Numerical Analysis of the Settlement of CFG Pile Composite Foundation Subgrade During Construction in High Speed Railway

Chengzhong Yang, Xiaoyu Wang and Shufang Wang

ABSTRACT

According to the typical geological conditions of Wuhan Guangzhou passenger dedicated line reinforced section by CFG pile, the FLAC3D finite difference program is used to simulate the settlement deformation characteristics of subgrade filling process. The settlement deformation is also calculated by theoretical method. By comparing the calculated results with the numerical simulation results the feasibility of the model is verified. Results show that: The uneven settlement as "basin" appears on the subgrade surface top. The maximum settlement is at subgrade centerline. It gradually decreases towards the slope. The settlement at shoulder is the smallest.¹

INTRODUCTION

According to the design and construction materials, the foundation layers of the section from top to bottom are: strong weathered sandstone, weathered sandstone and breccia rock, soft clay, silty clay. The foundation is treated by CFG piles. The pile diameter is 0.5m, length 7m, pile spacing 2m, pile top covered with gravel cushion layer 0.6m thick, arranged a layer geogrid in it. The embankment filling height is between 4m and 5m, The embankment body thickness is 1.0m. The thickness of bottom layer is 2.3m. The bedding surface layer thickness is 0.4m. Both embankment body and subgrade bottom layer use group A and group B filler. The surface layer of subgrade use graded crushed stone. The slope of subgrade is 1:1.5. As are shown in Figure 1.

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NUMERICAL ANALYSIS MODEL OF CFG PILE COMPOSITE FOUNDATION

Establishment of Numerical Model

Because the roadbed is banded structure, considering its symmetry when modeling, in order to reduce the computation unit and shorten the calculation time, take the right part of foundation and subgrade structure to analysis. The vertical depth of the model is 15m, which is two times higher than the height of the embankment. The transverse width is 24m, the subgrade bottom width is 12m and the longitudinal direction is 2m. Boundary constraint condition: The bottom boundary of the foundation soil is far away from the pile body; the load has little effect on it; it is regarded as a fixed boundary without displacement; horizontal and vertical constraints are imposed on the bottom of the model; the horizontal constraint is imposed on the central symmetry plane and the left and right sides; the upper surface of the model is set to free boundary. There are 22736 nodes and 19696 elements in the whole model grid. The mesh is shown in Figure 2.

This paper will use FLAC3D software for simulation analysis. In order to simplify the problem[1,2], it is assumed that the same material is homogeneous and isotropic, the constitutive relation of soil layers and the cushion foundation will use Mohr-Coulomb constitutive relation. Solid element is used to simulate the CFG pile and cushion. The contact surface is arranged at the contact place between the pile and the soil. Combined with engineering and references, the model parameters are shown in Table 1.

Settlement Characteristics of Subgrade Under static Load

According to the actual situation of the construction, the construction process of the embankment is simulated. The thickness of each layer of preloading soil is 0.4m, which is loaded by 8 times. The settlement deformation of high speed railway subgrade under static load is simulated by FLAC3D. The calculated results are shown in Figure 3.
It can be seen from the simulation results: in the process of filling roadbed, when the embankment is filled to the bottom layer of subgrade surface, the maximum settlement of embankment surface is 1.06cm; after paving bottom layer of subgrade preloading was carried out; After loading settlement of subgrade increased significantly; the maximum settlement of subgrade bottom reaches about 1.95cm; at the same time, the settlement of the embankment and foundation soil under the load of the soil mass increases; After unloading, the settlement of subgrade is rebound, but it will not return to the state of preloading. After unloading, the top surface layer of subgrade and track laying construction will be carried out.

<table>
<thead>
<tr>
<th>layer</th>
<th>thickness (m)</th>
<th>density (kg/m³)</th>
<th>bulk modulus shear (MPa)</th>
<th>modulus (MPa)</th>
<th>cohesion (KPa)</th>
<th>internal friction angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bedding surface</td>
<td>0.4</td>
<td>2050</td>
<td>400</td>
<td>185</td>
<td>4.24</td>
<td>32</td>
</tr>
<tr>
<td>bedding bottom</td>
<td>2.3</td>
<td>1950</td>
<td>298</td>
<td>9.9</td>
<td>42.0</td>
<td>22</td>
</tr>
<tr>
<td>Embankment body</td>
<td>1.0</td>
<td>1950</td>
<td>298</td>
<td>9.9</td>
<td>42.0</td>
<td>22</td>
</tr>
<tr>
<td>cushion</td>
<td>0.6</td>
<td>2000</td>
<td>420</td>
<td>195</td>
<td>20.5</td>
<td>32</td>
</tr>
<tr>
<td>silty clay</td>
<td>3.5</td>
<td>1960</td>
<td>9.68</td>
<td>5.55</td>
<td>6.35</td>
<td>22</td>
</tr>
<tr>
<td>soft plastic clay</td>
<td>2.5</td>
<td>1920</td>
<td>8.33</td>
<td>4.94</td>
<td>8.84</td>
<td>20</td>
</tr>
<tr>
<td>breccia rock</td>
<td>2</td>
<td>1980</td>
<td>12.7</td>
<td>7.8</td>
<td>10.3</td>
<td>23</td>
</tr>
</tbody>
</table>

Figure 3. Nephogram of subgrade settlement.
SETTLEMENT CALCULATION OF CFG PILE COMPOSITE FOUNDATION

According to the actual project, CFG pile composite foundation is regarded as the calculation object. The composite modulus method and the layer wise summation method are used to calculate the settlement deformation of the composite foundation\cite{3,4}. The formula is as follows:

\[ S = \varphi_s s' = \varphi_s \sum_{i=1}^{n} P_0 \left( Z_i \overline{a_i} - Z_{i-1} \overline{a_{i-1}} \right) \]

where: \( S \) – final settlement of foundation, mm; \( S' \) – the settlement calculated by the method the layer wise summation method; \( \varphi_s \) – empirical settlement calculation coefficient; \( n \) – the number of soil layers in the depth range of foundation settlement calculation; \( P_0 \) – Additional pressure at the base of the load standard value, KPa; the distance of soil layer \( i \) under foundation to the foundation top surface, m; \( Z_i \) – the distance of foundation bottom to the soil layer \( i \) bottom, m; \( a_i, a_{i-1} \) – the average additional stress coefficient at the foundation bottom of the calculation point to the bottom of the soil layer \( i \) and \( i-1 \).

Calculation results: if the deformation coefficient is 0.378, the compression capacity of the strengthened area is 9.12mm; If the correction coefficient is 0.2, the correction of the underlying layer is 1.91mm, and the final settlement of composite foundation is 11.03mm. The settlement of composite foundation obtained by numerical simulation is 9.8mm. The numerical simulation results are in good agreement with the calculation results. The results show that the model is reasonable and the results are reliable.

CONCLUSIONS

In this paper, a numerical model is established by using FLAC3D software combined with engineering example, and the settlement characteristics of CFG pile composite foundation during filling construction are analyzed. The conclusions are as follows:

(1) Subgrade filling construction settlement calculated by numerical simulation is relatively close to the settlement of composite foundation is calculated by using the composite modulus method and the layered summation method. It is proved that the model is reasonable and the settlement of composite foundation can be simulated well;
The uneven settlement as "basin" appears on the subgrade surface top. The maximum settlement is at subgrade centerline. It gradually decreases towards the slope. The settlement at shoulder is the smallest.

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