter and placed at a constant embedment depth with (D/d = 30 cm/10 cm= 3). The unit weight of sandy soil used is equal to 95% of a maximum density of 17.422 kN/m^3 and a relative density of 83%.

Table 1: Results of physical and chemical properties of the sandy soil.

Test	Index properties		Value	Specification
Sieve analysis test	Passing 4.75 mm, %		96.2%	ASTM D422
	Passing 0.074 mm, %		3.3%	
	D_{10}, mm		0.166	
	D_{30}, mm		0.290	
	D_{60}, mm		1.040	
	Coefficient of uniformity, Cu=D60/D10		6.265	ASTM D2487
	Coefficient of gradation, Cc=(D30)^2/(D10*D60)		0.487	
	Soil classification		SP(Poorly graded sand)	
Compaction test	Maximum dry density, kN/m^3		17.422	ASTM D698
	Optimum moisture content, %		12.5	
Water content	ω_n, %		2.35	ASTM D2216
Specific gravity	Gs		2.57	ASTM D854
Direct shear test	Cohesion, kN/m^2	Dry case	18.46	ASTM D3080
		Wet case	12.5	
	The angle of internal friction, deg	Dry case	40.57	
		Wet case	35.51	
Chemical tests	Gypsum,%		10.84	BS 1377: 990
	So_3 (%)		5.04	Part 3
	Organic materials (%)		0.86	
	Total soluble salts (%)		2.53	Earth Manual(E8)

2.2 Setup of the Model

For all model tests and after the completion of the soil preparation into the container, the sample is left for an hour for dry and submerged conditions. For submerged conditions, the height of the water is increased every (15) cm by adding water and waiting for it to stabilize. After that, the height is increased by another (15) cm, to ensure that the soil is saturated with water and that air into voids is expelled to the outside. After that, an incremental pullout load of the anchor is applied by using a dead load. The vertical displacement corresponding to the load is recorded using two electronic dial gauges with a sensitivity of (0.01) mm installed. Each load was held constant until the reading of the dial gauges stabilized. At the end of each test, the steel tank door was opened and the soil was carefully removed to monitor the movement of sandy soil and determine the failure zone.

3. RESULTS AND DISCUSSION

The test program involved testing sixteen models in two groups. The first group included the use of dry sandy soil only and its improvement by using a single layer of geogrid and studying the effect of the change in the depth of the geogrid from the soil surface (u) on the performance of the anchor plate; the values of u used were (10, 20, and 30 cm). The second group of experimental studies was performed to show the influence of water level oscillation on the anchor plate's behavior in sandy soils. Soil submersion was changed with different water levels (h=15, 30, and 40 cm) above the base of the anchor plate for soil cases only and soil improvement cases with a single layer of geogrid at depths (u=10, 20, and 30 cm). The results are presented and discussed in terms of the relationship between the pullout load in the (N) unit versus the resulting vertical displacement in the (mm) unit. (Note: (u) represents the distance measured from the soil surface to the geogrid layer.)

u= 30 cm u= 20 cm u= 10 cm

Figure 2: Photograph of geogrid layer location.

3.1 Effect of Geogrid Layer Location for Dry Condition

The pull-out load was gradually applied to the anchor plate, and recording of the vertical displacement generated for the first group models included an unimproved dry sandy soil model and the other improved with different locations of the one geogrid layer in dry sandy soil, as shown in Figure 3. From the figure, it can be noted that the ultimate uplift capacity of the anchor plate increases with the depth of the geogrid layer, and the highest value that can be obtained is when the geogrid layer is adjacent to the anchor plate (u = 30) which is (2609 N), with a significant difference from the case of not using the geogrid, which is (1226.5 N) is followed by the value obtained at u = 20 cm which is (1638 N) while at u = 10 cm, the geogrid layer is relatively far from the anchor plate, the ultimate uplift capacity is (1089 N).

According to the methodology of the experimental work, the relationship between the pullout load versus vertical displacements of the circular anchor plate. It can be seen that these curves are at different cases of the location of the improvement geogrid (u = 10 cm, u = 20 cm, u = 30 cm, and case of without geogrid). The shapes of the curves are non-linear relationships for all four model tests. It is also observed from this figure that changing the location of the geogrid layer used to improve the soil increases the ultimate pullout capacity as the depth of the layer increases up to the anchor plate. The failure state can be specified in each model test when there is a significant decrease in shear strength, and vertical displacement of the anchor plate increases without any additional load.

In the case of using geogrid, the rupture on the surface of the soil can be noticed as larger than in the case of not reinforcing it with geogrid, indicating the large mass of soil included in the participation in the anchor load. When u = 30 cm, the vertical displacement is gradual until the end of the test. In other words, the failure occurred by displacement, not shear failure. While it was noted that the failure was sudden in the other three tests, as a result of failure by shearing, soil collapse occurred. The results of experimental models were validated with the theories of many researchers. The models' embedment ratio (D/d) is 3, considered a shallow anchor (6). So, these results are compared with theories of shallow anchors.

The model of plate anchors in dry sand and without a geogrid layer is present as a reference for all models. The result for present model of experimental at ultimate pullout is (Pu = 1226.5 N). This result is in very good agreement with the theory of Mors (1959) (1) in which it was calculated based on the properties of this experimental model, and the result was the ultimate pull-out capacity = (1339.5 N).

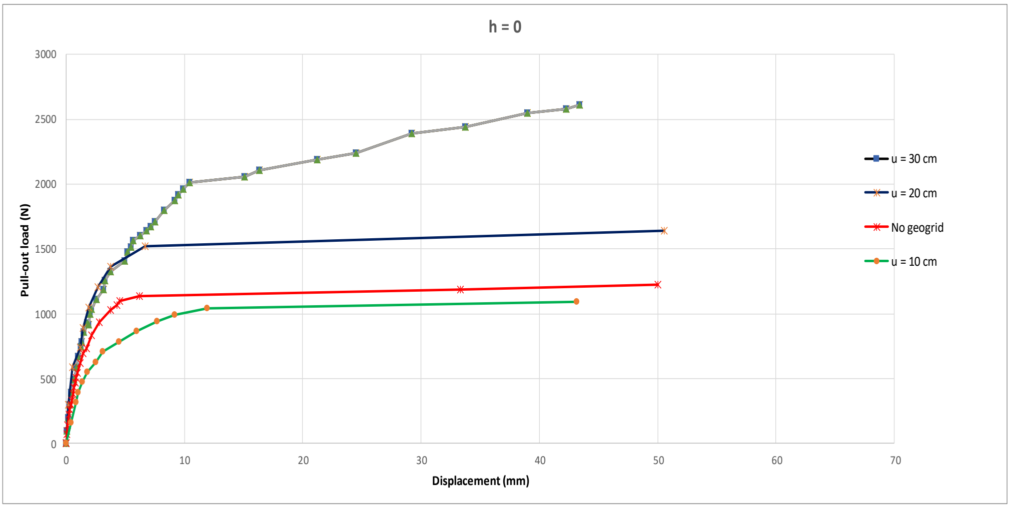

Figure 3: The effect of using the geogrid layer at different locations on pull-out load for dry conditions.

3.2 Effect of Geogrid Layer Location for Submerged Condition

Figure 4 shows the variation of the pullout load with the vertical displacement at different locations of the geogrid layer when water level at (h = 15 cm) above the base of the anchor plate .From the figure it is clear that, as in all tests, u = 30 cm produces the pullout load-displacement curve that gives the highest resistance against the displacement and that the ultimate uplift load is (1846.4 N), but for this time the next model by showing the high resistance to pullout load is (u = 10 cm) with ultimate uplift load is (1089 N) and not (u = 20 cm) which is within the effect of water in the case of the model (h = 15 cm)with ultimate pullout capacity is (833.8 N), which is less even than the case of (h = 15 cm and without using geogrid) which is (902.5 N) because in the case of granular soils(without geogrid), the soil strength parameters C and ϕ are not significantly affected when the soil is immersed in water, and this is proven by laboratory tests of direct shear tests of dry and submerged cases where the values of these tests are (C = 18.46 kN/m^2 and ϕ=40.57 degrees) for the dry case and (C = 12.5 kN/m^2 and ϕ=35.51 degrees) for the submerged case with water, while it is assumed that the decrease to be much greater in the value of (soil –geogrid) interface friction angle, since the increase in sliding and the decrease in friction caused by water between two different materials, namely (soil - geogrid), is much greater than in the case of sliding particles of one material it is the soil.

The variation of the pullout load with the vertical displacement at different locations of geogrid layer when water level at (h = 30 cm) above the base of the anchor plate is presented in Figure 5. From the Figure, it appears clearly that at (h = 30 cm) above the base of the anchor plate, where the entire soil above the anchor plate is submerged to saturation with water and homogeneously and in all cases under the influence of water, the variation in behavior in the curves of displacement versus the pullout load, as well as the difference in the ultimate uplift capacity depends only on the depth of the geogrid layer. These values are in the order (u = 30 cm, u = 20 cm , u = 10 cm, and no geogrid were 1187 N, 618 N, 412 N, and 314 N, respectively).

Figure 6 demonstrates the relationship between the applied pullout load and the vertical displacement at different locations of the geogrid layer when the water level at (h = 40 cm) above the base of the anchor plate. From the figure, it can notice the loss of the geogrid layer bearing it as a result of the high water content that caused the coincidence between the curves u = 10 cm and u = 20 cm, as well as the slight difference in the ultimate pullout capacity, where its value was (402.2 N) in the case of u = 20 cm and (382.6 N) for the possibility of u = 10 cm. Once again, the negative effect of the presence of the geogrid layer appears in the case of high water content at (h = 40 cm), after it appeared in the issue of partial water content of the soil above the anchor plate at (h = 15 cm), and for the same reasons mentioned when explaining Figure 3, but the difference between the ultimate pullout load of the cases of no geogrid and (u = 10 cm and u = 20 cm) when water level at (h = 40 cm) is relatively more significant than the difference between the ultimate pullout capacity of the cases of no geogrid and u = 20 cm when water level at (h = 15 cm) because of the difference in water content between the two points (h =40 cm and h = 15 cm) which leads to an increase in slip and thus a decrease in friction between the soil and the geogrid as previously explained in the figure (3) where the ultimate uplift value for the case of no geogrid when water level at (h = 40cm) is(490.5 N) Which is a relatively high number when compared to both values for the cases of (u = 10 cm and u = 20 cm and they are 382.6 N and 402.2 N, respectively), but the issue of u = 30 cm remains that it gives the highest value every time and for all water levels, where the ultimate pull capacity of u = 30 at (h= 40 cm) is (783 N).

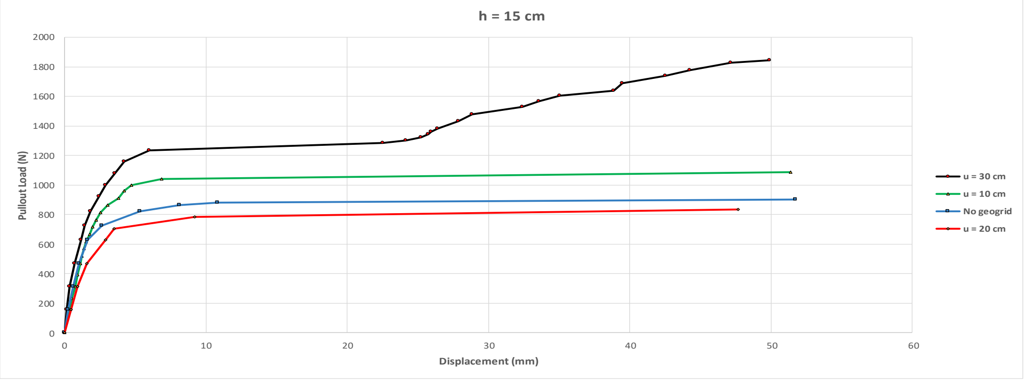

Figure 4: The effect of using the geogrid layer at different locations on pull-out load when (h=15 cm).

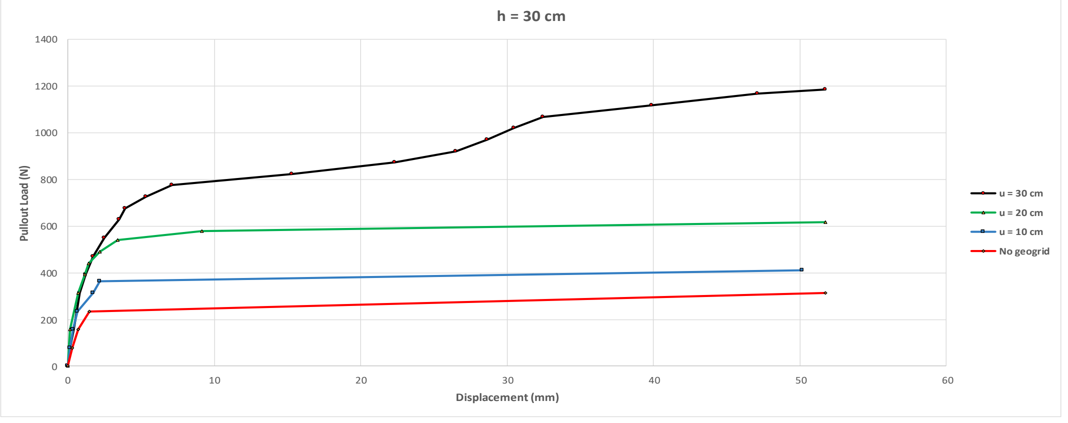

Figure 5: The effect of using the geogrid layer at different locations on pull-out load when (h= 30 cm).

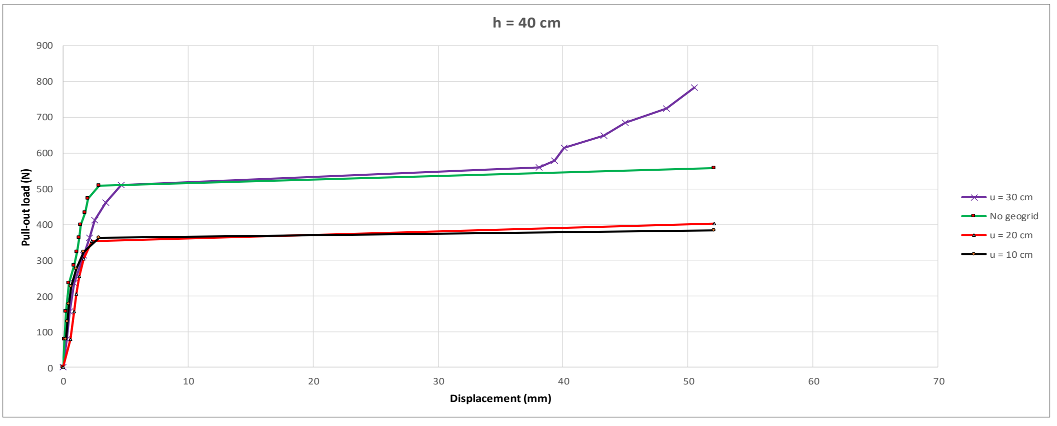

Figure 6: The effect of using the geogrid layer at different locations on pull-out load when (h= 40 cm).

3.3 Effect of Water Table Level Location

Figure 7 illustrates the variation of the pullout load with the vertical displacement at different water levels when the geogrid is not used. Generally, it can be noted that the ultimate pullout capacity of the anchor plate decreases with the increase in water level where the value of the Pu for the dry case is (1226.5 N). In comparison, when (h = 15 cm and h = 30 cm the values are 902.5 N and 314 N respectively). An exception to the above rule is the case of (h = 40 cm), the ultimate uplift capacity is (490.5 N) and this is greater than the case (h = 30 cm) because the presence of water above the surface of the soil increases the stability of the soil , as the hydrostatic pressure of water is added to the stress by the soil saturated with water when calculating the total stress applied to the anchor plate , which increases the strength of resistance to the pulling force , and this explains what happened in the above case .

The great convergence of the two-pullout load – displacement curves when using the geogrid at (u = 10 cm) with different water levels for each of the (dry and h = 15 cm) above the base of the anchor plate cases together can be observed in Figure 8. From the figure, it can be noted that the value was obtained for the ultimate uplift capacity for the dry condition which is (1089 N). This value is repeated in the case of model (h = 15 cm) because if the geogrid layer is placed at u = 10 cm from the surface of the soil, it will be far from the influence of water in the case of (h = 15 cm) from the base of the anchor plate. Therefore, it gave a similar result to the dry case. In addition, it can be clearly observed that when the geogrid layer is within the influence of water, a significant decrease occurs in the behavior of the anchor plate in uplift resistance, with a slight difference between the case of (h = 30 cm and h = 40 cm, which are Pu = 412 N and Pu = 382.6 N, respectively).

Figure 9 shows the variation of the pullout load with the vertical displacement at different levels of water when the geogrid layer is used at (u = 20 cm). From the figure, it can be seen that without the effect of water, the pullout resistance increases with increasing the depth of the geogrid layer, where in the case of u = 20 cm the ultimate uplift capacity was (1638 N) between the two ultimate uplift capacity for the cases (u = 10 cm and u = 30 cm) which are (2609 N and 1089 N), but As soon as the effect of water enters at (h = 15 cm) ,the behavior of the anchor plate in the resistance to pullout decreases by almost half, so it is (833.8 N) instead of (1638 N) in the dry state. Thus, the decrease in the resistance of the uplift capacity continues with the increase of the effect of water, and this seems clear, so when (h = 30 and 40 cm), the ultimate uplift capacity obtained (618 N and 402.2 N, respectively).

The variation of the pullout load with the vertical displacement at different water levels when the geogrid layer is used at (u = 30 cm) is presented in Figure 10. From the figure, it can be noticed that it is in the dry state; the pullout resistance increases with increasing the depth of the geogrid layer, where in the case of u = 30 cm, since the geogrid layer is adjacent to the plate anchor, the ultimate uplift capacity is the highest value among all instances, so Pu for this case is (2609 N) As in the cases mentioned in the previous diagrams, when water enters as an influencing factor, it makes the pullout resistance of the plate anchor decrease with the increase in the water level. Thus, the ultimate pullout capacity of each of (h = 15, 30, and 40 cm are 1846.4, 1187, and 783 N, respectively).

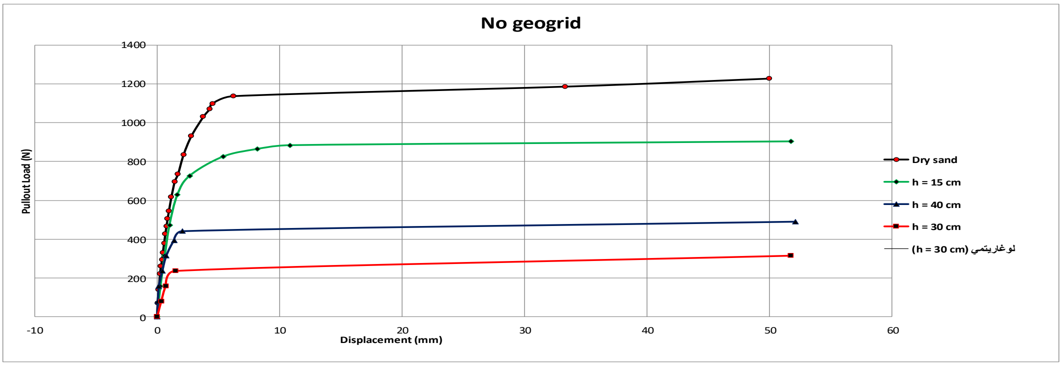

Figure 7: The effect of the presence of water at different levels on pull-out load without geogrid.

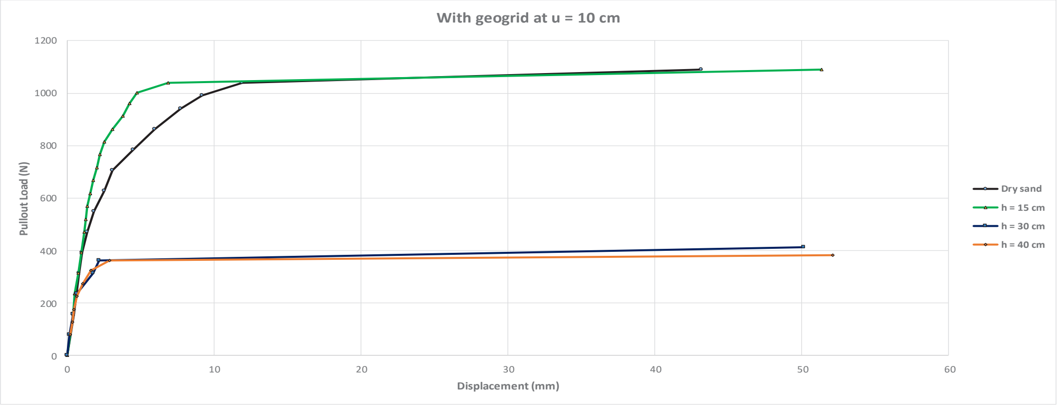

Figure 8: The effect of the presence of water at different levels on pull-out load with geogrid at u = 10 cm.

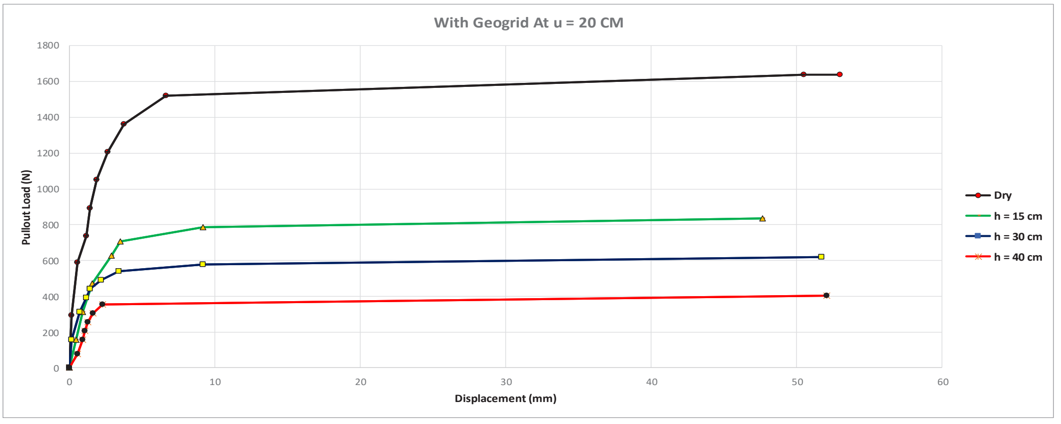

Figure 9: The effect of the presence of water at different levels on pull-out load with geogrid at u = 20 cm.

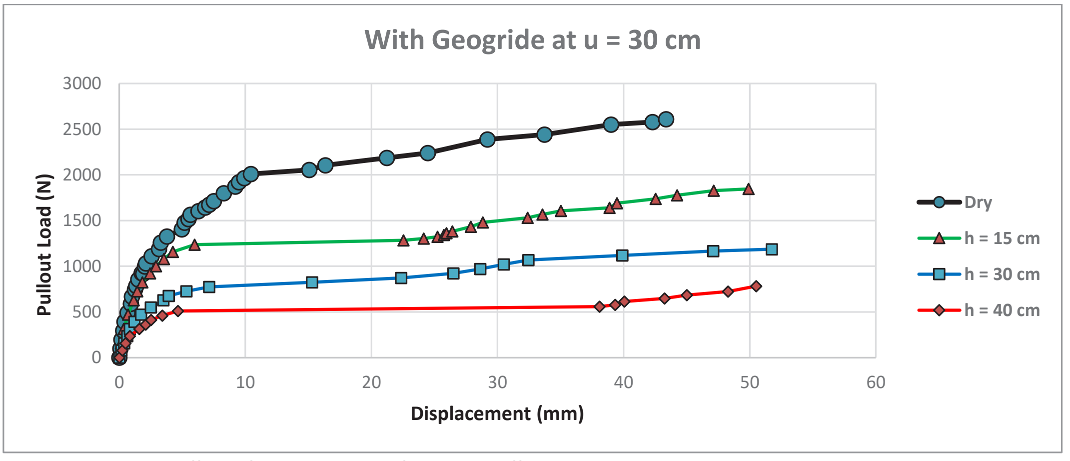

Figure 10: The effect of the presence of water at different levels on pull-out load with geogrid at u = 30 cm.

4. CONCLUSIONs

- Model tests of dry sand state carry more pullout load of the anchor plate than the submerged model tests.
- The uplift resistance decreases with the rising water level above the anchor plate.
- For dry and submerged conditions, the magnitude of the ultimate uplift capacity increases with increasing the depth of the geogrid layer (the geogrid layer is adjacent to the anchor plate).
- For a model test with geogrid layer location, u = 30 cm, the failure state can be recorded by settlement, not by shear failure; in other words, although increasing the depth of the geogrid layer is more expensive, it provides safety as the failure will be gradual and not a sudden collapse.
- The pullout load-displacement curve for model tests with (u = 20 cm, u = 10 cm, and without geogrid) is nearly linear over a large part before failure and a sudden failure can occur.
- Low effect of the geogrid layer when it is relatively far from the depth of the anchor plate.
- For all model tests, there is a small fissure in the surrounding soil of the anchor plate with a bulge at the ground surface level.
- When the geogrid layer is within the influence of water, a significant decrease occurs in the behavior of the anchor plate in uplift resistance.
- When the geogrid layer is relatively far from the anchor plate, it does not show any effect of the presence of the geogrid layer.
- The geogrid layer loses resistance where the congruence between the curves u = 10 cm and u = 20 cm is noted at (h = 40 cm) when the water table level is raised above ground surface level.
- (Negative effect) of the presence of the geogrid layer appears in the case of high water content at (h =40 cm) where the ultimate uplift value for the point of no geogrid when the water level at (h = 40cm) is (490.5N) Which is larger than both values for the cases of (u = 10 cm and u = 20 cm and they are 382.6 N and 402.2 N, respectively).

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