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Interaction between a large-scale triangular excavation and adjacent structures in Shanghai soft clay

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ABSTRACT

Despite much attention being paid to the performance of rectangular basement excavation, the deformation characteristics of triangular excavations and their effects on nearby structures are not fully studied. A large-scale triangular basement with a final excavation depth of 22.8 m excavated at two sides of a cut-and-cover tunnel was extensively instrumented in Shanghai soft clay. Differing from the wall deflection in rectangular excavations, the lateral movements at the top of retaining walls in a triangular excavation was up to 70% of the maximum wall defection even though the first concrete props were cast before commencement of the main excavation. Upon completion of the base slabs, the maximum lateral wall deflection (δ_{hm}) ranged from 0.05% *H* to 0.35% *H* (excavation depth). During subsequent construction of remaining concrete slabs, δ_{hm} increased by up to 50%. Prior to completion of the base slabs, heaves were induced in interior column and diaphragm wall resulting from excavation-induced stress relief. Measured maximum heaves in the interior column and diaphragm wall were 0.08% *H* and 0.06% *H*, respectively. Different deformation mechanisms were observed in the cut-and-cover tunnel and shield tunnel. Heave was induced in the cut-and-cover tunnel located within excavation zone with a maximum value of 7.9 mm. On the contrary, settlement was observed in the shield tunnel located outside of excavation zone with a maximum value of 8.0 mm. Because of corner effects in basement excavation, three-dimensional deformation mechanisms were observed in the existing pipelines running parallel and behind the retaining walls. Due to post-excavation wall deflection induced ground settlement, the incremental maximum pipeline settlement was up to 120% of that upon completion of the base slabs.

1. Introduction

Shanghai is one of the most important commercial and financial cities in China. To meet the demand for usable floor areas but also to reduce environmental impacts, a large number of deep basements have been excavated for underground metro stations. Any excavation inevitably causes stress changes in the ground leading to soil movement surrounding the existing basements. To verify design assumptions and reduce excavation induced adverse effects on surrounding structures, field monitoring is considered as an effective means since it can provide immediate feedback to designers and guidelines for directly comparable cases.

The performances of deep excavations has been studied by many researchers and engineers around the world (Ou et al., 1993; Ng, 1998; Long, 2001; Moormann, 2004; Wang et al., 2005; Kung et al., 2007; Liu et al., 2011a; Ng et al., 2012). A number of databases have been developed to estimate excavation-induced maximum lateral wall deflection and ground surface settlements behind retaining walls. By collecting measurements of six case histories in Shanghai soft clays, Wang et al. (2005) found that the maximum lateral wall deflection ranged from 0.13% *H* to 0.43% *H* (excavation depth). During basement excavation, movements were induced in the diaphragm walls and interior columns. It is obvious that substantial differential movements between retaining walls and interior columns affect the effectiveness of the retaining system (Liu et al., 2011a). As far as the authors are aware, studies on basement excavation induced vertical movements of diaphragm walls and interior columns are still limited.

Despite much attention being paid to the performance of rectangular basement excavations (O'Rourke 1981; Ou et al. 1998, 2000; Liu et al., 2005; Wang et al., 2005; Finno et al., 2007; Hsieh et al., 2008; Liu et al., 2011a; Tan and Li, 2011; Ng et al., 2012; Tan and Wei, 2012), research on triangular excavations is still limited. In Shanghai, first concrete props are normally cast

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when the excavation depth is about 1 m. Lateral movement at the top of retaining wall in rectangular basements is restrained due to the large compression capacity of the first concrete props. However, props in triangular basements cannot be constructed perpendicularly to the retaining wall. Thus, both axial compression and deflection are induced in the props in a triangular basement. So far, the deformation characteristics of triangular basement excavations are not well understood.

For the convenience of shoppers and users, there is an increasing demand for deep basements for buildings which are located close to or directly above existing tunnels (Burford, 1988; Chang et al., 2001; Sharma et al., 2001; Devriendt et al., 2010; Liu et al., 2011b). Burford (1988) reported measured maximum heaves of 50 mm and 41 mm in existing twin tunnels due to an overlying 12 m deep excavation in London clay. The clear distance between the tunnel crown and the formation level of the basement was less than 1 m. The rate of tunnel heave showed little sign of decreasing 27 years after commencement of basement excavation.

Chang et al. (2001) conducted a field study to investigate the deformation and movement in shield tunnels due to a nearby 21.1 m deep excavation. The basement was excavated at a side of the shield tunnel with a clear distance between them of half the final excavation depth (0.5 H_e). The tunnel cover-to-diameter ratio (C/D) was 2.4 and the tunnel invert was 0.6 m above the formation level of the basement. Cracks were observed in the reinforced concrete segments and the concrete slab at the tunnel invert was displaced.

Devriendt et al. (2010) reported displacements of twin tunnels due to a nearby 14 m deep basement excavation. The twin tunnels with C/D ratios of 5.8 and 6.7 were located at a side of the basement with a minimum distance between them of 7.2 m (0.51 H_e). The crown of existing twin tunnels was located 7.6 to 11.2 m below the formation level of the basement. A maximum tunnel heave of about 3.0 mm and a maximum lateral tunnel movement towards the basement of about 12.0 mm were observed.

Although a number of field studies were conducted to investigate excavation induced responses of shield tunnels, there has been much less attention made on the excavation effects on adjacent cut-and-cover tunnels (i.e., metro stations). To address the aforementioned issues regarding excavation in Shanghai soft clay, a large-scale triangular basement (353 m × 162 m × 245 m on plan) with a final excavation depth (H_e) of 22.8 m were extensively instrumented. A cut-and-cover tunnel supported by 40 m deep diaphragm walls was located in the middle of the large-scale triangular basement. The performance of deep excavation including wall movements, ground settlement behind diaphragm walls and interior column movements were reported and analysed. Moreover, excavation induced responses of the adjacent tunnel, pipeline and building were investigated.

1.1. SITE

This study concerns a large-scale triangular basement with a final excavation depth (H_e) of 22.8 m located in a commercial district of Shanghai. Fig. 1 shows a plan view of this site. The shape of the large-scale basement was approximately triangular with excavation geometry on plan of 353 m × 162 m × 245 m. An existing metro line crossed the entire excavated area, dividing it into two parts. Due to the presence of the existing metro station (i.e., cut-and-cover tunnel) and partition walls inside the basement, the large-scale triangular basement consisted of two major excavation zones (A1 and B1) and fifteen small excavation zones (A2–A9, B2–B8). An interchange station for four existing metro lines was located at the south side of the large-scale basement. At the east and west sides of the triangular basement, eleven utility pipelines with cover depths of about 2.3 m were buried within 25 m (1.1

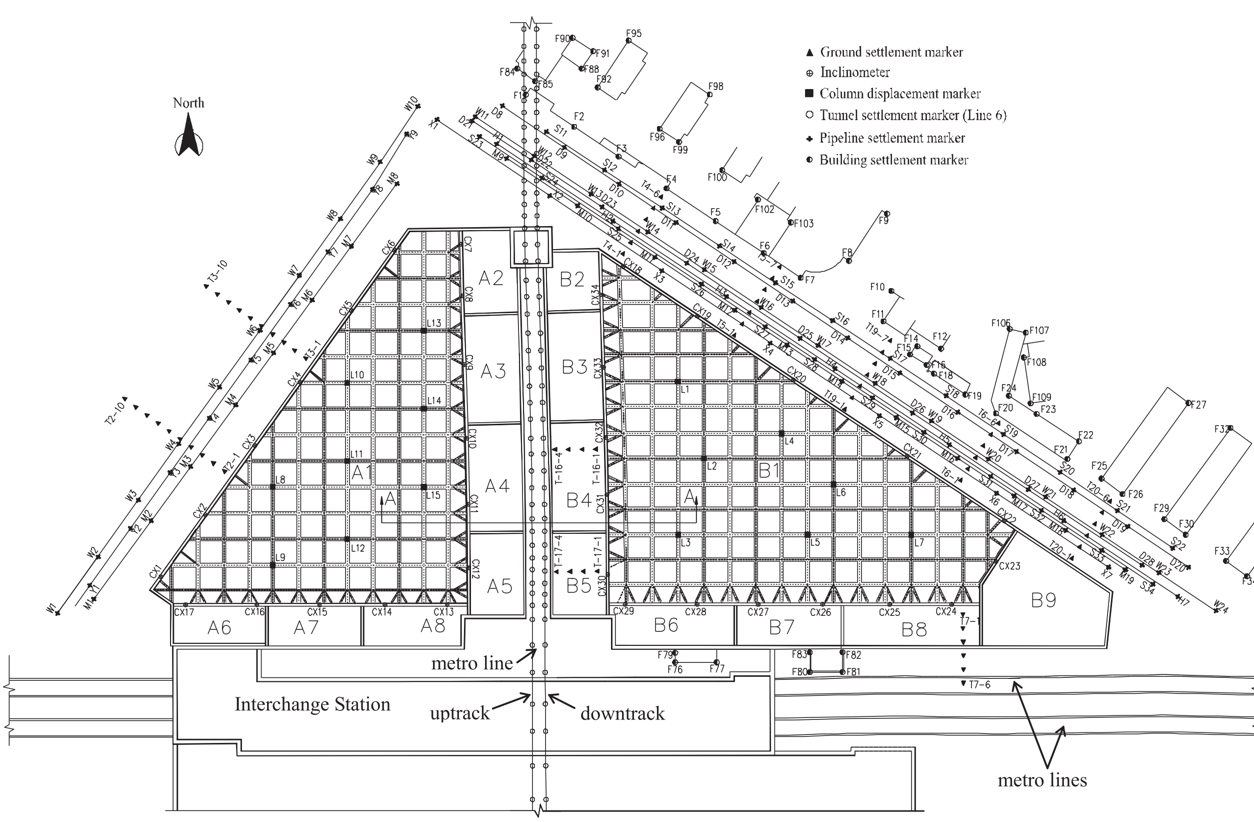

Fig. 1. Plan view of the site with instrumentation layout.