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Analysis of temperature field of embankment-CFG piles composite soft soil foundation system in cold regions

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Abstract. For the major projects built on the soft soil area in cold regions, the effective treatment of deep soft soil layer and the stable bearing capacity of foundation are of great importance. In this paper, the finite element model of embankment-CFG piles composite soft soil foundation for D3K629-D3K629+950 of Harbin-Dalian railway is established based on ABAQUS. The depth and regional distribution of freezing and thawing and distribution law of temperature field of CFG piles are studied. The results show that the horizontal position of 0-degree line is higher and the protective effect of embankment on the foundation is obvious when the embankment is higher. The embankment almost has no effect on the CFG piles near embankment foot. For the middle pile at the center of the embankment, the protection effect of the embankment is remarkable.

1. Introduction

The CFG piles composite foundation consists of CFG piles, soil between piles and cushion. This system is a very effective technique to deal with soft soil foundation because of the effect of consolidation and densification and it has been a hot point in recent. Hu [1] studied the stress and deformation characteristics of CFG piles composite foundation and analyzed the effect of pile spacing on the deformation of the foundation. Xiao[2] deeply analyzed the settlement of the soil between CFG piles and variation rule of pavement settlement. Zhao[3] pointed out that the relationship between settlement of embankment-CFG piles composite soft soil foundation and time presents three stages. Su[4] pointed out that the settlement of pile top of piled raft composite foundation is very small while the settlement of pile top of CFG piles composite soft soil foundation is much greater. By numerical simulation analysis, the bearing capacity and deformation characteristics of CFG pile composite foundation were discussed, and the influence of factors on the stress ratio of pile and soil was analyzed in his studies[5]. Xiong[6] established a three-dimensional finite difference numerical model of CFG pile composite foundation and studied the stress distribution , displacement of soil between piles. Chen[7] analysed the change law of the stress of CFG pile and soil between piles. Jia[8] established the three-dimensional finite element model of CFG pile and analyzed the relationship between the bearing capacity of single pile and composite foundation. Zhang[9] analyzed the time effect of the empirical coefficient and settlement coefficient of CFG pile composite foundation for high-speed railway and pointed out that the settlement coefficient decreases with time. Chen[10] studied the mechanical properties of CFG pile composite foundation and pointed out that the compression deformation of soil between piles is the main component of the deformation of CFG pile composite foundation.

The design theory of CFG piles composite foundation in cold regions cannot meet the needs of major engineering constructions at present. The CFG piles composite foundation in cold regions should not only satisfy the requirements of bearing capacity, but also be able to resist freeze-thaw cycles. However, the CFG piles composite foundation can only be designed according to the code for design of soft ground treatment without the consideration of freeze-thaw in cold regions. Hence, a better understanding with respect to the mechanism of freeze-thaw on CFG piles composite foundation is a subject of prime importance.

In the present study, the finite element model of embankment-CFG piles composite soft soil foundation is established based on the meteorological statistics of typical soft soil areas in Heilongjiang Province, China. The main objectives of this paper are to study the depth and regional distribution of freezing and thawing and analysis the distribution law of temperature field of CFG piles. In addition, this paper would be helpful to provide valuable reference for optimizing the design method of embankment-CFG piles composite soft soil foundation system in cold regions.

2. Finite element model

The finite element model of embankment-CFG piles composite soft soil foundation for D3K629-D3K629+950 of Harbin-Dalian railway is established based on ABAQUS according to the ratio 1:1. In the model, the depth of soil is 16m and the width of the extension is the width of the top of embankment, that is, the extension of the roadbed is about 25m. The origin of the model coordinates is the lower-left corner of the embankment, the X axis is positive in the right direction, and the Y axis is positive in the upward directions, as shown in Figure 1.

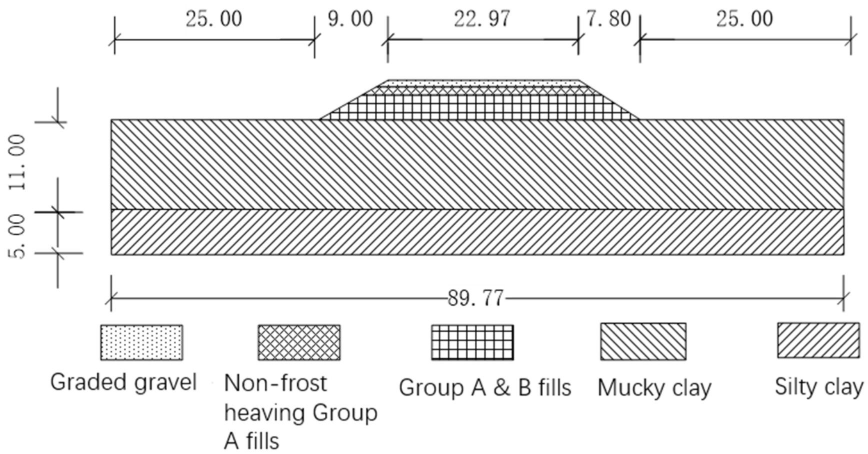

Figure 1. Size of embankment model

The embankment consists of five soil layers: the first layer is the graded macadam with 0.7 meters thick, the second layer is the non-frost heaving group A fills with 1 meters thick, the third layer is the group AB fills with 3 meters thick, the fourth layer is the mucky clay with 11 meters thick, and the fifth layer is the silty clay with 5 meters thick.

The layout of embankment-CFG piles composite soft soil foundation is shown in Figure 2. The diameter and the length of CFG pile are 0.5m and 9.2m respectively. The distance between piles is 1m. This system consists 25 CFG piles, which are numbered 1-25 from left to right. The cushion is the graded gravel with 0.25 meters thick.

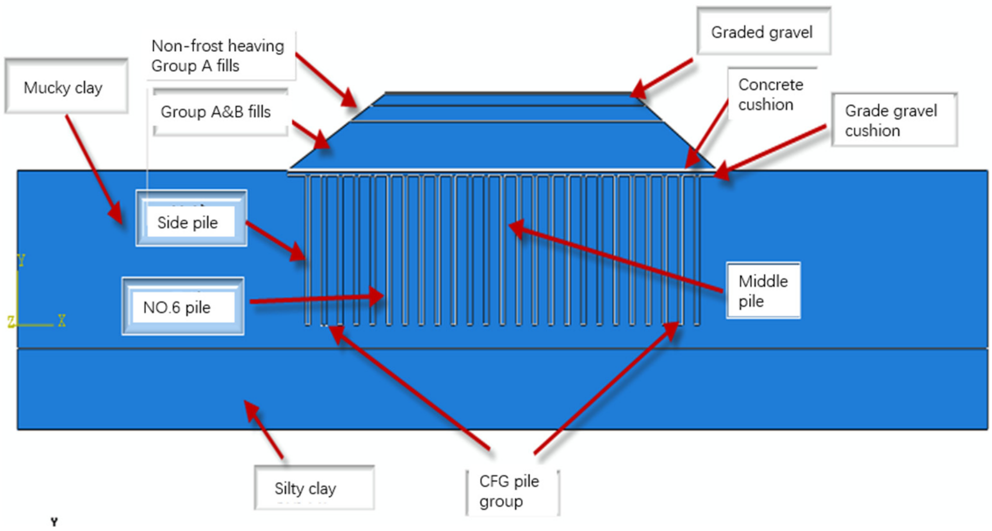

Figure 2. Layout of embankment-CFG piles system

The boundary condition of road surface is Dirichlet condition, the boundary condition of the right and lower boundary of the foundation is Neumann condition, the heat flux exchange coefficient is 15 W/(m^2·°C) and the interlayer thermal resistance coefficient can be expressed by Equation (1):

$$\lambda_1 = \frac{\lambda_{air}}{\delta} \tag{1}$$

The working conditions are listed in Table 1.

Table 1 Working conditions

Working conditions	Height of embankment /m	Thick of graded gravel /m	Thick of non-frost heaving group A fills /m	Thick of group AB fills /m
A	2.50	0.70	0.45	1.35
B	3.10	0.70	0.60	1.80
C	3.70	0.70	0.75	2.25
D	4.30	0.70	0.90	2.70
E	5.50	0.70	1.00	3.00
F	6.10	0.70	1.20	3.60
G	6.70	0.70	1.35	4.05
Real condition	4.70	0.70	1.00	3.00

Taking into account the large size of the model, the mesh of the key part is finer. The four nodes linear heat transfer quadrilateral element is adopted. The number of elements and nodes are listed in Table 2.

Table 2 Number of units and nodes

Working conditions	A	B	C	D	E	F	G	Real condition
number of elements	21880	22186	22608	22937	25571	25806	25943	23121
number of nodes	24853	25151	25560	25889	28547	28783	28921	26086

3. Analysis of temperature field of embankment-CFG piles composite soft soil foundation system

3.1. Depth and regional distribution of freezing and thawing

As shown in Figure 3, the temperature of soil under embankment foot is almost the same under different working conditions during freezing. The temperature of the soil layer first decreases and then increases with the increase of depth. At last, the temperature of the soil layer keeps on a constant value. The temperature of soil between piles with the depth of 0m-2.1m tends to increase with the increase of depth. For the soil between piles with the depth of 2.1m-6.25m, the greater the depth is, the higher the temperature is. The temperature of soil between piles is positive when the depth is greater than 6.25m and depth has no effect on temperature of soil between piles when the depth is greater than 8m.

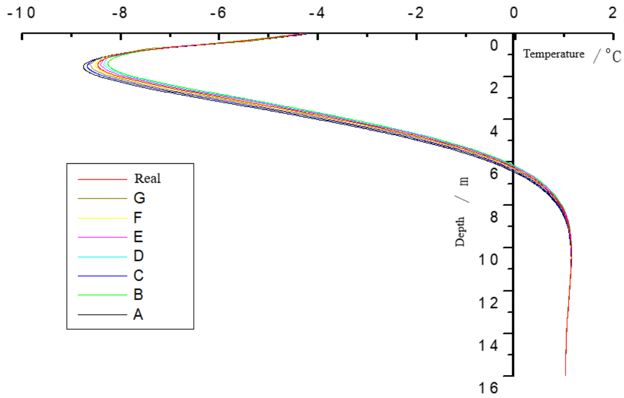

Figure 3. Temperature of soil under embankment foot

The soil temperature of embankment shoulder increases with the increasing depth, as shown in Figure 4. The soil temperature is 1°C and does not change when the depth is 11m. For the working condition A to G, the soil temperature is 0°C when the depths are 4.14m, 3.57m, 3.18m, 2.56m, 1.89m, 1.52m, 1.20m respectively.

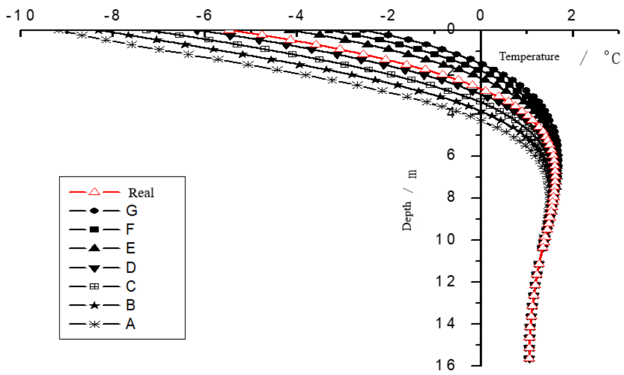

Figure 4. Temperature of soil of embankment shoulder

3.2. Distribution law of temperature field of CFG piles

The temperatures of the side pile, No. 6 pile and the middle pile at the 151 days are shown in Figures 5-7 respectively. During freezing, the 0-degree line of CFG piles with different embankment height is between 5.5m to 6.0m. Therefore, improving the embankment height has a slight protection effect on side piles while has a significant protection effect on No. 6 pile. For the middle pile, the freezing height reach 3.67m, 3.18m, 2.47m, 1.98m, 0.97m, 0.07m under working condition A to F. When the embankment height is greater than 6.7m, the middle pile under working condition G is not frozen.

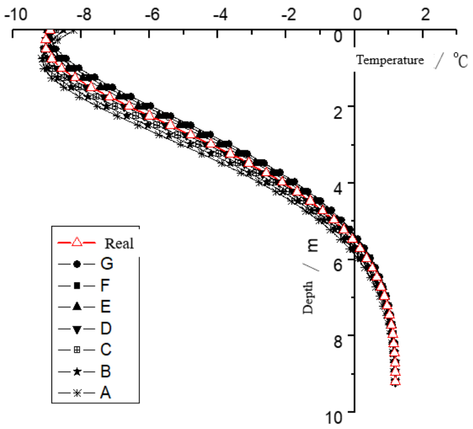

Figure 5. Temperature variation curves of side pile

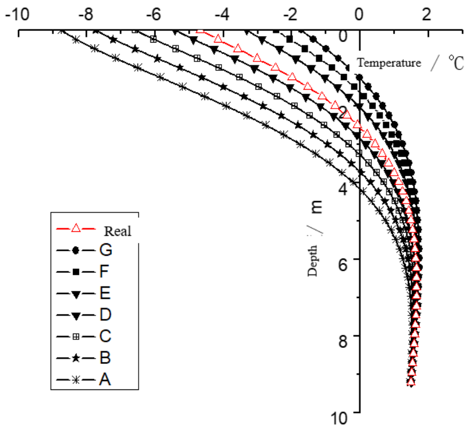

Figure 6. Temperature variation curves of No. 6 pile

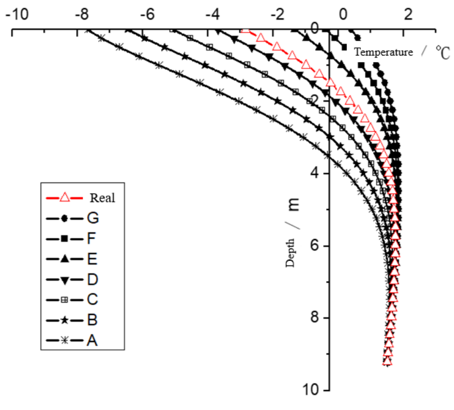

Figure 7. Temperature variation curves of the middle pile

4. Conclusions

The finite element model of embankment-CFG piles composite soft soil foundation for D3K629-D3K629+950 of Harbin-Dalian railway is established based on ABAQUS according to the ratio 1:1. The temperature field of embankment-CFG piles composite soft soil foundation system is studied. The results show that after freezing and thawing, the temperature of soil under embankment foot is almost the same when the working condition is different. The soil temperature of embankment shoulder increases with the increasing depth. Improving the embankment height has a slight protection effect on side piles while has a significant protection effect on No. 6 pile.

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