piles still have large redundancy. The bearing capacity eigenvalue of single pile composite foundation is 140KPa. Fig.5 is Q-S curves of test pile.

FIG.3 Photo of excavated test pile

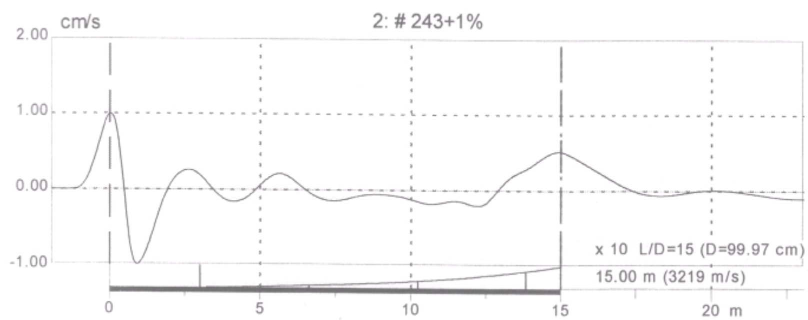

FIG.4 Wave shape of the small strain test

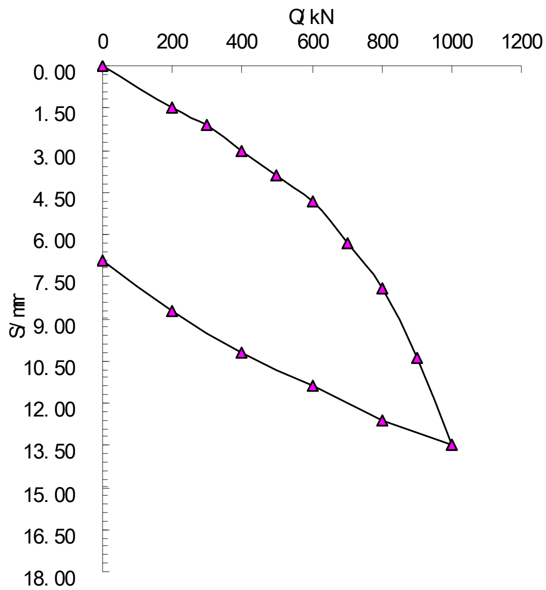

FIG.5 Q-S curves of test pile

When single pile composite foundation dead load test was conducted a 20cm thickness gravel cushion was paved under a 3.0 m×3.0 m rigid load plate, to adjust the pile and soil stresses. This makes the test condition more like the actual work conditions under the embankment load. In the test, 3 soil pressure cells were put under the cushion to measure the stress at different parts. At the same time, the stress of soil inside pile and on the top of pile were also measured by pressures cells. Fig.6 shows stresses in different part in the single pile composite bearing test. Test results show that the stress on the top of pile and soil between piles all have the trend of increasing while the load becomes bigger. The increase of stress on the top of pile is much more bigger than the stress of soil between and inside the pile. In the whole process of load adding, the stress of soil inside the pile is very small and remain relatively stable, this indicates that the soil inside the PCC pile has an effect of soil plug.

In the composite foundation test, the final pile-soil stress ratio is about 3.0. This ratio is obvious small, mainly due to the concrete is a rigid medium and the pressure cells can't fully contact with the pile body. So the measured pile stress is smaller.

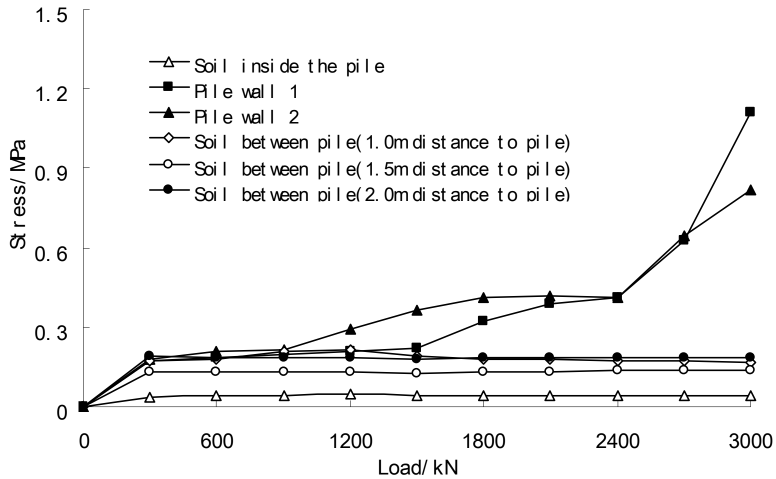

FIG.6 Stress in composition bearing test

4 CONCLUSION

The design, calculation, inspection of PCC pile under embankment flexible load are introduced combined with it's application in Yan-Tong highway ground improvement. The good improvement effect was proved by excavation test, small strain test and dead load test. The in-situ test results show that the quality of PCC pile used in Yan-Tong is very good. And the soil inside PCC pile has an effect of soil plug. Test results show that the bearing capacity of PCC pile is high, and the reinforcement effect is excellent. This technology has a lot of advantages such as easy quality controlling, fast piling constructing, fast embankment filling, time-limit saving and project cost saving.

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Performance Study and Numerical Calculation for Horizontal Bearing of Grouting Piles in Silty Soil Foundation

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Abstract: Because of the complexity of pile-soil interaction under the effect of horizontal load, the calculation theory and method for horizontal bearing pile are not perfect, so further study shall be conducted. Based on the basic field test of long elastic pile in a port project, the construction effect of cement injection pile has been evaluated according to the testing results in this paper. ABAQUS has been used for three-dimensional simulation calculation of the single pile in the testing area; smeared cracking model has been used for simulating the endurance of concrete; embedded element has been used to simulate the reinforcement bar in concrete. The inner force distribution in every elevation of pile has been calculated, and then compared with testing value and the results suggest that the precision of numerical calculation can meet the engineering requirements.

Keyword: Horizontal Load, Field Test, Smeared Cracking Model, Single Pile, ABAQUS, Finite Element

INTRODUCTION

In the past, due to various reasons, the horizontal endurance of vertical pile had always been used for safety margin. In fact, provided that the pile is inserted into soil for some depth, it can withstand certain horizontal load (HAN Li'an, et al, 2004), and the increase of pile diameter enhances the horizontal load that it can bear. In the construction of ports and dorks, the number of projects in which all horizontal load is borne by vertical piles has been increasing recently, so the study on the horizontal bearing feature of vertical piles in silt soil foundation should be conducted. Essentially, the force of pile under horizontal load is a complex process of pile-soil interaction, and the theoretical methods for horizontal bearing pile calculations can be divided into three types generally: elastic analysis, subgrade reaction method and finite element method. Based on the field test data of some port project, the endurance of pile foundation under horizontal bearing has been analyzed under the reference of the calculation of same type foundation, and finite element software, ABAQUS, has been used for three-dimensional simulation calculation to verify the feasibility of finite element calculation.

FIELD TEST

Description of test site and installation of instruments

The test was conducted on the basis of the treatment for Sanyang Port which located in Lianyungang City, Jiangsu Province, China. Thick muddy soil lay on upper part of the test site, the physical and mechanical indexes of every layer are shown in Table 1.

To comparatively analyzing the contribution of site conditions to the resistance coefficient of soil surrounding piles, the site where in-situ test being taken place was divided into two districts. 8 grouting piles were constructed in each district, 4 of them were test piles, the other four were used to provided reaction force, Area Ⅰ was reinforced by 140 cement injection piles, pile diameter was 0.5m, pile distance was 1.0m. 2 test piles, #a1 and #a1, 2 anchor piles, #b2 and #b2' were analyzed, basic parameters of these four piles were in Table 2. The hydraulic floor jack was used as force supply equipment, and the maximum force was 100T, much larger than the estimated maximum bearing capacity which was 60T (POULOS, H. G., 1971, Editorial Committee of Pile Foundation Engineering Manual, 1995). When the grouting pile is under operation, about 20 steel stress gauges were installed to measure the distribution of pile shaft force. To measure the lateral resistance of soil around pile, 13 earth pressures cells were buried around each testing pile. Calibration of all testing instruments was carried out before use, Low strain dynamic testing had been conducted on each pile, and the results showed that every pile was I class pile.

Table 1 Physical and mechanical indexes of every soil layer

No.	Soil layer	h_i m	ρ kg/m^3	$E_{s0.1\text{-}0.2}$ MPa	μ	φ °	C kPa
1	Clayey soil with laminated silt soil	3	1780	3	0.32	10	20
2	Mud and muddy soil with silt and silty sand	5	1710	2.5	0.31	12.5	20
3	Mud and muddy clayey soil	5	1650	8	0.30	11	25
4	Clayey soil and silty clayey with irregular lime concretions and silt	4	1880	7	0.30	12	28
5	Silty clayey soil with fine sands and sandy loam	3	1900	8	0.33	15	30
6	Medium-fine sands and multiple layer of loaml and sandy loam	2	1910	10	0.30	15	20
7	Silty clayey soil and clayey soil with laminated silt soil and irregular lime concretions	4	1950	12	0.33	14	40
8	Medium-fine sands with laminated loam	5	1980	15	0.31	25	10

Table 2 Basic parameters of pile formation

Pile No.	#b_2	#a_1	#b_2’	#a_1’
Length (m)	15	15	21	15
Diameter (m)	0.8	1.2	0.8	1.2

Testing results

To determine the critical load (H_{cr}) and ultimate load (H_u), the terminal of first straight-line segment of $H_0 - \Delta y_0 / \Delta H_0$ curve was used as horizontal H_{cr}, and the load corresponding to the terminal of second straight-line segment of $H_0 - \Delta y_0 / \Delta H_0$ curve was used as H_u. Horizontal force and force displacement gradient relation curve was drawn according to assorted testing data, #b_2 and #a_1 of Area I , #b_2’ and #a_1’ of Area II were selected for the comparison of different areas. The results of every pile are shown in Fig. 1, 2, 3 and 4.

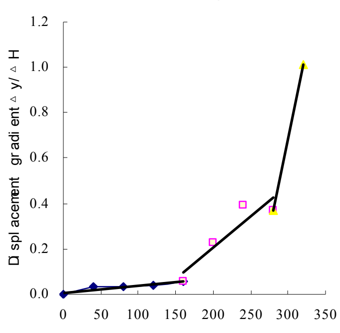

Fig. 1 Horizontal force and force displacement gradient of #b_2 pile

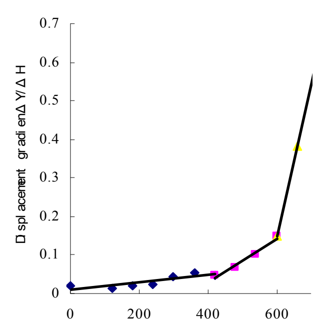

Fig. 2 Horizontal force and force displacement gradient of #a_1 pile

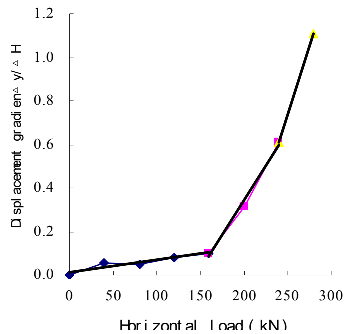

Fig. 3 Horizontal force and force displacement gradient of #b$_2$' pile

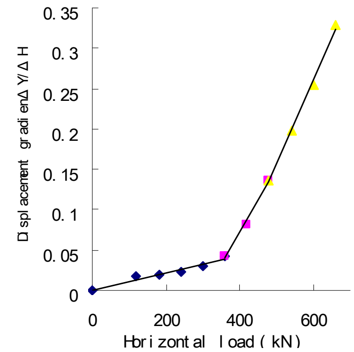

Fig. 4 Horizontal force and force displacement gradient of #a$_1$' pile

The H_{cr} and H_u of each pile can be obtained from the Fig.s. For #b$_2$' and #a$_1$', the terminals of second straight-line segment were not clear, the loads corresponding to the horizontal displacements of 10mm were used as Hu. The values of H_{cr} and H_u of each pile are shown in Table 3.

Table 3 H_{cr} and H_u of testing piles

Pile No.	#b$_2$	#a$_1$	#b$_2$'	#a$_1$'
H_{cr} (kN)	160	420	160	360
H_u (kN)	240	600	200	480

Comparing Fig. 1 with Fig. 2, in the area where cement injection piles were constructed, when the lengths of piles were the same, the H_{cr} and H_u of # b$_2$ are 160kN and 240kN, and the H_{cr} and H_u of # a$_1$ are 420kN and 600kN, respectively. The increase in pile diameter of 0.4m can increase the H_{cr} and H_u by 162.5% and 150%, respectively. Comparing Fig.3 with Fig.4, in the area where cement injection pile was not constructed, the same rule can be obtained, and the increases of H_{cr} and H_u by the enhancement of pile diameter are 125% and 140%, respectively. It can be seen that the increase of pile diameter can enhance H_{cr} and H_u of pile foundation.

Comparing Fig. 2 with Fig.4, H_{cr} and H_u of # a$_1$ are 420kN and 600kN, and H_{cr} and H_u of # a$_1$' are 360kN and 480kN, respectively. The construction of cement injection pile can increase H_{cr} and H_u by 16% and 25%, respectively. Therefore, the construction of cement injection pile can enhance the horizontal endurance of pile foundation moderately, but when compared with the enhancement by the increase of pile diameter, the effect is light.

SIMIULATION CALCULATION BY ABAQUS

Constitutive Model and Unit Selection

Mohr-Coulomb model was selected for soil body, (McClelland, B., et al, 1958) smeared cracking model was adopted for concrete of pile body(CHEN Li, et al, 2007) which are applicable to the nonlinear analysis of concrete component under low confining pressure caused by crack due to tensile. An 8-node hexahedron linear reduced integration (C3D8R) was adopted for the calculation of soil and pile body, linear elastic constitutive model was used for reinforcement bar, and T3D2 unit was used for simulation calculation, hard touching was adopted for pile-soil normal direction, and the penalty friction formula was selected for tangential direction (ZHUANG Zhuo, et al, 2004). The grids were divided just like Fig. 5 based on the constitutive model and unit.

Calculation Results

According to the grids and parameters, stresses, bending moments and deflections of pile were calculated by ABAQUS software. Taking #a$_1$ (Φ1.2m) pile as an example, distribution of pile shaft stress and bending moment were analyzed.

Pile shaft stress distribution

The stress distribution nephogram of pile body under load of every level is shown in Fig. 5.

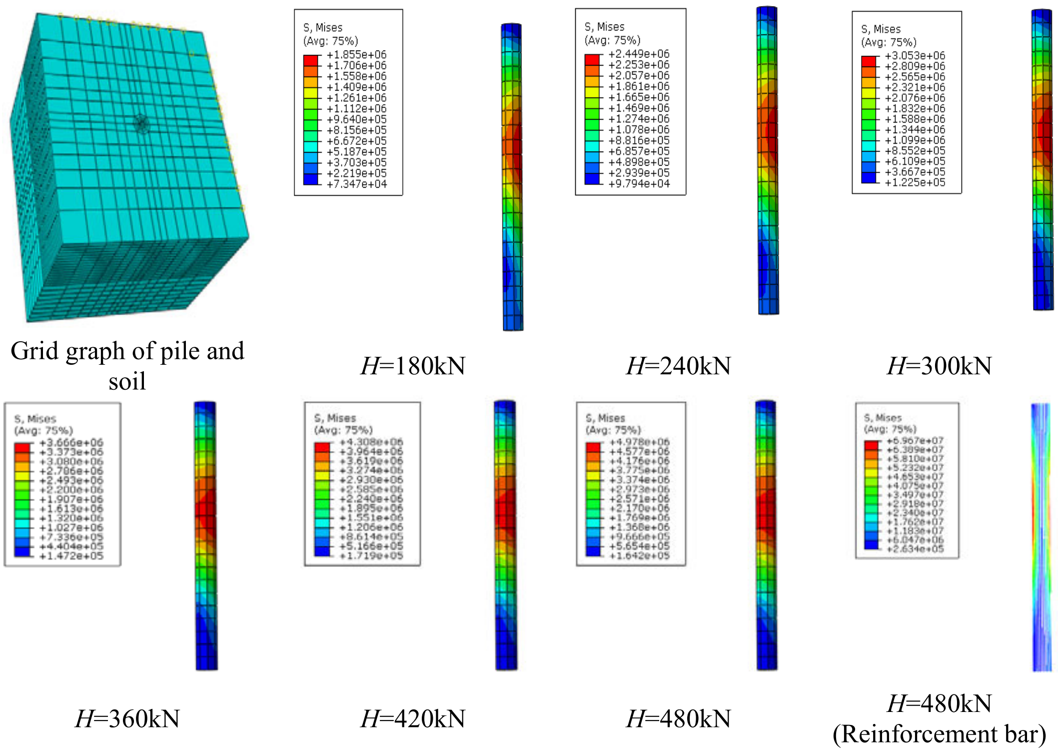

Fig. 5 Grid graph and stress distribution nephogram of pile body and reinforcement bar under load of every level

For intuitive comparison, Fig. 6 had been drew. It can be seen that the shaft stress increased with the growth of load, and the stress distribution under some level of load was increased firstly and then decreased, the maximum stress was about 1/3 depth below soil surface. During the horizontal load increased from 180kN to 480kN, the values of tensile stress and compressive stress in the same depth of the testing pile were almost the same, the stress distribution of pile was generally symmetrical. It indicated that the concrete of the tension side does not lose its function. Therefore, the reason of test termination was not the damage of pile body, but the large horizontal displacement of soil around pile, which led to the pile foundation not resisting horizontal load, and caused the termination of test. Thus, when designing large diameter grouting pile, the horizontal bearing should be controlled by displacement, so as to achieve a rational design.

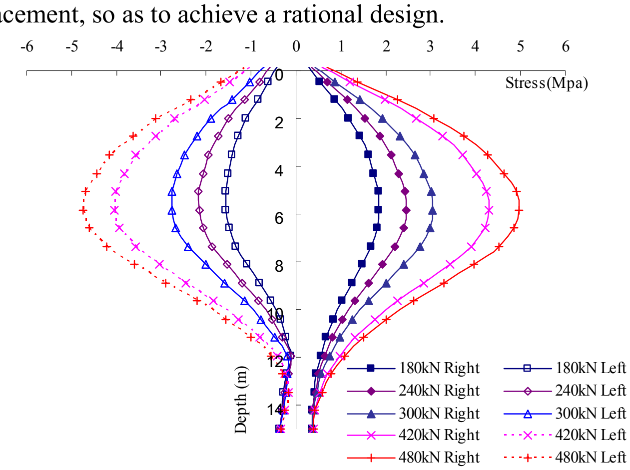

Fig. 6 Stress distribution curve of pile body under load of every level

Bending moment distribution

Because the steel stress gauges had been buried into the pile, the symmetrical stress can be measured, and suggesting that concrete did not crack, the calculation formula of bending moment can be obtained from the mechanics of material:

$$M = \frac{EI\Delta\varepsilon}{b_0} \tag{1}$$

Where b_0—the distance of measurement points of pull and pressure strain in the same testing section, m; I—moment of inertia of pile section, m^4, E—elastic modulus of pile, MPa, and the measured bending moment can be calculated from the formula mentioned above. In the calculation of finite element, order extraction method was used to obtain the bending moment value of every elevation, which was compared with measured value to verify the feasibility of software calculation. The comparison of calculated values between finite element and measured values under different loads of a_1 pile is shown in the following Fig.s:

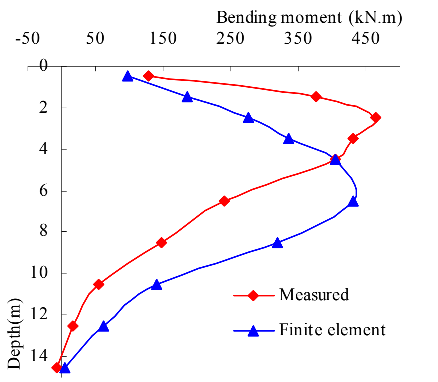

Fig. 7 Comparison curve of calculated bending moments and measured ones, *H*=180kN

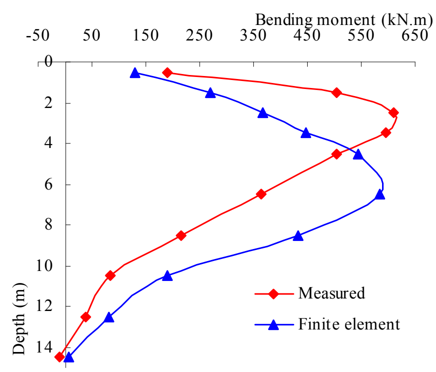

Fig. 8 Comparison curve of calculated bending moments and measured ones, *H*=240kN

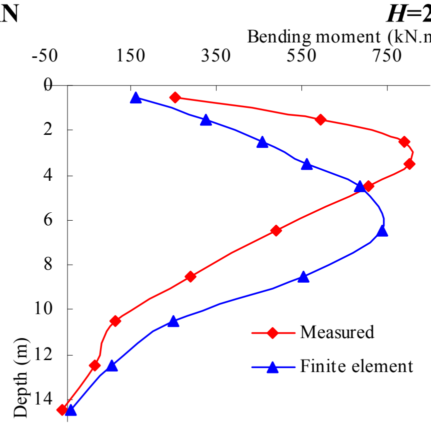

Fig. 9 Comparison curve of calculated bending moments and measured ones, *H*=300kN

Through analyzing the figures, it shows that the calculated values coincide with the measured values well. When the horizontal load *H*=180kN, the relative error of maximum bending moments is 6.7%. When *H*=240kN, the relative error is 4.6%. When *H*=300N, the relative error is 8.3%. From the relative errors, the maximum values of finite element correspond with the measured value.

From Fig. 7 to Fig. 9, it can be revealed that bending moments occur predominantly in upper pile, and increase with the growth of the horizontal load. The measured maximum bending moments occurred in 2.0m to 2.5m below the pile head, while the calculated maximum bending moments occurred in about 5.0m below the pile head. The reason for this was that the selection of calculation parameters for software was fixed values, but the compression moduli of soil around pile and pile body are the value related to the stress status, under low load, the compression moduli were overestimated by the software; and the compression modulus were underestimated by the software for high load. This is the main reason for the difference between finite element calculation and measurement. From bending moment distribution pattern, it is confirmed that the main action for resistance of pile foundation is from the upper soil, and the improvement of upper soil can enhance the horizontal endurance of pile foundation.

SUMARRY

- The increase of diameter, 0.4m, in the area where cement injection piles were constructed, the enhancement of H_{cr} and H_u of single pile were 162.5% and 150%, respectively. In the area without cement injection pile, the enhancement was 125% and 140%, respectively. Therefore, the increase of pile diameter can enhance the horizontal endurance of pile foundation greatly.
- The results of comparison between two areas showed that the construction of cement injection pile can increase H_{cr} and H_u of single pile by 16% and 25%. Therefore, the construction of cement injection pile can increase the horizontal endurance, but the amplitude is little.
- The calculated results of ABAQUS coincide with the measured results, and the bending moment and stress were mainly at the upper pile, and the measured maximum bending moment was 2.5m below soil surface, but the calculated maximum bending moment was 5 m below soil surface. The reason for the difference is that the compression modulus is a variable related to stress status, which has not been considered in soft calculation. However, the relative errors of the maximum bending moment of finite element calculation and measurement are less than 10%. Therefore, provided field test can not be conducted, finite element calculation is a practicable method.

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Finite Element Analysis and Experiments on Adaptability of Bridge-bump Treated With Wedged-shaped Flexible Geocell Slab

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ABSTRACT: Bridge-bump often occurred at transitional section between bridge and subgrade in the highway. In this paper, the gravity abutment was treated with Wedged-shaped Flexible Geocell Slab [WFGS] .The treatment effects of WFGS were analyzed by MSC-MARC, which was one of general nonlinear finite element analysis software. The vertical displacement [VD] changes of the top subgrade and Geocell layers, which had uneven foundation subsidence [FS], were simulated using finite element analysis [FEA]. Thus, the layout positions of test equipment were obtained. Then, large scale model experiment and simulated settling curves of post-construction were carried out to study the adaptability of WFGS. By observing deformations of embankment top and measuring vertical displacements of Geocell layer, especially differential settlement between embank and abutment, WFGS was shown effectively for bridge-bump treatment. With WFGS, the differential settlement was less than 1.5cm when the FS was less than 12cm. However, effects of Geocell were not good enough when FS was more than 15cm, the rigid approach slab should be used together in this situation.

KEYWORDS: WFGS, Bridge-bump, Finite Element Analysis, Large-scale Model Experiment, Adaptability

INTRODUCTION

Bridge-bump often occurs at transitional section between bridge and subgrade in the highway, which is harmful to road safety and structure durability. Much work has been carried out to solve the problems in the world. However, effective method has not yet been found. Geocell is a new geosynthetics with 3D structure which can be filled with sand, gravel or soil to get stronger lateral limits and stiffness [1-10]. With greater tensile-compression strength, shearing strength and stiffness, Geocell-soil complex can be used to treat the differential settlement between abutment and subgrade. By WFGS with one end is fixed on abutment, the bridge-bump of gravity abutment can be waked effectively. With greater restrictions of lateral deformation, the lateral swelling and soil deformations of WFGS can be restricted to decrease embankment deformations effectively. Vertical loads are evenly distributed by the net-support effect of deformed Geocell layers.

In Chang'an University, there is an indoor large-scale model test [LMT] platform which can be used to simulate FS. By FEA software, the vertical displacement changes of top subgrade and Geocell layers with uneven FS are simulated. Then, the positions of test equipment are obtained. So the adaptability of WFGS on gravity abutment filled with sandy soil can be studied.

NUMERICAL ANALYSIS

FEA software MSC-MARC is adopted to analyze the effects of WFGS which are used to treat the transition section between bridge and subgrade of gravity abutment. In the research, contacts