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Numerical Modeling of the Effect of Geocell Elements' Dimensions on Behavior of Circular Footings

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Abstract

Use of auxiliary elements in refining and betterment of engineering properties of soil have gained attention since a long time ago. Nowadays the effectiveness and capability of the soil reinforcing technique for giving proper practical solutions in various projects have resulted in this technique quickly gaining a place in geotechnical engineering. In this paper, the results of laboratory studies on such characteristics as width and height of the geocell element on load-bearing capacity and settlement of footings have been modelled numerically. It should be noted that the laboratory studies have been carried out in the uniaxial apparatus and analytical studies have been carried out utilizing the finite element software ABAQUS 6.11. by investigating the results it can be seen that in the case of using a geocell element in reinforcing the soil, the load-bearing capacity of the footing increases 1.65 times in comparison with the non-reinforced sample, while settlement in the reinforced footing – with geocell – is only 1.15 times more than the non-reinforced footing. Furthermore when the increase in load-bearing capacity of the footing has a significant importance, the best scenario is increasing the height of the geocell element. But when the footing's settlement is of significant importance, we can have more effective results by changing the width of the geocell element. By comparing the results from numerical and laboratory studies, an appropriate agreement is observed and in all cases the analytical studies have more conservative results compared to the results from laboratory studies.

Keywords: Geocell, Soil Refining, Load-Bearing Capacity of Footings, Numerical and Laboratory Studies

1. Introduction

As the most important construction material and the structure's main support, soil has been at the center of attention in construction from a long time ago. But due to its weakness of shear resistance and lack of tensile resistance, researchers have always tried to increase its load-bearing capacity and strength, and to improve its properties. In order to achieve these results, various methods have been utilized including mechanical refining methods such as compression, chemical refining methods such as stabilization with lime or cement, or using the notion of reinforced soil with auxiliary elements that have high tensile resistance [1]. Among these methods, the method of soil reinforcing has become known as an appropriate method of refining and betterment of soil due to low cost, ease of execution, and its high effectiveness in improving the soil's properties [2].

Reinforced soil has a structure consisting of two different materials that their co-performance minimizes the weaknesses of each of them, and in this notion, the soil bears compressive stresses and the reinforcement elements bear the tensile stresses [3].Today, soil reinforcement is used in stabilization of subgrade, road embankments, and paving as an effective and reliable method in refining and stabilizing soil layers as well as increasing the soil's load-bearing capacity and shear resistance, and decreasing its settlements. In this study, the behavior of circular footings on sandy bedding reinforced with geocell is investigated in laboratory and numerically [4]. Moreover, in laboratory and numerical studies the impact of parameters of width (b) and height (h) of the geocell element on increasing the load-bearing capacity of footings and reducing their settlement have been investigated [5]. It should be noted that the numerical studies have been carried out utilizing the finite element software ABAQUS 6.11 [6].

2. Research goals

With the considerable advances in technology and the use of modern materials for refining and increasing the load-bearing capacity of soil and decreasing its settlement, geocells are at the center of attention as a good example of such materials. With an eye on results from laboratory studies on behavior of reinforced samples with geocell elements, in this paper a numerical modeling of such parameters as width and height of geocell elements has been carried out.

3. Laboratory Studies

In order for a more thorough investigation of the effecting factors on footings' load-bearing capacity and the extent

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and mechanism of their impact, first we explain the procedure of building the sample, the properties of materials used in laboratory studies, and the procedure of loading the sample [7]. Afterwards, each of the parameters under investigation such as the width of the geocell element (b) and its height (h) are studied separately.

The materials used in the laboratory studies are soil and the reinforcing element, as described below.

3.1. Materials used

3.1.1. Soil

In the laboratory studies, clay is used as the test's bedding and coarse soil containing sand and gravel is used to fill the geocell elements. In order to prepare the preliminary provisions of the test, firstly dry clay is mixed with a predetermined amount of water. To reach the desirable water content, the moist clay is stored in a compressed state for a week in some containers.

Then the soil is put in the test box, evened gently, and is compressed in layers to the desired height by putting a wooden plate on its surface and striking it with a hammer using the guiding height marks on the box's sidewall. The physical and mechanical parameters of the soil used in the laboratory studies are set out below.

3.1.1.1. Clay

In this study, the soil used in preparing the laboratory samples' beddings is silty clay with 60% passage from a 75 mm sieve. Properties of this soil can be seen in table 1.

Table 1. Physical and mechanical parameters of the clay used in building the laboratory sample

Type of soil in the USCS system	Liquid limit (LL)	Plastic limit (PL)	Specific gravity of solid particles (G_s)
CL	40%	17%	2.66

3.1.1.2 Gravel and sand

The gravel and sand used in this study were used in dry state to fill the geocell elements in the laboratory sample. The complete properties can be seen in tables 2 and 3.

Table 2. Physical parameters of the gravel and sand used in building the laboratory sample

Type of soil in the USCS system	Coefficient of uniformity (C_U)	Coefficient of compressibility (C_C)	Effective diameter (D_{10})	Specific gravity of solid particles (G_s)	Maximum void ratio (e_{max})	Minimum void ratio (e_{min})
SP	2.22	1.05	360^{mm}	2.63	0.66	0.48

Table 3. Values of specific gravity and shear resistance of gravel and sand in various relative compactions of the laboratory samples

Relative compactions	Dry specific gravity (kN/m^3)	Internal friction angle of sand (Degrees)
48%	16.4	37
59%	16.6	39
70%	16.8	41

3.1.2. The reinforcing element

3.1.2.1. Geocell

The laboratory studies' reinforcing element are made of geocell. Geocells are manufactured from polymeric uniaxial geogrid and have square sections with voids that are 0.035×0.035 m. Properties of the geogrids and their connection in order to manufacture geocells – taken from the standard extreme-pressure test in ASTMS: D6637 – can be seen in table 4 [8].

Table 4. Physical parameters of geogrids and their connection in order to manufacture the geocell element

Properties	Value	
	Geogrid	Connection
Ultimate tensile strength	20 kN/m	7.5 kN/m
Ultimate strain	18%	28%
Primary module	18.3 kN/m	40 kN/m
Secant modulus in 5% strain	160 kN/m	42 kN/m
Secant modulus in 10% strain	143.4 kN/m	29 kN/m

3.2. Building the model

In the laboratory and numerical studies, the circular footing's physical model was built from solid steel with a diameter of 0.15 m and a depth of 0.03 m. The soil bedding was prepared in a tank with lengthm width, and height of 0.9 m. A circular hatch with a diameter of 0.095 m was built on the sidewall of the tank parallel to the center axis with a height of 0.11 m from the bottom of the tank. This circular hatch is for provision of voids under the clay layers of the bedding.

3.3. Procedure of loading the sample

In the laboratory studies, the voids are arranged at uniform distances from the surface of the clay layer. Then, the gravel layer placed on the clay bedding and the footing is fixed on it using a thin layer of cement and epoxy glue. Afterwards, the footing was loaded by a hydraulic jack placed against the frame's reaction. Stages of the test are shown in figure 1.

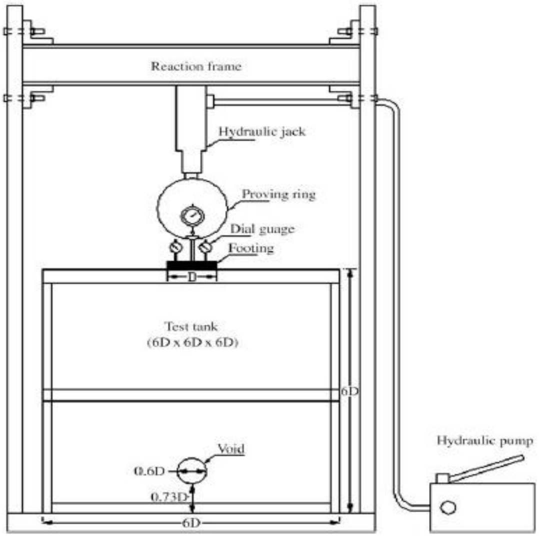

Fig. 1. Procedure of loading the laboratory sample

In order to prepare the test's bedding, moist soil is placed in the test's box and compressed in thick layers of 2.5 cm until the proper height is reached. By knowing the amount of water and density, the saturation ratio (S_r) of the soil is calculated. It is approximately 100%. The geocell layer forms at the outset of the compressed soils' bedding. Due to the better performance of square and rhombic geocell elements compared to the diamond shaped elements, all the geocell elements placed in the frame are prepared in square and rhombic patterns. After placing the geocell elements, these elements are filled with gravel and sand and the test is carried out with different variables and the load transferred to the footing's surface is evaluated by shafts and graded rings arranged between the bearing and the loading jack. Furthermore, changes in the footing are measured by two graded gauges placed at the footing's corner. It should be noted that in this test D is the footing's diameter, H is the non-reinforced sand layer's height, h is the geocell element's height, b is the geocell element's width, Dgs are the measuring gauges, and d_v is the diameter of the void in the clay bedding. These are illustrated in figure 2.

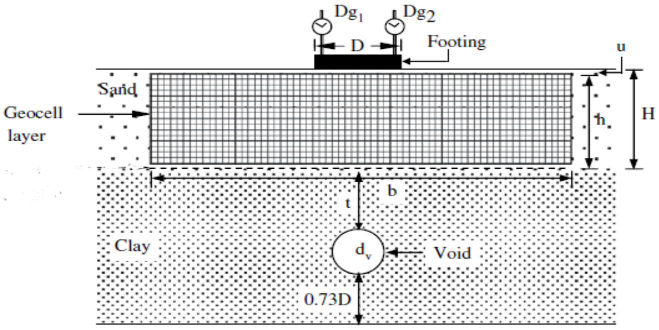

Fig. 2. Procedure of preparing the test's bedding

4. Numerical studies

In this study the numerical modeling of the laboratory samples was carried out utilizing the finite element software ABAQUS 6.11. This software was used in this analysis because it has the capability of solving problems ranging from a simple linear analysis to the most complex non-linear modeling [9]. It also has a very wide range of elements for analysis of any kind of geometry. In the next step, the geometry of the model with the dimensions given in the paper was created and all conditions were defined and fed into the software. Geometry of the model can be seen in figure 3.

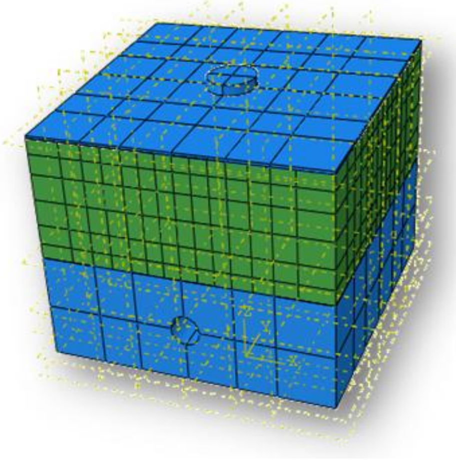

Fig. 3. Modeling of the circular footing utilizing ABAQUS 6.11

It should be noted that in order to model the non-linear behavior of clay, the CAM CLAY model was used. Sand's behavior was simulated using the DRUCKER PRAGER model [10]. Results from the numerical modeling and also the effects of changing the shape of the footing from circular to square and the results of comparing the load-bearing capacity of these two are set out below.

5. Results of numerical and laboratory studies

By investigating the impact of each of the effective parameters on load-bearing capacity of the footing and comparing the numerical and laboratory studies, the results below were reached that are set out separately.

5.1. Effect of the width of the geocell element (b)

Variations in the footing's load-bearing capacity against the percentage of its settlement in various widths of the geocell element (b) relative to the circular footing's diameter can be seen the diagram illustrated in figure 4.

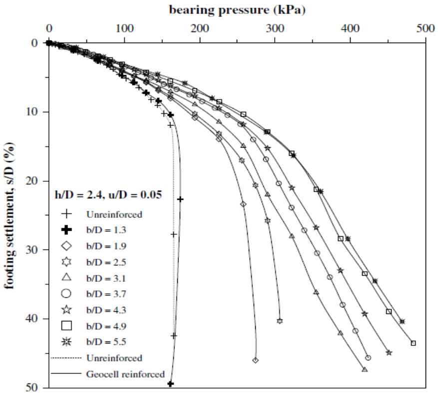

Fig. 4. Variations in the footing's load-bearing capacity against the percentage of its settlement in various widths of the geocell element (b)

As can be seen in results from the laboratory and numerical studies (table 5), in the case where the geocell element's width (b) is equal to the footing's diameter (D), existence of the geocell element doesn't have a significant effect on improving the load-bearing capacity. On the other hand, table 5 shows that by using a geocell element with a width approximately two times the footing's diameter (b/D=1.9), more than 60% increase in the load-bearing capacity and a considerable decrease in settlement is observed.

Table 5. Results of the load-bearing capacity improvement factor (IF_s) in different widths of the geocell element (b)

The variable parameter of the test b/D	The load-bearing capacity improvement factor (IF_s)							
	(s/D)= 1%	(s/D) =3%	(s/D) =5%	(s/D) =10%	(s/D) =15%	(s/D) =20%	(s/D) =30%	(s/D) =40%
1.3	1.00	1.00	1.00	1.03	1.04	1.04	1.04	1.00
1.9	1.00	1.21	1.30	1.30	1.43	1.53	1.59	1.63
2.5	1.11	1.24	1.32	1.32	1.49	1.66	1.78	1.84
3.1	1.11	1.38	1.43	1.55	1.59	1.72	1.99	2.25
3.7	1.13	1.43	1.48	1.56	1.71	1.85	2.13	2.40
4.3	1.13	1.43	1.53	1.60	1.78	1.94	2.23	2.55
4.9	1.13	1.49	1.66	1.74	1.94	2.13	2.40	2.76
5.5	1.39	1.49	1.73	1.72	1.94	2.14	2.44	2.81

It should be noted that the geocell element that is spread on the void at the distance of 0.65 times the footing's diameter and with a distance more than the void's diameter (d_v=0.6D), transfers the footing's pressure to the surrounding soil and causes an improvement in the footing's performance.

Therefore it can be said that in order to reach a more efficient performance, the geocell element's placing over the voids should be at least equal to the void's diameter (d_v) and so the footing's load-bearing capacity increases as the geocell element's width increases. This increase in improvement of the performance is significant when increasing b/D up to 4.9, but afterwards due to the limited stiffness of the geocell materials because of the fixed height and dimensions of their elements, the footing's pressure is transferred to a more confined area and therefore we'll have an insignificant increase in the performance improvement.

Furthermore, in order to investigate the circular footing's behavior more thoroughly, the physical model in the laboratory studies was numerically modelled in the finite element software ABAQUS 6.11 with the assumption of the geocell element's width ratio equal to b/D=3.7. Results from the laboratory and numerical studies can be seen in figure 5.

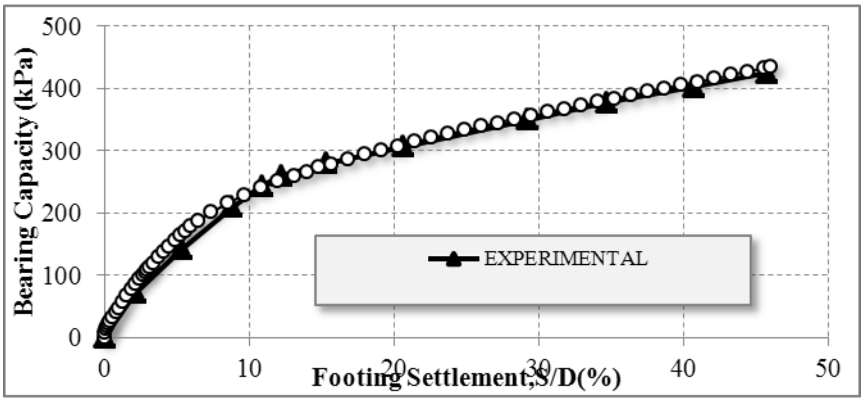

Fig. 5. Modelling of the circular footing with a geocell element with a width ratio of b/D=3.7

As is illustrated in figure 5, by increasing the geocell element’s width, the load-bearing capacity of the footing increases too.

Moreover, there’s a good agreement and consistency between results from the laboratory and numerical studies. This shows the accuracy of the studies carried out.

5.2. Effect of the height of the geocell element (h)

In order to investigate the effect of changing the geocell element’s height which is manufactured from polymeric uniaxial geogrid, we increase the geocell element’s height (the footing’s diameter is constant).

Results illustrated in figure 6 – taken from laboratory tests – show that the footing’s load-bearing capacity increases as the ratio of the geocell element’s height to the footing’s diameter (h/D) increases.

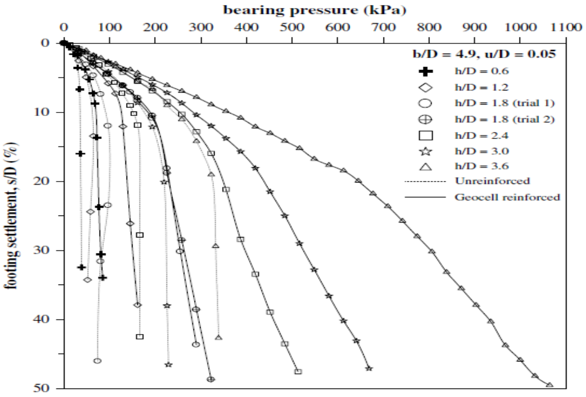

Fig. 6. Variations in the footing’s load-bearing capacity against the percentage of its settlement for different heights of the geocell element (h)

Table 6. Results of the load-bearing capacity improvement factor (IF_s) for various heights of the geocell element (h)

The variable parameter of the test h/D	The load-bearing capacity improvement factor (IF_s)							
	(s/D) =1%	(s/D) =3%	(s/D) =5%	(s/D) =10%	(s/D) =15%	(s/D) =20%	(s/D) =30%	(s/D) =40%
0.6	1.31	1.46	1.66	1.98	2.03	2.05	2.11	-
1.2	1.36	1.47	1.66	2.06	2.06	2.14	2.32	-
1.8	1.40	1.50	1.69	2.00	2.18	2.35	2.59	2.85
2.4	1.13	1.49	1.66	1.74	1.94	2.13	2.40	2.76
3.0	1.07	1.43	1.48	1.59	1.81	1.99	2.36	2.71
3.6	1.00	1.10	1.22	1.47	1.72	1.98	2.39	2.73

As can be seen in table 6, the footing’s load-bearing capacity increases as the geocell element’s height increases up to 1.8 times the footing’s diameter, while for ratios less than 1.8 and in large settlement the soil-geocell fabric breaks and from there on the geocell element plays an insignificant role in bearing the footing’s loadings. By increasing the height (h), the flexural and shear resistance of the geocell element increases and therefore it can bridge over the void efficiently and transfer the footing’s pressure to the confined soil volume. Thus in higher ratios of the height of the geocell element to the footing’s diameter (h/D≥1.8), the footing’s load-bearing capacity continues to increase until the footing’s settlement reaches 50%.

Finally we can conclude from these observations that the critical height of the geocell element that diminishes the void’s effect on the footing’s performance, is approximately 1.8 times the footing’s diameter.

In order to further the investigations on the laboratory studies’ results – by having in mind the effect of the geocell element’s height – a circular foundation was modelled with two different heights of the geocell element. Results are illustrated in figure 7.

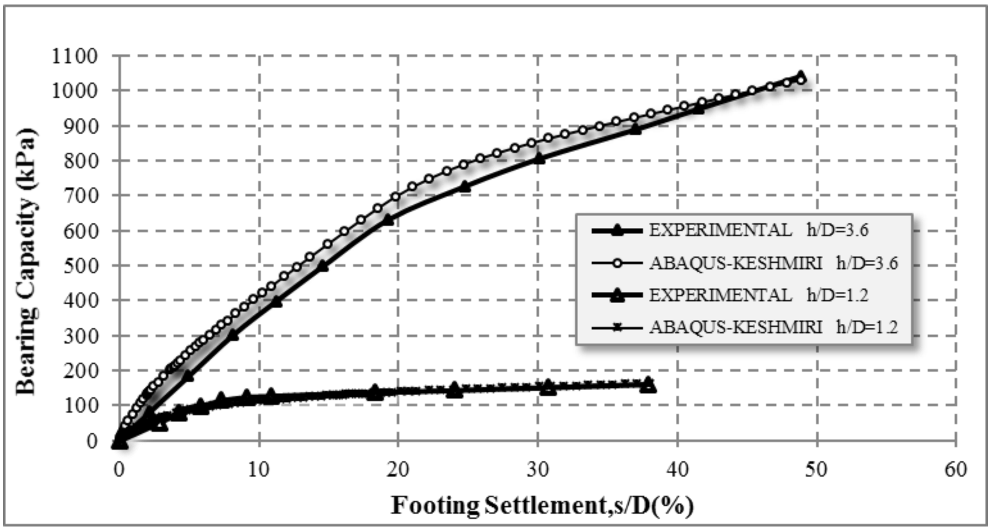

Fig. 7. Comparison of the modelling results of a circular footing with geocells of different height ratios

As can be seen in figure 7, the increasing trend of the foundation's load-bearing capacity as the geocell element's height increases can be clearly seen. Furthermore, the agreement between the results from the laboratory and numerical studies is acceptable and the difference is approximately 5%. This verifies the functioning of the numerical modelling for the purpose of this study.

6. Conclusion and discussion

By comparing the effective factors on footing's load-bearing capacity such as the width (b) and height (h) of the geocell element, it can be seen that if geocell elements are used to reinforce the soil, the footing's load-bearing capacity increases approximately 165% compared to the non-reinforced sample while the footing's settlement percentage increases by only 15% approximately.

Studying the variations in the geocell element's width (b) shows that increasing this parameter results in redistribution of the footing's pressure on a larger area of the soil under the footing and transfers the footing's pressure continuously on the voids which results in an increase in the footing's load-bearing capacity. Also as the geocell element's height (h) increases, stability and therefore the bending and shear stress of the geocell element increases and it efficiently transfers the foundation's pressure to the corresponding soil volume. This increases the footing's load-bearing capacity and decreases its settlement.

7. References

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