EXPERIMENTAL AND NUMERICAL STUDY OF UPLIFT BEHAVIOR OF ANCHORS EMBEDDED IN REINFORCED SAND

M. Makarchian[1], M. Gheitasi[2], and E. Badakhshan[3]
[1]Assistant Professor, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran
Makarchian@yahoo.com
[2]Former MSc Student, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran
[3]MSc Student, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran
Ehsan_civilmaster@yahoo.com

ABSTRACT

In this paper, an experimental and numerical investigation on behavior of uplift capacity of plate anchor with different diameters embedded in sand has been carried out. Two series of uplift loading tests were conducted in this study. First series of tests were in unreinforced sand and the second series of tests were in sand reinforced with multi-layers of geonet. To perform these tests, an apparatus was made for uplift loading on plate anchors embedded in a soil tank of size 0.6×0.6×0.6 m. Several parameters varied such as number of geonet layers (0 to 4), the embedment depth ratio (H/B=2, 3 and 4), and relative densities of sand (medium and dense conditions). It was observed that for all cases, the slope of uplift force-displacement curves remained constant in first stage; then, it was reduced until the ultimate failure of anchors. It has been observed that uplift force at failure increased, as the number of geonet layers increased, but for 4 layers, the increased load was negligible in comparison with 3 layers geonet. By drawing breakout factor diagrams versus embedment depth ratio, it was concluded that with increasing embedment depth ratio for anchor with different diameters breakout factor has been increased. Finite element analyses have also been conducted to compare the pullout load-displacement results with experimental observations.

Keywords: Anchor, geosynthetic, reinforced sand, pullout test, finite element method.

INTRODUCTION

There are many structures especially in industrial applications area where the foundations are subjected to large uplift forces or overturning forces. Typical of such structures are anchor cables of television and transmission towers, leg of elevated water tank, power transmission tower, tension cables for suspension bridges, tower and floating platforms that they are subjected to wind loading and wave forces. In this situation, an economic design solution is employing the anchor foundations. Plate anchors, belled piles, pedestal and drilled shafts are traditional anchor systems that can resist uplift forces because they are more economical to install. Numerous researchers have investigated many experimental and theoretical analyses studies of the pullout anchor capacity in sand, notably Balla (1961), Meyerhof and Adams (1968), Vesic (1971), Das (1978, 1980), Rowe and Davis (1982), Dickin (1988), Ilamparuthi and Krishnaiah (1999), Sawwaf and Nazir (2006), and Merifield (2006). They have investigated the influence of size, the depth of embedment and density of soil in behavior of anchors. In the area of enhancing resistance uplift Bouazza and Finlay (1990) studied the influence of two layered sand (fine and coarse sand) on uplift capacity of plate anchor. A good and common technique of improving the soil is the application of geosynthetics. Research on the behavior of plate anchors embedded in reinforced soil with geosynthetic is fairly limited. Krishnaswamy and Parashar (1994) studied the effect of geosynthetics inclusion on uplift behavior of circular and rectangular plate anchors in cohesive and cohesionless soil media. Ilamparuthi and Dickin (2001) reported a cylindrical gravel-filled geogrid cell located around the enlarged pile base provide the beneficial effect in enhanced resistance. Ravichandran and Ilamparuthi (2004) studied the experimental behavior of pullout loads anchors in submerged sand in unreinforced and reinforced with single layer of geogrid in both monotonic and cyclic mode of loading. In this paper, the influence of soil reinforcement on the uplift behavior of circular anchor buried in sand at various embedment depth; relative density of soil and the number of geosynthetics layers are investigated both by experimental and numerical methods.

LABORATORY MODEL TESTS

To investigate the effect of geosynthetic layers on uplift capacity of anchors, an experimental program was build in Soil Mechanics Laboratory, Bu-Ali University located in Hamedan, Iran. The schematic diagram of the apparatus is shown in Fig. 1. The test tank has inside dimensions of 600mm×600mm in plan and 600mm in depth. The tank was made from plexi glass and supported directly on two steel beams. The frame of apparatus was made of four steel columns (IPE 12) which were firmly fixed in the floor by using of roll bolts. The load application system is by means of the loading leverage that is consisting of two main elements: loading pan and balanced weight. The horizontal distance between them is 782 mm that the 690 mm it was used the active loading member and the 92 mm it was used the passive loading member. The balanced weight has 15.52 kg mass and used that the loading crowbar standing horizontally. A dial gauge was used to measure the anchor displacement. The model anchor was made of steel circular plate with 70 mm diameter and 6 mm in thickness. The anchor connecting rod was made from steel with 800 mm in length and 7 mm in diameter. The diameter of anchor was selected about 0.1 tank width to assure that the predicted rupture planes around the anchor model would be within the tank limit.

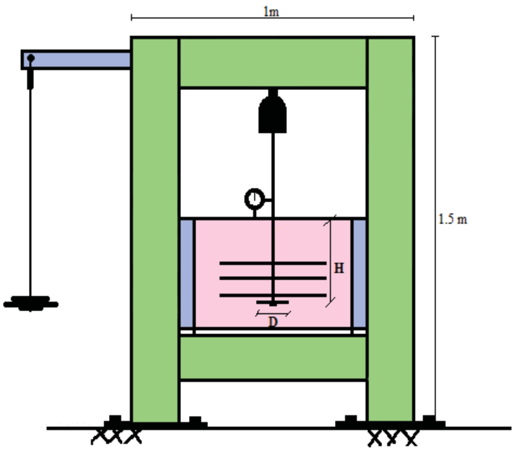

Fig. 1 Schematic view of the experimental apparatus

TEST MATERIAL

Sand

The soil used in this investigation was a uniformly graded sand with effective size D_{10}=0.18 mm, coefficient of uniformity C_u=2.36 and coefficient of curvature C_c=1.099. The grain size distribution curve was determined by the dry sieving method, and is shown in Fig. 2. On representative sand specimens were conducted laboratory tests for specific gravity, maximum and minimum dry density, minimum and maximum void ratio and direct shear tests for different densities of the sand. The sand properties are given in Table 1.

Table 1 Sand properties used in the tests

Parameter	Value
Maximum unit weight (kN/m^3)	16.4
Minimum unit weight (kN/m^3)	14.4
Maximum void ratio	0.890
Minimum void ratio	0.658
Specific gravity	2.72
Coefficient of uniformity	2.36
Coefficient of curvature	1.01
Classification	SP

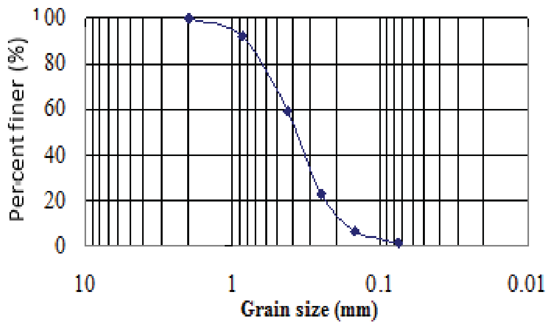

Fig. 2 Grain size distribution for test soil

The experiments were conducted at two relative densities of the sand for medium dense and dense conditions (D_r=50% and 70%), the average unit weights of the sand were 15.34 kN/m^3 and 15.74 kN/m^3 respectively. The estimated internal friction angle of the sand at these conditions determined by direct shear tests under vertical stress ranging between 40kPa until 160kPa, were 33° and 41° respectively.

Geosynthetic

According to the conclusion of Krishnaswamy and Parashar (1994) the use of civil engineering geogrid (CE131) with mesh aperture size 27×27 mm did not result in a substantial increase in the uplift capacity of the anchors. They concluded that it was due to it’s wider mesh opening and decrease in area of contact with the soil consequent, as there would be little opportunity for significant interlocking between sand particles and the apertures of the reinforcement.

The particle size of the sand in this investigation is fine and the biggest size of particles is 2 mm

(#10). Considering sand particle size in this study civil engineering geonet (CE121) was used which is manufactured by Meshiran Factory with a peak tensile strength of 7.68 kN/m as reinforcing material for the model tests. These geonets were manufactured of high density polyethylene grids. Typical physical and technical properties of the geonets were obtained from manufacture's manual of the product and are given in Table 2.

Table 2 Properties of geonet

Parameter	Value
Geonet opening size (mm)	8 × 6
Mesh thickness (mm)	3.3
Tensile strength (kN/m)	7.68
Extension at ½ peak load (%)	3.2
Extension at maximum load (%)	20.2
Load at 10% extension (kN/m)	6.8

EXPERIMENTAL SETUP

An experimental program was carried to investigate the uplift behavior of plate anchors with and without geosynthetic inclusions in different density of sand, in which the variables parameters were location and number of geosynthetic layers, depth of embedment and dry density of sand. In order to achieve homogeneous sand beds were employed tamping techniques and controlled pouring. Experiments were conducted at two unit weights of 15.34 kN/m^3 and 15.74 kN/m^3 for medium dense and dense conditions, respectively.

Based on many trials, the full sand layer divided to five portions and was uniformly spread in the tank and leveled properly. Each portion of sand was tamped 40 blows for medium dense condition and 56 blows for dense condition to give uniformly the required densities. A depth of 100 mm of sand was maintained below the base of the anchor plate in all the tests.

The anchor plate was connected to the anchor rod and seated firmly on the prepared bed of the sand. A hole equal to the one mesh aperture geonet was punched at center of the geosynthetic layers. The width of geonet layers based on studies Saran and Rao (2002) and Ilamparathi and Dickin (2001) was chosen 3*D* (*D*: diameter of anchor plate) in the present study. After placing the model anchor plate and the geosynthetics in positions subsequent layers of the sand were placed and compacted up to the level required for particular depth of embedment. It is noted that the first layer of geonet placed directly above the anchor plate (Krishnaswamy and Parashhar 1994) reported the higher uplift resistance resulted in this position and other layers in the tests involving more than one layer of reinforcement, the spacing between them maintained constant at 0.5 *D*.

Test Program

The experiments consist of six series of tests on circular anchor plate supported on both unreinforced and geosynthetic reinforced sand were carried out.

Details of the tests conducted in the apparatus are shown in Table 3. According to the test program the studied variables include the relative density (D_r), the number of geonet layers (*N*), the depth embedment ratios (*H/D*). It should be mentioned that all of the tests categorized the shallow anchors according to the report of Meyerhof and Adams (1968) in which the shallow or deep anchors were referred to embedment ratio depth and friction angle of the soil.

Table 3 Model tests program

Relative density D_r	Depth embedment ratio *H/D*	Number of geonet layers *N*
50%	2 , 3 , 4	0, 1, 2, 3, 4
70%	2 , 3 , 4	0, 1, 2, 3, 4

NUMERICAL ANALYSIS

Finite Element Modeling (FEM)

To verify the findings of the laboratory model test results, numerical analyses were performed on all the model tests of anchors in reinforced and unreinforced sand. The analysis was performed by using the computer program Plaxis.

Plaxis, which is a 2-dimensional finite element code for soil and rock analysis and is capable of modeling a wide range of geotechnical problems such as tunnels, retaining walls, excavations, piles and foundations, geogrid sheets and reinforced soils. The scaling and boundary effects due to the smaller model size exist in these numerical analyses. To avoid these limitations the geometry of the prototype anchor and reinforcement system was assumed to be ten times the laboratory model (the anchor diameter *D*=70 cm and thickness *t*=6 cm, width of soil 6×6 m). The bottom boundary of model was rough rigid, and side boundary was restrained horizontally. The properties of sand and reinforcement were assumed the same as in the laboratory model tests.

Finite Element Procedure

The elastic-perfectly plastic Mohr-Coulomb model was used for modeling the behavior of sand.

This model involves five input parameters; modulus of elasticity (*E*) and poison's ratio (*v*) for soil elasticity, angle of internal friction (φ) and effective cohesion (*c*) for soil plasticity and dilatancy angle (Ψ). The automatic mesh generation of 15 node triangle elements for the soil was used.

From consideration of symmetry, only half portion of the problem was taken into account to reduce the time required for analysis. The boundary conditions were chosen such that the displacement of the horizontal boundary is restricted in all directions, while vertical boundaries are restricted horizontally and free to move in the vertical direction. The anchor plate was behaved as 5 node elastic beam elements with two parameter of flexural rigidity (*EI*) and normal stiffness (*EA*). Geonet layers were modeled using geogrid structural 5 node elastic elements available in Plaxis. The elastic axial stiffness (*EA*) of the geonets per unit length was chosen from the manufacturer's manual. The interaction between the geonet and sand is modeled at both sides by using interface elements. The interface reduction factor (R_{int}) for the soil created a reduced wall friction compared to the soil friction. Analyses were performed under displacement controlled method. The parameters of the soil used in the finite element analysis are shown in Table 4.

Table 4 Soil properties used in FEM

Parameter	Medium dense	Dense
Young modulus (kN/m^2)	22400	44800
Cohesion (kN/m^2)	1	1
Friction angle (degree)	33	41
Soil unite weight (kN/m^3)	15.34	15.74
Poisson ratio	0.325	0.375
Interface reduction factor	0.75	0.75

RESULTS AND DISCUSSIONS

A total of 30 tests were carried out to determine the pullout capacity of anchor plate buried in geosynthetic reinforced sand. An additional numerical modeling with same parameters and conditions was carried out using the finite element method (FEM). The pullout load-displacement curves of anchor for both model tests and numerical analysis in an embedment ratio of 2 and different number of geonet layers in dense sand bed are shown in Figs. 3 and 4, respectively.

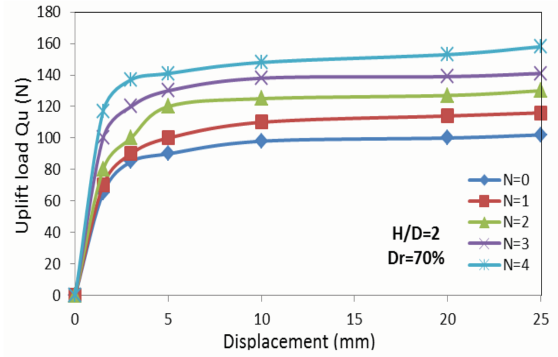

Fig. 3 Load-displacement curve for experimental tests

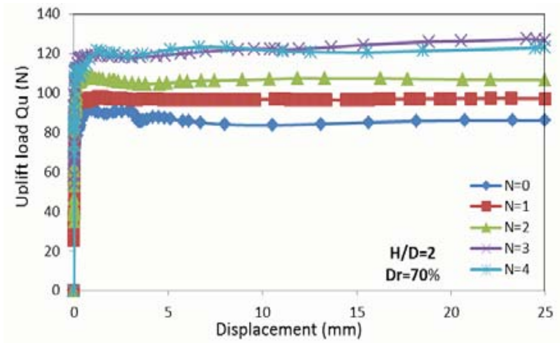

Fig. 4 Load-displecement curve for FEM

These figures clearly show the effect of increasing the number of geonet layers on improvement of the pullout load capacity for an embedment ratio. By comparing model tests and numerical analysis, it can be seen that the general trend of finite element model is similar to experimental tests, and a good agreement is obtained and difference is not so much.. First difference is the ultimate uplift displacement that in finite element model maximum uplift resistance was reached at a less displacement into the model test. Second difference depends on the ultimate pullout loads that in unreinforced sand the ultimate uplift load obtained from the experimental test was higher than the FEM, but in reinforced sand in all conditions the FEM was higher.

A summary of the ultimate uplift resistance of anchor plate for various test conditions are presented in Table 5. In order to determine the ultimate pullout capacity of anchor plate in unreinforced and reinforced sand, the tangent method was used. From the load-displacement curves by this method the ultimate anchor capacity is determined at the intersecting point of two tangent lines that pass through the starting and end portions of the curve (Jumkis 1967, Saran and Rao 2002).

Table 5 Result of tests on plate anchor with and without geonet

Dr=50%				Dr=70%			
N	H/D			N	H/D		
	2	3	4		2	3	4
0	92	115	224	0	94	125	233
1	105	153	300	1	115	164	310
2	119	175	344	2	124	182	373
3	125	224	361	3	134	236	394
4	137	247	386	4	153	274	441

EFFECT OF NUMBER OF GEONET LAYERS

The pullout improvement ratio (PIR) defined as the ratio of ultimate uplift load in reinforced case to the ultimate uplift load in unreinforced case. This nondimensional quantity (PIR) measured from both model tests and numerical analysis for variation of dept embedment ratio (*H/D*) and both medium dense and dense conditions against number of layers were shown in Figs. 5 and 6.

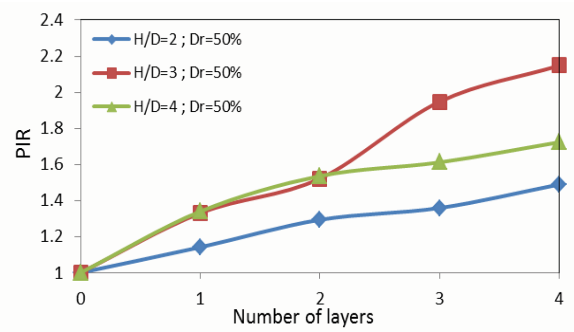

Fig. 5 PIR versus number of geonet layer for D_r=50%

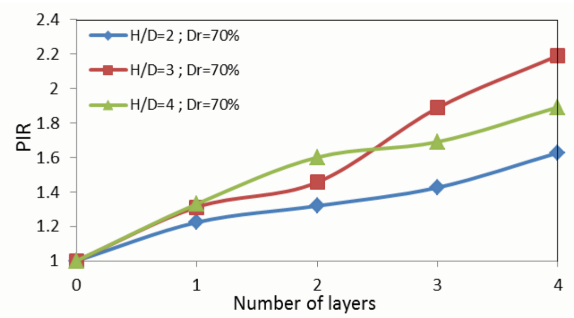

Fig. 6 PIR versus number of geonet layer for D_r=70%

The figures clearly indicate the effect of increasing the number of geonet layers on the PIR. However the first layer did fundamental result in increasing the PIR, but this rate of increasing was conducted until three layers of geonet and fourth layer had negligible influence in improvement in comparison with 3 layers of geonet.

It should be mentioned that in previous researches such as Krishnaswamy and Parashar (1994) related that only one layer of geosynthetic inclusion resting directly on top of the plate anchor is most effective for enhancing the uplift capacity of plate anchor, while introduction of an additional layer of reinforcement results in a reduction of the uplift capacity. This difference between the optimum number of reinforced layers from this research as compared to mentioned above may be attributed to the size of geosynthetic layer that Krishnaswamy was used 5*D* (*D*: diameter of anchor plate) while in present paper was used 3*D*. It seems that there is a relationship between the optimum number of geosynthetic layers and wide of the geosynthetic layers.

EFFECT OF EMBEDMENT DEPTH AND SOIL DENSITY

The pullout load in both reinforced and unreinforced conditions increased with embedment ratio. Also it was improved by increasing the density of soil, the maximum influence of density indicated in four embedment ratio approximately 16 percents.

Figures 5 and 6 indicated that in experimental cases the best effect of reinforcement was observed in three embedment ratio in both medium dense and dense conditions. The lower PIR for 4 embedment ratio is attributed to the deep plate anchors behavior which the failure surfaces do not reach the ground surface at the ultimate capacity condition.

The results of the displacement contours, obtained from Plaxis 2*D* on the anchor plate embedded in the sand are illustrated in Fig. 7.

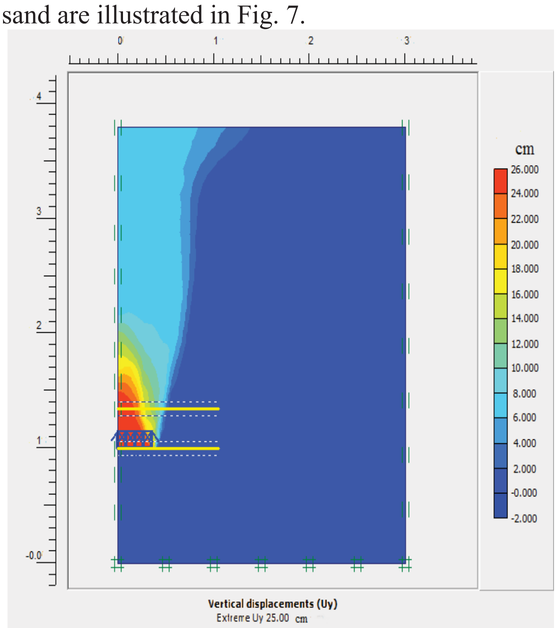

Fig. 7 Vertical displacement contours for anchor plate at *H/D*=4, reinforced with 2 layer and D_r=70%

BREAKOUT FACTOR

For anchor plate buried in both reinforced and unreinforced sand a non-dimensional factor was defined which is called breakout factor (F_q). It was calculated by using the following equation 1 that is defined as below:

$$F_q = Q_u / \gamma A H \qquad (1)$$

where Q_u is the ultimate uplift load, A, the plan area of anchor plate, γ, the soil unit weight and H is the depth of anchor embedment. In Figs. 8, 9, 10 and 11 presented the breakout factors (F_q) was calculated from the equation for both medium dense and dense conditions. It can be concluded that this factor is depended on the embedment ratio and the number of geonet layers. By increasing the number of layers, the breakout factor becomes greater irrespective of the soil density. Despite breakout factors enhanced by increasing the soil density, but these effects were very small; while the effect of embedment ratio is considerable. It was found out that for a given reinforcement numbers, the breakout factor increase with embedment ratio. The breakout factor in 3 embedment ratio had a reduction trend in early to two numbers of reinforced layers, and then behaved in increasing trend. It should be noted that for computing the F_q, the same quantity of unit weight for soil and geonet layers was used.

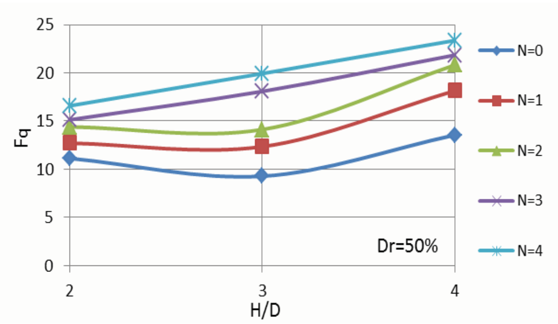

Fig. 8 Breakout factor versus embedment ratio for experimental tests in medium dense sand

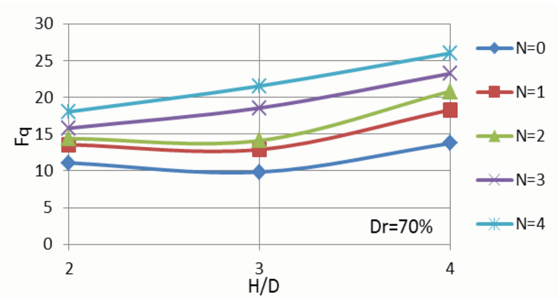

Fig. 9 Breakout factor versus embedment ratio for experimental test in dense sand

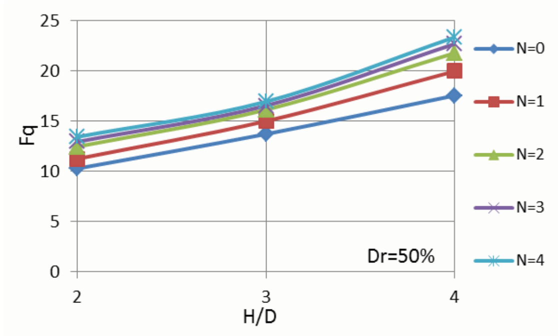

Fig. 10 Breakout factor versus embedment ratio for FEM in medium dense sand

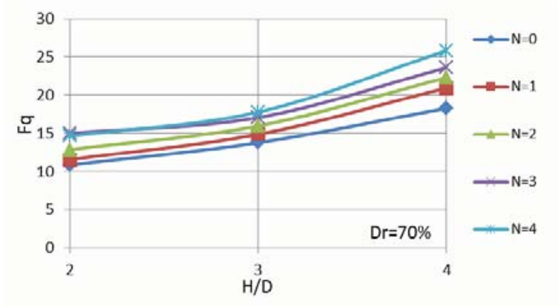

Fig. 11 Breakout factor versus embedment ratio for FEM in dense sand

CONCLUSIONS

Based on results obtained from the laboratory tests and numerical study carried out on circular anchor plate buried at reinforced sand with geonet layers, the following main conclusions are drawn:

- With increasing the embedment ratio, the ultimate pullout load enhanced for both reinforced and unreinforced conditions.
- The ultimate uplift load in dense sand condition is higher results than in medium dense sand condition, but this difference is less in comparison with the embedment ratio effect and reinforcement layers.
- The ultimate uplift load of anchor plates is increased by using geonet layers. In experimental tests, the fourth layer was little effect in increasing ultimate uplift load; but in finite element analyses, the fourth layer decreased evidently the ultimate uplift load in some analysis.
- In experimental tests, the vertical displacement was be needed to reach the ultimate pullout load is larger than FEM approximately five times.
- The PIR improves with increasing the number of geonet layers, but its improvement in 3 embedment ratio is greater at both sand conditions.
- The breakout factor is increased by the number of geonet layers in all embedment ratios and soil densities. In embedment ratio of 3 the breakout factor is lower than of 2; but by increasing the

number of geonet layers, this factor is become higher than 2 embedment ratio in same reinforced layer.

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