Effect of sand cushion reinforced with geogrid on heave of footing rested on expansive soil

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Abstract. The swelling phenomenon of expansive soil is considered one of the most serious problems that face geotechnical engineers. The principal purpose of this study is to investigate the effectiveness of geogrid for reinforcing sand cushion on the heave of isolated footing resting on a top of a sand cushion underlined by highly active expansive clay using the large-scale box model. An artificial case study was imposed to prove the cost-effectiveness of using geogrid reinforcement with sand cushion. After performing experiments, there are many important conclusions that have been extracted from this study, for instance, using biaxial geogrid leads to control the heave of swelling soil due to the tension developed in geogrid. As well, the heave of the footing decreases slightly when the thickness of the sand cushion layer is changed from 0.75B to B.

1 Introduction

Many buildings, pavements, airport runways, retaining walls, dams, and bridges are distressed by swelling soils. These natural high plasticity soils typically contain clay mineral montmorillonite that exhibits high swelling with the increase of water content (Chen, 1988). These types of soils are mostly found in arid and semi-arid climatic regions. Many locations in Egypt are well-known by the presence of swelling soils such as; Nasr-City, Cairo-Suez Road, El-Fayoum City, Kom Ombo City, Aswan City, New Valley, El Sadat City, and Sohag-Safaga highway (Elbeih & Soliman, 2015). With these soils experiencing volume changes, shallow foundation may exhibit surficial distress due to the swell-shrink behaviour which leads to cracks in these structures.
Several treatment methods are available for expansive soil for instance removing of expansive soil and replacing with a non-expansive material is a traditional method for reducing shrink-swell danger. The utilization of sand replacement below shallow foundation is studied as an adequate technique for reducing swelling pressure of expansive soils. Many researches suggested the use of treated and untreated sand replacement soil to reduce or control the heave of the swelling soil. Limited researchers have been done research on control of heave of swelling clays using geogrid.

https://doi.org/10.1051/e3sconf/202336802028

Daifalla & Witt, 2014 carried out the swelling tests on a mixture of bentonite-silt reinforced with a layer of geogrid placed horizontally at the mid-height sample. The test results showed that the geogrid reduced the swelling potential.
Al-Omari et al., 2019 investigated the swell and shrinkage for expansive soil by using the embedment of a geogrid in the expansive soil. It was concluded from the experimental work that the treatment of swelling soil using sand-filled geogrids is known to be successful. When the geogrid is filled with the same expansive soil, it causes a decrease of about 19 to 42% in the final swell. However, filling the geogrid with sand causes a decrease of about 35 to 64% in the final heave.
G. E. Abdelrahman et al, 2021 investigate the effect of sand cushion on reduce the heave of the expansive soil by doing experimental tests. The results demonstrated that the use of sand cushion reduces the heave of the footing by increasing the thickness of the sand cushion. Moreover, the rate decreases for sand cushion thickness greater than two-thirds of the footing width.
G. E. Abdelrahman et al, 2021 stated the benefit of using the reinforced sand cushion with triaxial geogrid on the heave of the swelling soil. it was concluded that using triaxial geogrid with sand cushion as a reinforcement element leads to reduce heave of the swelling soil due to the tension developed in geogrid.
The objective of this research is to investigate the effect of sand cushion thickness and lateral extension on the heave of the footing models resting on expansive soil. Also, the effect of reinforcing sand cushion with biaxial geogrid was taken into consideration and studied the importance of using it in reducing of heave of swelling soil.

2 Materials

A large-scale model is used in the experimental work remolded swelling soil and sand as a control section of the soil under the footing are used in the model. For reinforcement, geogrid is used to mitigate the heave of swelling soil.

2.1 Sand cushion

Fine to medium sand is used as sand cushion layers. The geotechnical properties of the used sand are determined by performing laboratory tests such as sieve analysis, compaction, and direct shear. The summary of the sand cushion properties is shown in Table 1.

Table 1. Sand cushion properties

Properties	Values	Test method
Specific gravity, G_s	2.65	Specific Gravity test
Fine (%)	1.16	Sieve analysis test
Coefficient of Uniformity, C_U	3.33	Sieve analysis test
Coefficient of Curvature, C_C	1.57	Sieve analysis test
Internal Friction Angle, ϕ	34	Direct box test

 https://doi.org/10.1051/e3sconf/202336802028

2.2 Expansive soil

The swelling soil used in this study is remolded soil from 40% bentonite and 60% kaolinite clay. The summary of swelling soil properties is shown in Table 2.

Table 2. Swelling soil properties

Properties	**Values**	**Test method**
Silt Content (%)	36	Hydrometer analysis
Clay Content (%)	64	Hydrometer analysis
Liquid Limit, L.L, (%)	134	Atterberg limit test
Plastic Limit, P.L, (%)	34	Atterberg limit test
Shrinkage Limit, Sh.L (%)	12	Atterberg limit test
Swelling Pressure, Ps, (kpa)	260	Swelling pressure test
Internal Friction Angle, ϕ (°)	15	Direct box test
Cohesion, C, (kpa)	91	Direct box test

2.3 Geogrid

Biaxial geogrid was used for reinforcing sand cushion as shown in Figure 1. The properties of the geogrid as supplied by the manufacturers are given in Table 3. Figure 2 illustrates the biaxial geogrid details.

Fig. 1. A photograph of biaxial geogrid

Table 3. The tensar biaxial geogrid properties

Product Characteristic	**Units**	**SS20**
T_{ult}	KN/m	20
Load at 2% strain	KN/m	7
Load at 5% strain	KN/m	14
Junction strength	%	95

https://doi.org/10.1051/e3sconf/202336802028

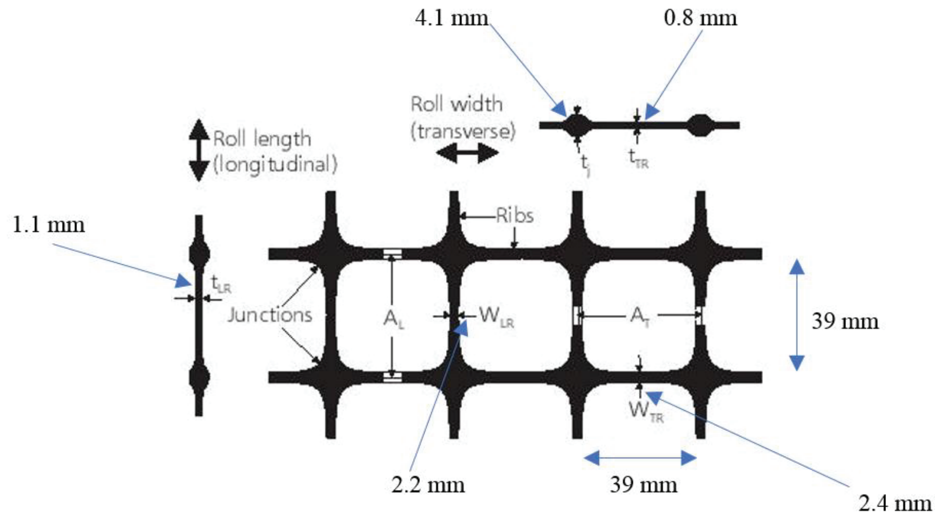

Fig. 2. The Biaxial geogrid details

3 Experimental work

A large-scale box model was prepared specially for this research. This model is aimed to measure the heave of footing which placed on the sand cushion with and without geogrid reinforcement due to expansive soil. The test apparatus consisted of five basic components: external tank, internal tank, model footing, loading system, and measuring devices. The model was taken with all its parts equal to 10% of the common condition of this system in reality.

The internal tank has many holes to allow water to pass through the soil from its sides. The model foundation used for tests was a rigid square steel block with dimensions of 100 mm (long) x 100 mm (width) x 10 mm (thickness) in order to simulate a rigid footing condition. The schematic of the experimental model is shown in Figure 3. Also, the photograph of large-scale box model at the laboratory shown in Figure 4.

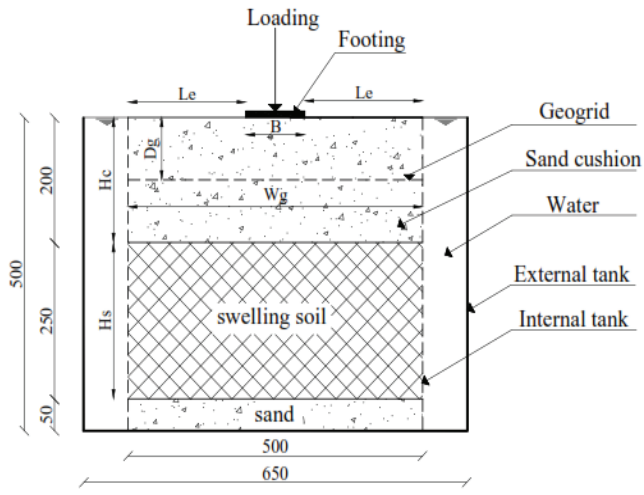

Fig. 3. Schematic experimental model (Dimensions are in mm)

https://doi.org/10.1051/e3sconf/202336802028

Fig. 4. The large-scale box model at the laboratory

Several experiments were conducted to illustrate the effect of the thickness of sand cushion with and without geogrid on the footing heave. The soil is placed in the model and compacted on layers until the maximum density is reached, and then the footing is laid and loading begins with the filling of the external tank with water. The heave of footing is measured using two dial gauges until no significant swell is observed.
Sand bed thickness was maintained constant as 50 mm in all tests, and the swelling soil thickness was constant as 250 mm. The sand and expansive clay have all been compacted to max dry density. Weight loads of 50 kg (50kpa) were applied on the footing. Sand cushion thickness of 0, 0.25B, 0.5B, 0.75B, and B are used when studying the effect of sand cushion thickness on the heave of footing. Also, lateral extension, Le, of the sand cushion is used equally to Hc, 1.5Hc, 2Hc, 2.5Hc, 3Hc, and 4Hc in the case of studying the impact of sand cushion width of on the heave of footing, where Hc is the sand cushion thickness.

4 Results and analysis

This section presents the results of the tests which were conducted by using a large-scale box model. Also, it discusses these results and provided the conclusions. the results of the test program provided that heave of the footing becomes constant after 12 days for all tests. At this time the swelling soil sample inside the box was almost saturated with water.

4.1 Effect of sand cushion thickness

The effect of variation of sand cushion thickness, Hc, on the heave of footing was studied. It is varied as follows: 0.25B, 0.5B, 0.75B, and B, where B is the width of footing. Also, one test (zero case) was performed on the swelling soil without a sand cushion to get the maximum possible heave of footing. Figure 5 shows the relationship between time and axial swell, A.S, for swelling soil with variable thickness of sand cushion. Axial swell, A.S, is equal to the ratio of footing heave to swelling soil thickness (ΔH/Hs). It was noticed that the heave became constant after the tenth day. Also, more than 90% of the total heave was reached after the six days.

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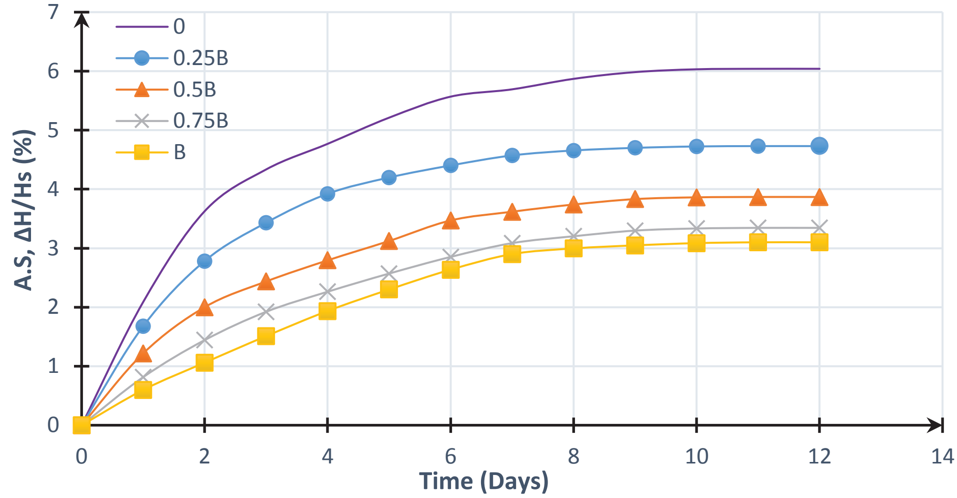

Fig. 5. Time-axial swell curves of the footing heave for varying thickness of the sand cushion

From the previous curves, it can be observed that the heave of footing decreases with increasing the sand cushion thickness. Moreover, the maximum axial swell is 6.04 % for swelling soil without sand cushion, while it reduced when using a sand cushion to reach the minimum axial swell is 3.10% when used sand cushion thickness is equal to the footing width. Thus, the maximum reduction percentage of heave was 48.68%. This reduction percentage reduces with decreasing sand cushion thickness to the minimum value of 21.69% at a thickness of 0.25B. Furthermore, these reduction percentages for 0.50B and 0.75B were 35.96% and 44.64%, respectively. Also, it was noticed that the rate of reduction percentage of heave reduces with increasing sand cushion thickness.

4.2 Effect of sand cushion reinforced with geogrid

The results of tests that show the effect of using sand cushion reinforced with biaxial geogrid on heave of footing due to the swelling soil are presented. The sand cushion thickness is as follows: 0.25B, 0.5B, 0.75B, and B. Figure 6 shows the time-axial swell curves of footing heave when using sand cushion reinforced with biaxial geogrid.

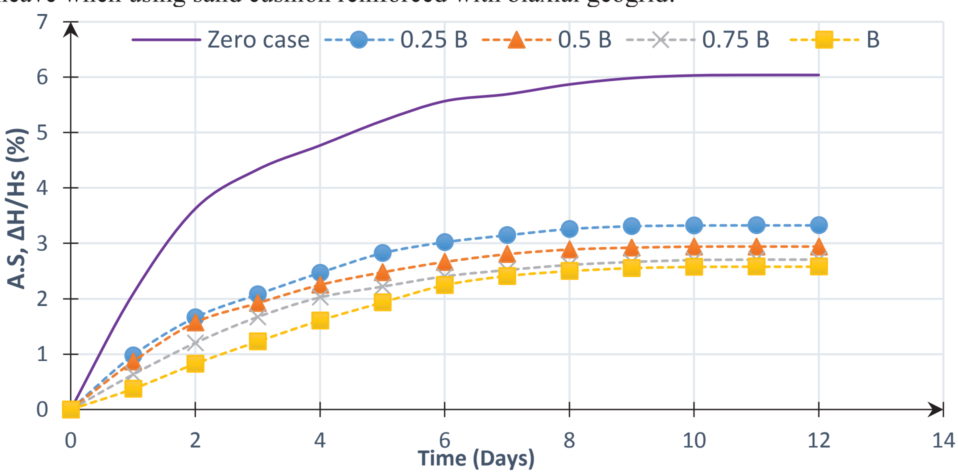

Figure 6. Time-axial swell curves for varying thickness of sand cushion reinforced with geogrid

Based on Figure 6, it was noticed that the heave of footing due to the use of sand cushion reinforced with free end conditions geogrid decreases with increasing the thickness of the sand cushion. Also, it was observed that heave of footing decreases slightly when the thickness of the sand cushion layer is changed from 0.75B to B. Besides, it was found that the maximum axial swell, A.S, is equal to 3.324% which occurs when using the sand cushion thickness of 0.25B, but the minimum axial swell is 2.578% when used sand cushion thickness is equal to the width of footing. In addition, the maximum reduction percentage of heave is equal to 57.32%, but the minimum reduction percentage is 44.97%. Thus, it was concluded that the maximum benefit of free end biaxial geogrid can be obtained if using the sand cushion layer with a small thickness.

5 Artificial case study

In this section, an imaginary case is imposed in the field to know the importance of using geogrid to reduce the heave of swelling soil. It is assumed that the land area is 1000 square meters, on which the structure is constructed and the average footing width is 2.5m. Also, it is assumed that the axial swell for this soil is required to reduce to 3% from 6% (the original condition for the swelling soil). The average price statement at the moment price (2020) is shown in the Table 4.

Table 4. The average price statements

S. N	Item type	Price per unit (US $)	Unit
1	Drilling	1.5	m^3
2	Sand	4	m^3
3	Biaxial geogrid	1	m^2
4	Compaction	0.25	m^2/one layer

The thickness of sand cushion required to reduce the axial swell from 6% to 3% (50% from the original axial swell of the soil) was found as follows 1.1B and 0.45B (2.75 and 1.125) for sand cushion only and sand cushion reinforced with geogrid, respectively. Table 5 shows the total price in the three cases.

Table 5. The total price in the three cases

Item	Alternatives			
	Sand cushion only		Sand cushion with geogrid	
	Value	Price (US $)	Value	Price (US $)
Thickness of sand (m)	2.75	-------	0.3	-------
Sand cushion (m^3)	2750	11000	300	1200
Drilling (m^3)	2750	4125	300	450
Geogrid (m^2)	-------	-------	1000	1000

Compaction (N)	11	2750	2	500
Total price (US $)*1000	17.875		8.44	
Saving money (%)	-------		53	

Based on Table 5, it is clear that in the case of the use of free end geogrid, it is possible to save more than 50% of the money that is spent in the case of using sand cushion only.

6 Conclusions

The main points concluded from the experimental work can be summarized as follows: -

- The treatment of swelling soil using sand cushion reinforced with biaxial geogrid is found to be effective mainly due to the effect of the tension developed in geogrid.
- Increasing the sand cushion thickness reduces the heave of footing but, the rate of reduction in the heave of footing decreases with increasing sand cushion thickness.
- The heave of the footing decreases significantly with increasing the thickness of the sand cushion layer until 0.75B.
- The maximum benefit of geogrid can be obtained if using the sand cushion layer with a small thickness.
- Regarding to the artificial case study, using sand cushion reinforced by geogrid may be reduce the cost of the soil improvement by more than 50% of using only sand cushion without any reinforcement.

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