Effect of Geogrid Aperture Size and Soil Particle Size on Geogrid-Soil Interaction under Pull-Out Loading

Mohammad Saleh Ahmadi and Parastoo Nikbakht Moghadam

Abstract— **In civil engineering applications, geogrid materials are widely used to reinforce retaining walls, roads, highways, and railway ballasts. Therefore, studying the geogrid-soil interaction under pullout condition is important for any successful design.**

In this work, five types of geogrid samples with various aperture dimensions were produced and used for conducting pull-out tests. Four types of soils with different particle size distribution (PSD) and grading were used for this purpose. It was found that aperture dimension is an influential factor in the pull-out resistance (POR) of geogrids and should be selected properly based on the PSD of the soil. Soil grading was also found to be an important factor in selecting aperture dimensions. It was observed that POR is more sensitive to transverse rib density of geogrids rather than their longitudinal rib density.

Keywords: **aperture size, interaction, geogrid, particle size, pull-out, soil**

I. INTRODUCTION

In recent years, geogrids have gained significant importance as soil reinforcement materials in civil applications. Owing to their high tensile strength and acceptable extensibility, they significantly increase load bearing capacity of the soil. Nowadays, they are widely used in such applications as road embankments and retaining walls, since they possess several advantages over existing methods in terms of cost effectiveness, stability and esthetical merits. Various advantages for application of geogrids have been reported in the literature [1-5].

As an important category of geogrids, "textile" or "coated-yarn" geogrids, are produced by weaving or knitting high tenacity yarns, and then coating the mesh fabric with polyvinyl chloride (PVC), latex or bitumen. These kinds of geogrids possess high degree of flexibility compared with two other common types of geogrids, i.e. "drawn-film" and "bonded-tapes" geogrids [6]. Their other advantages over drawn-film geogrids are high tensile strength and low creep properties [7].

Due to the aperture structure of all kinds of geogrids, they can interlock with the soil particles. Thus the applied stresses can be transferred from surrounding soil to the reinforcing elements by the developed bonds. Therefore, the pullout behavior of geogrids plays a significant role in the design of geogrid-soil structures.

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In the past decades some researchers have experimentally studied the role of different parameters affecting the interaction between geogrids or other geosynthetic reinforcements and soil.

Lopes and Lopes [8] studied pullout behavior of five different geosynthetics embedded in two different granular soils. They concluded that the influence of soil particle size on soil-geosynthetic interaction is important, but its significance depends on several factors. With drawn-film geogrids, the relative size of soil particles and geogrid apertures, and the thickness of the geogrid bearing members, determine the soil-geogrid interface shear resistance. A marked increase in soil-geogrid interface shear resistance was observed when the soil contained a significant percentage of particles with sizes slightly greater than the thickness of the geogrid bearing members, but smaller than the geogrid apertures.

Sugimoto *et al.* [9] conducted a series of laboratory pullout tests to investigate the pullout behavior of geogrid in sand under rigid and flexible boundary conditions. They found that the geogrid pullout behavior with the rigid front face is different from that with the flexible front face. They discussed the behavior of each geogrid.

Liu *et al.* [10] investigated the contribution of transverse ribs to the sand-geogrid interface shear. They showed that the transverse ribs provide additional contribution to the overall sand-geogrid interface resistance. This contribution is positively correlated with the tensile strength and the stiffness of geogrid ribs, but is negatively correlated with the percentage of open area of the geogrid.

Calvarano *et al.* [11] carried out an experimental static pullout test program on extruded (drawn-film) geogrids of different geometry and stiffness, embedded in different compacted granular soils. They indicated that a marked increase in the pullout resistance was observed in the soil with better mechanical characteristics that contained a significant percentage of particles slightly greater than the thickness of the bearing members, but smaller than the openings of the geogrids.

Kim and Ha [12] conducted large direct shear tests on three types of coarse grained soils to evaluate the effect of particle size on the shear behavior of coarse grained soils with/without geogrid reinforcement. The results showed that the cohesion of the soil reinforced with a stiff (drawn-film) geogrid was larger than that of the soil reinforced with a soft (textile) geogrid. The difference in the shear strength occurs because in a case with a stiff geogrid there is more contact area between soil particles and geogrid, leading to a reduction in the interlocking between soil particles.

Some other experimental research works, also emphasize on the important role of geogrid parameters in geogrid–soil interaction [13-16].

However, reviewing the literature in this field reveals that almost all research works are based on the commercially available types of geogrids. Although, they would be helpful in choosing appropriate products from available ones for specific applications, the available geogrids may not be in the same conditions to be compared with each other from the point of view of a technical textiles specialist. Therefore, the aim of this paper is to produce different kinds of textile geogrids with different aperture sizes under the same conditions and from the same materials (keeping their final tenacity constant) and then investigate their interaction with various soils with different particle sizes under pull-out loading.

II. Materials and Methods

For producing geogrid samples, high tenacity polyester yarn from Zhejiang Guxiandao industrial fiber Co., Ltd. was used. The specifications of the yarn are given in Table I.

TABLE I
SPECIFICATIONS OF THE HIGH TENACITY POLYESTER YARN

linear density (dtex)	3365
strength at break (N)	284.3
strain at break (%)	13.3
hot air shrinkage (%) (177 °C, 2 min, 0.05 g den^{-1} loading)	7.8

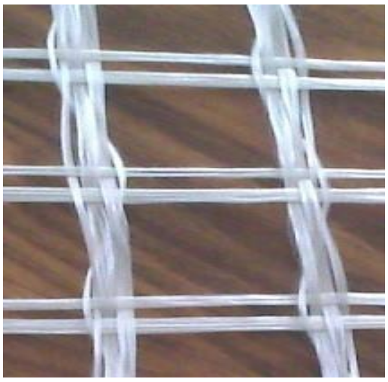

Fig. 1. The structure of one of the geogrid raw fabric samples.

The raw fabrics were woven on a sample weaving machine with Rib 2/2 pattern, using one leno yarn in every longitudinal rib for structural integrity. Fig. 1 shows the structure of one of the woven raw fabrics. Five samples were woven with different aperture sizes, but the same strength per unit length. Therefore, samples' structures were designed so that they had the same number of wefts per unit length and the same number of warps per unit width. This was possible by changing the number of yarns per longitudinal and transverse ribs. For example, as it can be seen in Fig. 2, geogrids (a) and (b) had different aperture sizes, but the same number of warps per unit width. This is to address the question of geogrid manufacturers; how to design the product aperture sizes for a given specific strength and how it affects the interaction of soil/geogrid under pull-out conditions.

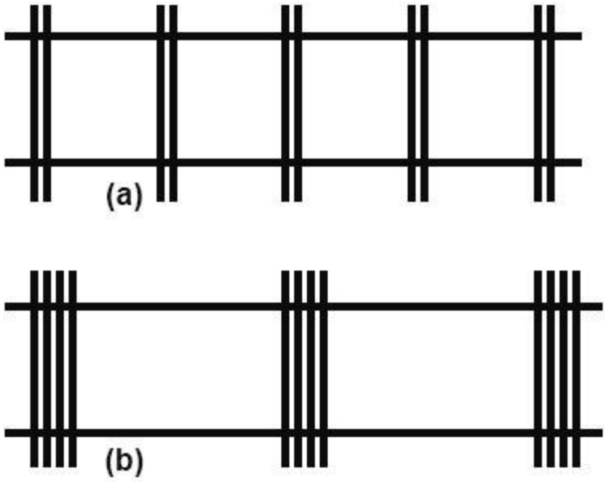

Fig. 2. Geogrid structures (a) and (b) with different aperture sizes, but the same number of warps per unit width.

The fabrics were then coated with a coating material based on PVC from Geo Shabakeh Parsian Co., and cured at 180 °C for 2 minutes. The aperture size of geogrid samples are given in Table II. Fig. 3 shows the photographs of produced geogrid samples.

TABLE II
SPECIFICATIONS OF GEOGRID SAMPLES

sample code	aperture size (mm) width (transverse direction)	aperture size (mm) length (longitudinal direction)
AA	18	18
BB	23	23
CC	31	31
CA	31	18
CB	31	23

Four kinds of soils with different particle sizes for using in pull-out tests were utilized in this study. The particle size distribution (PSD) of the soil was determined by sieve analysis. Some geotechnical properties of the soils are given in Table III. D_{10}, D_{30}, D_{50} and D_{60}, which are obtained by sieve gradation method, are the particle diameters that respectively 10, 30, 50 and 60 percent of the soil particles are finer than that particular diameter. D_{50} is known as the average particle size and D_{10} is termed as the effective particle size. The coefficient of uniformity (C_u) and the coefficient of curvature (C_c) are calculated using Eqs. (1) and (2) respectively:

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \quad (2)$$

Fig. 4 shows the PSD of the soils. Photographs of the soil samples are shown in Fig 5. As it can be seen from Table III and Fig. 4, S1, S3 and S4 are poorly graded soils,

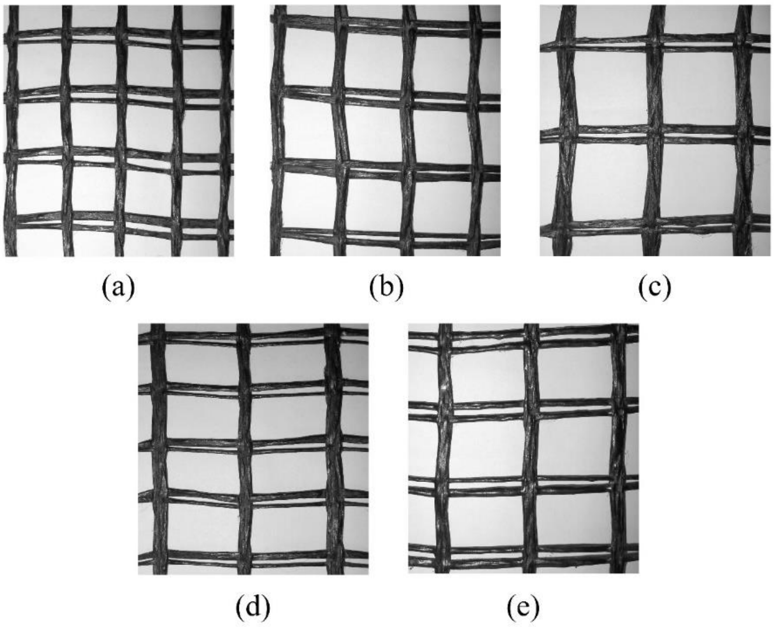

Fig. 3. Photographs of produced geogrid samples; (a) AA, (b) BB, (c) CC, (d) CA, (e) CB.

in which the range of particle size is narrow, however, S2 has a wider range of particle size and can be regarded as a well graded soil. A well graded soil is a soil that contains particles of a wide range of sizes and has a good representation of all sizes.

TABLE III
SOME GEOTECHNICAL PROPERTIES OF THE SOILS

soil code	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
S1	0.53	0.76	0.93	1.02	1.92	1.07
S2	0.62	1.36	2.60	3.50	5.62	0.85
S3	5.19	6.40	7.64	8.26	1.59	0.96
S4	18.24	21.25	23.61	24.79	1.36	1.00

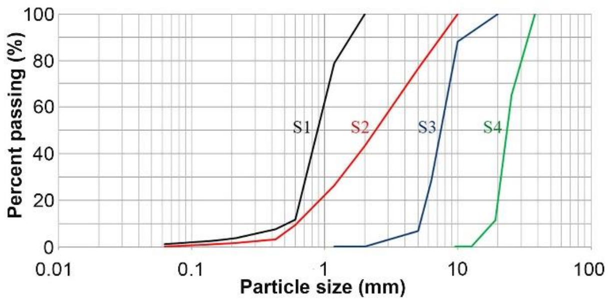

Fig. 4. Particle size distribution of the soils.

In order to measure the pull-out resistance of geogrids, a simple box with a length, width, and height of 250, 160, and 160 mm respectively, and a narrow opening in the front was built. Attaching this box to a universal testing machine made it easy to measure the pull-out force (Fig. 6). Although the measured force may not represent the exact pull-out force measured by a complex standard instrument, it provides good criteria for comparing samples under the same conditions. As illustrated in Fig. 6, the soil was first poured into the box and was compacted up to the opening level. The geogrid samples, with dimensions of 105 × 290 mm, were placed on the soil, with one side out of the box from the opening. The end of the geogrids was gripped by a metal clamp and was attached to the load cell of the testing machine with a steel cable with a diameter of 7 mm. After pouring the soil on the samples and compacting it up to the top level of the box, a thick nonwoven fabric and then the box lid were placed on the soil and a normal pressure of 3.75 kPa was applied. The nonwoven layer was used to uniformly distribute the normal force over total area. Five specimens from each geogrid sample were tested with each soil type. Tests were conducted using Shirley Testometric – Micro 350 universal testing machine with the rate of 170 mm min^{-1}.

Fig. 5. Photographs of the soil samples: (a) S1, (b) S2, (c) S3, (d) S4.

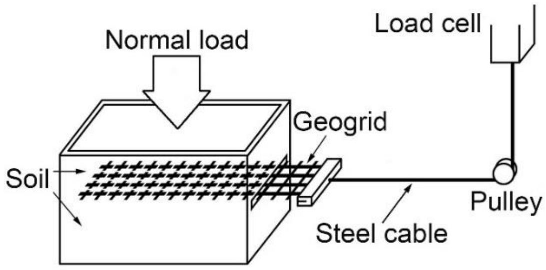

Fig. 6. Pull-out test set-up.

III. Results and Discussion

A typical force-displacement curve obtained from pull-out test is shown in Fig. 7. The maximum force value in the curve is regarded as the pull-out force. The pull-out force is used to calculate the pull-out resistance of the unit width of the geogrids according to the standard method BS EN 13738 (geotextiles and geotextile-related products; determination of pullout resistance in soil) using Eq. (3):

$$P = \frac{F \times N_g}{n_g} \tag{3}$$

where P is the pull-out resistance in N m^{-1}, F is the pull-out force measured in the test in N, N_g is the number of ribs per meter in the width of geogrid, and n_g is the number of ribs in the width of the geogrid test specimen.

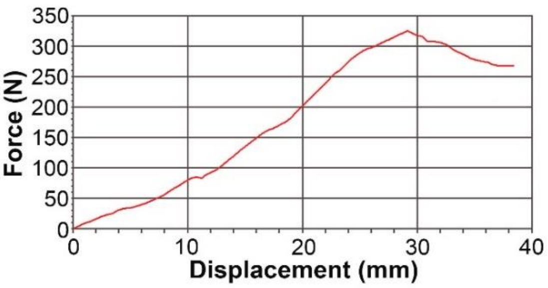

Fig. 7. A typical force-displacement curve obtained from the pull-out test.

Fig. 8 compares the average pull-out resistance (POR) of geogrids for the soil S1. Error bars in the figure illustrate the standard errors for each data set. As it can be seen, for S1 which has the finest particles among all soil types, the highest POR is achieved with geogrid AA, which has the smallest aperture size.

In fact, changing the aperture size of geogrids will have two distinct effects. First, it changes the area in which soil particles can be placed and interlock with the geogrid, and second, it changes the number of transverse and longitudinal ribs, which directly influences the frictional force between geogrid and soil. Comparing CA, CB and CC which have the same aperture width but different aperture length, shows that increasing the number of transverse ribs per unit length leads to an increase in the POR.

By comparing AA with CA, one can observe that increasing the longitudinal ribs per unit length will also increases the POR, however, its effect may be less considerable than increasing the transverse ribs (when it is compared with the difference between CA and CC).

On the other hand, in AA as a geogrid with the highest number of transverse and longitudinal ribs per unit length, the aperture area seems large enough for S1 particles to interlock suitably. Therefore, it shows the highest POR for this type of soil.

ANOVA analysis was employed on the data and confirmed the differences between data categories. The results of ANOVA analysis are summarized in Table IV.

The results of the pull-out test for soil type S2 are illustrated in Fig. 9. Considering AA, BB and CC as square mesh geogrids, it is obviously clear that BB has the highest POR, which shows that particles of S2 interlock best with BB apertures. The result of AA is higher than that of CC which can be related to the higher number of interacting ribs.

The result of CB is the highest among all samples, though its difference with that of BB is not statistically significant. The results may show that POR is more sensitive to the transverse ribs density rather than the longitudinal one. The decrease in the transverse ribs density from sample CB to CC leads to a considerable drop in POR, however, decreasing the longitudinal ribs density from BB to CB or even from AA to CA does not show any significant change. Therefore, considering the average particle size of the soil as D_{50}, one can conclude that for S2, a suitable geogrid may have an aperture length of about 9 times the D_{50} value. Aperture width may have a wider range (the variable range studied in the current work which was around 7-12 times the D_{50} value showed acceptable results, however, more tests are needed to check whether or not a wider range is acceptable).

TABLE IV
A Summary of ANOVA Data Analysis

source	type III sum of squares	df	mean square	F	Sig.	partial eta squared
corrected Model	1744946.750[a]	7	249278.107	12.653	0.000	0.451
intercept	11900043.400	1	11900043.400	604.046	0.000	0.848
soil	1502335.406	3	500778.469	25.420	0.000	0.414
size	225984.053	4	56496.013	2.868	0.027	0.096
error	2127658.771	108	19700.544			
total	15899608.847	116				
corrected total	3872605.521	115				

[a] R Squared = 0.451 (adjusted R squared = 0.415)

Pull-out resistance of samples for soil type S3 is shown in Fig. 10. It can be seen that CB has the highest value, and among square mesh samples BB shows the highest resistance. Since both BB and CB have the same transverse rib density, it can be concluded that among available aperture dimensions in this study, aperture length of 23 mm shows the best results for S3. It equals about 3 times the D_{50} value of the soil. Furthermore, the high POR value of CB shows that aperture width of 31 mm in the tested samples is the most suitable one. It is equivalent to around 4 times the D_{50} value of S3. However, since larger aperture widths are not tested in this work, it is recommended to perform more tests with wider range of apertures to find the most suitable aperture dimensions with higher accuracy.

Nevertheless, comparing the results of S3 with those of S2, one can see that despite the soils have different PSDs, they both match best with the same geogrid sample (CB). This may be due to the difference in the grading of the soils. As mentioned earlier, S2 is a well graded soil in which a wider range of particle size is available, while S3 is a poorly graded one. It can show that in well graded soils, the ratios of suitable aperture dimensions to D_{50} are higher values compared with those of poorly graded ones. In other words, in well graded soils, larger particles are more influential in selecting the geogrid aperture dimensions.

Based on previous findings, it may be concluded that for S1, which is also a poorly graded soil, geogrids with much smaller aperture dimensions than AA could lead to the highest POR. However, among the current samples, AA with the finest apertures gives the best results.

Similarly, S4 which is another type of a poorly graded soil, should match best with apertures far larger than the samples apertures in this study. So the aim of testing S4 is to study pull-out behavior when grid apertures are much smaller than the optimum values. The results of POR test on S4 are shown in Fig. 11. However, it should be noted that standard deviations (SDs) of the data in all samples were so high that significant difference between some samples could not be distinguished statistically. Even, increasing the number of tests per samples for this soil didn't lead to considerable drop in data SDs. This may be due to the fact that when the apertures are small, it will be a matter of chance that whether or not some particles or some parts of them can interlock with apertures; thus, high scattering of the pull-out data can be observed. Therefore, it seems impossible to make a good judgement on the results.

The findings show the importance of selecting proper dimensions for the geogrid apertures. Selecting small apertures results in improper interlocking between the soil and the geogrid and highly scattered results. The POR will not reach its maximum value, either. On the other hand, with large apertures, the frictional force between soil and geogrid and subsequently the POR will decrease.

Moreover, comparing Figs. 8-11 shows that an increase in the particle size of the soil results in an increase in the POR of the geogrids. This is consistence with the expectations, since larger particles produce higher anchorage force on geogrids. Fig. 12 illustrates the maximum POR value that was reached in each soil.

IV. Conclusion

The effects of geogrid aperture size and soil particle size on the pull-out resistance (POR) of woven geogrids were studied in this work. For this purpose five types of geogrids with various aperture sizes were produced using high tenacity polyester yarns and PVC coating materials. The samples were designed so that the number of yarns in the unit length of the geogrids remained the same.

Four types of soils with different particle size distribution and grading were used for the pull-out test. The tests were conducted using a universal testing machine equipped with lab-made testing apparatus.

Results showed that for each type of soil, there are optimum grid aperture dimensions based on the soil particle size. With smaller apertures soil and geogrid interlock improperly, which leads to low POR with highly scattered results. Large apertures decrease the frictional force between soil and geogrid and result in low POR.

It was concluded that selecting the proper aperture dimensions depends on soil gradation.

Moreover, it was found that the POR is more sensitive to the transverse rib density of geogrids rather than their longitudinal rib density.

It was observed that the soil particle size considerably influences the POR. Larger particles result in higher POR.

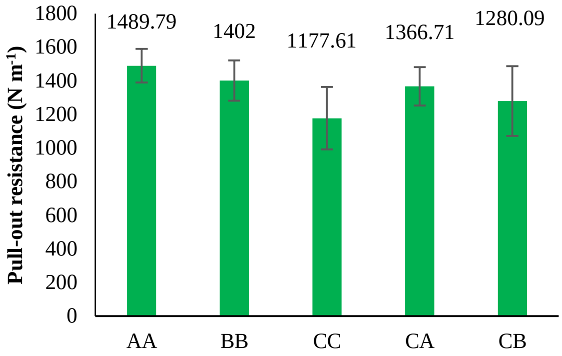

Fig. 8. Pull-out resistance of geogrid samples for soil type S1.

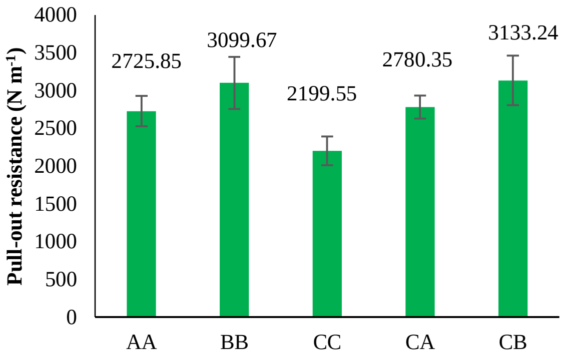

Fig. 9. Pull-out resistance of geogrid samples for soil type S2.

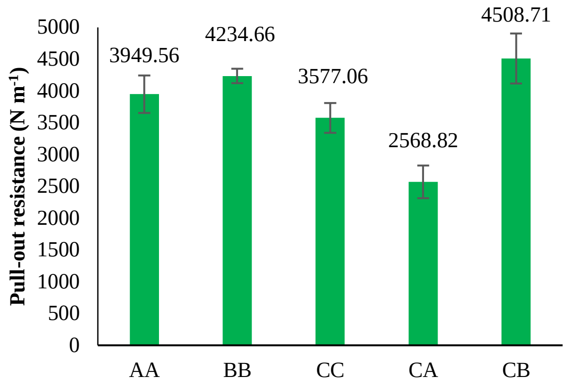

Fig. 10. Pull-out resistance of geogrid samples for soil type S3.

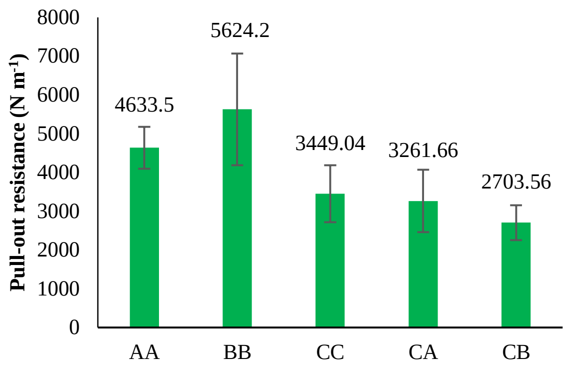

Fig. 11. Pull-out resistance of geogrid samples for soil type S4.

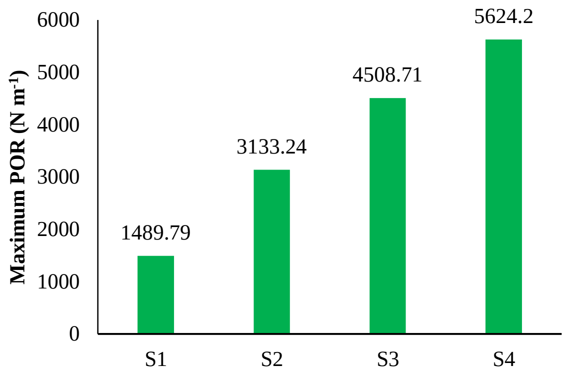

Fig. 12. Maximum pull-out resistance that was reached in each soil type.

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