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Research Article

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Behavior of Raft Foundation Resting on Improved Soft Soil with Conventional Granular Piles

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Abstract Soft soil is located in important regions all over the world along rivers and seas. Construction on natural soft soil is a risk due to its low shear strength and high compressibility. Using granular piles in soft soils is an effectively improvement technique. In this research the behavior of raft footing constructed on soft soil reinforced by end bearing or floating granular piles is studied numerically by using Plaxis 3D. A parametric study for a raft footing subjected to uniform loads under drained conditions is carried out by varying spacing distance, diameter and length of the piles. This study is done to investigate the effect of the various parameters on the bearing capacity, the settlement control, and bending moment of the footing. The results show that using granular piles in soft soil under raft footing decreases effectively the settlement and bending moment. These improvements increase as the increase of area replacement ratio and pile length, and as the decrease of the spacing ratio. Utilizing floating granular piles with length ratio of 0.75 is considered effective in reinforcing soft soil from the sides of improvement performance and economic.

Keywords Granular pile, Soft Soil, Settlement, Bending moment, Reinforcement

Introduction

The raft footing system is used when the level of applied loads is somewhat heavy and the bearing capacity of soil is weak. When raft footing is utilized on soft soil, the soft soil sustains from excessive settlement and low shear strength. Thus excessive consolidation settlement causes partial or full damage in the raft footing or in the building. The alternative solution is to use deep foundation as reinforced concrete piles or raft footing with reinforced concrete piles. But both solutions are expensive. The other solution is to improve the soft soil effectively under raft footing.

The granular piles method is the most effective to soft soil improvement. Granular piles have higher drainage ability and stiffness than the surrounding soft soil. Therefore, ground reinforcement by granular piles solves the problems of the soft soil under raft foundation by providing advantage of reduced settlement and accelerated consolidation process. A granular fill layer of sand or sand-gravel mixture is usually placed over the top of granular piles reinforced weak soils [1]. The carrying capacity of the granular piles depends mainly on the lateral support. The lateral support is provided by the native soft soil which depends on its shear strength. The stiffness of the granular pile also plays an important role in the increase of the stress concentration within the pile, which leads to increase the bearing capacity of the improved ground.

Various research papers have been published in the last three decades on granular piles [1-16]. Most of the research works dealt with the unit cell technique. But the unit cell technique doesn't match the modeling of granular piles especially near the edge and the corner of the raft foundation which have larger external bulking than piles near raft footing center. Hence, full scale three-dimensional modelling is used in the current research to reflect the reality.

Granular piles may be fully penetrated and resting on strong soil layer (i.e., end bearing granular piles) or partially penetrated (i.e., floating granular piles). Several researchers also studied the improvement efficiency of floating granular piles which depends on pile length, area replacement ratio and pile stiffness [17-24]. Several research works have also been conducted to understand the behavior of granular pile-improved ground under axi-symmetric condition. The granular pile-reinforced ground was analyzed with an axi-symmetric approach assuming the existence of an equivalent model of circular raft foundation resting on concentric stone rings with a granular pile at the center. The group of granular piles was substituted with an equivalent stone ring to keep the ratio of the granular pile area constant for the total area 6, [25-27].

The published literature in the behavior of raft footing rested on reinforced soft soil with granular piles is very limited especially with respect to long-term performance. Most of the past research utilized the axi-symmetric modeling which doesn't reflect the real behavior of the granular piles reinforced soft soil under raft foundation. The focus of the available studies has mainly been the settlement behavior of the improved ground. In the design of foundations, not only the settlement is a significant design factor, but the bending moment is also important design factor. The present research investigates the behavior of uniformly loaded raft footing constructed on improved soft soil by granular piles based on 3D numerical analysis considering parameters like piles spacing, diameter and length. The effects of the different parameters on the settlement and bending moment of the raft foundation are studied.

Numerical Modeling

The models of the non-reinforced and reinforced soft clay layer of 10.0 m thick with a group of different number of granular piles under raft foundation are idealized by Plaxis 3D program. The compacted sand with 0.5 m thickness is utilized as a mat layer. The groundwater level is at 0.5 m depth below the raft footing. Medium finite element mesh is used. The raft foundation has the dimension of 10 m x 10 m and thickness of 1 m. Quarter of the problem is idealized due to the symmetry. The model has a dimension of 50 m x 50 m to avoid the effect of the boundary conditions on the results as shown in Fig. 1.

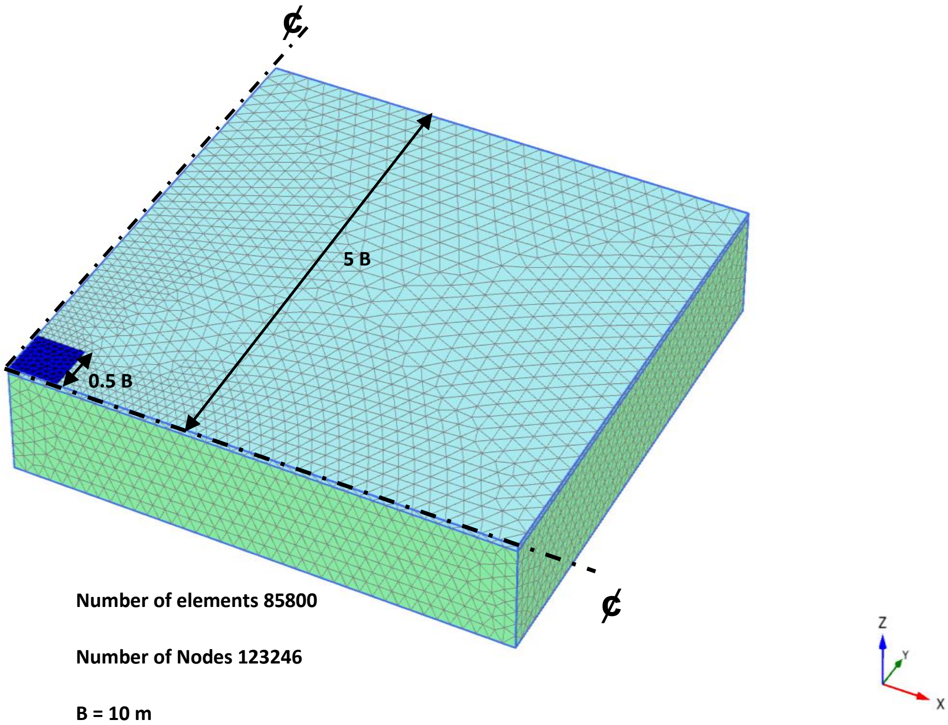

Figure 1: Finite Element mesh

The soft clay, sand layer and stone material are idealized by Mohr-coulomb Model which is available in Plaxis 3D library. The properties of these soils are adopted from the study of Tan et. al (2008) [28]. The raft foundation is elasticity idealized by Plate Model. The reinforced concrete of the raft footing has a modulus of elasticity of 2.1E7 kN/m². The used soil parameters are illustrated in table 1. The numerical analyses have been performed under an area load of 100 kN/m² applied on the non-reinforced and the reinforced soft soil. The effect of spacing between piles, pile diameter and pile length is studied on the footing settlement, and bending moment. The studied cases are illustrated in. table 2.

Table 1: Properties and shear strength parameters used for the soils

Parameter	Symbol	Granular pile, (Tan et al., 2008)	Sand, (Tan et al., 2008)	Soft clay, (Tan et al., 2008)
Material model	Type	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Loading	Condition	Drained	Drained	Drained
Young's modulus	E, (kN/m^2)	30,000	15,000	1100
Poisson's ratio	υ (-)	0.3	0.3	0.3
Cohesion	c´, (kN/m^2)	5	3	1
Friction angle	φ´°	40	33	20

Table 2: Studied cases

Group No.	Pile Diameter, d (m)	Spacing ratio between the Piles, (S/d)	Number of piles	Area replacement ratio, (Ar)	Pile length to the clay layer thickness ratio, (L/H)
A	1.0	2 3 4	9 4 1	0.197 0. 126 0.031	1
B	0.8 1.0 1.2	2	9 9 4	0.181 0.197 0.181	1
C	0.8	2	9	0.181	0.25 0.5 0.75 1

Results and Discussions

Effect of Spacing to Pile Diameter Ratio

Granular piles with diameter d = 1.0 m and different spacing ratios of S/d = 2, 3 and 4 are utilized to investigate the influence of spacing on the behavior of the reinforced soft soil under raft footing. Figure 2 depicts the settlement versus load relationships at a point under the center of the footing for the non-reinforced and the reinforced soft soil with different spacing distances between granular piles. As can be observed the soil without reinforcement has the largest amount of settlement, which is 858 mm. Utilizing a 0.5m-mat layer beneath the raft footing leads to decrease the settlement to the value of 713 mm. By using granular piles with spacing ratio of s/d = 4 the amount of settlement decreases to 79 % from that of the non-reinforced soil. In addition, among the granular piles with different spacing ratios, the case of spacing ratio of s/d = 2 has the best performance, decreasing the settlement to 480 mm which represents 56 % from that of the non-reinforced soil. Thus, it can be concluded that by decreasing the spacing of the piles and by increasing area replacement ratio the amount of settlement will be decreased.

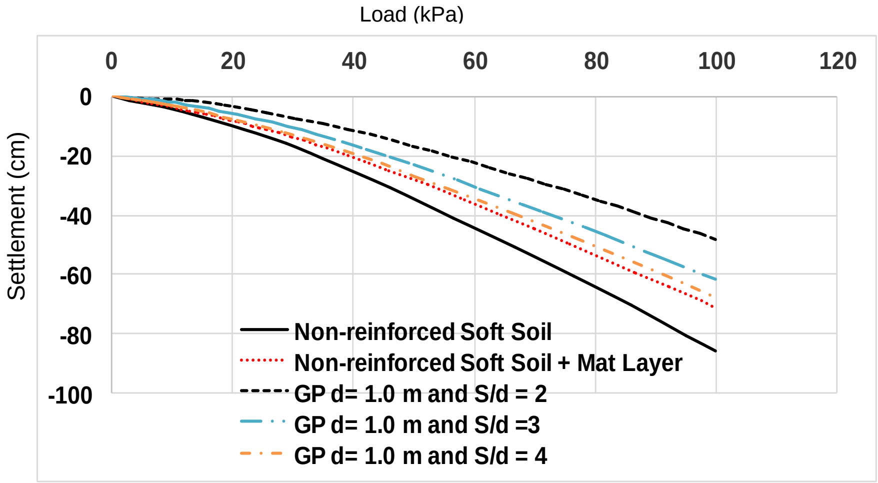

Figure 2: Load – settlement for the non-reinforced and reinforced soft soil with different spacing ratios

Figure 3 shows the bending moment distribution of the raft footing for the non-reinforced and the reinforced soft soil with granular piles using different spacing distances. The variation of bending moment for all cases is approximately the same. The maximum negative bending moment value is in the center of the raft. Beyond this value, the bending moment decreases gradually and it reaches zero at the edge. The existence of mat layer under the raft footing causes an increase in the bending moment in comparison to the case of non-reinforced clay and the case of reinforced soil with granular piles having S/d = 4. This is attributed to the influence of the differential settlement.

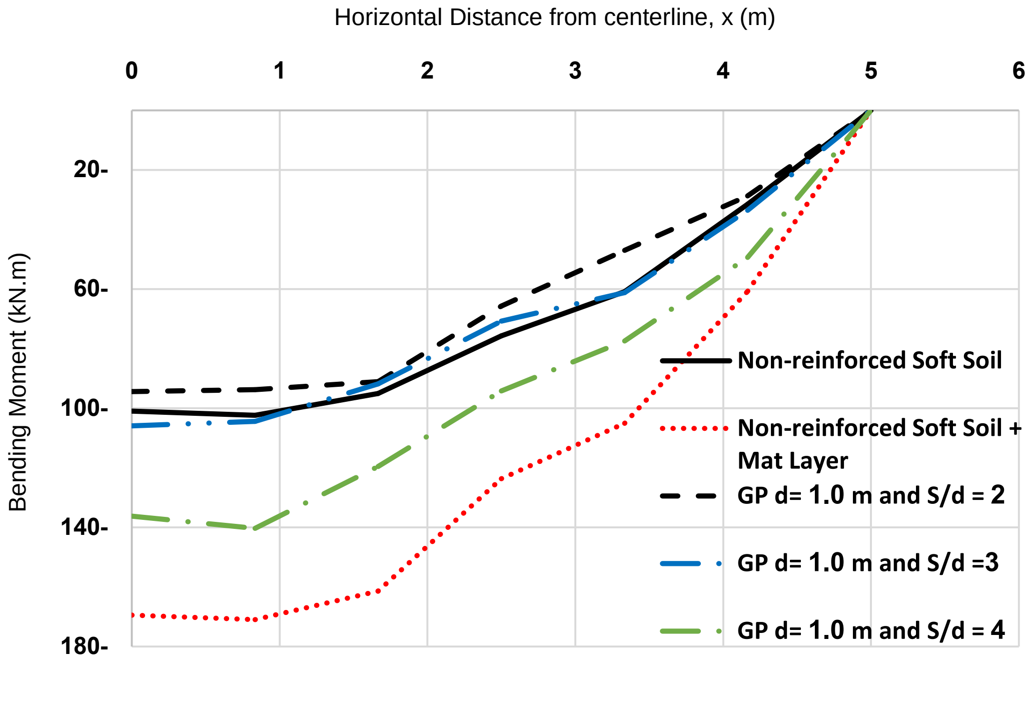

Figure 3: Bending moment distribution along footing for non-reinforced and reinforced soft soil with different spacing ratios

Using granular piles with spacing ratio smaller than S/d = 4 in the soft soil decreases the bending moment of the raft footing. The bending moment decreases as decreasing the spacing between piles and as increasing area replacement ratio. In addition, among the granular piles with different spacing, the case of spacing ratio of s/d = 2 has the best performance, decreasing the bending moment to 64 % and to 61 % from that of the non-reinforced soil at the footing center and at 2.5 m from the footing center, respectively.

Effect of Pile Diameter

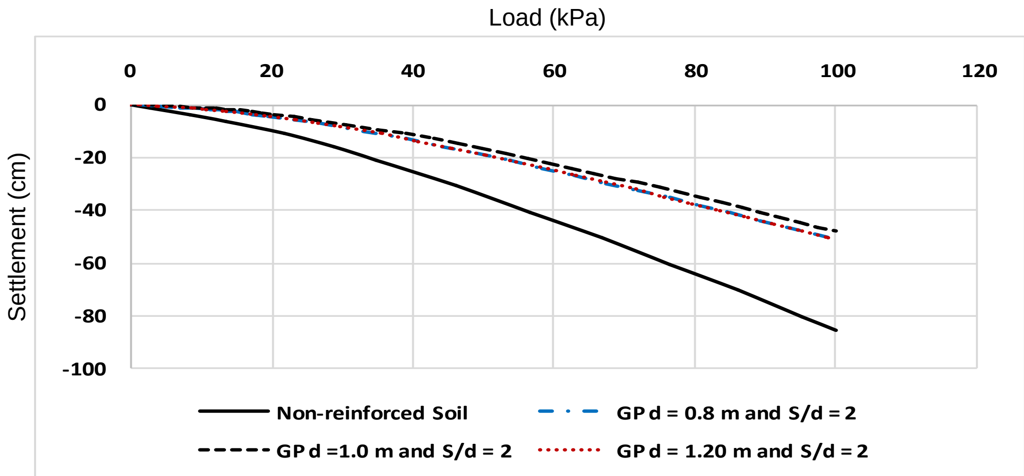

Figure 4: Load – settlement for the non-reinforced and reinforced soft soil with different diameters

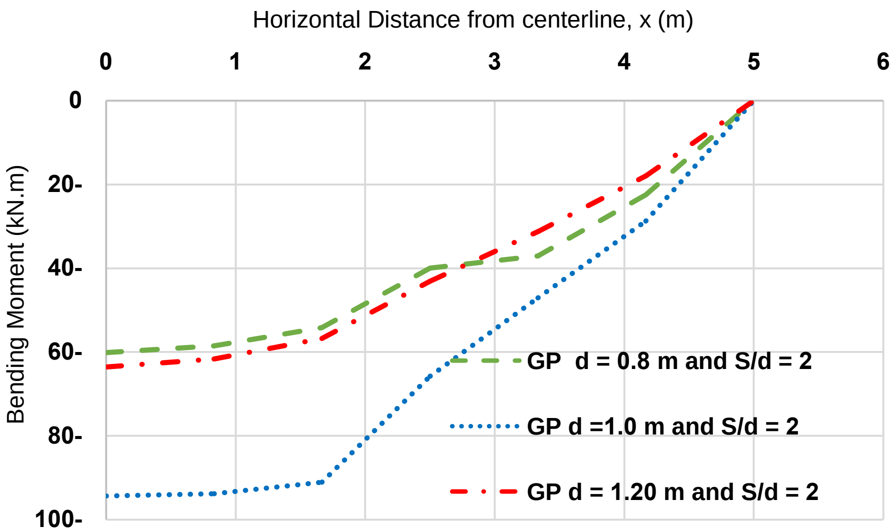

Figure 5: Bending moment distribution for the non-reinforced and reinforced soft soil with different pile diameters

It is observed from figure 4 that, the case of d = 1.0 m has somewhat greater bearing capacity when compared with the studied cases of d = 0.8 m and d = 1.2 m at the same spacing ratio of 2. Additionally, both cases of d = 0.8 m and d = 1.2 m have the same load-settlement relationship in spite of they have different number of piles. This is because of that the both cases have the same area replacement ratio, Ar. Both of the cases of d = 0.8 m and d = 1.2 m imply smaller bending moment values than the case of d = 1.0 m as shown in Fig. 5. This is attributed to that the case of d = 1.0 m has the greatest differential settlement in comparison with the other studied cases. The cases of d = 0.8 m and d = 1.2 m have approximately the same values of bending moment. The reasons of that are both cases have the same area replacement ratio and approximately the same differential settlement. Therefore using granular piles with d = 0.8 m and S/d = 2 is effective in reinforced soft soil.

Effect of Pile Length

Cases of reinforced soft soil with granular piles having d = 0.8 m, S/d = 2 and different piles lengths. The used length to soil layer thickness ratios are l/H = 1.0, 0.75, 0.5 and 0.25 to investigate the behavior of the end bearing and the floating granular piles in reinforcing soft soil. The case of the end bearing granular piles has the best performance in reducing the amount of settlement as depicted in Fig. 6.

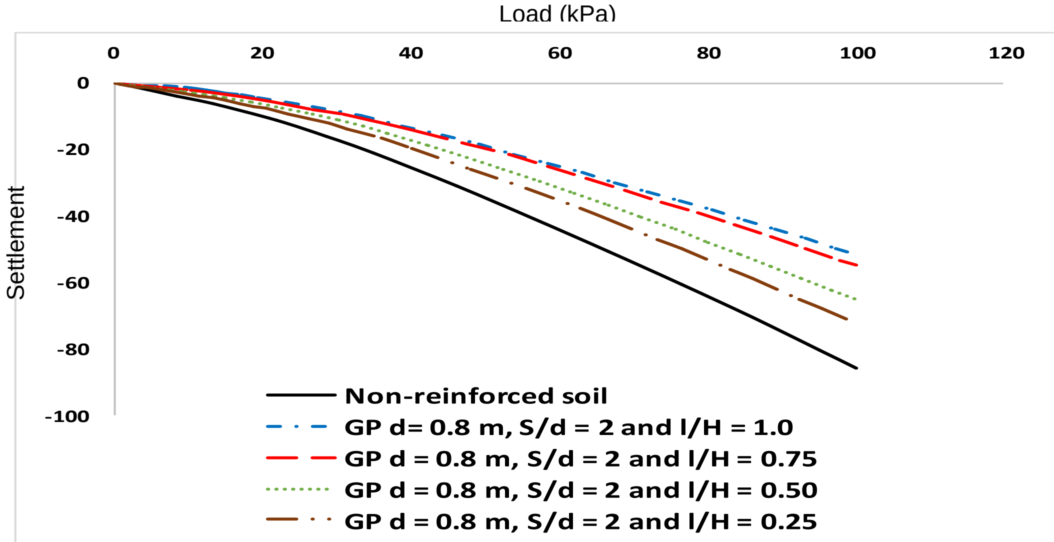

Figure 6: Load – settlement for non-reinforced and reinforced soft soil with different pile lengths

The amount of settlement increases as the decrement in pile length. The rate of raising settlement increases beyond the length ratio of l/H = 0.75. It can be noticed that the settlement values of the case of l/H = 0.75 is close to those of the case of l/H = 1.0.

Figure 7 shows the distribution of the raft footing bending moment for pile length ratios of 0.25, 0.5, 0.75 and 1.0. The cases of length ratios of 0.25 and 1.0 imply approximately the same bending moment values. While the case of length ratios of 0.5 and 0.75 appear bending moment values smaller than that of the cases of length ratios of 0.25 and 1.0. Additionally, the floating granular piles with length ratio of 0.75 have the smallest bending moment values in comparison with the other studied cases. The case of the floating granular pile with length ratio of 0.75 has smaller bending moment values and convergent settlement values in comparison with the end bearing case. Therefore, the floating granular piles with length ratio of 0.75 can be used to combine the good performance and economic.

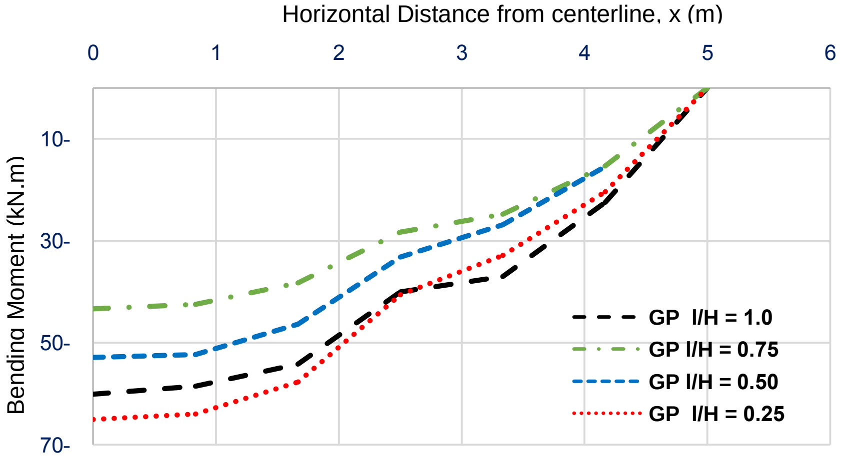

Figure 7: Bending moment distribution along footing for reinforced soft soil with different pile lengths

Conclusions

The non-reinforced and the reinforced soft with granular piles under raft footing were studied numerically using Plaxis 3D program. The soft soil was reinforced with granular piles having different numbers of piles and area replacement ratios. The influence of spacing between piles, pile diameter and pile length on the behavior of the reinforced soft soil was investigated. The results show that using 0.5 m- mat layer only reduces the settlement to 83 % from that of the non-reinforced soil. While this mat layer causes an increase in the bending moment value.

The amounts of settlement and bending moment reduce as the decrease of spacing ratio and the increase of the area replacement ratio. The diameter of the granular pile has a slight effect on the settlement of the reinforced soft soil at the same spacing ratio of 2. The case of the diameter of d = 0.8 m implies bending moment values smaller than those of the case of d = 1.0 m. Therefore, using granular piles with d =0.8 m and S/d = 2 has better performance in reinforcing soft soil than the other studied cases. The end bearing granular piles imply good performance in reducing settlement. The settlement decreases with increasing pile length. The floating granular piles with length ratio of 0.75 have somewhat a greater settlement amount and a smaller bending moment in comparison with end bearing granular piles. Therefore, using floating granular piles with d = 0.8 m, S/d = 2 and l/H = 0.75 is effective in improving soft soil under raft footing to gather between the good performance and economic

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References

[1]. Mitchell JK (1981) Soil improvement-state of art report. Proc. of 10th Int. Conf. on Soil Mechanics and Foundation Engineering, Balkema, Rotterdam, Netherlands, Vol. 4, 509-565

[2]. Balaam, N. P. and Booker, I. R. (1981). Analysis of rigid rafts supported by granular piles. International Journal for Numerical and Analytical Methods in Geomechanics 5, 379-403

[3]. Han, J. and Ye, S. L. (1991). Field tests of soft clay stabilized by stone columns in coastal areas in China. Proc. of the 4th International Conference on Piling and Deep Foundations, Stresa, Italy, 243-248

[4]. Priebe HJ (1995) The design of Vibro replacement. Ground Engineering, 28(12): 31-37.
[5]. Poorooshasb, H. B. and Meyerhof, G. G. (1997). Analysis of behavior of stone columns and lime columns. Journal of Computers and Geotechnics 20, No. 1, 47-70
[6]. Lee, J. S. and Pande, G. N. (1998) Analysis of stone-column reinforced foundations. International Journal for Numerical and Analytical Methods in Geomechanics 22, No.12. 1001-1020
[7]. Christoulas, ST., Bouckovalas, G. and Giannaros, CH. (2000). An experimental study on model stone columns. Soils and Foundations Journal 40, No. 6, 11-22
[8]. Shahu JT, Madhav MR, Hayashi S (2000) Analysis of soft ground-granular pile-granular mat system. Computers and Geotechnics, 27: 45-62
[9]. Bae, W., Shin, B. and An, B. (2002). Behavior of foundation system improved with stone columns. Proc. of the 12th international Offshore and Polar Engineering Conference, the Int. Society of Offshore and Polar Engineering, Kitakyushu, Japan, 675-678
[10]. Elshazly, H., Hafez, D. and Mossaad, M. (2007). Settlement of circular foundations on stone column-reinforced grounds. Journal of Ground Improvement 11, No. 3, 163-170
[11]. Deb K (2007) Modeling of granular bed-granular pile-improved soft soil. Int. J. of Analytical and Numerical Methods in Geomechanics 32:1267-1288
[12]. Madhav MR, Sharma JK, Sivakumar V (2009) Settlement of and load distribution in a granular piled raft. Geomechanics and Engineering 1(1): 97-112
[13]. Maheshwari P, Khatri S (2010) Nonlinear response of footings on granular bed-granular pile-reinforced poor soil. Int. J. of Geotechnical Engineering, 4(4): 435-443
[14]. Maheshwari P, Khatri S (2011) A nonlinear model for footings on granular bed-granular pile-reinforced earth bed. Applied Mathematical Modelling 35: 2790-2804
[15]. Maheshwari P, Khatri S (2012) Generalized model for footings on geosynthetic-reinforced granular fill-granular pile improved soft soil system. Int. J. of Geotechnical Engineering 6 (4): 403-414
[16]. Elsawy, M. B., 2013. Behaviour of soft ground improved by ordinary and geogrid-encased granular piles based on FEM study. Geosynthtics International Journal (An Official Journal of the International Geosynthtics Society), 20, Nr. 4, 276-285
[17]. Kirsch F (2006) Vibro granular pile installation and its effect on ground improvement. Proc. of the Int. Conf. on Numerical Simulation of Construction Processes in Geotechnical Engineering for Urban Environment, pp115-124
[18]. Kirsch F (2009) Evaluation of ground improvement by groups of vibro granular piles using field measurements and numerical analysis. Geotechnics of Soft Soil-Focus on Ground Improvement, Karstunen & Leoni (eds), Taylor & Francis Group, London, pp241-246
[19]. Borges, J. L., Domingues, T. S. and Cardoso, A. S. (2009). Embankments on soft soil reinforced with stone columns: numerical analysis and proposal of a new design method. Journal of Geotechnical and Geological Engineering 27, No. 6, 667-679
[20]. Zahmatkesh A, Choobbasti AJ (2010) Settlement evaluation of soft clay reinforced by granular piles, considering the effect of soil compaction. IJRRAS 3(2): 159-166
[21]. El-Garhy BM, Maraie M, Youssef AA (2011) Behavior of model Footings resting on soft clay reinforced by floating granular piles: experimental study. Int. J. of Geotechnical Engineering 5(4): 415-424
[22]. Shahu JT, Reddy YR (2011) Clayey soil reinforced with granular pile group: model tests and analysis. J. of Geoenvironmental and Geotechnical Engineering 137(2): 1265-1274
[23]. Kolekar YA, Murty D (2011) Numerical simulation of behavior of partially penetrating granular piles. Pan-Am CGS Geotechnical, pp107-112
[24]. Zhang L, Zhao M, Shi C, Zhao H (2013) Settlement calculation of composite foundation reinforced with granular piles. Int. J. of Geomechanics 13(3): 248-256
[25]. Mitchell, J. K. and Huber, T. R. (1985). Performance of a stone column foundation. Journal of Geotechnical Engineering 111, No. 2, 205-223.
[26]. Ambily P, Gandhi SR (2007) Behavior of granular piles based on experimental and FEM analysis. J. of Geotechnical and Geoenvironmental Engineering 133(4): 405–415
[27]. Ng K.S. and Tan S.A. (2014) Design and analyses of floating stone columns. Soils and Foundations, 54(3): 478-487.
[28]. Tan, S. A., Tjahyono and Oo, K. K. (2008). Simplified plane-strain modelling of stone column reinforced ground. ASCE, Journal of Geotechnical and Geoenvironmental Engineering 134, No. 2, 186-194.