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Mechanism of buttress walls in restraining the wall deflection caused by deep excavation

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ABSTRACT

This objective of this study is to investigate the mechanism and characteristics of buttress walls in restraining the wall deflection in deep excavations. The three-dimensional finite element method was used to carry out a series of parametric studies on the length, spacing, thickness, depth, and demolished sequence of buttress walls. The results indicated the following: when buttress walls were demolished along with excavation, the flexural rigidity enhanced by buttress walls to the diaphragm wall was unable to effectively reduce the deflection of a diaphragm wall; the effect of a buttress wall restraining the wall deflection mainly came from the frictional resistance between the surface of the buttress wall and the surrounding soils, thus, a longer length of buttress wall provided a greater effect. When the buttress wall was maintained during excavation, the buttress wall could effectively restrain the wall deflection; in addition to the frictional resistance between the surface and surrounding soils, the flexural rigidity of buttress walls could provide restraining effects on the deformation of the diaphragm wall. The influence of the thickness of a buttress wall on the wall deflection was insignificant for the maintained buttress wall. Under the conditions of equivalent total length of buttress wall, the restraining effect of increasing the length of a buttress wall was greater than that resulting from reducing the spacing between buttress walls. To effectively utilize the flexural rigidity enhanced by buttress walls to the diaphragm wall, buttress walls above the final excavation should be maintained until the end of excavation.

1. Introduction

Since many urban areas are limited in land resources, buildings and public works are dense, and to efficiently use underground space, new construction projects are often to carry out excavations in close proximity to existing buildings/facilities (Zhang et al., 2013; Li et al., 2017a). To avoid damage to existing buildings/facilities caused by excavation, when designing an excavation, the safety of existing buildings/facilities should be considered, and the necessary measures should be taken to protect those buildings/facilities. Those protection measures include zoned excavation (Chen et al, 2016; Li et al., 2017b), cross walls (Ou et al., 2006; Hsieh et al., 2013; Ou et al., 2013; Liu et al., 2016), ground improvement (Gaba 1990; Liu et al., 2005; Parashar et al., 2007), and underpinning the foundation of existing buildings/facilities (Huang, 1992).

Installation of buttress walls in an excavation area is another alternative to protect existing buildings/facilities during excavation. The adopted construction method is similar to diaphragm wall construction but with a finite length, in which one end is perpendicular and connected to the diaphragm wall. The basic configuration of the buttress wall is shown in Fig. 1. The basic concept of buttress walls is that they may achieve the effects of reducing diaphragm wall displacement and reducing the influence of the excavation on the existing buildings/facilities through the following two mechanisms. First, the diaphragm-buttress wall system is used to form an effect similar to the T-beam of reinforced concrete where the buttress wall enhances the flexural rigidity of the diaphragm wall, so that the deformation of the diaphragm wall can be reduced. Second, by the frictional resistance between the surface of the buttress wall and the surrounding soils, the lateral resistance of the retaining system is enhanced and thus reduces the deflection of the diaphragm wall.

Thus far, the frictional resistance between the buttress walls' surface and the surrounding soils is one of the main sources in reducing the wall deflection. Whether the flexural rigidity enhanced by buttress walls has good effects in reducing the wall deflection lacks rigorous studies. There is also a lack of specific research results on the influence of the dimensions of buttress walls, so the design of the buttress walls remains stalled at a semi-empirical stage.

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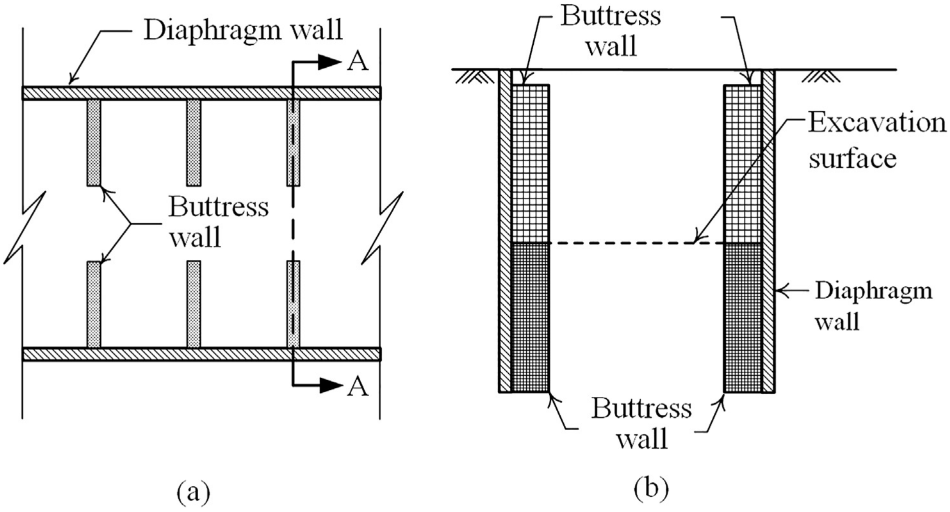

Fig. 1. Schematic diagram of buttress walls: (a) plan (b) A-A Section.

In view of this, this study first used the three-dimensional finite element method to conduct analysis of an excavation case with buttress walls. The analysis results are compared with those from the field monitoring data. Then, a series of parametric studies regarding the length, spacing, thickness, depth, and demolished sequence of buttress walls was conducted to clarify the mechanism and characteristics of buttress walls, and the influence of the dimensions of buttress walls on the deflection of a diaphragm wall.

2. Validation analysis

An excavation with the installation of buttress walls with good construction quality and good monitoring data, called as a UPIB building excavation, will be used for validate the analysis procedure. The UPIB excavation was installed with cross walls and buttress walls to reduce the wall deflection and ground settlement. The influence of cross walls on the deformation of diaphragm wall, as well as analysis and design have been studied by the author previously (Ou et al., 2006; Hsieh et al., 2012; Hsieh et al., 2013; Ou et al., 2013; Hsieh and Ou, 2016). No more study or descriptions regarding the performance of cross walls were shown in this paper. The details of the UPIB excavation, the subsurface soil conditions and the monitoring results can be found in the above mentioned literature; only a brief summary is presented in this section.

2.1. Project overview

Fig. 2(a) shows the UPIB excavation plan, the allocation of the buttress walls and cross walls and the instrumentation. The excavation area was 121.8 m × 66.1 m in plan. Three buttress walls with 12 m and 15 m in length were constructed in east and west sides, respectively, while three and one buttress wall with 6 m in length were in south and north sides, respectively. In addition, three cross walls with about 26 m of spacing were constructed in the north-south direction. No buildings/facilities existed near the excavation site.

Fig. 2(b) shows the profile of the excavation and the subsurface soil conditions together with their physical properties and strength parameters. The ground water in the clay was located at GL-3 m (GL refers to the ground surface level) but in the silty sands/well-graded gravels (SM/GW) layer at GL-10 m, the excavation depth was 32.5 m, which was completed in nine stages using the top-down construction method. A diaphragm wall of 1.5 m in thickness (t_{dw}) and 57.5 m in depth (H_t), was used as an earth-retaining system. The compressive strength of the concrete (f_c') of the diaphragm wall was 27.5 MPa. Each floor slab was constructed directly after an excavation stage, and no de-watering was involved prior to stage 6. At stage 7, 8 and 9, the groundwater level in the SM/GW layer was lowered from GL-10 m to GL-11.67 m, from GL-11.67 m to GL-16.80 m and GL-16.80 m to GL-21.56 m, respectively.

The buttress walls and cross walls, 1.0 m in thickness (t_{bw}), and 55 m and 45 m in depth respectively, were constructed directly after the completion of the main diaphragm walls. The buttress walls and cross walls were dismantled during the process of excavation. The buttress walls and cross walls between GL-1.5 m and GL-22 m were cast with 13.7 MPa concrete, and those below GL-22 m were cast with 24.0 MPa concrete.

Twelve inclinometer casings were installed in this project (numbered from SO1, SI2–SI12). The casings passed through the bedrock and penetrated into the rock for 5 m, so as to keep its bottom locating at a fixed position. Ten settlement monitoring profile, each of them corresponding an inclinometer, were allocated (Fig. 2(a)).

2.2. Numerical analysis and material parameter

A three-dimensional finite element computer program, PLAXIS 3D (2013) was used as a basic numerical analysis tool in this study.

On the west side of the UPIB, only buttress walls were installed and the shape was more close to the rectangular. Therefore, these walls were the object of this study for validation analysis. For simplification, only the block labeled as “Analysis block” in Fig. 2(a) was adopted for analysis, thus the sections of SI9-SET9 and SI10-SET10 on the west side of the UPIB were selected for validation.

Fig. 3 shows the finite element mesh used for the analysis. The depth of mesh was set at 67 m, considering that bedrock would not deform during excavation. The horizontal boundaries were set at the distance four times the final excavation depth from the diaphragm wall to minimize the boundary effect. The boundary of the bottom surface was restrained in all directions, and the vertical boundaries were restrained in the horizontal direction.

The hardening soil model (Schanz et al., 1999), referred as the HS model, was adopted to simulate the behavior of soils, including clayey soil and SM/GW under the undrained and drained conditions, respectively. The HS model requires the parameters of secant stiffness (E_{50}^{ref}) corresponding to the reference stress, p^{ref}, the tangent referential stiffness for primary oedometer loading (E_{oed}^{ref}), the unloading/reloading referential stiffness (E_{ur}^{ref}), and the power for stress-level dependency of stiffness (m).

In this paper, $p^{ref} = 100$ kPa. For clay, m is set equal to 1.0, and E_{ur}^{ref} can be estimated according to Lim et al. (2010).