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Properties of composite foundation of deep mixing cement piles and geotextile-reinforced cushion at Wenzhou Grain Depot

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ABSTRACT: Based on the practice of soft ground treatment at Wenzhou Grain Depot, some results of in-situ test and numerical analysis are presented. Influences of the geotextile-reinforced cushion on settlement and stress ratio of pile-to-soil are discussed. The results of studies show that the effectiveness of reducing settlement and differential settlement of foundation is evident by using the method of deep mixing cement piles and geotextile-reinforced cushion. The geotextile-reinforced cushion can broaden the stress pervasion angle of the ground and improve the bearing capacity of soil. It can also reduce the stress ratio of pile-to-soil and cause a more uniform distribution of stress in the ground.

1 INTRODUCTION

Wenzhou City is located in eastern China, where the soil is a kind of typical soft one with high water content, large void ratio, low permeability, high compressibility and low bearing capacity. Wenzhou Grain depot was of a brick and concrete structure with the length of 60 m and width of 21 m, which had exterior main walls with the height of 7 m. The integral rigidity of the grain depot was not very strong and a certain settlement of foundation would possibly result in the crack of the building. Hence, the grain depot was sensitive to the settlement and especially differential settlement of foundation. The grain depot was built on the low land, so it needed large area backfill to reach the design demand of the ground level. And the height of the grain can reach 6 m high when the grain depot is full. So the bearing capacity of the foundation must be larger than 120 kPa according to the design requirement.

The grain depot built on soft soil foundation was strictly limited by bearing capacity and differential settlement, and the natural soil foundation could not satisfy the requirement for its normal work. Deep mixing cement piles were widely used to improve the bearing capacity and reduce the settlement of composite foundations in Wenzhou (e.g. Lin 1989, Chen and Xie 1997). And geotextile-reinforced cushion was also used to reduce differential settlement effectively (e.g. Vidal 1969, Kurian, Beena and Kumar 1997). Both of the two methods had some advantages and disadvantages respectively and can not meet the requirements with bearing capacity and differential settlement for the grain depot alternatively. In this paper, the soft ground treatment method of deep mixing cement piles and geotextile-reinforced cushion was presented and had been used in the grain depot project.

2 SITE CONDITIONS AND GROUND TREATMENT PROCEDURE

The site field was the typical thick and deep soft soil ground in Wenzhou City. The soils comprised two layers of mucky soils, whose void ratios were 1.88 and 1.76, and whose water contents were 68.2% and 63.2% respectively. The total thickness of them was up to 25 m. They were overlain by a miscellaneous fill with the depth less than 0.5 m and they were on the silty clay with the depth more than 20 m, as shown in Table 1.

Table 1. Physical-mechanical properties of different soil layers.

Soil layer	Name	w %	γ kN/m^3	e	C_{cu} kPa	I_p	E_s MPa
I	Clay	33.5	18.8	0.95	17	21.3	6.26
II-1	Muck	68.2	15.8	1.88	10	24.1	1.06
II-2	Muck	63.2	16.3	1.76	10	23.2	1.50
II-3	Silty Clay	45.7	17.1	1.31	10	20.3	3.28

Varying with some other ground treatment methods, the method of deep mixing cement piles and geotextile-reinforced cushion was available for in the grain depot project. The diameter of deep mixing cement piles was 500 mm and the cement quantity was 15%. The length of deep mixing cement piles varied from 12 m to 18 m for the indoor ground of grain depot. And the length of piles was 20 m for the strip foundation under main walls. The gravel cushion with thickness of 20 cm, geotextile-reinforced cushion with total thickness of 90 cm were in turn above the deep mixing cement piles. The geotextile-reinforced cushion consisted of 3 layers of geotextile, and was filled with 30 cm sands for each layer. The cross section of this reinforced structure is shown in Fig. 1.

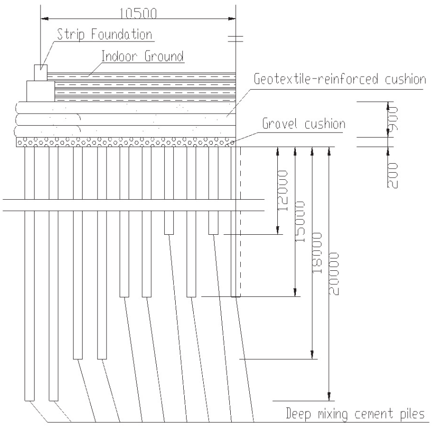

Figure 1. Cross section of the reinforced structure.

In order to analyze the effectiveness of the ground treatment method, some observation points such as soil pressure gauges and soil settlement meters were laid in the ground and shown in Fig. 2.

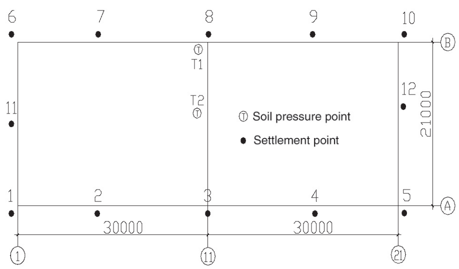

Figure 2. Location of observation points in Wenzhou Grain Depot.

3 EXPERIMENTAL RESULTS AND ANALYSIS

3.1 *Settlement results and analysis*

The in-situ settlement-time curves were shown in Fig. 3. The maximum and minimum of settlements were 127 mm and 98 mm at the last of testing (March 5, 2002) respectively. In order to analyze the influence of geotexitle-reinforced cushion on settlement, the numerical analysis using finite element method had been applied. In the analysis, the moduli of compressibility of the gravel cushion, geotextile-reinforced cushion and composite foundation were 12 MPa, 25 MPa and 15 MPa respectively. The modulus of compressibility of each soil was the same as that of natural soil. The possion's ratios of gravel cushion, geotextile-reinforced cushion, composite foundation and soil were 0.25, 0.2, 0.25 and 0.30 respectively. The value of load for the numerical analysis was 124.5 kPa, the same as that in use.

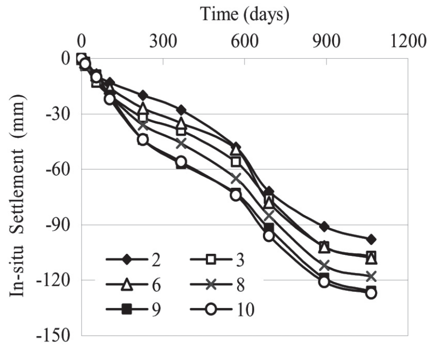

Figure 3. Observed settlement-time curves of Wenzhou Grain Depot.

The software FEMLAB was used to analyze the final settlements of the strip foundation in the condition of plane strain. The maximum and minimum of settlements considering the geotextile-reinforced cushion were 126 and 105.1 mm, while 145 and 110 mm for no considering its effect. Figure 4 shows the comparison of observed settlements and FEM results. In Fig. 4, section planes 1 and 2 are consisted of settlement points from 1 to 5 and from 6 to 10 respectively. It is shown in Fig. 4 that the results of FEM considering the geotextile-reinforced cushion are in accord with the in-situ results in a sense. It is also shown that geotextile reinforced cushion has

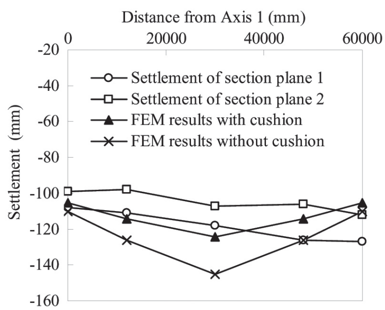

Figure 4. Comparison of observed settlements and FEM results.

obvious effect on the differential settlement and maximum settlement and can reduce the maximum and differential settlements. The cushion can reduce more than 10% the maximum settlement according to the FEM analysis.

The behavior of soft soil foundation treated by deep mixing cement piles has been changed, and the settlements have been reduced. The geotextile-reinforced cushion can restrict the lateral deformation of the foundation by the tensile effect of geotextile and cause a more uniform distribution of stress in the ground. It may also decrease the shear deformation of the foundation and result in the increase of the deformation modulus of cushion materials. The bending stiffness of geotextile-reinforced cushion also increases greatly. So the geotextile-reinforce cushion can reduce the settlement of foundation and especially the differential settlement. Compared with observed settlements of another project in Wenzhou (Lin 1989), the differential settlements of Wenzhou grain depot have been reduced obviously after the geotextile-reinforced cushion applied.

3.2 *Stress ratio of pile-to-soil results and analysis*

The geotextile-reinforced cushion may cause change of the stress property, which is different from that of the deep mixing cement piles composite foundation. According to the model experiment results of four piles within a foundation cap (Lin 1989), the stress ratio of pile-to-soil increased with the rise of load in the earlier applying load stage. When the load reached certain value, stress ratio of pile-to-soil decreased with the rise of load and became approximately constant gradually. The regularity of stress ratio of pile-to-soil in Wenzhou Grain Depot project is similar to that in the model test. It had been verified in the in-situ static loading test of composite foundation with four piles or single pile within a foundation cap by Duan et al (1993).

From Fig. 5, the stress ratio of pile-to-soil changes slightly within indoor part, its value varies from 3.23 to 4.33. The regularity of stress ratio of pile-to-soil under strip foundation is similar to that of the model test by Lin (1989), but the changes of stress ratios of pile-to-soil are relatively small. An approximate linear increase of the stress ratio of pile-to-soil under geotextile-reinforced cushion can be seen in Fig. 5, and its values vary from 1.88 to 3.34. All those show that stresses on piles and soils are slightly different from each other and the cushion can improve the bearing capacity of soil among piles.

The stress of this kind of composite foundation can be distributed more uniformly than that of ordinary deep mixing cement piles composite foundation, because the geotextile-reinforced cushion improves the contacting condition between foundation and deep mixing cement piles. And that will result in more uniform distribution of top loading of piles and soils

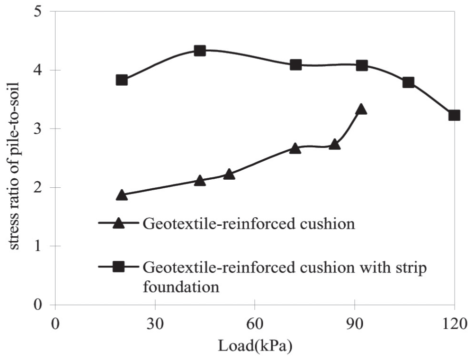

Figure 5. Curves of stress ratio of pile-to-soil and load at Wenzhou Grain Depot.

and decrease the load sharing ratio of pile-to-soil. So the cushion can broaden the stress pervasion angle of foundation, reduce the stress ratio of pile-to-soil and make the stress of foundation much more uniform. So it can prevent the punching shear failure which is possible to occur.

4 CONCLUSIONS

Based on the practice of soft ground treatment at Wenzhou Grain Depot, the influences of the geotextile-reinforced cushion on the settlement and stress ratio of pile-to-soil are discussed. It can be concluded as follows:

(1) The effectiveness of reducing settlement and differential settlement of foundation is evident by using the soft ground treatment with deep mixing cement piles and geotextile-reinforced cushion.
(2) The geotextile-reinforced cushion restricts the lateral deformation of the foundation and makes the stress of the foundation uniformly. It will result in decrease of the foundation shear deformation and increase of the deformation modulus of cushion materials. The geotextile-reinforced cushion can broaden the stress pervasion angle of foundation and improve the bearing capacity of soil among piles. The bending stiffness of geotextile-reinforced cushion also increases greatly.
(3) The problems of settlement and differential settlement of grain depots on soft ground can be solved by this kind of foundation treatment method.

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