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Pullout resistance of an innovative geogrid system embedded in a granular soil

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ABSTRACT: As an important reinforcing substance in practice, geogrids have been broadly used in dealing with different geotechnical problems. In this study, a new system called “anchored geogrid” (AG) for increasing pullout resistance is introduced. This system is formed by adding steel transverse elements (a set of steel equal angles) to the simple geogrids made from high-density polyethylene (HDPE), by means of bolts and nuts with high resistance. The optimization analysis shows that a spacing-to-depth ratio (s/d) of the steel transverse elements in an AG system of two gives the maximum pullout resistance for the AG system in sandy soil with small particles. In general, AG system with the optimum spacing-to-depth ratio ($s/d=2$) is capable of increasing the pullout resistance of the ordinary geogrid system by up to three times.

RÉSUMÉ :

Comme substance de renforcement importante dans la pratique, les géo-grilles ont été largement utilisés pour faire face à différents problèmes géotechniques. Dans cette étude, un nouveau système appelé (anchored geogrid) (AG) pour augmenter la résistance au retrait est introduit. Ce système est formé par l'ajout d'éléments transversaux en acier (un ensemble d'angles égaux en acier) aux géo-grilles simples en polyéthylène haute densité (PEHD), au moyen de boulons et écrous à haute résistance. L'analyse d'optimisation montre qu'un rapport espace / profondeur (s / d) des éléments transversaux en acier dans un système AG de deux donne la résistance maximale à l'arrachement pour le système AG dans un sol sablonneux avec de petites particules. En général, le système AG avec le rapport d'espacement / profondeur optimal ($s / d = 2$) est capable d'augmenter jusqu'à trois fois la résistance à l'arrachement du système ordinaire de géo-grille.

KEYWORDS: Geosynthetics, Pullout resistance, Anchored geogrid, MSE walls.

1 INTRODUCTION

A geogrid is geosynthetic material employed to reinforce soils and enhance the overall performance of foundations, slopes, roadways and walls (Tran et al. 2013). A pullout test allows to study the tensile stress applied on the reinforcement systems and to define the evolution of the soil-reinforcement interaction (Khedkar and Mandal 2009). During the last few decades, the pullout mechanisms of various extensible and inextensible reinforcements have been numerically, analytically and experimentally investigated by many different researchers (Khedkar and Mandal 2009, Abdelouhab et al. 2011, Abdi and Zandieh 2014, Bergado et al. 1992, Ezzein and Bathurst 2014, Mosallanezhad et al. 2016).

To ensure better interfacial interactions, different researchers have tried to increase the interaction by making changes to the soil-reinforcement interface, or to the reinforcement itself (Abdi and Zandieh 2014, Mosallanezhad et al. 2016). Mosallanezhad et al. (2016) tried to improve the pullout resistance of ordinary geogrids by adding anchors made of high-density polyethylene (HDPE) using industrial strips. By employing this system, the pullout resistance of conventional geogrid increased markedly. In this study, the pullout resistance of a new reinforcement system, applied on a large-scale in a sandy soil, has been examined experimentally. This system is fabricated by adding rigid bearing transversal elements (a set of steel equal angles) to the conventional HDPE geogrids. This reinforcement system is called “anchored geogrid” (AG). The rigid bearing transverse elements are connected to the ordinary geogrid by means of nuts and bolts. It should be noted that, at the connection point between the bolts and the transverse geogrid ribs, a washer made of PVC is used. By using this washer, no harm is incurred to the geogrid transverse ribs (Fig. 1). The results of this study indicate a considerable increase in the pullout performance of

this system in pullout mechanism compared to that of conventional geogrids.

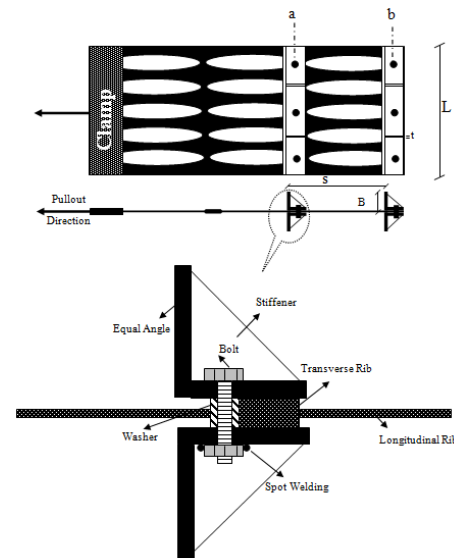


Figure 1. The features of the reinforcement system of anchored geogrid (AG)

2 Laboratory investigations

2.1 Laboratory pullout tests

A series of pullout tests was designed in order to evaluate the optimum ratio of spacing-to-depth of rigid bearing transverse elements (s/d) opt. A total of 21 pullout tests were conducted,

under different applied normal stresses of 10, 20 and 30 kPa, and with anchorage/bearing elements with different leg lengths (B) and depths (d=2B).

2.2 Test apparatus

In this research, a large-scale pullout test apparatus was fabricated based on ASTM D6706-01 (2013). The experiment apparatus consisted of one rigid pullout box, an airbag, a loading clamp assembly, a hydraulic actuator, and all the instruments needed to record the required data for analysing the pullout tests (Fig. 2).

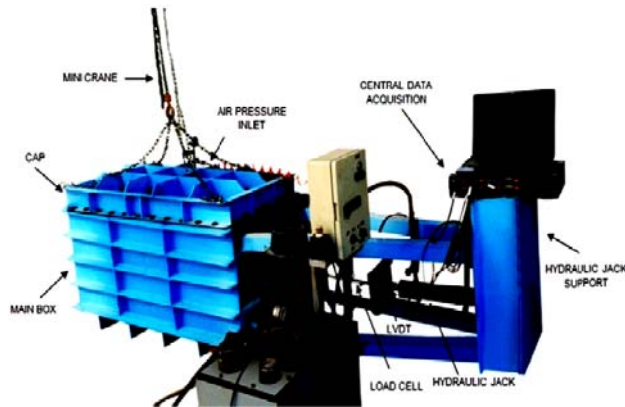


Figure 2. Schematic of large-scale pullout apparatus

2.3 Testing materials

2.3.1 Geogrid

In this study one HDPE-extruded uniaxial geogrid was used as the base geogrid. This product is manufactured by the Tenax International Corporation, under the name “TT 060 SAMP”. In Table 1, the geogrid material properties, as provided by the manufacturing company, are shown.

Table 1. Geogrid material characteristics

Geogrids	
Aperture size MD, longitudinal (mm)	220
Aperture size TD, transverse (mm)	13/20
Tensile strength at 2% strain (kN/m)	17
Peak tensile strength (kN/m)	60
Yield point elongation (%)	13

MD: machine direction (longitudinal to the roll)
 TD: transverse direction (across roll width)

2.3.2 Soil sample

The soil used in this investigation was sandy soil, which was classified as poorly graded sand (SP), based on the Unified Soil Classification System (USCS). The main properties of this soil are shown in Table 2.

Table 2. Soil properties used for sample preparation

Soil	
Maximum dry unit weight (kN/m ³)	17.8
Dry unit weight (kN/m ³)	16.3
Minimum dry unit weight (kN/m ³)	14.3
Uniformity coefficient (C _u)	3.37
Coefficient of curvature (C _c)	0.78
Angle of friction (φ°)	33
Cohesion (c) (kN/m ²)	5.0
Relative density (D _r %)	63

2.3.3 Bearing elements

Steel equal angles were used as transverse elements (anchorage members). The length of the different anchorage elements was selected in accordance with the geogrid’s width (about 30 cm). In Table 3, the different arrangements of transverse elements in the AG system are presented.

Table 3. Geometric specifications of the anchored geogrid

Arrangement No.	Leg length (steel equal angles) (cm)	Arrangement of the anchorage elements (as in Fig. 1)	Depth of the anchorage elements (cm)
1	2	b	4
2	2	a, b	4
3	4	b	8
4	4	a, b	8
5	6	b	12
6	6	a, b	12

2.4 Sample preparation and test procedure

The sand was prepared in the pullout box with six horizontal layers of about 8 cm. After compacting the first three layers of soil, the conventional geogrid or AG system was laid on the compacted soil while the front end of the reinforcement had been connected to the clamp.

After connecting the displacement sensors, soil layers were loaded and compressed, until the upper half of the pullout box was also full. The relative density of the sand was 63% and the unit weight of the soil was 16.3 kN/m³. For the next stage, an airbag was placed over the soil. After completing all the aforementioned tasks, the pullout force could be applied, in a controlled stress rate method (uniform rate of load application; not exceeding 2 kN/m/min).

3 Results and discussion

In Fig. 3, the pullout resistance of both the reinforcement systems used in this research, under different overburden pressures, is illustrated. As can be observed in this figure, by adding only one transverse element and forming the AG system, one can improve the pullout resistance of an ordinary geogrid significantly, especially under low overburden pressure. One of the advantages of the AG system compared to the conventional geogrid system is the considerable flexural rigidity of its transverse members. Generally, the flexural rigidity of the transverse elements can influence the pullout resistance. On the other hand, taking into account the limited thickness of the bearing ribs of geogrid in the production procedure, the amount of passive resistance accumulated during the pullout procedure in front of these ribs is likewise limited. As the bearing resistance produced in front of the transversal elements is the most effective factor in producing pullout resistance, one can significantly increase the passive resistance of conventional geogrid by adding transversal elements to it.

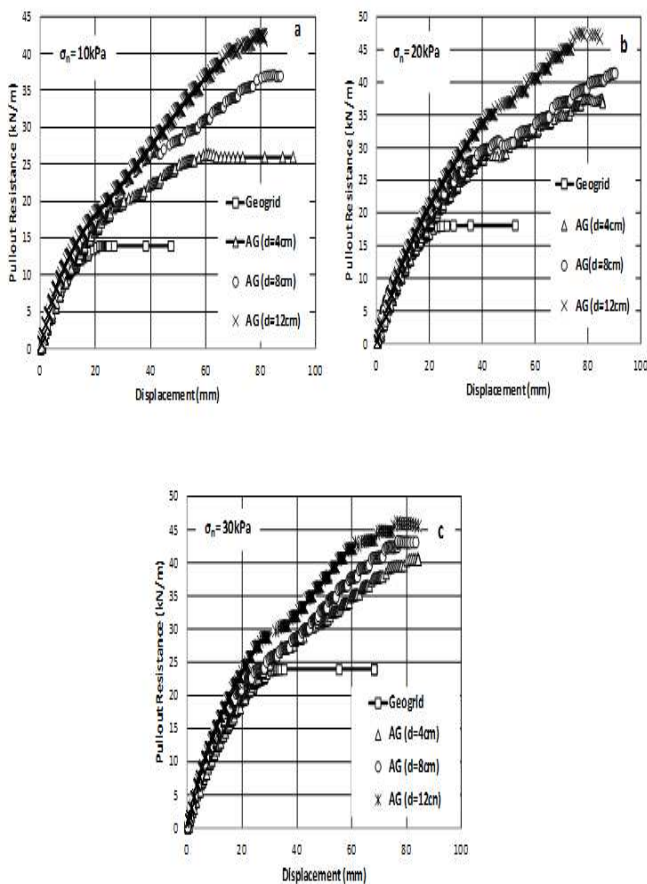


Figure 3. Comparing the pullout resistance of anchored geogrid systems made of steel transverse elements with different depths, under different overburden pressures (σ_n): (a) $\sigma_n = 10 \text{ kPa}$; (b) $\sigma_n = 20 \text{ kPa}$; (c) $\sigma_n = 30 \text{ kPa}$

From the results of the tests (Fig. 3), it becomes clear that under low overburden pressures (10 kPa) — along with an increase in the depth of the transverse elements (d) in the AG system — the pullout resistance of this reinforcement can be increased. Under this overburden pressure, complete pullout only occurred in the AG systems employing transverse elements of 4 and 8 cm depths (Fig. 3a). With an increase in the overburden pressure to

20 kPa, the amount of confinement pressure — and, as a consequence, base geogrid elongation and the passive resistance of the AG system — is increased. Thus, under this overburden pressure, complete pullout will not take place even for the smallest transverse elements (d = 4 cm) until the desired displacement (9 cm). Finally, under an overburden pressure of 30 kPa, an increase in the depth of the transverse element has no significant effect on the amount of pullout resistance. This point can be explained by the fact that, with an increase in the depth of the transverse elements (d) and as a result of its bearing area ($L \times d$), the pressure imposed on the soil via these elements (passive state of stress) is reduced and, as a consequence, a state of failure will occur due to the greater bearing stress. Thus, as was observed in Fig. 3c, even the smallest transverse element (d = 4 cm) continues to resist against the pullout force until the predetermined displacement (9 cm), and complete pullout has not occurred by this displacement. Consequently the transverse element of 4cm depth functions to anchor the end of the geogrid, which is indicative of the fact that a state of failure has not yet been attained against this transverse element. It is clear that, with an increase in the depth of the transverse elements (to 8 or 12 cm) — and a consequent rise in their bearing element area — their displacement will still be very small, indeed almost negligible (as with d = 4 cm). In other words, under high overburden pressures and until the end of the tests, the far end of the AG systems employing different depths of transverse elements showed very little — almost negligible — displacement. By increasing the pullout force, only the amount of elongation and, as a result, the strain of the base geogrid (even up to the point of rupture) was increased. In this state (under high overburden pressures), the bearing resistance of the transverse elements is not mobilized completely.

3.1 Effect of increasing number of transverse elements on pullout resistance of anchored geogrid

In order to evaluate the effect of the number of transverse elements on the pullout resistance of the AG system, another transverse element on the axis a was added, with a fixed spacing (s) (about the length of the longitudinal aperture of the base geogrid) in relation to the transverse element on the axis b (corresponding to Arrangements 2, 4 and 6 in Table 3). In Fig. 4, the pullout resistance for the AG systems employing one and two transverse elements at different depths is compared. As can be observed in Fig. 4a, the AG system using transverse elements of 4 cm depth saw an improvement in performance, to some extent, with the increase in the number of anchorage elements, under different overburden pressures. However, with the increase in overburden pressure, the difference in the performance of the AG system (n = 1, 2) in the pullout mechanism is reduced. As can be seen in Fig. 4a, complete pullout only took place under low overburden pressure (10 kPa), with the increase in the number of elements (n = 2). It is clear that, with the increase in the number of transverse elements, in equal conditions and in cases where complete pullout has occurred, the extent of dilation of the soil in the pullout mechanism also increases, which in turn increases the interaction coefficient between the soil and the reinforcement. Thus, under low overburden pressure in which complete pullout has taken place, the difference in the pullout resistance of the AG system (n = 2) compared to that of the AG (n = 1) system, made with the transverse elements of 4cm depth, is more than it is under the other overburden pressures.

On the other hand, with an increase in the depth of the transverse elements to 8 cm, the increase in the number of transverse elements also leads to an improvement in the performance of the AG system (n = 2) in relation to the AG

system ($n = 1$), under all overburden pressures (Fig. 4b). At the same time, with an increase in the depth of the steel transverse elements to 12 cm, the performance of the AG system (with one or two transverse elements with a fixed spacing (s)) under all overburden pressures in the pullout mechanism becomes almost equal (Fig. 4c). In other words, adding further transverse elements with a fixed spacing (s) does not cause an improvement to the performance of the anchored geogrid system. The reason for this phenomenon may be attributed to the interference of the transverse members. In general, if the distance between the transverse elements is reduced, significant non-uniformities of passive pressure are developed between the transverse elements, which are the result of interference between the transverse elements (Palmeira, 2009).

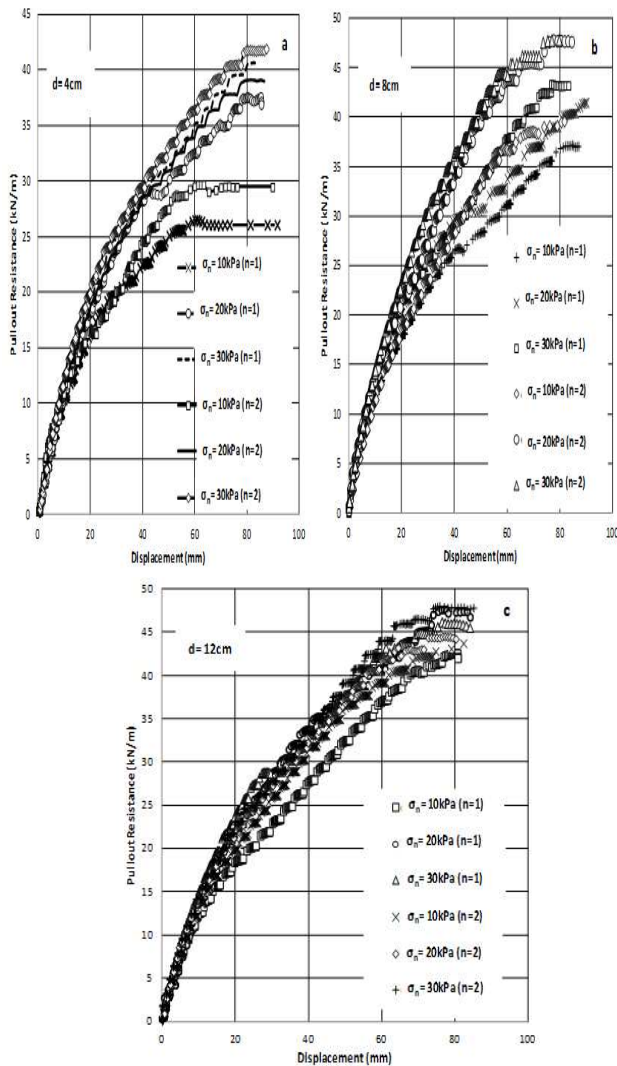


Figure 4. Pullout resistance of anchored geogrid systems employing one or two transverse elements with different depths (d): (a) $d = 4\text{ cm}$; (b) $d = 8\text{ cm}$; (c) $d = 12\text{ cm}$

On the other hand, if the distance between the transverse elements is fixed, the possibility of interference between the transverse members increases as their depths (d) increase, which in turn can prevent a complete interaction between the soil and the steel transverse elements. In general, as the depth of the transverse elements continues to increase, not only does the pullout resistance not increase but it might actually decrease, due to the higher interference between the transverse elements

(Khedkar and Mandal, 2009). Thus, increasing the interference between transverse elements (with the increase of their depths at a fixed distance) causes no significant differences to be observed on the pullout resistance vs. displacement charts for the AG systems (employing one or two anchorage elements). On the whole, optimization analysis shows that the optimum spacing-to-depth ratio $(s/d)_{opt}$ of the steel transverse elements in an AG system, made by HDPE geogrid, depends on the overburden pressure. For practical purposes, one can consider the optimum aspect ratio $(s/d)_{opt}$ to be 2, as a conservative value, for all overburden pressures in sandy soils with small particles.

4 CONCLUSION

Based on the test results, the following conclusions can be made:

- 1) If an AG system is made using even a single transverse element of the appropriate depth (d), this system will be capable of completely anchoring the end of the base geogrid in the soil in the pullout mechanism, until the predetermined displacement.
- 2) In AG systems made with a single transverse element having a certain bearing area ($L \times d$), if under a certain overburden pressure complete pullout does not occur (in other words, a state of failure is not produced against the anchorage element), an increase in the overburden pressure will not have a great effect on the increase of pullout resistance in this reinforcement system.
- 3) AG system, made by HDPE geogrid, with the optimum spacing-to-depth ratio ($s/d=2$) is capable of increasing the pullout resistance of the ordinary geogrid system by up to three times.

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