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Influence of cement-fly ash-gravel pile-supported approach embankment on abutment piles in soft ground

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ABSTRACT

Abutment piles in soft ground may be subjected to both vertical and horizontal soil movements resulting from approach embankment loads. To constrain the soil movements, the soft soil ground beneath the approach embankment is often improved using composite pile foundations, which aim at mitigating the bump induced by high-speed trains passing through the bridge. So far, there is limited literature on exploring the influence of the degree of ground improvement on abutment piles installed in soft soil grounds. In this paper, a series of three-dimensional (3D) centrifuge model tests was performed on an approach embankment over a silty clay deposit improved by cement-fly ash-gravel (CFG) piles combined with geogrid. Emphasis is placed on the effects of ground replacement ratio (m) on the responses of the abutment piles induced by embankment loads. Meanwhile, a numerical study was conducted with varying ground replacement ratio of the pile-reinforced grounds. Results show that the performance of the abutment piles is significantly improved when reinforcing the ground with CFG piles beneath the approach embankment. Interestingly, there is a threshold value of the replacement ratio of around 4.9% above which the effect of CFG pile foundations is limited. This implies that it is essential to optimize the ground improvement for having a cost-effective design while minimizing the risk of the bump at the end of bridge.

1. Introduction

In railway engineering, it has been well recognized that the engineering problems associated with the so-called “bump at the end of bridge” in the bridge approach embankment (BAE) are challenging to the long-term operating safety and comfort of railways. The bump is mainly caused by abrupt changes in track stiffness, which are associated with structural and foundation discontinuities, differential settlement of the backfill, etc. On the other hand, construction of the approach embankment over soft grounds may result in significant vertical and horizontal soil movements. The soil movements may in turn induce additional stresses and displacements in neighboring abutment piles. In consequence, an intolerable movement or even structural failure of the piles or bridge structure may take place (Tavenas et al., 1979). Therefore, it is of great interest for researchers to study the behavior of abutment piles subjected to soil movements resulting from approach embankments. For instance, a series of reduced scale model tests was conducted by Chen et al. (1997) and Pan et al. (2000) to examine the response of single pile or pile groups subjected to lateral soil movements. Ellis and Springman (2001) later carried out two-dimensional (2D) plane-strain analysis using finite element method (FEM) to investigate the pile-soil interaction of a pile-supported bridge abutment over soft grounds. Similar studies were also conducted by Bransby and Springman (1997) and Stewart et al. (1994) using three-dimensional (3D) FEM analyses combined with centrifuge model tests and field tests in order to derive recommendations for the design of abutment piles subjected to lateral soil movements. Additionally, Jeong et al. (2004) studied the time-dependent behavior of pile-reinforced soft clay grounds induced by staged construction of embankment.

The studies mentioned above only focus on approach embankments resting on natural soft soil grounds without improvement. This is because these studies are contextualized in engineering

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background of highway embankments which require less strict control of differential settlement. On the contrary, the approach embankment of high-speed railways requires a much more strict settlement control. Thus, pile foundations are often adopted beneath the approach embankment in order to minimize the influence of soil movements on abutment piles. So far, a few researchers have examined the effects of the soft soil ground improvement under embankment loads on the behavior of abutment piles. A numerical study performed by Zheng et al. (2013) showed that mechanical properties of soft soil beneath approach embankments have a considerable impact on the response of abutment piles. Jiang et al. (2012) and Wang (2012) investigated the effects of ground improvements beneath an approach embankment on the differential settlements between the bridge abutment and its approach embankment in different construction scenarios. However, the influence of pile-supported approach embankments on the behavior of abutment piles has not been addressed.

This paper describes the results of a series of centrifuge model tests and 3D numerical simulations, in order to understand the behavior of abutment piles while varying the replacement ratio (m) of composite pile foundations beneath an approach embankment. Emphasis is put on the analyses of axial force, bending moment, contact pressure and horizontal displacement developed in the abutment piles. Recommendations are provided for optimizing the ground improvement design for the bridge approach embankment in order to ensure the long-term stability of the high-speed railway track.

2. Centrifuge modeling

2.1. Experimental setup

In this study, four centrifuge model tests were conducted at the Geotechnical Centrifuge Facility of Southwest Jiaotong University, using a 100g t centrifuge system with a maximum acceleration of 200g and an effective radius of 2.7 m. Details on the centrifuge can be found in Xiao et al. (2017). The model container used for the centrifuge model tests is made of aluminum alloy and has dimensions of 800 mm × 600 mm × 600 mm (length × width × height). The scaling laws reported by Ng and Lu (2014) were applied for the centrifuge model tests. All the centrifuge model tests were performed at a nominal radial acceleration of 80g, thus the same vertical effective stress profile will be produced during the centrifuge model tests as that for a prototype 80 times larger in dimensions. The schematic layout of the centrifuge model test is presented in Fig. 1.

The model ground consists of a soft silty clay layer of 100 mm in thickness, which is underlaid by a layer of 250 mm-thick overconsolidated clay. The abutment piles contain three rows of piles having a length of 195 mm and an external diameter of 12 mm. The center-to-center pile spacing is 37.5 mm along the pile row and 40 mm between pile rows (see Fig. 2). The concrete pile cap is 32 mm thick, connected with the retaining wall as a whole by cast-in-place, which was designed to be rigid in bending compared to the piles. The model embankment has front and side slopes at a ratio of approximately 1.5:1. Four replacement ratios (m = 2.2%, 3.1%, 4.9% and 8.7%) of composite pile foundation are considered. Table 1 summarizes the pile parameters utilized in the 4 centrifuge model tests, including the concrete-fly ash-gravel (CFG) and abutment piles. Note that the corresponding values at the prototype scale are listed in square brackets.

2.2. Soil properties and sample preparation

The soil used for the centrifuge model tests was sampled from a field testing site in Chengdu. It is called "Chengdu clay" and is a typical soft clay in Chengdu Plain. The upper silty clay layer was prepared from the slurry of Chengdu silty clay, while the lower clay was prepared from the slurry of Chengdu clay. For the model tests with similar properties of both silty clay and clay in site, the density and water content were regarded as the major controlling parameters, followed by the strength index. The soil samples obtained from the field were air-dried and crushed mechanically and then passed through the 2 mm sieve. Afterwards, the air-dried soil powder was mixed with water to reach required water content using deaired water and then mixed mechanically. The clay slurry was deaired for at least 24 h under vacuum condition. Owing to the given soil unit weight, the weight of test soil per height of soil layer in container needed in the tests can be determined beforehand. Then the clay slurry was placed horizontally in layers bottom-up to the height of 25 cm by 2 cm thickness of each filling layer in the strongbox. The silty clay was placed by the same way up to the height of 35 cm. Consolidation and quick direct shear tests for the remolded soil samples were carried out to determine the physical

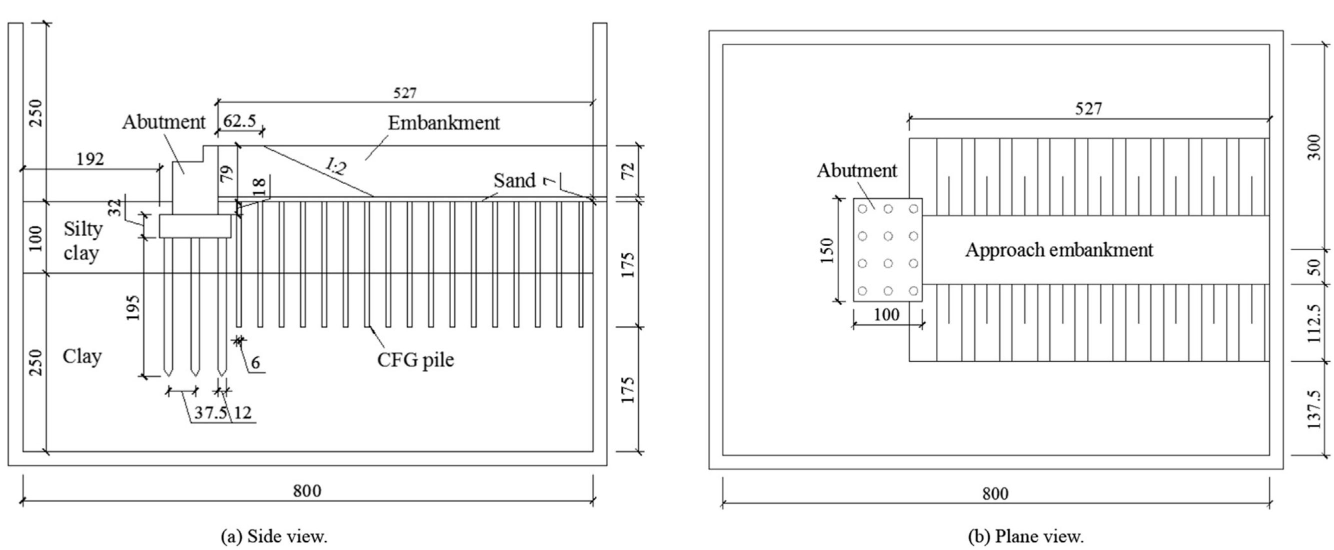

Fig. 1. Schematic layout of bridge approach in the centrifuge model tests (unit: mm).