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Behavior of single pile adjacent to slope embedded in reinforced sand under lateral load

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***Abstract*— this paper investigates the lateral behavior of a single pile embedded in reinforced layered slope. The effect of using layers of geo-grid as reinforcement for slope on the lateral pile capacity was studied. The analysis has been achieved using numerical simulation based on Plaxis 3D Foundation software. The problem under investigation was validated with the available field results to confirm the effectiveness of the adopted model in simulation the large scale piles. The pile was assumed to consist of linear and elastic material; the soil behavior was modeled based on the Mohr Coulomb failure criterion. An interface element was applied to the pile-soil and reinforcement-soil boundaries to accommodate the slip which may occur between these two materials. A series of numerical models were run to determine the lateral pile capacity at different number of geo-grid with a variable width and length. The results are shown in terms of load-deformation curves for the lateral loading portions. It has been found that soil reinforcement has a great effect on the lateral response of vertical piles located adjacent to slope and subjected to lateral load. Maximum benefit of reinforcements on the pile performance can be derived with geo-grid layers placed at vertical spacing S/D=1.55. It is also found that to get the beneficial effect of such technique the reinforcement should be installed with an adequate width equal to 15.44 D and length around 30.88D.**

***Keywords*— piles, lateral load, numerical analysis, layered slope, soil reinforcement**

I. INTRODUCTION

When a pile is subjected to lateral loading, the interaction that ensues between the pile and the surrounding soil is a topic replete with issues. The nature of soil is an obvious source of complexity, but so too are the pile and the dependence of its behavior on the nature of the soil present. The use of Geosynthetics to stabilize active landslides, and as a preventive measure instable slope, has become one of the important innovative slope reinforcement techniques in recent years. Under lateral loads, the piles not only may induce slope failure, particularly at shallow depths, but also may undergo severe reduction in its lateral capacity. There have been several studies reporting the effect of sloping ground on the lateral capacity of vertical pile in/near slope as stated by[1to 9].

[1], analyzed the influence of a slope on the behavior of single laterally loaded pile. It was reported that the deflection of a pile in a slope could be 1.6 times that of the same pile in level ground. [4] And [5] performed centrifuge tests to study the responses of piles in/near a slope under lateral loads. The results showed that, for a pile at the crest of a 1(V):2 (H) slope, the lateral resistance is approximately 0.70 times those for the reference pile in level ground. [10] studied the behavior of a strip footing supported on an earth slope stabilized by installation of a row of piles and vertical sheet pile, [8] studied the behavior of laterally loaded single vertical pile embedded in reinforced layered sand slope experimentally. However, the effect of such soil reinforcement on the overall behavior of laterally loaded vertical pile constructed near stabilized slopes has not yet been numerically investigated. Therefore, the aim of this research was to define more clearly the response of pile located near reinforced slope with layers of geogrid. The results of the finite element model are analyzed and compared to the results of the scale test. It also aimed to achieve a strategy to increase the pile lateral capacity near slopes.

I. GEOMETRY OF THE 3D FINITE ELEMENT MODELS

In this paper, analysis and parametric study of laterally loaded pile foundation near reinforced slope has been conducted. The study is performed using powerful finite element based software, Plaxis 3D foundation 2010. Plaxis 3D is a finite element program, developed for the analysis of deformation and stability in geotechnical engineering. A number of parameters were selected according to their effect on the response of piled system; some are taken to be constant while others are varied.

A. PARAMETRIC ANALYSIS OF PILE SLOPE SYSTEM

A typical soil slope 1(V):1.73(H) is considered and the slope is stabilized using the layers of Fortrac geo-grid. The properties of the geo-grid reinforcement are shown in Table 1.

B. MATERIAL MODELING

For laterally loaded pile under static condition, several researchers have adopted the Mohr-Coulomb (MC) soil model to represent the behavior of soils as [9]. The Mohr-Coulomb model is a linear-elastic perfectly-plastic model with a fixed yield surface. The yield surface is defined by model parameters and is not affected by plastic straining. In this model, plasticity is associated with the development of irreversible strains according to [11].

C. INTERFACE PROPERTIES

To simulate the interaction between a structure and soil interface elements can be applied. Without an interface the structure and the soil are tied together: no relative displacement (slipping/gapping) is possible between structure and soil. By using an interface, node pairs are created at the interface of structure and soil. From a node pair, one node belongs to the structure and the other node belongs to the soil as shown in Fig. (1). the interaction between these two nodes consists of two elastic-perfectly plastic springs. One elastic-perfectly plastic spring to model the gap displacement and one elastic-perfectly plastic spring to model slip displacement.

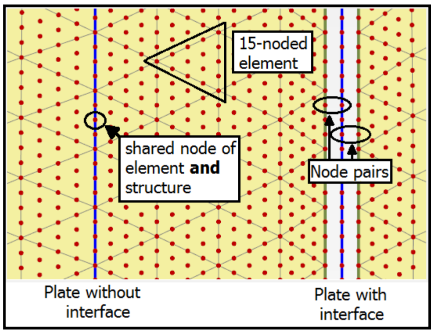


Fig. 1.The interface element & nodes that created

The level at which (plastic) slipping occurs is directly controlled by the strength properties and the R_{inter} value of the relevant material set. The elastic shear and normal stiffness of the interface springs are internally calculated from the stiffness properties of the relevant material set. Changing the R_{inter} influences both the stiffness and the strength properties of the interface; When using very low values for R_{inter} the interface stiffness may become so low (it has a quadratic dependency on R_{inter}) that it results in (possibly unrealistic) gapping or overlapping between soil and structure; Gapping is also possible between the structure and the soil when the tension cut-off of the relevant material data set is activated (meaning that no tension is allowed in the interface).

D. Standard boundary fixities

Plaxis automatically imposes a set of general fixities to the boundaries of the geometry model.

E. Mesh generation

In Plaxis, the soils are modeled with 15-node wedge elements. The 15-node wedge element is composed of 6-node triangular elements and 8-node quadrilateral elements as [11]. Regarding the model geometry, two main factors that affect the computed results are mesh size and model boundaries. For model boundary consideration, [12] suggest that boundary effects on the computed results (displacement and stresses around the pile) are not significant when the width of the soil mass is greater than 40D and the height of the soil mass is greater than L+20D where L is the pile length and D is the pile diameter. In the generation of finite element mesh for each numerical model, the dimensions of the soil mass are chosen arbitrarily to be large enough that the effects of model boundary are insignificant. The 3D finite element mesh for the baseline of the geometry of the piles near slope is shown in Fig. 2. According to [9].

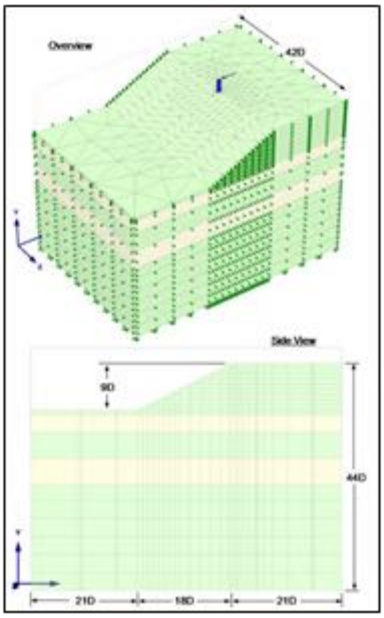


Fig. 2. Finite Element Mesh for the Baseline Pile near slope According to [9].

II. DESCRIPTION OF THE MODEL

Model circular piles with 0.32385 m (12.75 inch) outer diameter, whose thickness ($9.525*10^{-3}$ m) was fabricated from steel tube. The pile was 9.144 m in length. The parameters and series used in this analysis are shown in Fig. 3. & Table (4). There are several factors that affect the lateral resistance of a pile but the dominant one is the pile stiffness, which determines whether the pile behaves rigidly or as flexible pile. [13] showed that a laterally loaded pile behaves as a rigid pile based on the value of the stiffness factor λ. In cohesive soils, this factor is calculated as

$$\lambda = (k_h / 4E_p I_p)^{(1/4)} \qquad (1)$$

Where

E_p = modulus of elasticity of the pile material (21.4 × 107 kN/m^2); I_p = moment of inertia of the pile cross section (4.51 ×10^{-9} m^4); and k_h = subgrade modulus for pile (FL^{-2} dimensions).

[13] Suggested that the embedment depth of the pile has to be less than (1.5/λ) to be considered as a free-head short rigid pile and greater than (2.5/λ) for behavior as a long elastic pile. The Poisson's ratio γ of 0.495 was selected for cohesive soils under undrained loading instead of 0.5 to avoid numerical difficulties. The Poisson ratio of 0.35 was assumed to be appropriate for the cohesionless layers as stated by[14]. The material properties for the MC model used for the soil and linear elastic isotropic material properties of the piles according to the model of [9].

Fortrac T is a flexible, extremely high-strength geo-grid that has been used for reinforcing soil. Fortrac geo-grid are manufactured from high modulus, low-creep synthetic raw materials and coated with a layer of protective polymer. It has high stability at the rib junctions. Fortrac can be supplied in various aperture sizes and in standard strengths of between 20 and 400 KN/m. Its width of five metres reduces overlaps to a minimum according to [15]. Its proprieties are given in Table (1).

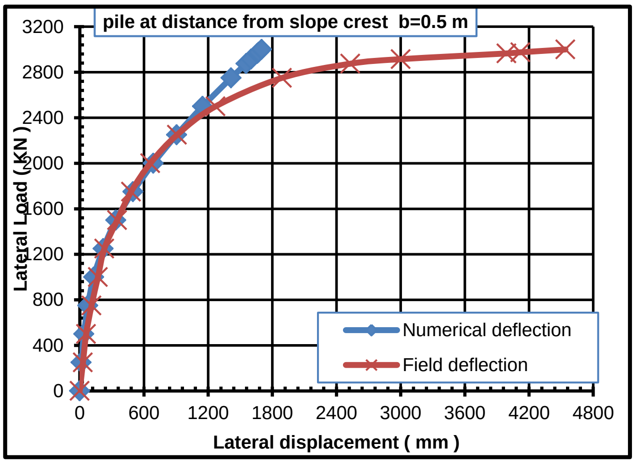
TABLE 1: Engineering properties of geo-grids

Structure	***Mono-oriented ortrac T geo-grids***
Polymer type	PET (polyester)
Tensile strength at 2% strain (kN/m)	11
Tensile strength at 5% strain (kN/m)	25
Peak tensile strength(kN/m)	800

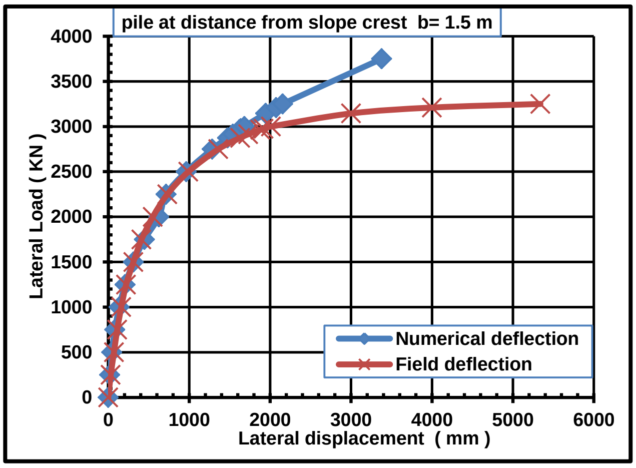
III. VERIFICATION OF NUMERICAL MODELS

To demonstrate the capability of the constructed numerical soil-pile simulation, Case studies were used for verification the finite element model of the whole geotechnical structure. The effect of ground inclination and pile-soil adhesion on the lateral behaviour of piles at the crest of clay slopes has been investigated through numerical analyses by [16]. The soil was modelled as a linear elastic – perfectly plastic Tresca material with undrained shear strength cu, undrained Young's modulus Eu, Poisson's ratio γ_u = 0.49 and bulk unit weight γ = 18 kN/m3. The pile was assumed linear elastic with a Young's modulus of E_p = 2.9 × 107 kPa and Poisson's ratio of γ = 0.1. For piles of D = 1 m diameter and L = 20 m length in undrained clay with cu = 50 kPa and Eu = 10 MPa. The slope inclination was considered h = 45°.

The various normalized pile to slope distances b/D ranging from 0.5 (pile at slope crest) to 6.5 where b is the distance of pile from the slope crest.



a) *At pile location from slope crest (b= 0.5 m)*



b) *At pile location from slope crest (b= 1.5 m)*

Fig. 3. Comparison of finite element results with data obtained from [16]

Fig. 3 presents the relationship between the lateral load versus the lateral pile deflection for both filed and numerical analysis. It has been found that, the numerical results follow the trend of the field results and a good agreement is achieved. Accordingly, in the view of the fact that the adopted Plaxis 3d version is capable of predicting the behavior of lateral loaded pile near sloping ground. It was decided to use the computer package for the analyses proposed in this research.

IV. ANALYSIS PROCEDURE AND STUDIED PARAMETERS

TABLE 2 *shows the studied strategy for the problem under investigation and Fig. 4 confirms the definition of adopted variables in this research*

TABLE 2: MODEL TESTS PROGRAM

Series	***Constant parameters***	***Variable parameters***
1	θ=30◦, H/D = 28.24, b/D= 0.0, W/D=15.44, L/D= 30.88, u /D = 2.48, s/D=1.55, e/D=2.82, Rein. Type 800	N=1, 2, 3, 4
2	θ= 30◦ , H/D = 28.236 , b/D= 0.0 , n=1, W/D=15.44 , L/D= 30.88, e/D=2.82, Rein. Type 800	u/D = 0.927, 1.55 , 2.48 , 3.1, 3.7
3	θ= 30◦, H/D = 28.236, b/D= 0.0, n=4, W/D=15.44, L/D= 30.88, u /D= 2.48, e/D=2.82, Rein. Type 800	s/D = 0.927, 1.55, 2.48
4	θ= 30◦, H/D = 28.236, b/D= 0.0, n=4, s/D=1.55, L/D= 30.88, u /D=1.67, e/D=2.82, Rein. Type 800	W/D = 6.18, 9.27, 12.36, 15.44, 18.53, 21.62
5	θ= 30◦, H/D = 28.236, n=4, W/D= 15.44, L/D= 30.88, u /D= 2.48, s/D=1.55, e/D=2.82, Rein. Type 800	b/D = 0.0 , 2, 4, 8, 10, 12, 14, -4
6	θ= 30◦, H/D = 28.236 , b/D= 0.0 , n=4 , W/D=15.44 , s/D=1.55 , u /D= 2.48 , e/D=2.82, Rein. Type 800	L/D =9.27, 12.36, 18.53, 24.71, 30.88, 37.1

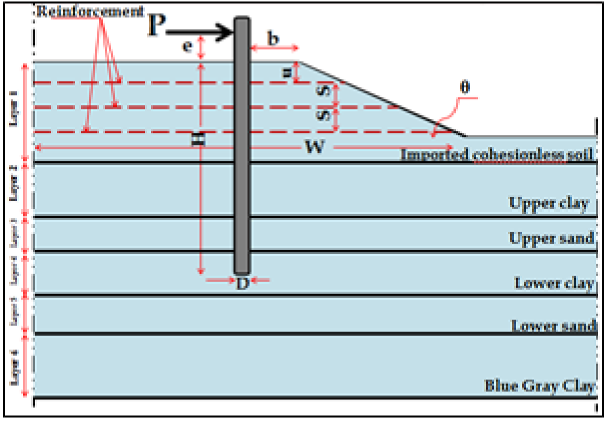


Fig.4. the studied parameters in numerical analysis by 3D plaxis

- **H** = embedment pile length
- **b** = distance of pile from slope crest
- **θ** = slope angle
- **e** = free distance of pile from the ground surface where lateral load acted
- **u** = distance of the first reinforcement layer to the ground Surface
- **S** = the vertical distance between layers of reinforcement
- **W** = width of reinforcement layer
- **L** = Length of reinforcement layer
- **n** = number of reinforcement layers .

The diameter of pile **D** is always constant

V. RESULTS AND DISCUSSION

A 3-dimensional finite element analysis was performed in attempt to simulate the lateral loading test results of the piles installed near slope. The FEM analysis was aimed at providing information on the effects of soil slope on the lateral capacity of piles. In addition, a parametric study of the soil properties was conducted for the 0D pile.

According to [8] the lateral bearing load improvement of the pile due to slope stabilization is represented using a non-dimensional factor, lateral resistance improvement (LRI) factor. This factor was derived by dividing the pile lateral load for a given pile located in stabilized slope at a specific lateral displacement by the lateral load of the same pile when placed in non-stabilized slopes at the same lateral displacement. The pile lateral displacement (y) is also expressed in non-dimensional form in terms of the pile diameter (D) as the ratio (y /D, %). In this discussion, the effect of the different parameters on the pile lateral capacities for different cases has been estimated from the load-deflection diagrams. Because of there is no definite failure pattern where no clearly peak point, considering the ultimate loads corresponding to the point wherein lateral deflection of pile equal 10 of pile diameter according to [17],[18] and[19].

1. EFFECT OF THE NUMBER OF GEOGRID LAYERS

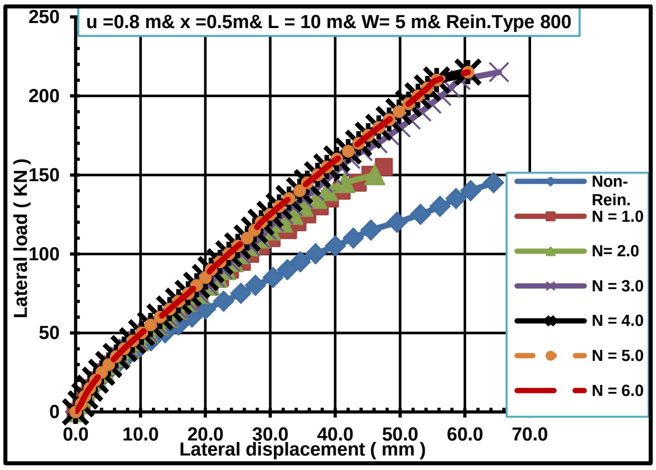


Fig.5. Typical variations of pile lateral load against Lateral displacement for different number of geo-grid layers

Typical variations of lateral loads with lateral displacement for a 0.32385m diameter pile located at the crest of a reinforced slope at different geo-grid numbers are shown in Fig. 5. This figure clearly indicates that the inclusion of the geo-grid layers resulted in an increase in the lateral load capacity of the model pile at the same displacement ratio. Comparing the curves at displacement ratio of (y /D = 10%). It has been found that the existence of such reinforcement can significantly improve the load displacement curves. A gradual increase in the lateral load capacity is achieved as the number of geo-grid layer is increased. Its noticed that, using four layers of geo-grid increased the lateral pile load by 49.15%, of non-stabilized slope, this findings are agree with the results of [8].

This increase in pile lateral resistance can be attributed to a reinforcement mechanism which derived from the interaction and friction between the geo-grid and the sand, as illustrated in Fig. (6). the geo-grid was generally made with integral high-strength junctions between longitudinal ribs and transverse bars to provide stress transference from stressed zones of soils to unstressed ones. When sand material is compacted over the geo-grid layer, it partially penetrates and projects through the apertures creating an interlocking action between the sand and the grid. This interlock enables the geo-grid to resist the horizontal shear stresses built up in the soil mass in front of the laterally loaded pile. The reinforcement transfers them to stable layers of soils in the back of the pile and thereby improve the lateral resistance of the pile. It is worth mentioning that in cases on non-reinforced slopes, at large displacement ratios, a gap between the pile and the soil at the back of pile was observed, while in tests with geo-grid reinforcement placed in dense samples, soil lateral movements were observed at the back of the pile. The measured lateral loads for piles embedded in both reinforced and non-reinforced slopes at displacement ratios of 10 % for the different studied parameters are given in Table 3. These results are discussed in the following.

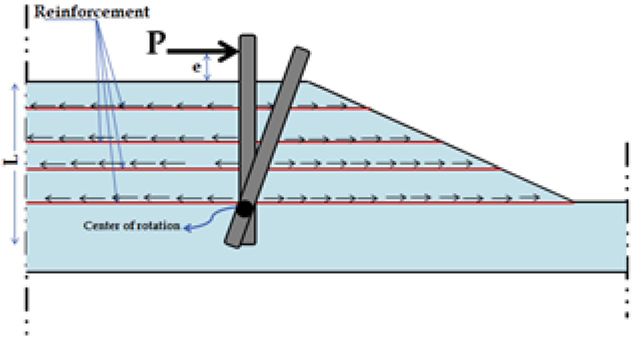


Fig .6. Mobilized stresses in geo-grid layers

TABLE (3): NUMERICAL RESULTS FOR PILE LOCATED ON THE CREST OF REINFORCED SLOPE, SERIES 1

Test results	***N (b / D= 0.0)***				
	Non-Rein.	***1***	***2***	***3***	***4***
P(N), at y/D=10%	89.4	114.29	121.42	126.29	133.34

While Fig. 7 shows the variation of the improvement of pile loads determined at displacement ratio of (y /D of 10 %). It is clearly indicated that increasing the number of geo-grid layers has a significant effect on improving the pile lateral resistance. For a slope reinforced with four geo-grid layers a gain in the pile lateral resistance as much as 49.15% of the pile lateral load in non-reinforced slopes was obtained. Also, slope reinforcement has much pronounced effect for piles placed closer to slope crest. However, it seems that there are not an optimum number of reinforcement layers after which the load improvement becomes constant.

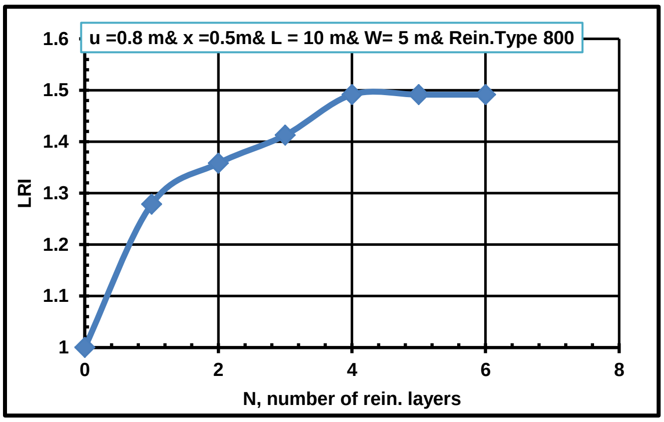


Fig .7. Variation of LRI with the number of geo-grid layers (b/D = 0)

2. EFFECT OF THE DEPTH OF THE FIRST GEOGRID LAYER

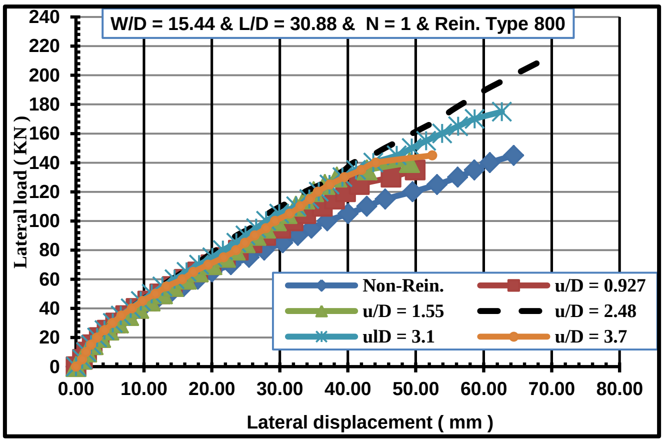


Fig .8. Typical variations of pile lateral load against layer lateral displacement for different vertical first distance for one layer

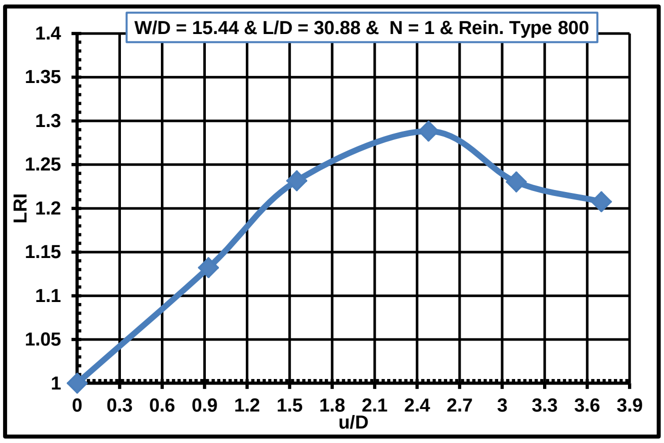


Fig .9. Variation of LRI with the first vertical

The ratio u/D represents the depth of the geo-grid layer to the ground surface. The effect of this depth on the ultimate lateral load is studied using only one layer of geo-grid placed in loose sand at different depths of ground surface.

The typical variation of pile lateral load against layer lateral displacement for different vertical first distance for one layer is illustrated in Fig. 8. It can be seen that the ratio u/D has a great effect in the lateral pile capacity, as the ratio increased up to value of u/D = 2.48 the pile load capacity is significantly increased. While over this range the load pile capacity is sharply decreased. For confirmation, Fig. 9 shows the variation of the LRI of laterally loaded pile against the normalized depth u/D at displacement ratio y /D of 10 %. The pile lateral resistance decrease with the increase in depth of the reinforcement layer. Also, the maximum improvement was obtained at depth ratio of (u/D=2.48) which increases the lateral pile load by 28.83%, more than that of non-stabilized slope. Comparing these results with [8], it can be seen that the results are in a close agreement with, according to [8] have the maximum increasing at depth ratio (u/D= 2.6). It can be concluded that the reinforcing mechanism in improving the pile lateral resistance depends on both the ground movement patterns and the location of potential failure surfaces of soil in front of the pile, the shear stresses transferred by the geo-grid, and the mobilized resistance of soil at the back of the pile. The result of series 2 is shown in Table (4).

Table (4): Numerical results for pile located on the crest of reinforced slope, series 2

Test results	***u/D***					
	Non-Rein.	***.927***	***1.55***	***2.48***	***3.1***	***3.7***
P(N), at y/D=10%	89.4	101.21	110.095	115.17	109.977	107.96

3. Effect of Geogrid Spacing

The load deflection curves of piles near slope with different spacing are plotted in Fig. 10. This figure demonstrated that the pile lateral capacity is improved well at minimum pile spacing. The optimum spacing which provided a higher values of later capacity is found to be at S = 1.55D. Fig. 11 shows the variation of the pile lateral resistance improvement measured at pile displacement ratio of y /D=10 % against the normalized pile spacing S/D. This again justified that geo-grid reinforcements are much more effective in improving the pile lateral resistance when placed at closer spacing. For the same displacement ratio, y /D, it can be seen that the load resistance of the pile increases initially with the vertical spacing until reaching a maximum value after which it comes down with increasing the vertical spacing. The maximum resistance occurred at a normalized vertical spacing S/D=1.55. The run result of this series 3 is tabulated in table (5).

Table (5): Numerical results for pile located on the crest of reinforced slope, series 3

Test results	***s/D***			
	Non-Rein.	***.927***	***1.55***	***2.48***
P(N), at y/D=10%	89.4	119.58	133.34	109.55

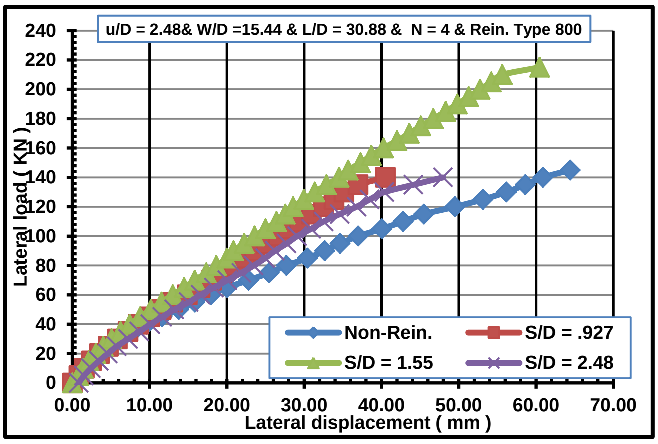


Fig.10. Typical variations of pile lateral load against lateral displacement for different spacing of geogrid layers

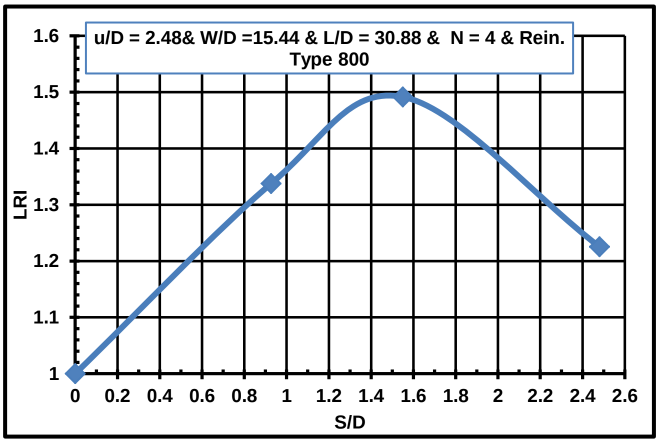


Fig .11. Variation of LRI with spacing of geogrid layers The maximum improvement in lateral pile capacity only due to spacing of geogrid layers is about (15.8%)

4. EFFECT OF GEOGRID WIDTH

From Fig (12, 13) it has been clearly that the lateral capacity of pile increase with increasing the width of reinforcement layers until a maximum value then any increasing in width is useless and lateral pile capacity don't affected by such increase in the geo-grid width. It has been found that at width ratio W/D = 15.44 the higher improvement in the lateral capacity is obtained. Over this rage there is no appreciable effect of increasing the width of reinforcement because of the ultimate lateral capacity is remained constant. Therefore for the current investigated case, the optimum width is documented at W/D = 15.44. Table (6) is also shown the obtained results that clearly described the effect of geo-grid width on the lateral pile capacity.

TABLE (6): NUMERICAL RESULTS FOR PILE LOCATED ON THE CREST OF REINFORCED SLOPE, SERIES 4

Test results	***W/D***						
	Non-Rein.	***6.18***	***9.27***	***12.36***	***15.44***	***18.53***	***21.62***
P(N), at y/D=10%	89.4	111.37	121.51	126.29	133.34	133.34	133.34

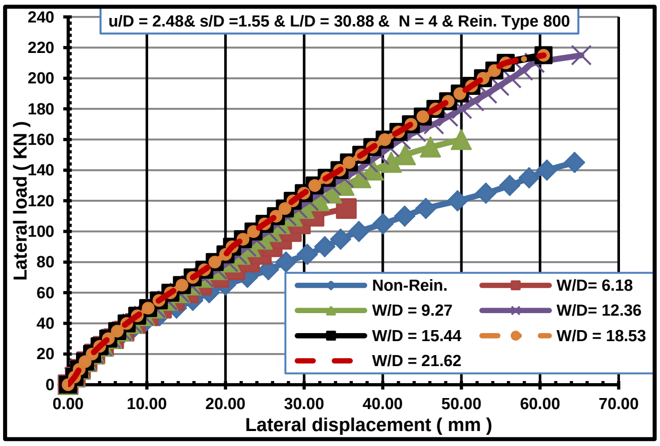


Fig .12. Typical variations of pile lateral load against lateral displacement for different width of geogrid layers

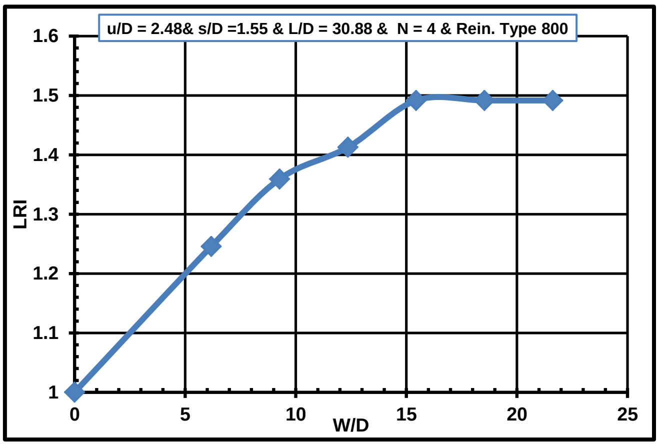


Fig .13. Variation of LRI with width of geogrid layers

5. EFFECT OF PILE LOCATION RELATIVE TO SLOPE CREST

Fig.14. Shows the variation of the lateral load improvement of the pile against the normalized pile locations relative to slope crest; it clearly shows that maximum benefit of slope geo-grid reinforcement is obtained when pile is placed at the slope crest. As the pile location moves away from the crest, the lateral resistance improvement of the pile becomes less, although the pile lateral resistance in reinforced slopes increases. However, this decrease in the lateral resistance improvement is obvious until a value of about b/D > 4, after which the pile acts like in the baseline ground. After this distance the increasing in lateral pile capacity is about (24.07%) than pile located at slope crest. The ratio b/D represents the closeness of the pile to the crest of the ground slope.

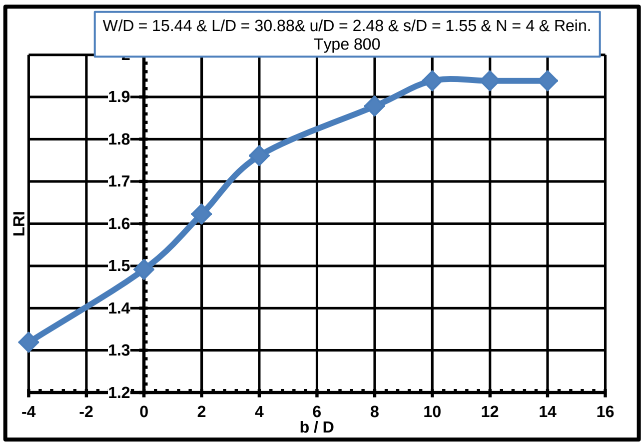


Fig .14. Variation of LRI with horizontal space of pile from slope crest

6. EFFECT OF GEOGRID LENGTH

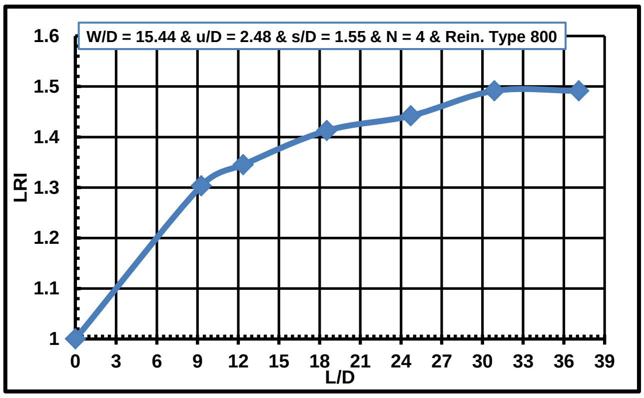


Fig .15. Variation of LRI with length of geogrid layers

The Variation of LRI with length of geo-grid layers is shown in Fig .15. It has been found that the lateral capacity of pile increase with increasing the Length of reinforcement layers until the optimum value of L = 32D. Then any increase in geo-grid length is useless. Over the range of L =30.88D, the lateral pile capacity don't affected by such increase in geo-grid length.

VI. CONCLUSIONS

The effect of reinforcing a soil slope using geo-grid layers on the lateral behavior of vertical single pile located adjacent the slope crest was investigated. Based on the numerical investigations carried out on the model pile embedded in reinforced layered sand slope, the following main conclusions are drawn:

1. Stabilizing an earth slope using geo-grid reinforcement has a significant effect on improving the lateral capacity of vertical single pile located near the slope crest.
2. The improvement in pile lateral resistance was found to be strongly dependent on the location of reinforcement layers at the first vertical spacing of reinforcement layer u/D = 2.48.
3. For the tested configurations, increasing the number of geo-grid layers leads to significant improvement in pile lateral resistance. However, it seems that there are not an optimum number of reinforcement layers after which the load improvement becomes constant.
4. Inclusion of geo-grid reinforcement is very effective in improving the pile lateral resistance when placed at shallow depths with closer spacing. Maximum benefit of reinforcements on the pile performance can be derived with geo-grid layers placed at vertical spacing S/D=1.55.
5. To get the beneficial effect of such technique the reinforcement should be installed with an adequate width equal to 15.44 D and length around 30.88D.
6. Soil reinforcement is more effective for piles located closer to the slope crest. The influence of the slope on the pile performance can be neglected once the pile is placed a distance of more than four diameters from the slope crest.

REFERENCES

[1] Poulos, H. G. . "Behavior of laterally loaded piles near a cut or slope." Austral. Geomech. J., 6 (1), 6–12, (1976).

[2] Schmidt, H. G. . "Large diameter bored piles for abutments."Proc., 9th Int. Conf. on Soil Mechanics and Foundation Engineering, (1977).

[3] Terashi, M., Kitazume, M., Manuyama, A., and Yamamoto, Y. "Lateral resistance of a long pile in or near the slope." Proc., Centrifuge '91. H.-Y. Ko. And F.

Mclean, eds., Balkema, Rotterdam, the Netherlands, pp. 245-252, (1991).

[4] Bouafia A. and Bouguerra A. “Centrifuge testing of the behavior of a horizontally loaded flexible pile near to a slope.” International Journal of Rock Mechanics and Mining Sciences and Geomechanics, Vol. 33(3), (1996).

[5] Mezazigh, S., and Levacher, D. “Laterally loaded piles in sand: Slope effect on p-y reaction curves.” Canadian Geotechnical Journal, 35, 433-441, (1998).

[6] Zhang, L., Francisco, S., and Ralph, G.. “Ultimate lateral resistance to piles in pp. 78-83, (2005).

[7] Chae K.S., Ugai K., and Wakai A. “Lateral resistance of short single piles and pile groups located near slopes.” International Journal of Geomechanics, 4(2), 93-103, (2004).

[8] El Sawwaf, M. “Lateral resistance of single pile located near geosynthetic reinforced slope.” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 132, No. 10, (2006), p.p. 1336-1345, (2006).

[9] Nimityongskul, N., Barker, P. and Ashford, S., A. Effects of Soil Slope on Lateral Capacity of Piles in Cohesive and Cohesionless Soils, The Kiewit Center for Infrastructure and Transportation, Oregon State University, School of Civil and Construction Engineering (347 pages), (2012).

[10] El Sawwaf, M., and Nazir, A. “Behavior of circular footings resting on confined granular soil.” J. Geotech. Geoenviron. Eng., 131(3), 359–366, (2005).

[11] Brinkgreve, R. B. J., and Swolfs, W. M. Plaxis 3D foundation version 2 user’s manual, Plaxis B.V., Netherlands, (2007).

[12] Karthigeyan, S., Ramakrishna, V. V. G. S. T., and Rajagopal, K. “Numerical investigation of the effect of vertical load on the lateral response of piles.” Journal of Geotechnical and Geoenvironmental Engineering, Vol. 133(5), pp. 512-521, (2007).

[13] Broms, B. B. “Lateral resistance of piles in cohesionless soils.” J. Soil Mech. Found. Div., 903, 123–156, (1964).

[14] Bozorgzadeh, A. “Effect of structural backfill on stiffness and capacity of bridge abutments.” Ph.D. thesis, Dept. of Structural Engineering, University of California, San Diego, (2007).

[15] HUESKER Synthetic GmbH, WWW.HUESKER.com.

[16] Konstantinos .G., Georgiadis.m., Development of p–y curves for undrained response of piles near slopes Computers and Geotechnics 40 (2012) 53–61, (2012).

[17] Terzaghi, K., Discussion of the Progress Report of the Committee on the Bearing Value of Pile Foundation. Proc. ASCE, Vol. 68, (1942).

[18] Tomilson, M.J., Pile Design and Construction Practice. A View Point Publication, London, (1980).

[19] Bahloul, A. Nasr, Reduction of Lateral Pile Capacity in Sand Due to an Adjacent Slope, International Conference on Geotechnical Engineering, October 3-6, Sharjah – UAE, (2004).

[20] Taha, A., M. and Elnaggar, M., H., Static and Seismic Performance of Geosynthetics- Strengthened Pile Foundations, Ph.D., The School of Graduate and Postdoctoral Studies The University of Western Ontario London, Ontario, Canada, (2014).

[21] Marto, A., Oghabi, M. and Eisazadeh, A., the Effect of Geo-grid Reinforcement on Bearing Capacity Properties of Soil under Static Load; A Review, EJGE. Vol. 18 [2013], Bund. J, p.p.1881-1898, (2013).

[22] Adams, M., Nicks, J., Stabile, T., Wu, J., Schlatter, w. and Hartmann, J., Geosynthetic Reinforced Soil Integrated Bridge System, Synthesis Report, FHWA-HRT-11-027, Federal Highway Administration, U.S. Department of Transportation, No. of Pages 64, (2011).