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Laboratory Study on Reinforced Expansive Soil with Granular Pile Anchors

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ABSTRACT

Granular Pile Anchor (GPA) considers one of the solution foundation techniques, designed to mitigate the lifting of the sole resulting from expansive soils. This study work is to investigate the uplift movement response of GPA in expansive soil and evaluation performance in this soil. The effects of several parameters, such as length (L) of GPA and diameter (D), the thickness (H) of expansive clay layer and the existence sandy soil layer are investigated. The results evidenced the effectiveness and ability of GPA to reduce the lifting movement of the expansive soil and presented that the lifting movement can be decreased with rising length to some extent and the GPA diameter. The lifting movement of GPA-Foundation System is controlled by 3 separate variables, these are L/H and L/D ratios and diameter. The lifting movement can be decreased by up to (47%) if GPA is embedded in layer of expansive soil at L/H = 1, and by 83% if GPA is in expansive soil and extensive sandy soil is embedded at L/H = 1.4 with the similar GPA diameter and foundation.

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1. INTRODUCTION

Until the end 1930s, geotechnical engineers did not recognize the damage associated with buildings on extensive soils. In 1938, the US Bureau of Reclamation made the first recorded observation of ground lifting. documented evidence of the problems related with expansive soils is worldwide. According to Jones and Holtz [1], the damages in light weight buildings and roads caused by expansive soils attained to $2.2 billion in USA only. At bottom tip of pile, pore water pressure is increased due to vibration source [2]. In South Africa over (R100 million) is spent on affecting remedial works on buildings on expansive soils [3]. There are many methods that can be utilized to reduce the damage effects from expansive soils. This includes replacement of soil, chemical, and physical treatment and the use of special techniques. Nine essential additives in addition to three mixed additives with different ratios have been used and implemented during the installation of helical pile and some of these additives gave good treatment for problem of expansive soil. The use of these methods is retained over a long period of time [4, 5]. However, many of them have certain limitations and can be very expensive [6]. Stone columns or granular piles are a known technique for soil improvement, which can reduce the build-up and increase the load-bearing capacity of soft clay beds [7, 8]. GPA foundation resisted swelling with increase diameter and length of pile as a result from friction around the perimeter of pile [9]. The results of numerical study depicted that the influence of GPA foundation to be a valuable in solving problems of swelling in expansive soil [10]. This study is an endeavor to better understand the GPA performance and behavior in expansive soils to decrease resistance and lift the pullout load. The following parameters are investigated: GPA footing system performance under swelling and the GPA adequacy and validity as a reliable solution to the problems of expansive.

Various parameters are examined that are taken into account in GPA design, such as the length of GPA system (L), the diameter (D), expansive soil layer depth (H) and the depth in sandy layer (stable region).

2. EXPERIMENTAL PROGRAM

2. 1. Materials Used Three materials are used in this study; these can be described as the following:

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1. A bed of foundation is represented by expansive soil.
2. Sand is used in granular pile material and stable zone.
3. Steel as a matter for shallow foundation, rod of anchor and anchor plate.

2. 2. The Properties of Expansive Soil The expansive clay soil utilized in present research was produced artificially by admixing Iraqi bentonite from the city of Al-Anbar / Bushayrah Valley, 35 km south of the base of Al-Waleed military, at a depth of 3.5 m from natural ground level, with natural soil from Al-Khalis region with ratio of (1:1). Table 1 presented the routine tests results of expansive soil.

2. 3. Sand Properties The material, which is used as stable zone and a granular pile, is poorly graded dense clean sand obtained from the local markets. Table 2 presented the laboratory tests results.

2. 4. Granular Pile Anchor System The anchor parts of granular piles consists from steel rod and plate of circular shape. To perform the anchor system, the steel rod penetrate the granular pile and connected with model footing in upper end by a bolt, while, the other end (lower end) is connected with anchor plate by a bolt also. The diameters of anchor plate are chosen in the same diameters of GPA models. The dimensions of the anchors (rod and plate) are shown in Table 3 and in Figure 1.

2. 5. The Model Footing Steel circular plate with (20 cm) diameter and (3 mm) thickness is utilized as a shallow footing model. A hole of (30mm) diameter is fixed at the center of footing in order to connect with steel rod of GPA by bolt, as shown in Figure 2.

TABLE 1. Summary of properties of expansive soil used

Test description	Soil Property	Value
Atterberg Limits (ASTM D-4318)	Liquid limit(L.L),%	91
	Plastic Limit(P.L),%	38
	Plasticity Index(P.I),%	53
Specific Gravity (ASTM D-854)	Specific Gravity (Gs)	2.75
Grain size analysis (ASTM D-422)	Gravel,%	2
	Sand,%	43
	Silt and Clay %	55
	UnifiedSoil Classification System(USCS)	CH
Consolidation (ASTM D-3084) Method (A)	Swelling Potential, %	15
	Swelling Pressure, kPa.	210
Standard Compaction Test(ASTM D-1557)	Max. Dry Unit Weight,(kN/m^3)	13.5
	Optimum Moisture Content(O.M.C),%	16

TABLE 2. Summary of the properties of sandy soils

Test Description	Property	Value
Grain Size Analysis (ASTM D-422)	D10(mm)	0.10
	D30(mm)	0.17
	D60(mm)	0.22
	Coefficient of Uniformity (Cu)	2.20
	Coefficient of Curvature (Cz)	1.31
	Unified Soil Classification System (USCS)	SP
Specificgravity (ASTM D-854)	Specific Gravity (Gs)	2.69
Maximum Unit Weight(ASTM D-4253)	Max. Unit Weight , kN/m³	16.7
Minimum Unit Weight(ASTM D-4254)	Min. Unit Weight, kN/m³	13.3
Chosen	Experimental Relative Densities (Dry) ,%	80
Calculated	Experimental Unit Weight (Dry), kN/m³	16

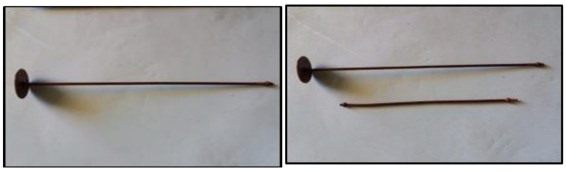

Figure 1. Plates of anchor system

TABLE 3. Dimensions of anchors (rod and plate)

Anchor rod	Length (mm)			Diameter (mm)
	250	300	350	30
Anchor plate	Diameter (mm)			Thickness (mm)
	25	50		3

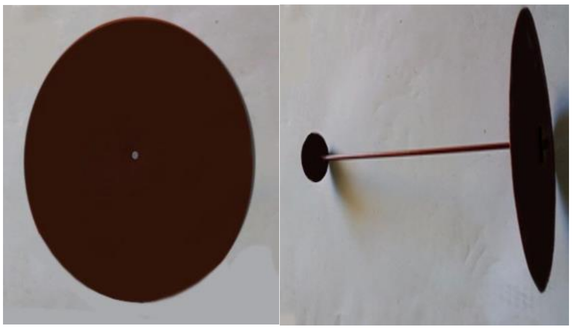

Figure 2. Plates of model footing and anchor system

2. 6. The Test Tank (Container Model) and Testing Frame

Shallow footing model, granular pile anchor model, sandy soil and the expansive clay soil below placed in a cylindrical steel tank to simulate the real case in the field as well as possible. The test tank is made of (4 mm) thick steel plate with interior dimensions of (31 cm) in diameter and height of (55cm). The upper distance of 10cm of height of container is lifted in order to perform the saturation process of soil within the test tank.

2. 7. The Models of Granular Pile Anchor

The test program is performed on single GPA with various lengths and diameters. The diameter of granular pile anchor (D) is varied as 2.5 and 5 cm. For each diameter, the length of granular pile anchor (L) varies from 250, 300, and 350 mm; these lengths of GPA are taken as a function of L/H where (H) indicates that expansive soil bed depth (H = 25 cm), because, the ratio of L/H is became as 1, 1.2 and 1.4. Consequently, the range of the L/D ratio of the granular pile anchors varied from 5 to 14. In total, six GPA models in addition to unreinforced model were used in the testing program as shown in Figure 3.

2. 8. Granular Pile Anchor Installation

The following procedure is used in order to install the GPA in expansive soil bed and sand layer:

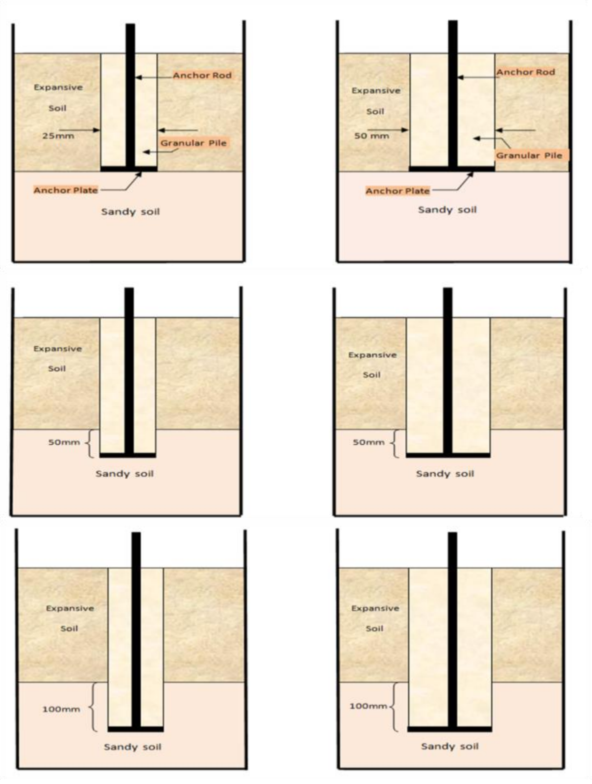

Figure 3. Details of cross sections of (GPA) models used in this study

1. After preparing and compacting the expansive soil bed, the nylon cover is removed and the top surface is leveled.
2. The hole is carefully made in the middle of the expansive soil bed surface and sand layer by gradually bringing a steel pipe with the specific diameter to the desired depth. Verticality of steel pipe is controlled during test.
3. The unit of the anchor rod with the lower anchor plate with the specific depth and diameter is inserted perpendicularly into the hole. At the same time, the hole is gradually filled with poor sand and gently compacted utilizing a steel stuffing rod with the desired relative density (80%). Finally, a GPA with dry unit weight of 16 kN/m³ is formed at the specific depth and specific diameter.

2. 9. Testing Procedure

The swelling test is performed on a bed of expansive soil, which is not reinforced and reinforced with GPA. After the preparation of an expansive soil and sand layers, the test configuration steps are followed to perform the unreinforced and reinforced tests with GPA expansive soil and sand beds as:

1. The model foundation is placed in the middle of the soil bed itself for the case of unreinforced expansive soil and linked with a bolt to the steel rod anchor.
2. The 0.01 mm accuracy dial gauge with is positioned on the surface of footing and attached to the frame of loading with specific instruments in order to record the reading of swelling during the swelling process.
3. From the container top, water is added gradually to the soil bed.
4. After (30-60) days, the saturation is approximately completed. All readings are recorded during this period.
5. At the test end, the moisture content of the samples of soil taken at different depths of the soil bed is verified to certify the saturation degree. The degree of saturation must be reached (100%).

3. TEST RESULTS AND DISCUSSION

Many factors are investigated such as GPA size, L/D, Ls/H and L/H ratios. The results are analyzed, discussed and displayed in simplified manner.

3. 1. Uplift Movement of Unreinforced and Reinforced with GPA

A first reference test was performed on an unreinforced, expansive soil bed under the model foot to determine the degree of improvement that was achieved after the introduction of the GPA. One model test is performed on unreinforced expansive soil to obtain the final uplift movement. Figure 4 shows the time-uplift movement relationship curves. It can be seen that, the relationship is not linear and the uplift movement of expansive soil bed continuously increases with time up to maximum values of 40 mm at time of 60 days. At this step, the saturation of the expansive soil is adjusted and the test is completed. Also, the typical relations are noticed of uplift movement-time of six reinforced models of GPA at various cases. In general, the uplift movement does not appear linear and rises continuously over time until reached equilibrium after 30 days. The rate of uplift movement suddenly reduced after about 20 days for reinforced soil is due to cylinderical sand layer around rod anchor which allows to water seep through expansive layer and increase swelling at the begginig period of test. When soil is saturated the swelling begins to decrease. At this stage, the swelling is stopped and the saturation is completed. The uplift movement of GPA reduces with GPA extended to sandy layer. This indicates the efficiency of (GPA) in decreasing the uplift movement. This is consistent with literature [9-16].

3. 2. Effect of GPA Size on the Uplift Movement Results

Figure 5 shows the variation of the maximum uplift movement with diameters and lengths of GPA. The results reflect the effect of GPA on the uplift movement response of GPA-Foundation System and capability of GPA in reduce the uplift movement of expansive soil bed. It can be clearly observed that, for a given diameter of GPA the uplift movement reduces with augmented embedment length of GPA. This reduction of uplift movement can be attributed to the effect of anchor system afforded in the granular pile anchor, which made it tension-resistance member, and friction or shear resistance rallied around cylindrical pile soil volume interface, which resist forces resulting from swelling pressure of expansive soil bed. This behavior in agreement with data reported in literature [9-16].

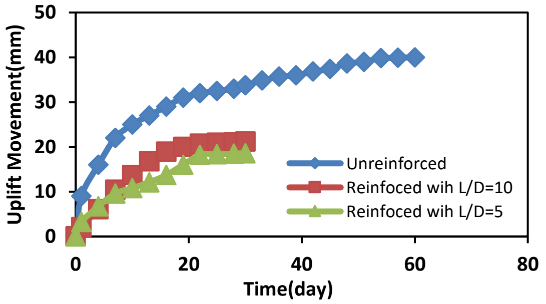

Figure 4. Uplift movement–time relationship for Unreinforced and reinforced of length to diameter ratios L/D=10 and L/D=5

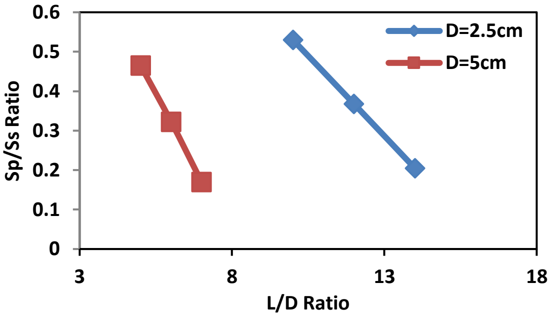

Figure 5. Variation of the normalized ratio (Sp/Ss) with (L/D ratio) of (GPA) for two diameters

3. 3. Effect of L/D Ratio of GPA on the Uplift Movement Results

Figure 5 shows the relation between the proportion of maximum uplift movement with and without GPA reinforcement, Sp/Ss and L/D ratio of GPA, where Sp denoted as maximum uplift movement of foundation with reinforcement GPA. It can be seen that the max. Uplift movement of footing with GPA reinforcement reduces with rising of L/D ratio of GPA for a given diameter and expansive soil bed thickness (H), this is due to augmenting in its length. This performance may be assigned to the augment the surface area of GPA and its weight that causes increasing in pullout resistance along the GPA-soil interface against the swelling pressure. This performance agrees with the results of laboratory, field, and numerical results reported in literature [9-16].

3. 4. Effect of L/H Ratio on the Uplift Movement Results

Figure 6 shows the relationship between the Sp/Ss ratio and L/H ratio for various cases of diameters. The figure reflects the L/H effect on the maximum uplift movement of footing with GPA reinforcement. Generally, the uplift movement reduces with the increase in the ratio L/H because of anchoring effect of GPA. A significant reduce was noticed at L/H=1.4, i.e., the GPA extended halfway down the sandy soil. This performance may be explained that as the swelling pressure effect of expansive soil reduces with rising L/H ratio, pullout resistance of GPA with length becomes equal to 1.4 depth of the expansive layer, which means GPA contributes to the reduction of the uplift movement.

3. 5. Effect of Ls/H Ratio on the Uplift Movement Results

It is obvious from Figure 7; the maximum uplift movement reduces with increasing extended length in sand layer. The part of pile depth extended in sand soil is affected frequently on reducing uplift movement. This figure depicts the dimensionless ratio Sp/Ss plotted anti Ls/H ratio, a depth of extended of pile in sand layer to the depth of expansive soil. A proposed relationship was noticed within a limited number of model tests achieved for specified soil. Extrapolating the results gives the ratio Sp/Ss=0; this mean no uplift movement at this depth. In field, the required fixed depth at which no movement in pile may be concluded from this relation. The factor of safety is high in this case because all models tests were not included the applied load, which certainly reduces uplift movement.

3. 6. Degree of Improvement

The results of the uplift movement of both the reinforced and the unreinforced expansive soil with GPA are combined and compared according to Figures 5 and 6 to evaluate the effectiveness and ability of GPA in decreasing the uplift movement. As previously stated, the unreinforced untreated expansive soil has reached a last uplift movement 40mm for 60 days. Since no technology was provided in the expansive floor to stop the lifting movement, the expansive floor swelled completely. However, in the case of reinforced treated expansive soil bed with GPA, the uplift movement is reduced considerably. It can be concluded from the results that there are three main variables that control the uplift movement performance of GPA which were L/H, L/D and Ls/H ratios. The uplift movement of GPA was influenced by me one or two or all of these variables, a decrease in uplift movement and the improvement degree rise with rising L/D, Ls/H and L/H ratios. The proportion of decrease in uplift movement and the improvement degree can be articulated as a percentage of maximum uplift movement without using GPA as in this equation:

$$\text{Degree of Improvement (\%)} = \frac{Ss-Sp}{Ss}x100 \ldots\ldots (4.1)$$

where Ss and Sp represent the maximum uplift movement of the footing without and with GPA reinforcement. It should be observed that a slight decrease in uplift movement was noticed at L/H=1, L/D=10 and D=2.5cm of 47% as a degree of improvement, whereas greater decrease in uplift movement was noted in L/H=1.4, L/D=14 and D=2.5cm of 80 % as an improvement degree. This reflects an individual's ability and efficiency (GPA) to reduce the uplift movement when extended in stable layer. The degree of improvement in the reduction of the uplift movement is summarized in Table 4.

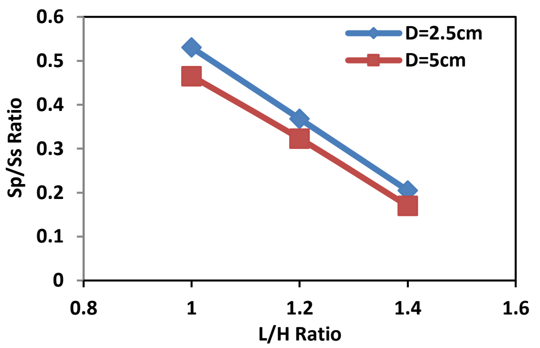

Figure 6. Variation of the normalized ratio (Sp/Ss) with (L/H ratio) of (GPA) for two diameters

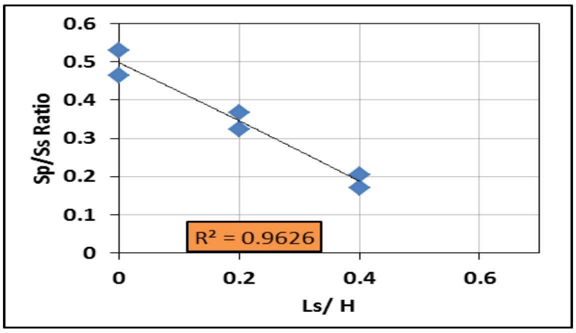

Figure 7. Dimensionless relationship of ratio Sp/Ss with ratio Ls/H of GPA

TABLE 4. Degree of improvement for all cases

L/D Ratio	Improvement Degree %
10	47
12	63
14	80
5	54
6	68
7	83

4. CONCLUSIONS

Conclusions of this study are summarized as follows:

1. The installation of GPA in expansive soil effectively decreases the values of uplift movement for the different groupings of the GPA, diameter (D) and length (L), the amount of uplift movement decreases with augmenting length and diameter.
2. Three main parameters affecting and controlling movement of (GPA). These are the ratios of length to diameter (L/D), extended length in sand layer to depth of swelling soil (Ls/H) and the length to the thickness of expansive soil (L/H).
3. The maximum reduction of approximately (47%) in the lifting movement is noted when (GPA) is integrated at (L=H) and reaches (83%) at (L = 1.4H). This means that (GPA) is suitable choice for structure constucted on expansive soil.
4. The time required to increase rate of saturation of expansive soil is clearly reduces when installing (GPA) in expansive soil and sandy soil.
5. A dimensionless relationship may be used to determine the safe depth in sand layer to provide a sufficient anchorage. Future studies are required to establish formula that gives values of movement in any embedment depth.

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Persian Abstract

چکیده

لنگر شمع گرانول (GPA) یکی از تکنیک های پایه حل می باشد ، طراحی شده برای کاهش برخواستن از جا کنده شدن و برداشتن تنها حاصل از خاکهای گسترده است. هدف از این مطالعه بررسی واکنش حرکتی رو به بالا (GPA) در عملکرد گسترده خاک و ارزیابی آن در این خاک است. تأثیر پارامترهای مختلفی از جمله طول (L) از (GPA) و قطر (D) ، ضخامت (H) لایه رس وجود لایه خاک شنی بررسی شده است. نتایج به اثبات رساندن اثربخشی و توانایی (GPA) در کاهش حرکت بالابر خاک توسعه پرداخته را نشان می دهد که حرکت بالابر را می توان با افزایش طول تا حدی و قطر (GPA) کاهش داد. حرکت بلند کردن سیستم (GPA-Foundation system) توسط (۳) متغیر جداگانه کنترل می شود ، اینها [(L/H) و (L/D)] و قطر هستند. اگر (GPA) در لایه ای از خاک وسیع در (L/H=1 تعبیه شده باشد ، و اگر (GPA) در خاک گسترده و شنی گسترده باشد ، حرکت بالابر را تا ٤٧٪ کاهش می یابد. خاک در قطر و پایه مشابه (GPA) مشابه (L/H=1.4 تعبیه شده است.