Granular Piles Reinforced with Geosynthetics

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ABSTRACT: The granular pile occurs excessive settlement because of bulging deformation at the top, so the bearing capacity decreases. A series of laboratory loading tests is carried out to study the effect of reinforcement on the bearing capacity of the granular pile, and the testing results show that the bearing capacity can increase significantly with the insertion of geogrid in the granular piles. A method is suggested to estimate the load - settlement relation of the granular pile and of the reinforced one, directly using the results of pressuremeter test and triaxial test. The caculating results are consistent with that of the model tests and with that of finite element method.

1 INTRODUCTION

It is the most possible that granular piles occur bulging failure in the upper, so if bulging is restrained, for that many measures have been proposed, the bearing capacity should increase. Madhav (1982) have reported to use geotextile to reinforce the granular pile, and carried out laboratory loading tests, but the applied total load was measured only, so it is not clear that reinforcement affect on the bearing capacity of the granular pile itself.

Many methods have proposed to estimate the load - settlement relation of the granular pile, in which the method suggested by Hughes, Withers & Greenwood (1975) is convenient and reliable, but for the granular pile reinforced with geogrid, the suitablity is in doubt because of the assumption that the vertical to horizontal stress ratio in the granular pile does not change significantly during settlement.

2 TESTING EQUIPMENT AND METHOD

The soft soil used is silty soil with 60% silt, 23% sand, and 17% clay, and with plasticity index of 8.

The granular material used is a uniformly graded and rounded gravel with a mean grain size of 3.5 mm.

The geosynthetics is substituted with steel net with an aperture size of 2mm×1.5mm and with a diameter of steel rib of 0.24mm. The strength and stiffness of steel is about 10 times those of geogrid in practice.

The silty sample with a central cylindrical cavity is obtained by consolidated the remolded soft soil in the modified triaxial cell equipped with a central thin tube under a consolidation pressure of 160 kPa.

The granular pile is installed in the internal cylindrical cavity of the consolidated silty soil sample by placing layers of gravel, which are compacted by light tamping to the required relative density of 68%, and the diameter of the pile installed was 42.5mm. The layers of geogrid are placed at the desired depth in the above procedure for the reinforced granular piles.

The laboratory loading tests are performed on the modified triaxial apparatus with a constant axial strain rate of 0.3 mm / min of the rigid loading plate, with a diameter, d_s, of 42mm for the loading tests on the single granular pile, and with a diameter, d_t, of 81.5mm for the tests on the composite foundation. The applied total load and the surcharge on the soft soil are measured simultaneously so that the load supported by the granular pile can be determined, the detailed description of test apparatus and procedure is given by Cai & Li (1992).

The diameter of the triaxial cell D = 300mm, the triaxial cell to loading plate diameter ratio $D/d_s = 7.1$, so the effect of the triaxial cell on the bearing capacity can be negligible for the loading tests on the single granular pile. Despite $D/d_f = 3.7$, the ultimate bearing capacity of the unreinforced granular pile in the composite foundation is more than 10% that of the single unreinforced one, and the difference is caused by the restraint on the pile provided by the surcharge on the surrounding soft soil, therefore, the effect of the triaxial cell is also negligible for the loading tests on the composite foundation.

3 TESTING RESULTS

3.1 Single Granular Pile

Fig. 1 shows the load-settlement curves of single plain granular pile and of single reinforced ones, indicating that the bearing capacity of the granular pile can increase significantly with the insertion of geogrid in the pile, the larger the number of layers, the higher is the improvement in the bearing capacity, when the number of layers is 4, the bearing capacity increases by 60%.

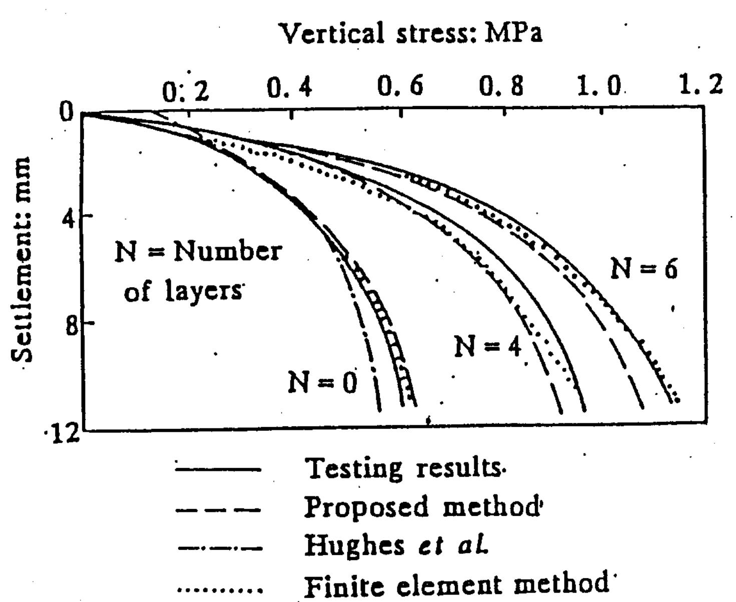

Fig. 1 The relation of the load - settlement of the reinforced granular piles

The plain granular pile and reinforced ones are cut to measure their shape after tests, for the former, bulging occurs in the upper of twice pile diameter, as reported by Hughes& Withers (1974) and Hughes, Withers& Greenwood (1975), for the latter, because bulging deformation is prevented by geogrid, radial deformation decreases in the upper, increases in the deep, and trends homogeneous along the pile.

3.2 Composite Foundation

The effect of three parameters on the composite foundation of the reinforced granular pile is studied in laboratory loading tests. The parameters are following:

(1) Depth below plate of the first layer of geogrid u, expressed in dimensionless form as $u/(d_f - d_p)$, where d_f and d_p are diameter of the loading plate and the granular pile, respectively.

(2) Vertical spacing of layers of geogrid $\Delta Z/d_p$.

(3) Number of layers of geogrid N.

The ultimate bearing capacity, q_0, for the composite foundation of the unreinforced granular pile is 285 kPa at a settlement, s, of 5.8mm, or $s/d_f = 0.07$. For convenience in expressing and comparing test data, the bearing capacity ratio (BCR) is defined as:

$$BCR = q_r/q_0 \tag{1}$$

where q_0 is defined as above and q_r is the ultimate bearing capacity of the foundation of the reinforced granular pile at a settlement corresponding to the settlement at the ultimate bearing capacity for the composite foundation of the unreinforced granular pile.

3.2.1 Depth of top layer of geogrid

The BCR increases with increasing the depth of the top layer of geogrid u up to a special depth ($u/(d_f - d_p) = 0.5$), after which it decreases. Fig. 2 shows the variation of BCR with the depth of top layer of geogrid.

Because the surcharge on the soft soil provides the restraint on the lateral deformation in the upper, the depth occuring bulging is larger than that in the single granular pile, as proved by the deformed shape of the granular pile measured after the test (Cai & Li, 1992), therefore, only the top layer of geogrid is placed at some depth, its role can bring into play.

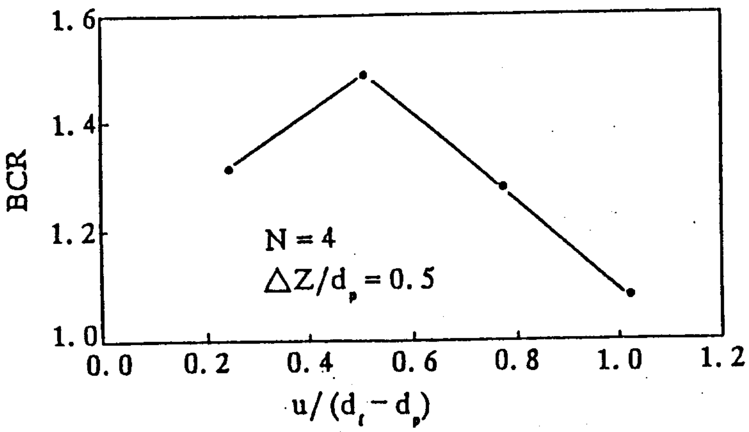

Fig. 2 BCR variation with depth of top layer

3.2.2 Vertical spacing of the layers of geogrid

Fig. 3 shows a typical variation of BCR with vertical spacing of the layers of geogrid. The trend established shows that the BCR increases with increasing ΔZ up to a special spacing of ΔZ half of d_p ($\Delta Z/d_p = 0.5$), after which it decreases.

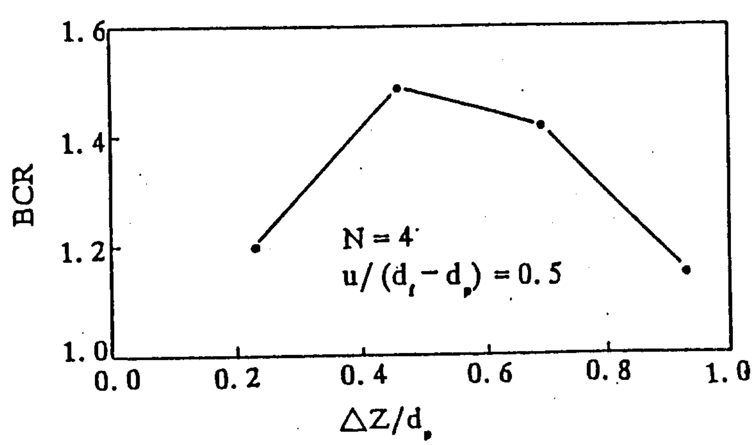

Fig. 3 BCR variation with vertical spacing

3.2.3 Number of layers of geogrid

Fig. 4 shows the response of the BCR to the number of layers of geogrid. The BCR increases with an increasing number of layers of geogrid to an optimum value of N = 4, after which there is a little benefit in increasing the number of layers of geogrid.

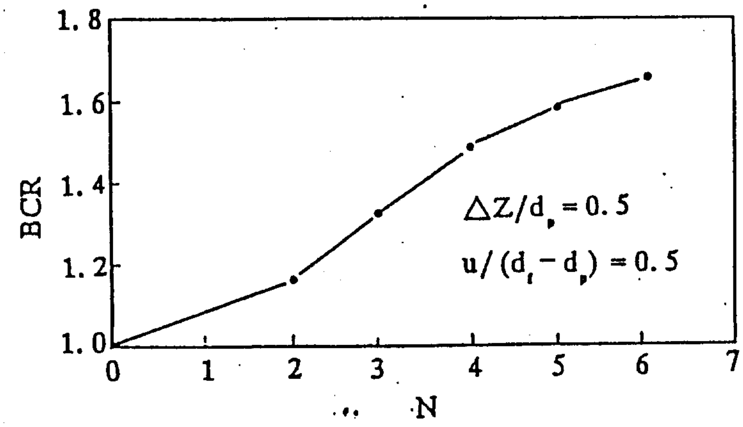

Fig. 4 BCR variation with number of layers

All testing results indicate that the improvement in the bearing capacity with the insertion of geogrid is siginificant, and the larger the number of layers of geogrid placed at the part with big deformation, the fuller is their founction, the higher is the improvement in the loading capacity of the reinforced granular piles.

4 SETTLEMENT ANALYSIS

The granular pile expands axisymmetically to press the surrounding soil, and the soil provide restaint on the pile, the stress state of the pile is similar to that in the triaxial test, so is the stress state of the soil to that in pressuremeter test. So the settlement of the granular pile and the reinforced ones can be caculated by making the horizontal stress and strain coordinate on the pile - soil interface. The axial strain of the ith layer pile can be obtained by iteration, the procedure is as follows:

(1) The horizontal stress in the pile $\sigma_h = \sigma_v/R_0$, asuming the vertical to horizontal stress ratio $R_0 = \sigma_v/\sigma_h$, where σ_v is the mean vertical stress, determined from the difference between the total load and the total shear on the pile - soil boundary, as suggested by Hughes, Withers & Greenwood (1975).

(2) The lateral stress in the soil $\sigma_r = \sigma_h$, and the radial strain ε_r is obtained from the radial stress - strain curve from the pressuremeter test. If σ_r does not exceed the in situ lateral stress at the depth, $\varepsilon_r = 0$.

(3) The volume stain in the pile ε_v is determined

with the triaxial test according to $\sigma_3 = \sigma_h$ and $R_0 = \sigma_1 / \sigma_3$, and the axial strain $\varepsilon_a = \varepsilon_v - 2\varepsilon_r$.

(4) The new vertical to horizontal stress ratio $R_1 = \sigma_1 / \sigma_3$ is obtained from the stress ratio – axial strain curve and the obtained ε_a.

(5) If $| R_1 - R_0 |$ > an expected small value, then go to step 1 with $R_0 = R_1$; otherwise, stop.

The total vertical settlement of the granular pile under a certain applied load is given by Eq. 2:

$$s = \sum_{i=1}^{n} \varepsilon_{ai} H_i \qquad (2)$$

where H_i is the thickness of the ith layer of the granular pile.

The real lateral tress is larger than that in natural condition, because the granular pile installation makes the soil produce some lateral deformation, the difference can be determined from the practical bulging in the installation procedure.

The forgoing method is also suitable for the reinforced granular piles only if the triaxial test is carried out on the sample reinforced with geosynthetics with same material and vertical spacing.

The load – settlement relation of the granular pile and the reinforced ones caculated with the forgoing procedure is presented in Fig. 1, in which the results with the method suggested by Hughes, Withers & Greenwood (1975) and with finite element method (Li & Cai, 1993) are also provided. It shows that the load – settlement curves obtained with the suggested method are consistent with the testing results and that with finite element method, and are more rational than that with the method proposed by Hughes, Withers & Greenwood (1975). It also indicates that the method proposed by Hughes, Withers & Greenwood (1975) is not suitable for the reinforced granular pile because the vertical to horizontal stress ratio changes significantly during settlement.

5 CONCLUSION

A series of laboratory loading tests has been performed on the modified triaxail apparatus, the results have shown that the bearing capacity of either the single plain granular pile or the composite foundation can increase significantly with the insertion of geogrid, for the composite foundation, the best reinforcement function is obtained under $u/(d_f - d_p) = 0.5$ and $\Delta Z/d_p = 0.5$, and the optimum number of layers of geogrid where the ultimate bearing capacity increases by 46%.

For either the unreinforced granular pile or the reinforced ones, the load – settlement relation obtained with the suggested method are consistent with the testing resülts and that with finite element method. Because the vertical to horizontal stress ratio changes significantly during settlement, the method proposed by Hughes, Withers & Greenwood (1975) is not suitable for the reinforced granular pile.

REFERENCES

Cai Fei and Li Guangxin (1992) Study of granular piles reinforced with geogrid (in Chinese), *Proceedinds the third National Symposium on Geosynthetics*, Yizheng, 137 – 141.

Hughes, J. M. O. and Withers, N. J. (1974) Reinforcing of soft cohesive soil with stone column in soil, *Grounding Engineering*, 3: 42 – 49.

Hughes, J. M. O., Withers, N. J. and Greenwood, D. A. (1975) A field trial of the reinforcing effect of a stone column in soil, *Geotechnique*, 1: 31 – 44.

Li Guangxin and Cai Fei (1993) Application of the pressuremeter test on the calculation of the load – settlement relation of gravel pile (in Chinese), *Site Investigation Science and Technology*, 6: 30 – 33.

Madhav, M. R. (1982) Recent developments in the use and analysis of granular piles, *Symposium on Recent Developments in Ground Improvement Techniques*, Bangkok, 117 – 129.