Pull-out behavior of an innovative Grid-Anchor system

Le comportement d'un système nouveau "Grid-Anchor" par défaut d'adhérence

N. Hataf
Professor, Civil Engineering Department, Shiraz University, Shiraz, Iran

A. Sadr
Graduate student, Civil Engineering Department, Shiraz University, Shiraz, Iran

ABSTRACT

With increasing use of geosynthetics in earth structures the need to develop more efficient reinforcement elements becomes evident. In this paper an innovative geogrid system is introduced and tested. The pull-out test has been used to highlight the capabilities of the product. Experimental investigation along with numerical studies using a finite element computer code was carried out. It was found that the ultimate pull-out resistance of Grid-Anchor is more than that for ordinary geogrid. Analytical study has been performed and the effect of anchor group on the ultimate resistance of geogrid was investigated.

RÉSUMÉ

Avec l'utilisation croissante des applications "geosynthetics" dans la structure de la terre, le besoin de développer des éléments de renforcement plus efficaces se fait sentir de plus en plus et devient évident. Ce document présente un système "geogrid" innovant testé et validé. Dans ce but, un ensemble de tests a été effectué pour montrer les capacités de ce produit. Des investigations expérimentales ainsi que des calculs numériques basées sur un programme informatique traitant des éléments finis ont été également réalisées. Ces éléments accompagnés des études analytiques réalisées sur l'effet de groupe d'"anchor" ont permit de mettre en évidence l'ultime résistance de Grid-Anchor, ce qui a démontré son efficacité plus importante par rapport à un "geogrid" ordinaire.

Keywords: Pull-out - anchor- overburden pressure- dilatancy

1 INTRODUCTION

Performance of pull-out test is necessary to study the behavior of interaction between soil and geosynthetics. The test results can directly be used in design and analysis of internal stability of reinforced earth structures. The effect of reinforcements is to mobilize additional shear stress in soils by bearing the tensile force, making pull-out resistance an essential behavior.

Interaction mechanism for geotextile and other planar geosynthetics is purely through skin friction and usually evaluated by using direct shear test. Grid reinforcements such as geogrid are characterized by a combination of transverse and longitudinal ribs. These ribs provide passive and interface shear contributions. Interaction mechanism of grid reinforcement is evaluated by pull-out test. Pull-out resistance, $P_R = P_u$, is determined by the following relations:

$$P_R = 2L\sigma' f_b \tan\phi' \tag{1}$$

Where, L, σ' and ϕ are the length of specimen, effective overburden pressure and the friction angle of soil, respectively. f_b is a constant related to interaction between soil and reinforcement obtained from analytical analysis (Jewell et. al, 1985) or experimental methods. Vertical anchors, as same as transverse members of geogrids, resist against horizontal loads via mobilizing the passive resistance of soil. Major types of vertical anchors are plate and block anchors. In this paper a new geosynthetics named by the first author "Grid-Anchor" (patent No. 33989 in I.R.I.) will be introduced. Grid-Anchor consists of geogrid and anchors attached to it. With conducting pull-out test on the common geogrid and the new geosynthetics, the behaviors of two reinforcements are compared. Analytical analysis is also used to estimate the ultimate pull-out resistance of Grid-Anchor. Finally pull-out test is simulated using the finite element code (PLAXIS-2D) and the results were compared with experimental data.

2 PREVIOUS STUDY

2.1 *Pull-out behavior of reinforcements*

Review of previous studies shows considerable differences between the reported experimental results. This is attributed to variety in the affected parameters on pull-out resistance of geosynthetics. Between these parameters, effect of boundary condition such as apparatus dimensions, friction between soil and side walls and distance between specimen and side walls are dominant (Palmeira and Milligan, 1989). Density of soil also has important effect on the behavior of reinforcement.

With increasing of density (compaction), that portion of reinforcement length which takes part in the mobilization of resistance against pull-out decrease (Lopez and Ladeira, 1997).

Palmeira and Milligan (1989) showed that the interference of passive bearing mechanism of transverse members (DI) causes the decrease in the ultimate pull-out resistance and this effect has inverse relation with S / B, where S and B are the distances between transverse members and the thickness of them, respectively. This circumstance has been attributed to local increase of normal stress in front of transverse member and simultaneous decrease behind them (Palmeira, 2004). Ultimate bearing resistance of geogrid, P_R, may be determined by (Jewell 1990):

$$P_R = 2\left(\frac{L_r}{S}\right) L_r W_r \sigma' f_b \tan\phi \tag{2}$$

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-909

$$f_{bearing} = \alpha_s \left(\frac{\tan\delta}{\tan\phi}\right) + \left(\frac{\alpha_s B}{S}\right)\left(\frac{\sigma'_b}{\sigma'}\right)\left(\frac{20 - B/D_{50}}{10}\right)\frac{(1 - DI)}{2\tan\varphi} \quad (3)$$

$$\left(\frac{S}{\alpha_b B}\right)_{\varphi} = \left(\frac{\sigma'_b}{\sigma'}\right)\frac{1}{2\tan\varphi} \quad (4)$$

DI is degree of interference and is defined as:

$$DI = \left(1 - \frac{1}{n}\right)\left(1 - \frac{(S/\alpha_b B)}{(S/\alpha_b B)_{\phi}}\right) \quad (5)$$

where, L_r and W_r are the length and the width of specimen, α_s is the fraction of solid area, α_b is the fraction of lateral area of ribs without junctions, D_{50} the mean particle size, n the number of bearing members, δ is the interface friction angle and σ_b is the passive bearing resistance developed behind the ribs that proposed by Jewell et al. (1985) :

$$\frac{\sigma'_b}{\sigma'} = \exp\left[\left(\frac{\pi}{2} + \varphi\right)\tan\varphi\right]\tan\left(\frac{\pi}{4} + \frac{\phi}{2}\right) \quad (6)$$

In addition to experimental study, researchers have used numerical approaches to simulate the pullout behavior of geosynthetics. Bergado et al. (2003) using PLAXIS software simulated pull-out test and studied on interaction mechanism between hexagonal wire mesh and soil.

2.2 *Horizontal pull-out resistance of anchors*

Vertical anchors exhibit the passive mechanism similar to retaining walls. Various analytical methods, estimate ultimate pull-out resistance of vertical anchors (Dickin and leung, 1985). Akinmusuru (1978) experimentally exhibited that the behavior of anchors depends on the buried depth and therefore it is divided into 3 categories of shallow, intermediate and deep anchors. Soil resistance parameters, roughness of anchor, lateral earth pressure coefficient, geometry characteristics and distance between rows of anchors in group anchors are the factors affecting on pull-out resistance of vertical anchors (Ovesen and Stromann, 1972, Rowe and Davis, 1982).

3 EXPERIMENTAL RESEARCH

3.1 *Apparatus and materials description*

Apparatus in this research (figure1) consisted of box, including soil and specimen, system of application vertical load, system of application horizontal load, instruments of horizontal load transmission to reinforcement and gauges of force and displacement measurements to determine the force and displacement at the free end of specimen (attached to the clamp). Length, width and height of box were 35, 30 and 35 cm respectively. The box was made from thick steel plate welded at the edges. Two layers of thick nylon lubricated with grease, used to decrease the roughness of walls. The front wall has a slot 20mm wide and 22cm long. Because of anchors attached to geogrid, this large width was necessary. Clamping device consisted of rigid plates, located at the top and bottom of the specimen and bolted together. The tensile force was transmitted to clamp thereby two rigid bars and a hydraulic jack. Three thick layers of a kind of polymer put between top rigid plate and the soil for uniform distribution of overburden pressure on the surface.

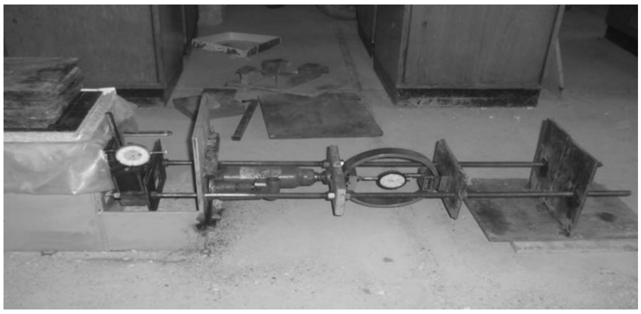

Figure 1. Pull-out test apparatus

Well graded sand with uniformity coefficient of 7.78 and curvature coefficient 1.2 was used. Minimum and maximum sizes of particles were 6 and 12 mm, respectively. Results of direct shear test conducting on sand showed $\varphi = 43^{\circ}$ and cohesion equal to zero. One type of biaxial geogrid was used in all tests. Dimensions of specimen were 16 cm in width and 25 cm in length. Elastic normal stiffness, apparture and thickness of bearing members were 28kN/m^2 , 27*27 mm^2 and 2 .2 mm respectively. Grid-Anchor was made by attaching anchors to the longitudinal members of geogrid (figure 2). Anchors in fact consisted of 2 plastic cubes that attached together and to geogrid by the means of polymeric fastening with adequate tension resistance. This fastening can be attached under any angle, and in this research the angle was 45°. Every Grid-Anchor included eight anchors in 2 rows.

Length and thickness of anchors (cubes) was 30 and 11 millimeters, also distance between anchors at each row and distance between 2 rows was 60 mm.

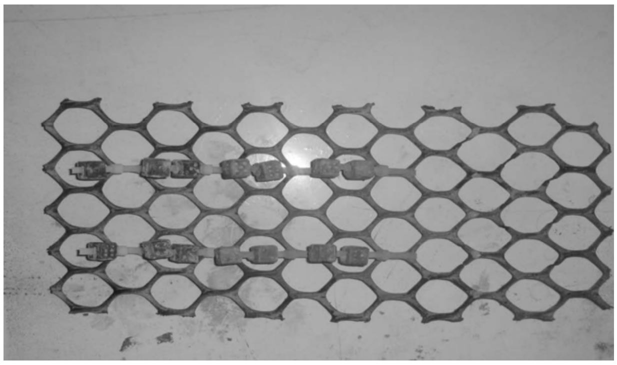

Figure 2. Grid – Anchor system

3.2 *Test procedure*

Pull-out test was performed with measuring the clamp displacement as well as relative force at 5 overburden pressures, 4,8,12 and 18kPa for each reinforcement.

3.4 *Test results*

The tensile force-displacement relationship under 8kN/m^2 and 18kN/m^2 overburden pressure has been shown in figure 3.Trend of all curves to ultimate state, denotes the gradual development of resistance mobilization against pull-out (Moraci and Recalcati, 2006). It is clear that Grid-Anchor reinforcement exhibits more resistance than ordinary geogrid, whereas the displacement for reaching ultimate resistance in Grid-Anchor is less. In the other hand, Grid-Anchor showed stiffer behavior than common geogrid, denoting the preference of Grid-Anchor capability in the mobilization of resistance.

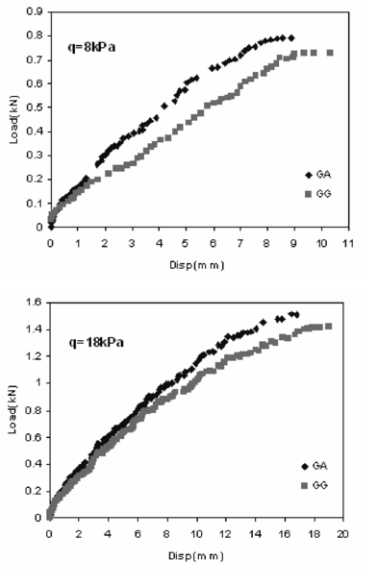

Figure 3. Comparison between behavior of geogrid and Grid-Anchor under 8 and 18 kPa

This increase is attributed to passive resistance mechanism of anchors. Figure 4 shows apparent interaction coefficient (defined as $\mu=P_u$ / (2Aq) and q is the overburden pressure). It was found that interaction coefficient of Grid-Anchor is more than geogrid, especially at very low overburden pressures. It is note worthy to see in this figure that μ decreases when normal pressure increases. This has also been reported by other researchers (Moraci and Recalcati, 2006; Alfaro and Pathak, 2005). The important phenomenon that occurs during pull-out test on the strip reinforcement is constraint dilatancy. It is the reason of low interaction coefficient at high overburden pressure because in this condition local normal stresses decreases. When the vertical anchors are pulled, soils moves from front face to behind (similar to transverse members of geosynthetics) and hence amplify the effect of constraint dilatancy. Over the transverse members, $\Delta\sigma'$ is higher than in between ribs or voids (Teixeira et al. 2007).

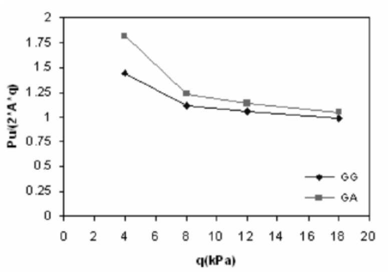

Figure 4. Variation of μ against overburden pressure

The relationship between pull-out stress and overburden pressure for both reinforcements has been shown in figure 5. It is observed, at both reinforcements, this relationship is linear and therefore follows the Mohr-Coulomb law. According to this figure, the friction angle at both reinforcements is 60º that is 40% higher than internal friction angle of unreinforced soil.

Significant point in this figure is the parallelism of lines. In the other word, anchors did not have any influence on friction component of geogrid. It is coincident with pervious research on deep anchor (Rowe and Davis, 1982).

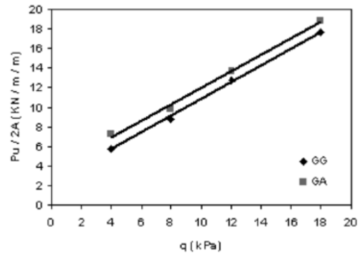

Figure 5. Relationship between ultimate pull-out stress (P_u/2A) and overburden pressure

4 ANALYTICAL RESEARCH

Different equations have been derived to estimate the ultimate pull-out resistance of vertical anchors in this research the assumption of cubic anchor group was investigated. Bowels (1996) proposed the following expression:

$$P_u = P_P - P_a + F_t + F_b + F_s \tag{7}$$

where, P_p and P_a are the passive and active force and F_b, F_t and F_s are the friction force at the bottom, top and sides of the anchor, respectively. F_b, F_t and Fs are very small (because of small dimension of cubes), hence were ignored

$$P_p = (d + h/2)\gamma \times k_p hB + qk_p hB \tag{8}$$

$$P_a = (d + h/2)\gamma \times k_a hB + qk_a hB \tag{9}$$

B and t are the width and thickness of anchor, δ is the friction angle between soil and anchor, q is the overburden pressure and k_p, k_a and k_0 are the lateral earth pressure coefficients that obtained from Coulomb equations for inclined retaining walls.

It is shown that the above relations are functions of δ. Davis (1968) with assumption of fully rough anchor, derived equation (10). In this study this equation was used to obtain the maximum friction angle between soil and anchor. In this relation, ψ = φ-30 according to Vermeer (1990).

$$tg\,\delta_m = \frac{\cos\psi \sin\phi}{1 - \sin\psi \sin\phi} \tag{10}$$

It is important to note that relation (7) is more applicable for cubic anchor with small height and large width. Small width to height ratio of anchors in this research caused the 3-D mechanism. Hence the correction factor to 2-D results proposed by Hansen (1966) with the following expression was used.

$$M = 1 - (k_P - k_a)^{0.67}\left[1.1E^4 + \frac{1.6F}{1+5(B/h)} + \frac{0.4(k_p - k_a)E^3F^2}{1+0.05(B/h)}\right] \tag{11}$$

$$F = 1 - (B/S)^2$$

$$E = 1 - h/(d+h)$$

S is the center to center distance between two rows and d is the depth of anchor. This correction factor is applied only on passive and active forces. Therefore to estimate the pull-out resistance, equation (7) can be modified as equation (12).

$$P_u = M(P_P - P_A) \tag{12}$$

Figure 6 compares the experimental results with combination of equation (3) and (12). 3D behavior assumption of cubic anchors as well as considering the distance between rows showed good agreement with experimental results. It was then tried to use the reasonable range of δ. It can be seen that fully roughness assumption ($\delta = 38^{\circ}$) with respect to polymeric genus of cubes is overestimating the pull-out resistance and considering $\delta = \varphi/3 = 14^{\circ}$ yields better agreement.

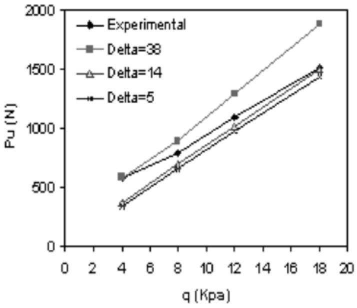

Figure 6. Comparison between analytical and experimental results

5 NUMERICAL STUDY

As mentioned earlier, PLAXIS (2D) was used to simulate the pull-out test. To model the anchors, fixed-end anchor elements, the default tool in the code, was used. Two load systems represented the vertical and horizontal loadings. Vertical load system as overburden pressure was constant during analysis but horizontal load system increased gradually according to experimental loading. The results of numerical study are presented separately for each overburden pressure, in figure 7. In addition, the elongation of Grid-Anchor during pull-out at $\sigma' = 4$kPa was investigated by PLAXIS (Figure 8) and it was found that just a portion of length took part to mobilize the resistance. Therefore it is better to arrange the group of anchor as close to active end as possible.

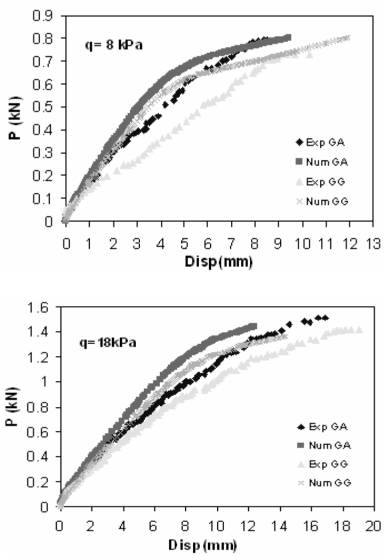

Figure 7. Comparison between numerical and experimental results for q = 8 and 18 kPa

6 CONCLUSION

In this research an innovative reinforcement (Grid- Anchor) was tested and its efficiency was compared to common geogrid by experimental, numerical and analytical approaches.

Experimental research showed despite less displacement, Grid-Anchor showed greater resistance at failure. Measurement of apparent interaction coefficient (μ) also proved the better efficiency of Grid-Anchor at mobilization of soil resistance against pull-out. Attached anchors to the geogrid, increased the passive resistance, hence had similar operation with transverse members of geogrid. 3-D behavior assumption of cubic anchors group, that is more reasonable, yielded good agreements with experimental results. Finally, simulation of pull-out test by commercial finite element code (PLAXIS-2D) exhibited good agreement with experimental results. Numerical analysis also showed that the whole length of reinforcement does not experience elongation and therefore arrangement of anchor group as close to the active end as possible is strongly recommended.

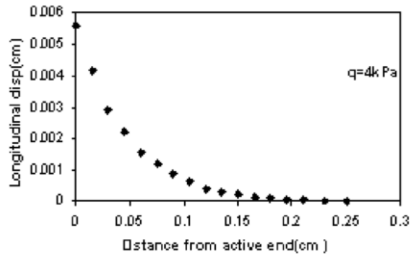

Figure 8. Grid – Anchor elongation during pull-out test by PLAXIS

REFERENCES

Akinmusuru, J.O. 1978. Horizontally loaded vertical plate anchors in sand. *Journal of the geotechnical engineering division* 104: 283-286

Alfaro, M.C. & Pathak, Y.P. 2005. Dilatant stresses at the interface of granular fills and geogrid strip reinforcements. *Geosynthetics international* 12: 239-252

Bergado, D.T.S. Youwai, C. Teerawattanasuk, P. & Visudmedanukul., 2003. The interaction mechanism and behavior of hexagonal wire mesh reinforced embankment with silty sand backfill on soft clay. *COMPUTERS AND GEOTECHNICS* 30: 517-534

Bowels, J.E., 1996. *Foundation analysis and design*. New York: Mc-Grow Hill press

Davis, E.H. 1968 Theories of plasticity and failure of soil masses. In soil mechanics-selected topics (ed. I. K. Lee). London: Butterworths

Hansen, J.B., 1966. Resistance of Rectangular Anchor Slabs. *Danish Geotechnical Institute.* Copenhagen: Denmark. 21: 12-13

Jewell, R.A., Milligan, G.W.E, Sarsby, R.W., Dubois, D.D., 1985. *Interaction between soil and geogrids; Proceeding of symposium on Polymer Grid reinforcement in civil engineering*. London, Thomas Telford Ltd, 18-30

Jewell, R.A. 1990. Reinforcement bond capacity. *Journal of Geotechnique* 40: 513-518

Lopez, M.L. & Ladeira. M.1997. Influence of Confinement, Soil Density and Displacement Rate on Soil-Geogrid Interaction. *Journal of Geotextile and Geomembrane* 14: 543-554

Moraci, N. & Recalcati, P. 2006. Factors affecting the pullout behavior of extruded geogrids embedded in a compacted granular soils. *Journal of Geotextile and Geomembranes* 24: 220-242

Ovesen, N.K. & Stromann, H. 1972. Design Methods For Vertical Anchor Slabs in sand; *Proceedings of speciality conference on performance of earth and earth-supported structures.* 1418-1500

Palmeira, E.M. & Milligan, G.W.E. 1989. Scale and other factor affecting the results of pull-out tests of grids buried in sand. *Journal of Geotechnique* 39: 511-524

Palmeira, E.M. 2004. Bearing force mobilization in pullout tests on geogrids. *Journal of Geotextile and Geomembrane* 22: 481-509

Rowe, R.K. & Davis, E.H. 1982. The behavior of anchor plates in sand. *Journal of Geotechnique* 32: 25-41

Teixeira, S.H.C. Bueno, B.S. & Zonberg, G.J. 2007. Pullout resistance of individual longitudinal and transverse geogrid ribs. *Journal of Geotechnical and Geoenvironmental Eng* 131: 37-50

Vermeer, P.A. 1990. The orientation of shear bands in biaxial tests. *Journal of Geotechnique* 40: *223-236.*