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ORIGINAL ARTICLE

Experiment of geosynthetic tensile strength in soil-geosynthetic interaction by pull-out test

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Soil reinforcement has a long history to improve its shear and tensile strength. The new way of soil reinforcement was developed by Henry Vidal in France (1960). In recent years, the use of geosynthetics has been increased to reinforce the soil structures. Due to the increasing use of geosynthetics, it is necessary to examine the stability of the reinforced soil structures by geosynthetic and also their analysis for internal and external stability. The use of reinforced soil by geogrid is preferred in economic and operational terms than the other methods for the earth structures stability. In this research, the soil-geogrid interaction parameters were studied in pull-out mode and a large-scale laboratory pull-out apparatus was used to study the geogrid tensile strength effect on the soil-geogrid interaction and five types of geogrids with different tensile strength were used. The results of the experiments showed that if the vertical pressure on the specimen is zero, all the geogrids are extruded out in the pull-out mode and do not rupture. Vertical pressure has a great effect on the increase of the t pull-out strength and when the tensile strength becomes higher, the greater vertical force is required on the surface of the sample in the pull-out box, so that its pull-out strength becomes active entirely. By increasing the tensile strength of the geogrid, the pull-out force of the geogrid becomes greater and the displacement of the geogrid sample is reduced inside the pull-out box. The results showed that by compressing the soil sample and placing it up and down the geogrid plate, the pull-out force is increased.

Keywords: Soil structures; pull-out; tensile strength; interaction; soil; geogrid

Introduction

Reinforcing soil by human have a long history and the study of the reinforced soil's history shows that the use of the reinforced soil by human backs approximately to 4-5 thousand BC; they used straw to reinforce the clay and clay bricks, the use of reinforced soil has been seen in parts of the wall of China. The used reinforced materials in the past were bamboo sheets, straw, straw and bark. Modern methods for reinforcing soil were introduced by the French architect and engineer Henry Vidal in 1960. His research and other researchers led to the development the modern method of reinforced soil. Since the soil is weak in terms of tensile strength, the soil is reinforced with materials that are appropriate for tensile strength. When the reinforcement material is placed inside the soil, the soil is reinforced, which is a method for the mechanical reinforcement of the soil. A composite material is created by reinforcing the soil, although the nature of the soil does not change, but soil engineering properties will be improved, including the shear strength, soil bearing capacity and tensile strength of the soil. The soil structures in civil engineering are constructed by a large volume of soil such as retaining walls, embankments, soil dams, abutments etc. The technology of using geosynthetics became widespread in Europe and the USA in the 1970s and the, and then the use of these materials was common in Asian countries. It was used in Iran, for the first time in Koohrang Power Plant, by Japanese companies and then in the southern ports of the country as well as for reinforced soil projects. Nowadays, with the advancement and development of this technology in Iran and the increasing number of specialists in this field, effective steps have been taken to replace this technology with the traditional methods which results of it is the use of its benefits, including increasing the efficiency of soil structures, safety, economic savings and reducing the runtime of projects, as well as the use of land and soils that have not already been used in the structures for the resistance and safety reasons.

In recent years, many retaining walls and embankments have been created around the world using the modern reinforced sand technique. The passage of time has shown the structures that have been created by the modern method of the reinforced soil have had a good performance. Farrag, et al., (1991), Pullout resistance of geogrid reinforcements; in his study, the effect of limiting pressure, soil density, boundary conditions and reinforcement characteristics over the displacement response of the selected grids in the sand was investigated (1991). The results show that increasing the thickness of the soil reduces the effect of the up and down boundaries. The thickness of the soil is necessary at 30cm upward and downward of the grid to eliminate the effect of these boundaries. Also, the tensile strength increases in the higher densities. Sugimoto et al.

(2001) Influence of rigid impact and flexible geogrid face in the pull-out tests; in this study, they examined the rigid and flexible geogrid behavior in the sandy soil which is under the pull-out test. The results show that rigid geogrid behavior is quite different than the flexible one. For these geogrids, the deformation and expansion of the pressure under the same pulling force are lower; therefore, tension is created at a larger level. Alagiyawanna et al. (2001) Influence of longitudinal and transverse members on geogrid pullout behavior during deformation; the results show that, the mobilization of the tension depends on the degree of strain of the geogrid. It is also observed that the contribution of the longitudinal members in the pullout force will be greater than the transverse members in geogrids. Racana, et al., (2003) Pull-out response of corrugated geotextile strips; the results of this study show that the stress in the corrugated geotextile strips is less than the flat and without corrugated one, which results in a reduction of the length of the necessary restraining. Palmeira, (2004) Bearing force mobilization in pull-out tests on geogrids; the results show the influence of parameters such as the reinforcement free length, the test velocity and interaction between members on the geogrid bearing force mobilization. Subaida, et al. (2008) Experimental investigations of tensile and pullout behavior of woven coir Geotextiles; in the tensile test, the tensile strength of geotextile is a function of fiber resistance, yarn properties and geotextile woven pattern. Abdi & Arjomand (2011), Evaluation of the interaction of fine-grained soil in thin layers of sand; the results show that with gradual increase in the thickness of the sand layer around the geogrid, the shear strength of the contact surface gradually increases and the thickness increase more than the optimal amount does not have much effect on the shear strength increase, and the wetness of the sand increases the shear strength at the contact surface.

Shi et al. (2013) , Investigating the interaction of soil and geogrid under pull-out test; in this study, the one-way and two-way geogrid were used and the results indicate that one-way geogrid has a softness behavior and the two-way geogrid shows the stiffness behavior. Lajevardi et al. (2013), Analysis of the interaction of the reinforced soil reinforcement with steel welded mesh by pull-out test, results showed that the mobilized friction resistance is increased by increasing the metal meshes in the transverse direction. The vertical tension of 20 to 140 kPa has been used in this test.

Suksiripattanapong et al. (2013), Pullout resistance of bearing reinforcement embedded in coarse-grained soils; in this study, pullout resistance of bearing reinforcement embedded in coarse-grained soils has been investigated. The results show that the friction resistance of bearing reinforcement is mainly controlled by the coarse-grained of friction, regardless grading. Jahed and Karim (2014), Investigating the behavior of the reinforced silty by the steel grid in the pull-out test; in this experiment, a galvanized steel grid was used with four longitudinal and transverse bars with the longitudinal and transverse bars with diameters of 9.015 mm and 6.35 mm respectively and a vertical stress of 20 to 115 kPa. The results show that when the steel grids are in a high strain, the internal friction angle of the soil becomes critical. Abdulvahhab et al. (2010), the physical and numerical model of the pull-out behavior of the geosynthetic reinforcement strip; in this study, the common surface behavior of geosynthetic and metal strips was investigated under the vertical stresses by performing several pull-out tests. The results show that the behavior of these two types of reinforcement (metallic and synthetic) is very different. Isla and Ruano (2015), experimental study and investigation of the effect of the pull-out test on steel fibers; the aim of this study is steel fibers with lengths of 35, 50 and 60 mm and aggregate type. The results show that the length of the fiber causes changes in the strength of the pull-out. Abdi and Zandieh (2015), the numerical and laboratory analysis for the large-scale of the interaction of the fine-grained and embodied geogrid soils in thin layers of sand under the pull-out test; the results show that the increase of the vertical overhead leads to increase the grain lock and clamp, surface friction, and thus improving the strength against the pull-out. Huang, J., (2015) Experimental and numerical study of geosynthetic reinforced soil over a channel; the results showed that the internal angle of friction of soil impacts on the applied stress on geosynthetic and the amount of the settlement. By increasing the internal friction angle of the soil, the applied stress decreases on the geosynthetic stress. Lajevardi et al. (2014), experimental study of the geosynthetic anchorage effect on geometric parameters and anchorages efficiency; in this study, with three-dimensional numerical modeling and performing pull-out tests on two reinforced soil types (sand and grit), with three types of geosynthetics (Two types of geotextiles and one type of geogrid) and analysis of their mobilization results and the capacity of geosynthetic anchorages for the simple and anchorage system, and the anchorage system with a return length, concluded that there is an optimal length for the above part of the geosynthetic in the anchorage system with a return length. Lajevardi et al. (2015), the study of pilot tests on two types of anchorages (with the simple performance and the anchorage system with a return length); in this study, the displacement method of geosynthetic is investigated in the sand-geotextile, sand-geogrid and grit- geotextile before and after testing. In the performed tests, some small displacements occurred in the soil mass at the top of the reinforcement, which is remarkable for the anchorage system with a return length. The uplift decreases with increasing the return length of the above anchorage. The uplift in the sand is similar to the uplift in the grit, but its amount is greater than the grit.

Research purposes

The study aims to investigate and analyze the soil-geogrid interaction, because the soil-geogrid interaction is very important for designing and operating the structure of reinforced soil, and it can be very complicated, depending on the type and characteristics of the reinforcement materials. Therefore, in order to improve the geosynthetic behavior in the soil and to better understand this behavior, laboratory testing is required. It can be said that the use of geosynthetics is an economic and ecological solution and also an engineering solution. Therefore, the pull-out test is carried out to learn more about how this material works in improving the soil quality and investigating the effect of different parameters on the increase of the soil strength.

Test method

Testing device

Testing apparatus includes the pullout box, holder's legs, jack, air bag; the air bag is used to apply the vertical force to upper surface of the soil sample, and equipments of the horizontal force, measuring and applying systems of the horizontal force measuring and the geogrid shifting are in the cutting box (Figures 1-4).

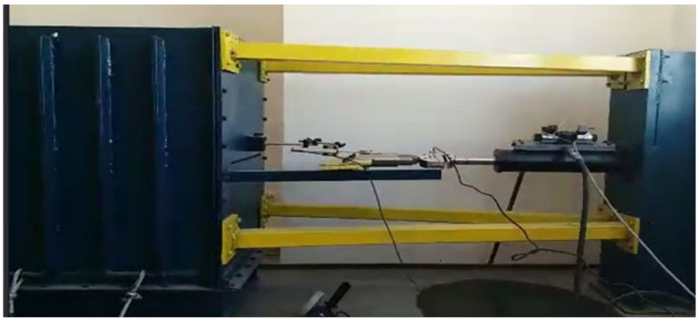

Figure 1. Pullout apparatus.

Pull-out box

The pull-out box is a Rectangle cube with the length of 120cm, width of 60cm and a height of 100cm.
The pull-out box has been made by the steel sheets, and to increase the strength of it, the steel straps are welded to the outer wall of the pull-out box.

Applying the vertical force

The vertical force is applied by the air bag above the pull-out box. The pressure of the air bag is supplied by an air compressor. The air compressor has an adjustable pressure regulator which adjusts the amount of required pressure of the sample by the air bag.

Applying the tensile force

The tensile force is applied by a hydraulic jack. The magnitude of the horizontal force is measured by a load cell between the clamp attached to the geogrid and the hydraulic jack. The velocity of the applied tensile force was 1mm/min at all stages of the test.

Geogrid displacement measurements

The horizontal displacement of the geogrid is measured by changing the position sensors placed in the pull-out box in four areas inside the pull-out box.

Friction of the inside surfaces of the pull-out box

In order to reduce the friction effect of the inside surfaces of the pull-out box, these surfaces were greased and a transparent, resistant plastic layer was placed on it, and on the front of the box a 15cm metal profile was placed; in fact, with this operation, there is no any vertical stress on first fifteen-centimeter of the geogrid.

Preparation of samples

The soil used for the test was completely dry and it was passed from a No. 40 mesh for having a monotonous mode in the test samples. The sifted soil was prepared for the required volume of the pull-out box. The soil was the sand type with a friction angle of 40 degrees. The soil was placed in six layers inside the pull-out box. Each poured layer was compressed inside the pull-out box by a rigid steel plate and then the next layer of soil was poured into the pull-out box. After the three layers of soil were poured inside the pull-out box, a geogrid was placed on the surface of the soil with a less surface than the compressed soil in the pull-out box. Three layers of soil were poured on the geogrid, and these layers are compressed like the three layers below the geogrid.

Figure 2. Type of the soil.

Figure 3. Geogrid.

Figure 4. A view of the upside of the pull-out box.

After filling the pull-out box with the soil, a 100 × 60 cm steel rigid plate was placed under the air bag. The surface of the steel plate is less than the surface of the pull-out box, because a part of the geogrid plate is placed inside two metal profiles, and the vertical force applied only to metal profiles. In this case, the vertical force is not applied to geogrid, as shown in Figure 3. After placing the air bag above the steel plate, the pull-out box door is closed by steel bolts and the pressure required is provided by an air compressor.
The end of the geogrid is closed to the clamp after passing through the cover. The command of applying the force is adjusted by a connected electrical system to the computer to test conditions appropriately (Figure 5).

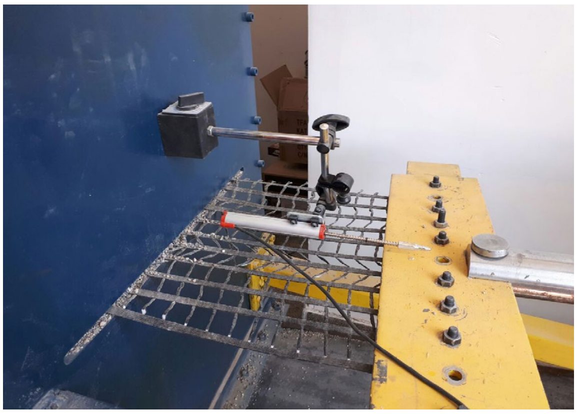

Figure 5. A sample of an attached geogrid to the pull-out clamp.

Conditions of the end of the test

The test ends when the rupture occurrence of a geogrid sample occurs as tearing or splitting of geogrid springs about 10 cm displacements in the longitudinal and transverse directions.
Rupture occurs usually when the geogrid sheet is pulled out, or due to the geogrid is torn. In the conducted tests, ruptures occurred due to the amount of vertical and horizontal forces and the tensile strength of the geogrid in both cases; the geogrid rupture and the exiting the geogrid plate from the pull-out box.

The used Geogrid samples in tests

In this research, five types of geogrid are used that their characteristics are in accordance with Table 1.

Table 1. Geogrid characteristics.

Characteristics	1	2	3	4	5
Brand	CE161	SQ15	CE131	PET	CE153
Tensile strength KM/M	-06Jul	-05May	-08May	5	-01Jun

In the performed tests, the soil type used was dry sand, and the geogrid were cut in such a way that its members were crossover and longitudinal in the sides. The geogrid samples had a 35 cm width that are placed in the center of the pull-out box and the edge of the samples was apart from the each edge of the pull-out box about 12 cm. The length of the geogrid samples was 120 cm centimeters, that 20 cm of it was used to attach the clamp and 15 cm of it was embedded inside of the cover in the front of the pull-out box, which was under the vertical stress, but there was not any sand on it. The sizes of the test samples were the same and tests were performed without overhead pressure and with three overhead pressure in 30, 50 and 65 Kpa.

Strength graphs of the geogrids' pull-out

The strength of the pull-out is calculated by dividing the horizontal force applied by the horizontal jack on the geogrid sample width under the test. During testing, the vertical stress is constant that is applied by the air bag to the upper surface of the sample. The graphs after the tests in fixed vertical stress: the stored data in the computer by the Excel in such a way that the pull-out force on the vertical axis of the graph and the displacement of the geogrid are plotted on the horizontal axis.

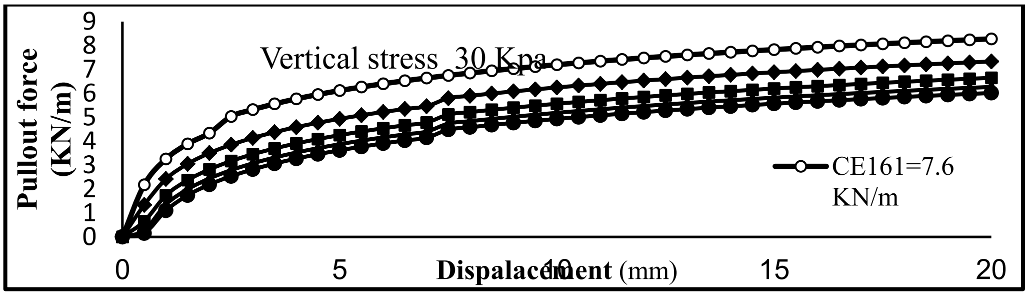

Figure 6. Graph of the pull-out force of geogrids displacement under the 30 kpa vertical stress.

According to Figure 6, a geogrid under 30 kPa vertical pressure that has a higher strength needs more pull-out force to displacement from the outside of the pull-out box. The initial slip of the graph is due to the slight deformation of the geogrid that is attached to the jack clamp, and according to Figure 4, the metal profile is placed to reduce the effect of the vertical wall in the front of the pull-out device on the results of the test.

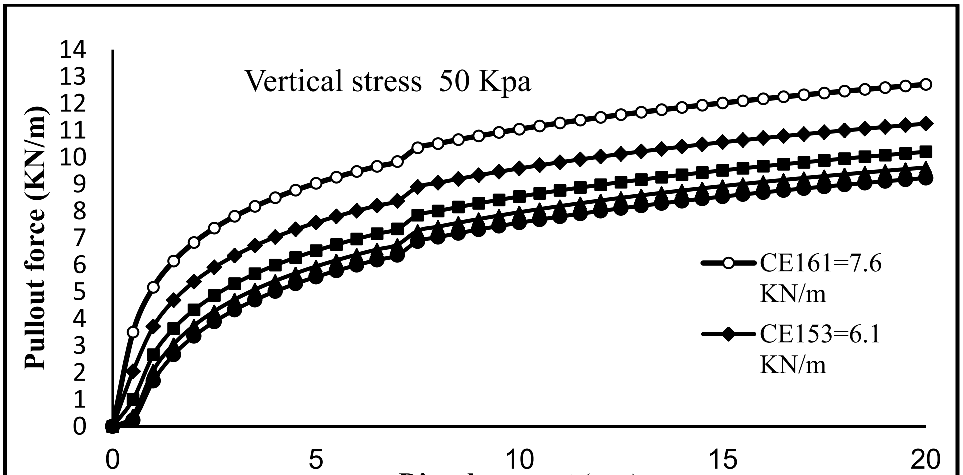

Figure 7. Graph of the pull-out force of geogrids displacement under the 30 kpa vertical stress.

In Figure 7, the vertical stress is equal to 50 Kpa and according to Figure 7, the amount of pull-out force has increased and a geogrid with a higher tensile strength starts to displace in the direction of pulling out of the pull-out box As shown in Figure 8, as the displacement of the geogrid increases, the amount of pull-out force also increases, according to the high and low soil clash of the geogrid sheet.

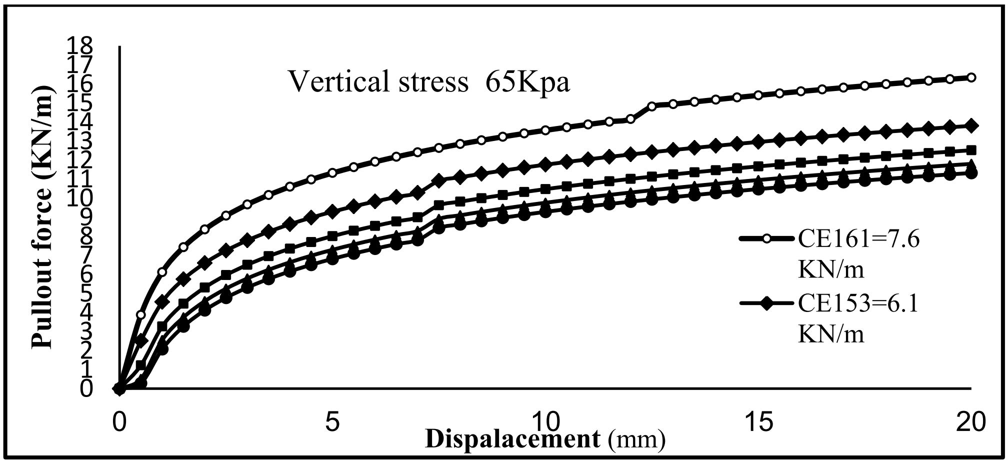

Figure 8. Graph of the pull-out force of the geogrids displacement under 65 kpa vertical stress.

In Figure 9, the vertical stress of 65 kPa is raised to the upper surface of the sample in the pull-out box by the air bag that is enclosed in the pull-out box. The value of pressure inside the air bag is adjustable by an air compressor and a pressure regulator. In Figure 9, with increasing vertical stress, the value of pull-out force has also increased. According to the graphs of Figures 7-8, the geogrid with a higher tensile strength have more pull-out force than other geogrids.

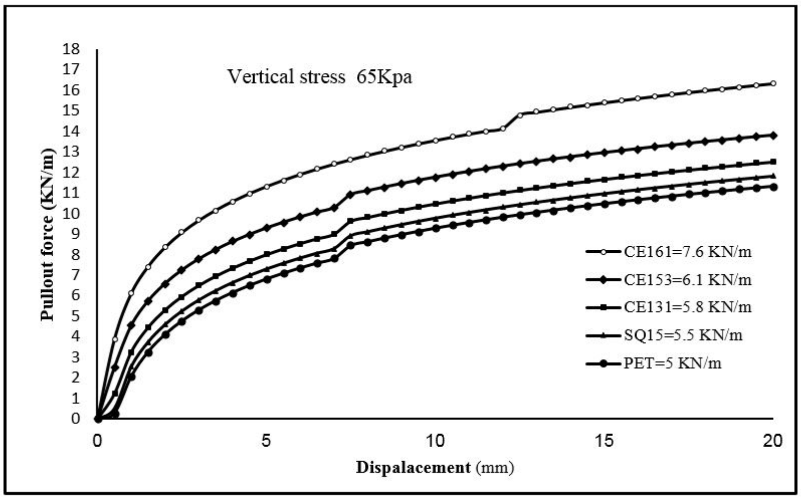

Figure 9. Graph of the pull-out force of the geogrids displacement under 65 kpa vertical stress.

Results of the tests

Various factors affect the interaction of soil-geogrid. One of these factors is the tensile strength of the geogrid; the tensile strength of the geogrid has a more effective effect on the interaction between the soil and the geogrid. The results of the experiments show that, if the tensile strength of the geogrid is higher under higher vertical pressure, the interaction between soil and geogrid increases. In other words, as the vertical force increases, the value of pull-out force increases in displacement of the geogrid.

The results of the tests show that in a situation where the vertical pressure is not applied, all geogrids are pulled out of the inside of the pull-out box without any rapture. Under the same vertical force, and if the velocity of applying the pull-out force is uniform, geogrid with more tensile strength will be less likely to rupture.

The results of the experiment show that by increasing the length of the geogrid inside the soil mass, the possibility of slipping and exiting the geogrid is reduced, regardless of the vertical pressure. It seems that according to the type of soil and geogrid characteristics, there is an optimal length to prevent the pull-out of the geogrid. In this regard, Lajevardi et al. have confirmed the geotextile optimal length for using geotextile according to the soil type.

According to displacement measurements of the geogrid different points in the tests, the displacement values are more at the points near the beginning of the pull-out box. As an example, displacement in the first 10cm of the sample is greater than the displacement at a distance of 30cm, regardless of the geogrid tensile strength. And the displacement of the 30cm point is more than the 45cm point and the displacement of the 45cm point is more than the 60cm point. With increasing the vertical force, the displacement of different geogrid points varies in such a way that by increasing the vertical force to 65 KN, the geogrids' pull out occurs as a rupture.

It seems that although the use of geogrid to reinforce the soil can improve the shear strength and soil tensile parameters, but according to the results of the experiments, this improvement in soil engineering parameters will increase much more if the soil becomes more compact. In other words, in addition to using geogrid for reinforcing the soil, the soil layers must also be compacted to improve the soil and geogrid interaction and efficiency.

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