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Structure optimisation of a diaphragm wall with special modelling methods in a large-scale circular ventilating shaft considering shield crossing

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ABSTRACT

In the design of a circular diaphragm wall, it is most important to determine the number of wall panels and vertical joint stiffness to achieve a desired retaining structure style. In this paper, a numerical model with special methods considering the modelling of panel joints and shield crossing the ventilating shaft was proposed: the joints between panels were simulated with the hinge mode of connection type, the interaction between surrounding soils and diaphragm wall simulated with ground springs, and the excavated soils within the shield tunnel simulated with solid elements were performed to model the stress release when shield crossing. With this model, six different operating cases considering the change of number of panels and joint stiffness were analysed in the Meizizhou ventilating shaft. The numerical results suggested the diaphragm wall with 24 panels and joint stiffness 100% of the panel stiffness (i.e., case 1) was optimal considering shield crossing the shaft in terms of evaluating the displacements, hoop stresses and vertical bending moments of wall panels.

1. Introduction

The circular diaphragm wall, acting as a type of retaining structures, is configured by several separate wall panels and vertical joints between panels. Because of their spatial circumferential arching effects, circular diaphragm walls can endure large hoop stresses and vertical bending moments when facing water and ground pressures. Compared with a rectangular diaphragm wall, a circular diaphragm wall can exhibit a better stability of the structure for its integral rigidity and less radial deformation or deflection (Bruce et al., 1992; Chen et al., 2012).

In the last decades, much research in the areas of construction of excavations and the installation of diaphragm walls has been done in both theoretical and technological aspects (Demoor, 1994; Gourvenec and Powrie, 1999; Ng et al., 1995; Powrie and Li, 1991; Schafer and Triantafyllidis, 2004). During the excavation and installation of wall panels in circular diaphragm walls, panel dimensions and their configurations have significant effects on the displacements and stresses of the surrounding ground and retaining structures (Ng and Yan, 1998; Poh et al., 2001). Scale effects of wall panels substantially influence the load transfer mechanism between panels, particularly in the case of soft soil, where a limited panel length is intentionally applied to make full use of the effect of arching (Comodromos et al., 2013; Gunn and Clayton, 1992). According to some literature (Arai et al., 2008; Conti et al., 2012; Demoor, 1994; Gourvenec and Powrie, 1999; Ng and Yan, 1998, 1999), numerical modelling is most available to get reasonable panel sizes including length, depth and width. Besides, vertical joints between panels influence the load transfer of panels regarding their connection function. Generally, the lower joint stiffness is, the more sufficiently panels deform. However, there seems to be no research considering the effect of vertical joints between panels in designing circular diaphragm walls.

Referring to shield crossing existing building structures, only several relevant literatures were published (Sirivachiraporn and Phienwej, 2012; Wei, 2012; Wei et al., 2012; Xu et al., 2015; Yamaguchi et al., 1998). Wei (2012) perfumed a simulation considering the interaction of building-soil-tunnel by 3D MIDAS/GTS software, where the strip foundation masonry building vertically crossed by a shield tunnel. They (Wei et al., 2012) also simulated the grillage beams foundation frame building with a 30 degree crossing by a Double-O-Tube (DOT) shield tunnel and analysed the effect of construction on the building.

This paper focused on a large-scale circular ventilating shaft crossed by a shield tunnel through establishing a

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three-dimensional numerical model considering the modelling of panel joints and shield crossing the ventilating shaft with some special methods. To determine the optimal structure of the diaphragm wall, six cases were analysed and compared with respect to the number of the panels and the joint stiffness.

2. Basic information regarding the Meizizhou ventilating shaft

In this paper, the Meizizhou ventilating shaft, designed as a circular shape, was chosen to analyse the structural optimisation of the diaphragm wall. The shaft is located in a pond at the end of Meizizhou islet in Nanjing city in China. The local climate is humid, and the rainfall is abundant all year. An existing Yangtze levee is located around 20 m west of the ventilating shaft. The Yangtze River plays an important role in recharging the underground water of this region; as a result, the water table is nearly flush with the natural ground level.

According to the site geological and hydrogeological conditions as well as flood control requirements, the Meizizhou ventilating shaft is designed as a circular diaphragm wall with a lining wall and four reinforced concrete ring beams (including the top ring beam, the first ring beam, the second ring beam and the third ring beam) in it, as shown in Fig. 1. The circular diaphragm wall has an inner diameter of 26.8 m, an outer diameter of 29.2 m and a thickness of 1.2 m. It is excavated to the depth of up to 44.452 m (Because the ground level is at +8 m, the excavated altitude is at −36.452 m, see Fig. 1). Considering shield crossing the shaft after the construction of the shaft, the altitude of the centre of the shield tunnel crossing shaft is positioned at −23.417 m, and the diaphragm wall is designed at the depth of 62.452 m (i.e. at −54.452 m). Being a ventilating shaft, the shaft must meet the safety and stability requirement during the process of shield tunnel crossing. Hence, the determination of the optimal structure of the circular diaphragm wall is a formidable problem that engineers must face in the primary design stage.

3. Numerical model with special modelling

Numerical simulation is certainly a desired approach to be used in analysing the structure of the circular ventilating Shaft. In the design of diaphragm walls, the strata-structure method and load-structure method are often used. Considerable research has been done using the strata-structure method with respect to the soil-structure interaction of diaphragm walls in terms of analysing ground displacements and installation of diaphragm walls (Jarddine et al., 1986). In this study, because we primarily focus on the structural optimisation of the diaphragm wall, the load-structure method is preferentially chosen to establish a three dimensional calculation model of the ventilating shaft according to the construction features of Meizizhou ventilating shaft (see Fig. 2), where the interaction between soils and structures is not the focus for us.

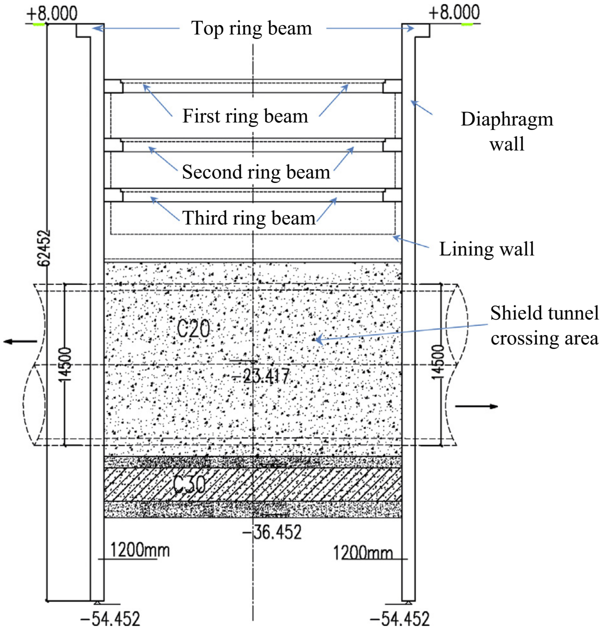

Fig. 1. Profile sketch of the Meizizhou ventilating shaft.

3.1. Numerical model

In this model, the diaphragm wall, lining wall and base plate of lining are simulated by three-dimensional shell elements, the ring beams (also including the top ring beam) are simulated by three-dimensional beam elements, the soil within the shield tunnel is simulated by three-dimensional solid elements, and the joints between diaphragm wall panels are simulated by connector elements. In addition, the interaction between the inner side of the diaphragm wall and soils (not seen) is simulated by ground springs.

Boundary conditions: vertical freedoms are fixed at the base plate of the diaphragm wall, and the inner surface of the diaphragm wall is restrained by normal ground springs. The unit elastic resistance coefficient of the ground springs is defined at 1.7×10^7 N/m, as derived from the data of site survey and in-situ experiments. The active earth pressure and external water pressure including the uplift water pressure are applied to the outer surface of the diaphragm wall, as shown in Fig. 3.

3.2. Modelling method of panel joints

Little attention has paid to the effect of panel joint stiffness on the displacements and stresses of circular diaphragm walls. In this study, the HINGE mode in connection types in ABAQUS was proposed to model panel joints between wall panels in the diaphragm wall.

In ABAQUS, the connection type HINGE is used to join the position of two nodes (i.e., nodes a and b, as shown in Fig. 4) and to provide a revolute constraint between their rotational degrees of freedom. Connection type HINGE imposes kinematic constraints and uses local orientation definitions. Predefined Coulomb-like friction in the HINGE connection relates the kinematic constraint

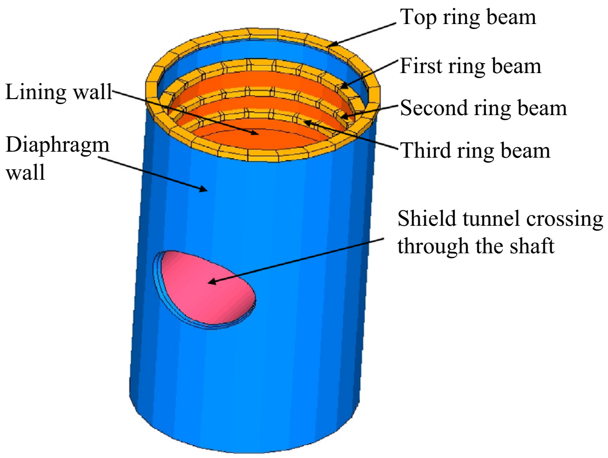

Fig. 2. Structural map of the ventilating shaft.