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Three-dimensional deformation behaviour of a multi-propped excavation at a “greenfield” site at Shanghai soft clay

Y. Hong [a], C.W.W. Ng [b,1], G.B. Liu [c,2], T. Liu [d,*]

[a] College of Civil Engineering and Architecture, Zhejiang University, Hangzhou, China
[b] Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
[c] Department of Geotechnical Engineering, Tongji University, China
[d] College of Environmental Science and Engineering, Ocean University of China, China

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ABSTRACT

Despite the large number of excavation-induced ground deformations reported in the literature, it is still not easy to differentiate ground deformations due to excavation in congested sites (where the ground is strengthened by underground structures) from those due to excavation in “greenfield” sites. To investigate and compare excavation-induced ground deformations in “greenfield” sites and congested sites, in this study a multi-propped excavation at a “greenfield” site in Shanghai soft clay was heavily instrumented and the measured ground deformations were compared with those reported from six excavations conducted under similar conditions but in congested sites in Shanghai. Field measurements from the “greenfield” site show that near the centre of the excavation, the maximum ground settlement ($\delta_{v\text{-}max}$) ranged from 0.22% to 0.27% of the final excavation depth (H_e), with a major influence zone extending to $3H_e$ behind the wall. The six excavations (near the main station) at congested sites in Shanghai had $\delta_{v\text{-}max}$ values ranging from 0.01% to 0.1% H_e (with a mean of about 0.05% H_e) and so were about 20% of that at the “greenfield” site. In addition, the major influence zone of ground settlement at the “greenfield” site extended 33% further than those at the congested sites. On the other hand, the measured maximum lateral wall displacement $\delta_{h\text{-}max}$ (0.24–0.37% H_e) at the “greenfield” site was comparable to those (0.13–0.43% H_e) at the congested sites. Due to the corner effect (soil arching around corners) at the “greenfield” site, the average $\delta_{h\text{-}max}$ and $\delta_{v\text{-}max}$ near the corners of the site were 45% and 36% smaller than those near the centre. The maximum tilt of ground perpendicular to the excavation was 1/1064, which was similar to that parallel to the excavation (1/1050).

1. Introduction

For excavations in soft clay in densely built urban areas, the induced deformations (including ground surface settlement and lateral wall displacement) can have serious consequences on surrounding structures. Many case histories have been reported during the past decades which helped with the understanding of the deformation characteristics associated with deep excavations in soft clay. Based on the reported field data, empirical and semi-empirical equations and design charts have been proposed to predict excavation-induced ground deformations (Peck, 1969; Clough and O’Rourke, 1990; Hsieh and Ou, 1998; Long, 2001; Moormann, 2004; Liu et al., 2005, 2011; Wang et al., 2010; Tan and Wei, 2012). Despite the large number of excavation-induced ground deformations reported in the literature, it is still not easy to differentiate between ground deformations due to excavation in congested sites (where the ground is strengthened by underground structures) and those due to excavation in “greenfield” sites. In addition, the existing empirical studies that rely on various case histories may lead to contradictory results, due to the differing ground conditions, construction sequences and workmanship (Moormann, 2004).

To address the two limitations described, in this study a deep excavation at a “greenfield” site in Shanghai clay was heavily instrumented and closely monitored. The observed deformation characteristics were then compared with those reported from six carefully selected excavations that took place under very similar conditions (Wang et al., 2005) but in congested sites in Shanghai,

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* Corresponding author.
E-mail addresses: chrishy85@gmail.com (Y. Hong), cecwwng@ust.hk (C.W.W. Ng), gobinlik@online.sh.cn (G.B. Liu), ltmilan@ouc.edu.cn (T. Liu).
[1] Tel.: +852 2358 8760; fax: +852 2358 1534.
[2] Tel./fax: +86 21 65985013.

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and with those recorded in a database of excavations in soft clay worldwide (Long, 2001; Moormann, 2004). Moreover, the three-dimensional deformation characteristics around the "greenfield" site were also investigated.

The case history reported in this paper offers an unusual opportunity to study the characteristics of ground deformation at a "greenfield" site and provides reliable and comprehensive data for numerical modellers to verify their constitutive model and model parameters.

2. Site

Fig. 1 shows a plan view of the site. An area of 150 m long and 18 m wide was excavated in the southeast corner of the New Hong Qiao Central Park (which is 576 m by 466 m). Prior to the development of the park in the early 1990s, the area was farmland. This site can therefore be considered as a "greenfield" site.

The area was excavated to accommodate a two-storey interchange station (Gu Bei Station) for two orthogonally crossing subway lines. The underground structure consists of a 14.5 m deep main station over most of the length and a 16.4 m deep launching shaft at either end.

To obtain the soil profile and characterise the geotechnical parameters of the site, seven boreholes (each about 50 m deep) were made around the excavation area (see BH1 to BH7 in Fig. 1). The data obtained from the seven boreholes are described in the following section.

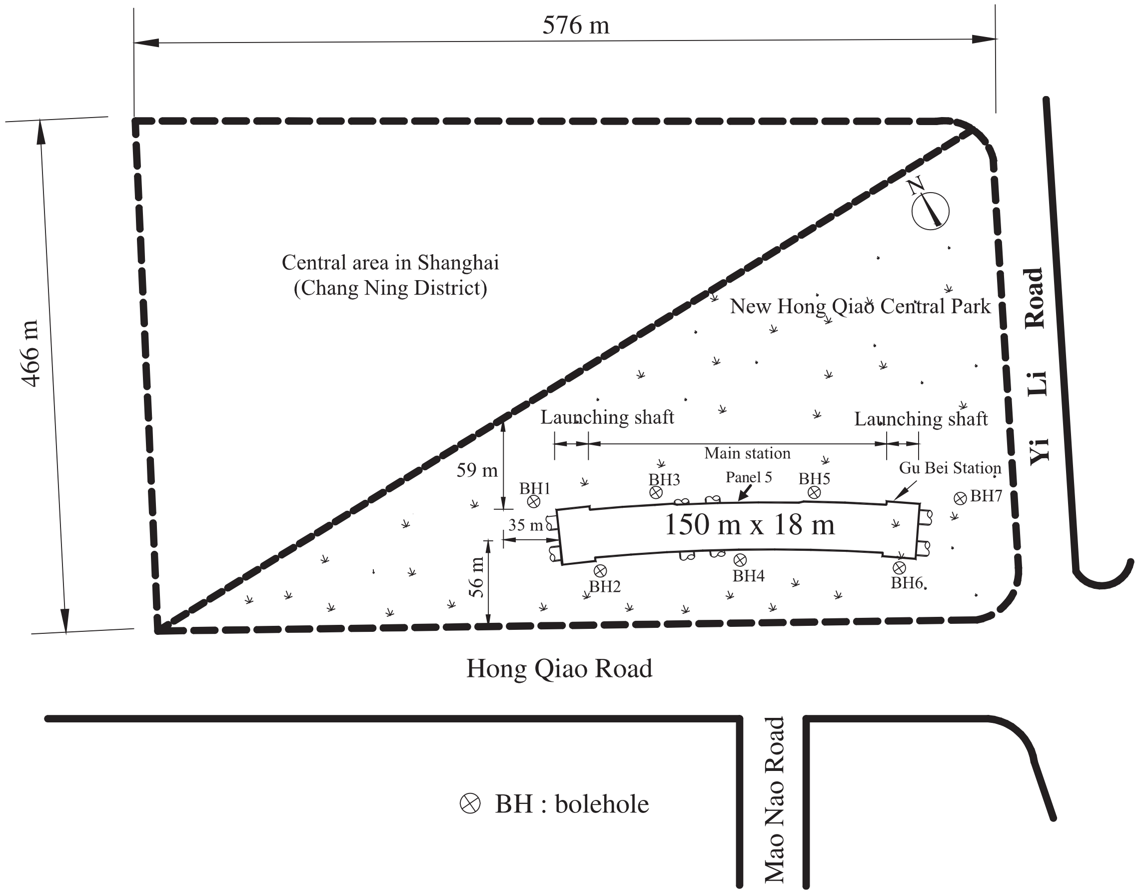
2.1. Ground conditions

Shanghai is located on the southern bank of the Yangtze River along the coast of the East China Sea. Alluvial sediments were deposited in Shanghai during the Quaternary period, as a result of changes in climate and sea levels. These strata are largely uniform and present to a depth of 400 m (Lee et al., 1999). The depth of engineering significance for this 14.5 m deep excavation was about 50 m below the ground surface. Fig. 2 shows the soil profile obtained from the seven boreholes (BH1 to BH7, see Fig. 1). Fig. 3 illustrates the vertical profile and properties of the soil obtained from a typical borehole (BH3).

Six strata were present within the first 50 m below the ground surface. The uppermost clay layer (firm clay) was slightly overconsolidated due to desiccation (Liu et al., 2005) while the underlying clay layers were generally normally consolidated (Lee et al., 1999). The water table was located at about 0.6 m below the ground surface.

Around the excavation area, the thickness of each soil stratum was relatively uniform. This made it possible to compare excavation-induced deformations at different locations of the site.

Both in-situ and laboratory tests were carried out to obtain geotechnical parameters of the soil. The undrained shear strength was obtained by in-situ measurements using vane shear tests. As shown in the figure, the c_u/p' ratio was around 0.38, which was similar to that ($c_u/p' = 0.4$) measured by field vane tests from another excavation site in Shanghai (Liu et al., 2005). It is well



Note: This figure is not drawn to scale

Fig. 1. Pan view of the site.