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Modelling analysis of the influence of shield crossing on deformation and force in a large diaphragm wall

Guojun Wu[a,*], Shanpo Jia[b,*], Weizhong Chen[a,c], Jianping Yang[a], Jingqiang Yuan[a]

[a] State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, China
[b] Research Center of Geomechanics and Geotechnical Engineering, Yangtze University, Jingzhou 434023, Hubei, China
[c] Research Center of Geotechnical&Structural Engineering, Shandong University, Jinan 250061, China

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ABSTRACT

The effect of a shield crossing an existing underground infrastructure needs to be evaluated, yet there are few studies on this subject. In this study, to model the influence of a shield crossing on a large diaphragm wall, a detailed three-dimensional numerical model with special methods considering the effects of the panel joints and the shield crossing has been developed. The panel joints have been simulated by a HINGE mode of the connection type, and the effect of shield crossing has been realized by modelling the excavated concrete using the solid elements, which interact with the surrounding soils that have been simulated with the ground springs. After analysing the characteristics of the deformation, maximum and minimum principal stresses, vertical and circumferential bending moments in the diaphragm wall, the maximum deformation, and the largest maximum and minimum principal stresses are at the perimeter of the shield tunnel. Further, for the bending moment, the largest negative vertical and circumferential bending moments are at the perimeter of the shield tunnel, yet the largest positive vertical and circumferential bending moments are distributed around the perimeter of the shield tunnel. For the largest tensile stress and vertical bending moment, there are large changes in the diaphragm wall around the shield tunnel, which is detrimental to the diaphragm wall. Considering the effect of the shield crossing, the diaphragm wall should be reinforced according to the results of the numerical analysis during the design and construction stages.

1. Introduction

As a type of retaining structures, when a circular diaphragm wall is subjected to water and earth pressures, it can carry heavy loads, and circumferential and vertical bending moments due to its spatial arching effects (Bruce et al., 1992; Chen et al., 2012; Tan, 2015; Tan and Wang, 2015). Therefore, it is increasingly used as part of underground infrastructures. The circular diaphragm wall is commonly composed of separate wall panels and vertical joints between the wall panels. Using the vertical joints to connect these panels together, these separate panels are formed as a continuous monolithic structure (Emam, 1999).

As the panel joints (especially the vertical joints) are the weakest parts of a diaphragm wall, due to their function in connecting the panels, their role in influencing the load transfer mechanism of the panels is significant. Although many studies were performed on the installation of diaphragm walls and the construction of ground excavation in the theoretical and technological aspects (Comodromos et al., 2013; Demoor, 1994; Gourvenec and Powrie, 1999; Ng et al., 1995; Powrie and Li, 1991; Schafer and Triantafyllidis, 2004; Segura-Castillo et al., 2014), there are only a few studies on the behaviours and performance of the joint system. Chen et al. (2016a, 2016b) investigated the effect of three main design parameters of longitudinal steel plates in cross-plate joints on the shear capacity with experimental results. Further, using three-dimensional finite-element modelling, they predicted the shear bearing behaviour of the cross-plate joints. After showing the possible damage failures of joints, Ewald and Schneider (2015) suggested that firm, straight, and clean joint must be implemented before concreting the secondary element in order to minimize the risk of diaphragm wall pits.

In recent years, there is an increase in the construction of vertical shafts and large-scale circular underground facilities, down to a depth of 60–100 m (Ariizumi et al., 1999; Goto et al., 1995). When a shield crosses shafts or diaphragm walls, due to the interaction of the shafts (walls) and the shield tunnel, large deformations and stresses in the shafts (walls) can occur, which threatens the safety and stability of the shafts (walls). Therefore, the effect of the shield crossing on the safety and stability of the shafts (walls) need to be evaluated (Wu et al., 2017). Using numerical modelling, similar studies have been carried out on the

* Corresponding authors.
E-mail addresses: gjwu@whrsm.ac.cn (G. Wu), jiashanporsm@163.com (S. Jia).

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influence of the shield crossing on the objects, such as buildings, tunnels, pile foundations and other structures (Liu et al., 2009; Sirivachiraporn and Phienwej, 2012; Wei, 2012; Xu et al., 2015; Yamaguchi et al., 1998). However, there are few studies on the influence of shield crossing on shafts or walls, including the distributions of the displacement, force (stress and moment) when the shield is shielding-in and shielding-out from the shafts (walls), which is a major concern for the stability of shafts (walls).

As discussed above, the shielding crossing and the way the load is transferred are the most important factors which impact the safety and stability of the retaining structures. In this study, a special modelling method has been developed to model a diaphragm wall being crossed through by a shield tunnel. The model can consider the influences of the shielding crossing through the diaphragm wall and the load transfer of the panel joints. Hence, it can be used to study the characteristics of the deformation and force (stress and moment) in the diaphragm wall influenced by the shield crossing. By establishing a three-dimensional numerical model, the influence of the shield crossing on the deformation and force (stress and moment) of a large diaphragm wall have been analysed and evaluated.

2. General situation of the diaphragm wall

The diaphragm wall, as a part of the Meizizhou ventilating shaft in Nanjing, China, is located in a pool at the tail of the Meizizhou isle. The Meizizhou ventilating shaft has been designed as a circular concrete structure, with a circular diaphragm wall, a lining wall and four reinforced concrete ring beams, as shown in Fig. 1. The four ring beams are the top ring beam, the first ring beam, the second ring beam and the third ring beam, and they are all used as purlins. The circular diaphragm wall has an inner diameter of 26.8 m, and an outer diameter of 29.2 m (i.e., the thickness is 1.2 m). Considering the foundation stability of the whole structure, the diaphragm wall will be constructed to the depth at the altitude of −54.452 m. Since the altitude of the ground level is +8 m, the length of the diaphragm wall is actually 62.452 m. The soils within the diaphragm wall have been excavated to the altitude of −36.452 m, where the base plate is built for sealing the whole ventilating shaft. After the diaphragm wall is completed, it will be crossed by a tunnel boring machine (TBM) to form a section of a shield tunnel for transportation. The diameter of the shield tunnel is 14.5 m, and the centre of the shield tunnel is positioned at the altitude of −23.417 m. From the top to the bottom of the diaphragm wall, the ground layers are silt, silty clay, fine sand, medium and coarse sand, respectively, whereas the bearing bed is in the pebble layer. In addition, the ventilating shaft is situated near an existing large levee, which has been used for flood prevention from the Yangtze River. Hence, the ventilating shaft is subjected to abundant water supply. Therefore, the engineering geology and hydrogeology conditions are challenging.

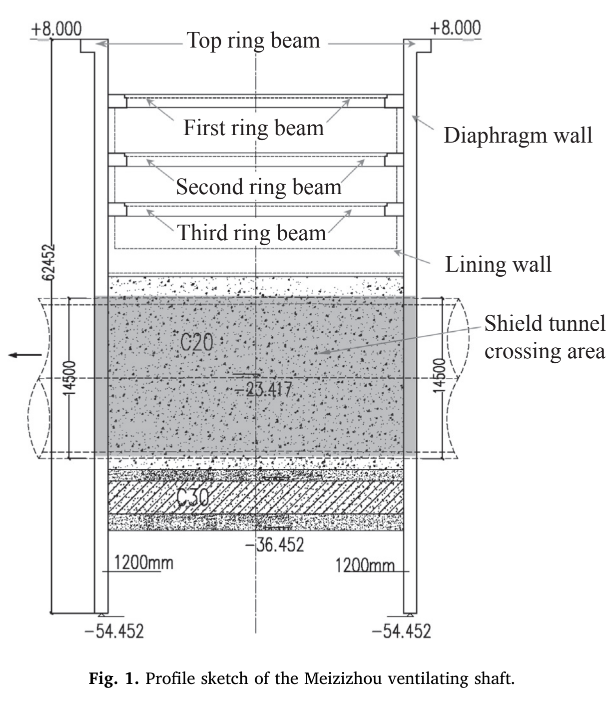

Fig. 1. Profile sketch of the Meizizhou ventilating shaft.

Being a challenging project, the Meizizhou ventilating shaft must meet the requirements of safety and stability during the construction, especially during the period when the shield tunnel crosses the diaphragm wall. Hence, it is regarded as a key part of the entire project. In this study, the numerical model has been used to analyse the Meizizhou ventilating shaft, and to determine the characteristics of the deformation and stress at the diaphragm wall. The results can then be used in the design and construction of the diaphragm wall.

3. Modelling of shield crossing the diaphragm wall with special methods

In order to study the stability and safety of the diaphragm wall when the shield crosses the ventilating shaft, numerical simulation is a desirable approach.

3.1. Numerical model

3.1.1. Model of the diaphragm wall

When establishing an analysis model for a diaphragm wall, the strata-structure model is often used to analyse the ground deformation and the interaction of the ground and the support structure (Jarddine et al., 1986). Further, if the emphasis is on the structure of the diaphragm wall, the load-structure model is often used to analyse the force/stress and the deformation in the diaphragm wall. In this study, the focus has been on the diaphragm wall considering the shield crossing. The ground outside the diaphragm wall can be ignored and the interaction of the ground and the structure can be simplified by using spring elements to link the ground to the structure, as shown in Fig. 4. In this way, the numerical simulation is less time-consuming. The numerical model has been developed using the code ABAQUS.

In this model, the diaphragm wall has 24 panels (Fig. 2), and the cross-plate joints (Wu et al., 2017) and the lining wall as well as the base plate of the lining are simulated using the three-dimensional shell elements. The ring beams (including the top ring beam) are simulated using the three-dimensional beam elements. In addition, the soil within the diaphragm wall, which will be excavated during the shield crossing, is simulated using the three-dimensional solid elements which interact with the diaphragm wall. These components of the ventilating shaft are shown in Fig. 3. For the modelling of the panel joints, and the crossing of the diaphragm wall by the shield, the details are in Sections 3.2 and

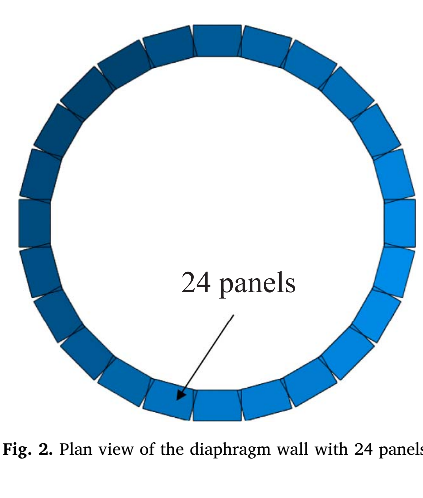

Fig. 2. Plan view of the diaphragm wall with 24 panels.