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Research Paper

Settlement and load transfer mechanism of pile group due to side-by-side twin tunnelling

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ABSTRACT

Development of underground transportation systems often involve twin tunnels, which may encounter existing pile groups during construction. Since many previous studies mainly focus on the effects of single tunnelling on single piles, settlement and load transfer mechanism of a pile group subjected to twin tunnelling are not well investigated and understood. To address these two issues, two three-dimensional centrifuge tests were carried out in this study to simulate side-by-side twin tunnels (excavated one after the other on both sides of the pile group) at two critical locations relative to the pile group, namely next to (Test TT) and below the toe of the pile group (Test BB). Moreover, numerical back-analyses of the centrifuge tests are conducted by using a hypoplastic model, which takes small-strain stiffness into account. Both measured and computed results show that the induced tilting of the pile group in Test TT is significantly larger than that in Test BB, with a maximum percentage difference of 120%. On the other hand, a slightly smaller (about 13%) settlement of the pile group is induced in Test TT, as compared to that in Test BB. This is because the pile group in Test TT is partially located within the major influence zone of tunnelling-induced ground settlement while the entire pile group in Test BB is bounded by the major influence zone of ground settlement. Two distinct load transfer mechanisms due to twin tunnelling are identified, i.e., the load in the pile group in Test TT transfers downwards from the pile shaft to the pile toe while the load in the pile group in Test BB transfers upwards from the pile toe to the pile shaft. Apart from load transfer along each pile, load re-distribution also occurs among piles during twin tunnelling. In both Tests TT and BB, axial load at pile head only reduces at a pile closet to the advancing tunnel face and the reduction is re-distributed to the other three piles. The load re-distribution among piles results in a maximum increase of axial force of 10% in Test TT.

1. Introduction

Tunnelling is an effective means to meet the rapidly increasing traffic demand in congested cities. Construction of tunnels is likely to encounter existing underground structures such as pile foundations. To understand influence of tunnelling on existing piles, a number of studies have been carried out based on field monitoring [39], centrifuge modelling [2,15,18,23,26,27], numerical analysis and analytical analysis [4,5,12,19–21,28,29,41].

In spite of the numerous previous investigations on this subject, little attention was paid to twin tunnelling effects on pile groups, except the research work reported by Pang et al. [39]. They reported a field and numerical investigation on an existing pile group subjected to side-by-side twin tunnelling near its middle depth in Singapore clay. Ground settlement, distribution of axial force and bending moment in piles at the end of the first tunnelling were reported. However, tunnelling-induced pile responses such as settlement of the pile group, load transfer along each pile and load re-distribution among piles have not been the focus of their study. Ng et al. [36] investigated the responses of a pile group subjected to piggyback (i.e., vertically aligned) twin tunnelling based on centrifuge and numerical investigation. Compared to the piggyback configuration, it appears that the side-by-side (i.e., horizontally vertically aligned) twin tunnelling is more frequently encountered in practical engineering [11,16,31,35,37].

In view of the aforementioned issues, this study aims at investigating settlement and load transfer mechanisms of a pile group subjected to twin tunnelling. To achieve this objective, two three-dimensional centrifuge experiments were carried out to simulate in-flight advancement of side-by-side twin tunnels (one after

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the other) on both sides of an axially load 2 × 2 pile group in dry sand. The only variable that differed between the two tests was buried depth of the twin tunnels, which were located either next to (Test TT) or below the toe (Test BB) of the pile group. The centrifuge tests were back-analysed by three-dimensional finite element analyses, in which a hypoplastic constitutive soil model was employed. Measured and computed results are compared and interpreted, with particular attention paid to settlement and load transfer mechanism of the pile group due to twin tunnelling.

2. Centrifuge model tests

2.1. Test programme and setup

Fig. 1 illustrates schematic diagrams (elevation views) of the two centrifuge tests (i.e., Tests TT and BB). The model container had a plan dimension of 1250 mm × 1250 mm (i.e., 50 m × 50 m in prototype scale) and a depth of 850 mm (i.e., 34 m in prototype scale). The two tests were carried out at the Geotechnical Centrifuge Facility of the Hong Kong University of Science and Technology [34], at a centrifugal acceleration of 40*g*. Scaling factors between the model and the prototype are summarised in Table 1.

Both Tests TT and BB were carried out in medium dense dry sand (prepared by pluvial deposition method), with an average relative density of 66% and 64%, respectively. Mechanical properties of the sand used, Toyoura sand, are summarised in Table 2. As shown in Fig. 1(a), Test TT was intended to investigate responses of an axially loaded 2 × 2 pile group due to side-by-side twin tunnelling next to the pile toe. The pile cap was elevated by 110 mm from the ground surface and hence the embedded depth of each pile was 490 mm (19.6 m in prototype). Deadweight of 8.6 kg was mounted on the top of the pile cap to simulate a working load of 5.5 MN (in prototype). To determine this working load, an

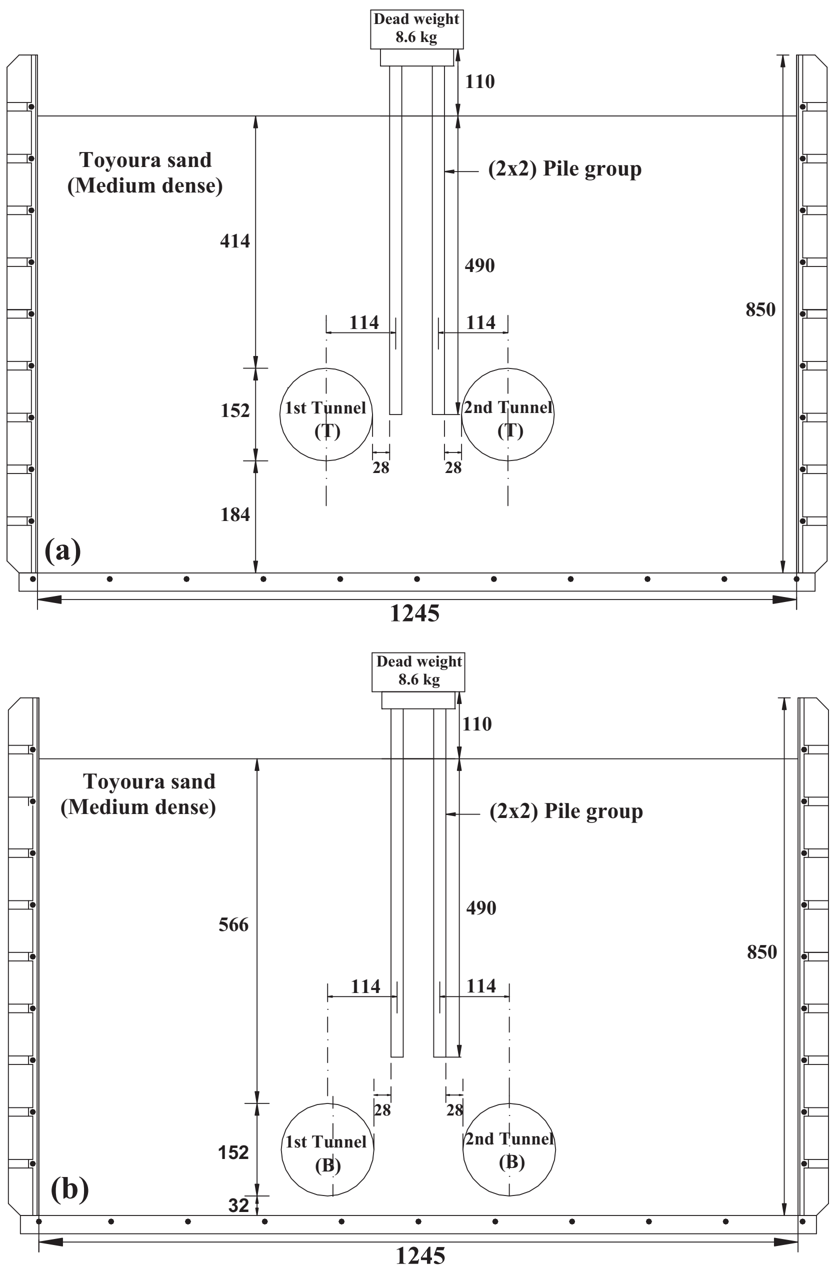

Fig. 1. Elevation view of centrifuge tests: (a) TT and (b) BB. All dimensions are in mm in model scale.