Analysis of the Effect of Groundwater Exploitation on High-Speed Railway Pile-Slab Structure Subgrade

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Abstract: Land settlement produced by groundwater exploitation may cause larger deformation of the high-speed subgrade. To meet the settlement control requirements after construction of the high standard of high-speed railway subgrade, Pile-Slab composite foundation treatment technology keeps developing and applying in high-speed railway construction. However, the settlement deformation calculation theory of Pile-Slab composite foundation is not mature, in particular, the research for Pile-Slab composite foundation deformation caused by groundwater exploitation is seldom, which is far behind the requirements of engineering practice. To study the effect of exploiting groundwater near the high-speed railway on Pile-Slab composite foundation deformation, in this paper, we establish 3D fluid-solid coupling model using ABAQUS, analyze the effect of different groundwater exploiting quantities on high-speed railway subgrade when CFG piles are used to strengthen the foundation, and compare to the result with no CFG piles. The analysis shows that in the condition of pumping water, CFG Pile-Slab composite foundation has a significant effect on decreasing subgrade lateral deformation and settlement which are reduced by 70%.

Keywords: 3D fluid-solid coupling model, CFG piles, groundwater exploitation, subgrade settlement.

1. INTRODUCTION

Over exploitation of groundwater is the main cause of land settlement. At present, land settlement in more than half of the provinces in China is caused by excess exploitation of groundwater, among them, more than fifty cities are faced with serious settlement, north china plain where Beijing is located has been the largest groundwater funnel area in the world [1]. China has the longest operation mileage and largest scale of construction of high-speed railway in the world and will build more lines according to <Middle and Long-Term Railway Network Planning > (adjusted in 2008). High-speed railway ballastless track is so sensitive to foundation settlement deformation that large distortion will appear because of the land settlement, then, it will affect the forced deformation and service life of the ballestless track, affect the safe and steady operation of the train [2]. According to <Regulation on the Administration of Railway Safety> [3], in the range of 200m outwards of lateral side of high-speed railway embankment slope toe, cutting slope top and bridge, it is forbidden to pump groundwater. Now, problems of subgrade settlement have been produced due to over exploitation of groundwater in some areas of China, for example, near to Tianjin DK119~DK123 of Jing-Hu high-speed railway, there exists larger subsidence areas, it has a big hidden trouble for running security. *Via* field survey, the settlement is closely related to over exploitation of groundwater from a power plant well [4].

High-speed railway underline engineering deformation is required to be controlled in a certain limit at home and abroad [5]. To satisfy the requirements of foundation strength, deformation and seismic behavior, especially for meeting the settlement control requirements after construction of the high standard of high-speed railway subgrade, Pile-Slab composite foundation treatment technology keeps developing and applying in high-speed railway construction [6, 7]. Pile-Slab composite foundation technology has the characteristics of little settlement, well-control uneven settlement, high strength, stability and good durability. However, because the technology of Pile-Slab composite foundation is complicated, the settlement deformation calculation theory of Pile-Slab composite foundation is not mature, in particular, the research for Pile-Slab composite foundation deformation caused by groundwater exploitation is seldom, which are far behind the requirements of engineering practice. Therefore, it is very necessary to carry out the study of the effect of groundwater exploitation on Pile-Slab structure subgrade [8-10].

In this paper, we establish 3D fluid-solid coupling model using ABAQUS, analyze the effect of different groundwater exploiting quantities on high-speed railway subgrade when CFG piles are used to strengthen the foundation, compare to the result with no CFG piles, and provide theory guidance for high-speed railway construction and operation maintenance.

2. NUMERICAL ANALYSIS MODEL AND PARAMETERS

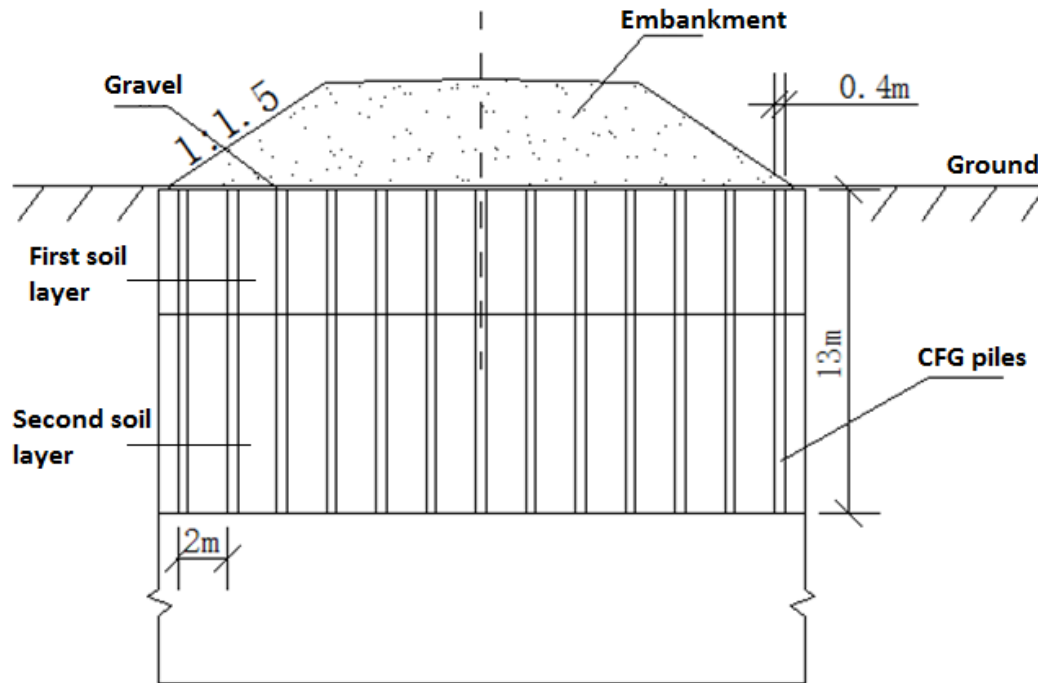To study the effect of exploiting groundwater on high-speed railway subgrade when CFG piles are used to

Fig. (1). Cross section of CFG piles reinforcement subgrade of fengyang test section in jing-hu high-speed railway.

strengthen the foundation, in this paper, we choose Fengyang test section CFG piles foundation of Jing-Hu high-speed railway as the study object to build finite element model. Fengyang test section in Jing-Hu high-speed railway is designed to lay ballestless track and CFG Pile-Slab composite foundation treatment technology is used to strengthen the foundation. The reinforcement section is 90 meters long, the pile diameter of CFG is 0.4 meters, pile length is 13 meters, the pile spacing is 2 meters, and section schematic diagram can be seen in Fig. (**1**).

According to investigated arrangement of four pumping wells near railway, the wells are linear paralleling to the railway from north to south, and the well spacing is 100~124 meters, only 60 meters latest to the railway. To simplify the model, we only consider a single pumping well which is 60 meters apart from the center line of subgrade. The pumping speed is at 500m³/d, 750m³/d and 1000m³/d. The model area is 100×100m² and mainly includes embankment, formation, pumping well and CFG piles. The formation soil is simulated by C3D8RP elements, piles, gravel cushion, reinforced concrete slabs and subgrade are simulated by C3D8R elements. The piles need special treatment, that is, the cylinders should be transformed into square piles in equal sectional area.

In the model, the thickness of subgrade is 4.2 meters, the width of roadbed is 13.6 meters, the subgrade slope is 1:1.5; the thickness of formation soil is 28 meters which is divided into four layers, two of them are in strengthened areas which are 13 meters in total, and the first layer is 5 meters, the second layer is 8 meters. The thickness of substratum is 23 meters which is divided into two layers, the third layer is 5 meters, the forth layer is 10 meters. The pumping well diameter is 1.5 meters and the length is 13 meters. The groundwater level takes 5 meters below the earth's surface, and the pumping depth is through the whole aquifer stratum

(the depth is 5~13m). Cross section of the model can be seen in Fig. (**2**).

Refer to laboratory test, field test and literatures, the calculation parameters of foundation soil layers, subgrade, gravel cushion, reinforced concrete slabs and CFG piles in certain conditions are shown in Table **1**. The model schematic diagram of subgrade, formation, CFG Pile-Slab composite foundation is shown in Fig. (**3**).

3. CALCULATION RESULTS

According to CFG piles foundation reinforcement engineering example in Jing-Hu high-speed railway and pumping groundwater actual conditions near railway, 3D fluid-solid coupling model is established, and comparison for the calculation results can be seen in the figures.

3.1. Subgrade Lateral Deformation

From the above Fig. (**4**), we can see that, for using or not using CFG piles, subgrade lateral displacement along railway longitudinal length presents a upward convex morphology, that is, the subgrade section which the pumping well corresponds to has the largest lateral deformation, and the closer to the ends, the smaller the lateral deformation is. The largest displacements at subgrade center which the pumping well corresponds to in different conditions can be seen in Fig. (**5**).

It can be seen from Fig. (**5**) that, with three different pumping yields, the effect of CFG piles on subgrade lateral displacement is obvious. Comparing using CFG piles to non-piles, we can find that the lateral displacement presents a significant decline by 70%, for example, in the condition of pumping yield 750m³/d, the largest lateral displacement is
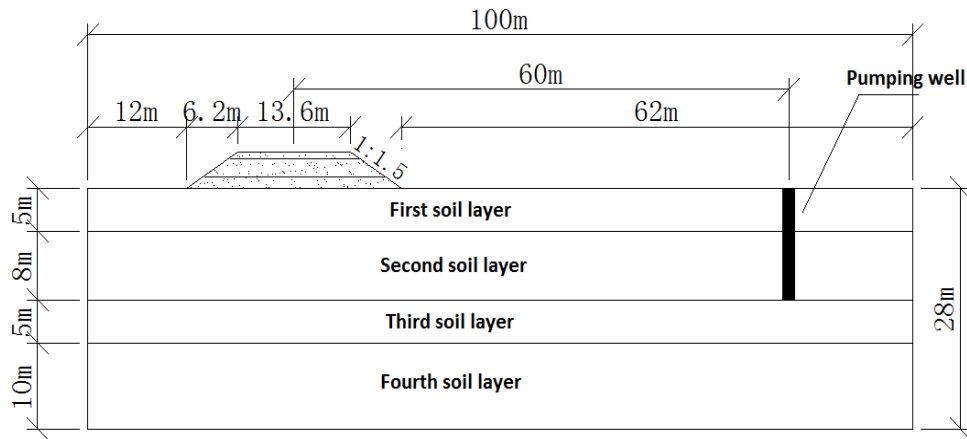
Fig. (2). Cross section of the model.

Table 1.   Parameters of different soil layers.

Layer Name	Thickness (m)	Density ρ (kg/m³)	Void Ratio e	Young Modulus E (Pa)	Poisson Ratio μ	Permeability Coefficient (m/s)
Subgrade surface layer	0.4	1950	/	1.5E8	0.25	/
Subgrade bottom layer	2.3	1800	/	1.8E8	0.25	/
Subgrade body	1.5	1700	/	5.0E7	0.25	/
First soil layer	5	1910	0.82	1.8E7	0.30	9.6E-8
Second soil layer	8	2010	0.67	2.8E7	0.25	8.7E-8
Third soil layer	5	2100	0.1	1.5E8	0.15	1.0E-9
Fourth soil layer	10	2310	0.1	5.0E8	0.15	1.0E-9
Gravel cushion	0.2	2100	/	1.2E8	0.15	/
Reinforced concrete slab	0.5	2400	/	3.0E10	0.10	/
CFG pile	13	2300	/	2.0E10	0.10	/

11.15mm with non-piles while 3.39mm with CFG piles, decreased by 69.9%. So, applying CFG piles to strengthen the foundation for controlling lateral displacement of the subgrade in the condition of pumping groundwater can acquire a remarkable effect.
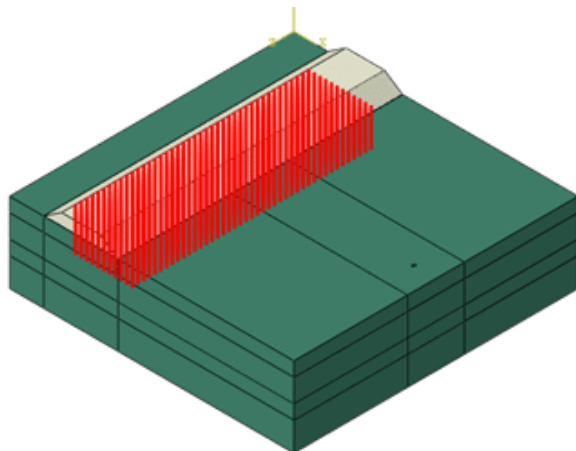

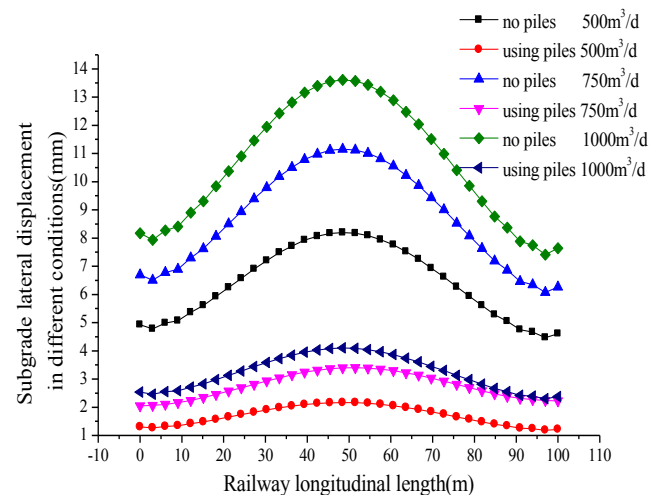**Fig. (3).** The model schematic diagram of subgrade, formation, CFG Pile-Slab composite foundation.

Fig. (4). Subgrade lateral displacement along railway longitudinal length in different conditions.

3.2. Subgrade Settlement

It can be seen from the above Fig. (**6**) that, for using or not using CFG piles, subgrade settlement along railway

longitudinal length shows a concave shape, that is, the subgrade section which the pumping well corresponds to has the largest settlement, and the closer to the ends, the smaller the settlement is. The largest settlements at subgrade center which the pumping well corresponds to in different conditions can be seen in Fig. (**7**).
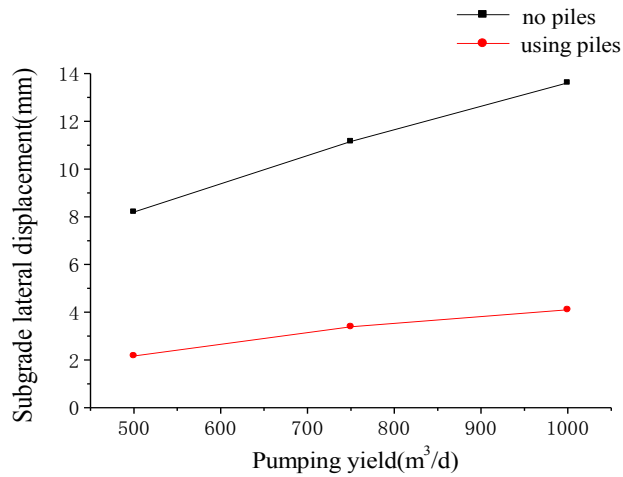

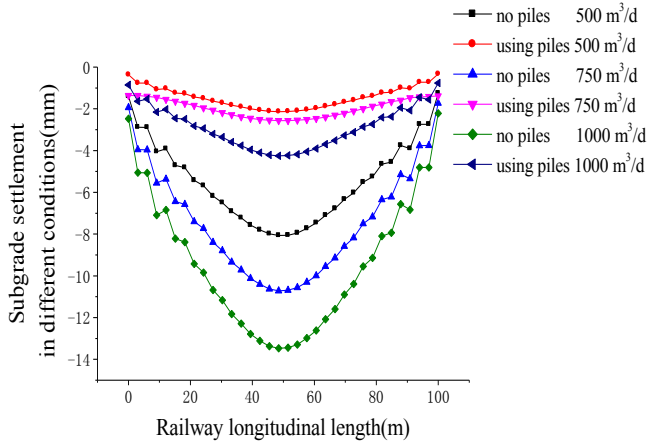**Fig. (5).** Subgrade largest lateral displacement in different conditions.

Fig. (6). Subgrade settlement along railway longitudinal length in different conditions.
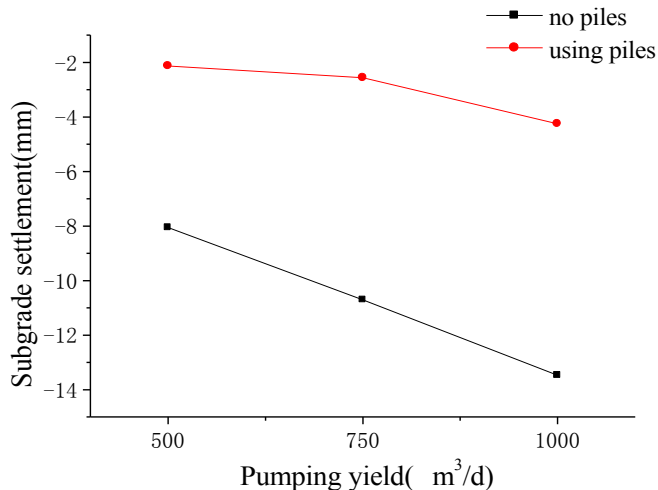

Fig. (7). Subgrade largest lateral displacement in different conditions.

CONCLUSION

In this paper, by using ABAQUS, we study the effect of groundwater exploitation on the Pile-Slab structure subgrade, establish 3D fluid-solid coupling model, and compare the high-speed railway subgrade deformations in two conditions: using CFG piles and non-piles. We can get the following conclusions:

(1) With three different pumping yields, CFG pile has obvious function in reducing the lateral deformation of subgrade. Compared with non-piles, the lateral displacement has a larger decline by approximately 70% when we use CFG piles to consolidate subgrade. For example, in the condition of pumping yield $750 m^3/d$, the largest lateral displacement is 11.15mm with non-piles while 3.39mm with CFG piles, decreased by 69.9%.

(2) With three different pumping yields, CFG pile also plays a significant role in reducing subgrade settlement. The settlement, using CFG piles to strengthen the subgrade, has a larger decline by approximately 75% compared to that with non-piles, which is coincidence with the law of the lateral displacement. For example, in the case of pumping yield $750 m^3/d$, the largest settlement is 10.71mm with non-pile, and it changes to 2.56mm when we use CFG piles, decreased by 76.1%.

(3) In view of the significant effect of Pile-Slab composite foundation on controlling subgrade deformation of high-speed railway caused by groundwater exploitation, it is suggested that when we build high-speed railway in regional subsidence areas, it should be combined with engineering practice, applying CFG Pile-Slab composite foundation rationally, so as to meet the requirements of controlling subgrade post-construction settlement, reduce the influence on ballestless track and ensure train operation safety.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

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