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Evaluation of influence of vibrations generated by blasting construction on an existing tunnel in soft soils

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ABSTRACT

The controlled blasting technique is employed, for the first time, on the diaphragm wall of an existing road tunnel in soft soils in the city of Shanghai, and therefore, safety demands on evaluation of influence of the blasting vibrations on the tunnel are highly required. Based on the practical blasting scheme of four sections of diaphragm wall of the tunnel to be exploded in three groups, the field monitoring of blasting vibrations is carried out on the bottom plate of the tunnel and the blasting vibration effects on the tunnel are measured throughout the blasting construction. The sequential characteristics of vibration velocities and accelerations of the tunnel structure are obtained from the field blasting tests. In order to fully understand the safety criterion of the blasting vibrations on the tunnel, a 3D numerical model is established by the finite element software ABAQUS. The numerical simulation results are confirmed by field monitoring data. Based on the monitoring data and numerical results of the tunnel subjected to blasting loads, results show: (1) the blasting energy is transferred mainly along the vertical direction; (2) the basic frequency domain of the tunnel responses caused by the explosion is relatively in a lower frequency range; (3) distinct vibration response spectra of the tunnel structure are observed along the horizontal and vertical directions; (4) the performance of the tunnel subjected to the blasting construction is in a critical state of safety and thus the blasting construction scheme should be implemented carefully. Finally, critical issues on evaluation of the blasting construction are fully discussed and evaluated, which provide a reference for other similar projects.

1. Introduction

Tunnels constitute a major part of civil infrastructure and serve as public transportation facilities, water passage, and other purposes such as electricity or communication cable installation (Yu et al., 2013a). With the rapid development and upgrade of infrastructures in China, there is a rising number of blasting construction near or on existing tunnels (Jiang and Zhou, 2012). The blasting vibration during operation can damage the neighboring or existing tunnel structure and endanger the construction projects. Therefore, it is necessary to thoroughly evaluate the dynamic responses of the tunnel subjected to blasting vibration to guarantee the safety of the tunnel during construction.

The influences of blasting vibration on underground structures have been studied by a number of researchers using field experiments (Ahmed and Ansell, 2011; Ansell, 2004; Nateghi, 2011; Ozer, 2008) and numerical simulations (Feldgun et al., 2008; He et al., 2011; Lu et al., 2011; Ma et al., 1998; Wu et al., 2004; Zhu and Tang, 2006). In most of the studies, the blasting construction is limited to rock blasting. The elements affecting rock blasting are drilling length and diameter, over-burden, the explosive characteristic, rock mass strength and characteristics. However, no experimental or numerical study of the effects of blasting vibration on underground structures in soil medium, especially in soft soils, has been reported. The theoretical research on blasting vibration in soft soils is vacant and the safety criterion of blasting vibration velocity for adjacent tunnel is still undetermined.

In this paper, based on the blasting construction of the diaphragm walls of an existing road tunnel in soft soils, the field monitoring is required to obtain actual structural vibrations of

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the tunnel from the blasting operation. The vibration monitoring program, including monitoring equipments, monitoring points, vibration measurements and measurement techniques, is developed to fully satisfy requirements of the field monitoring. According to the monitoring data of the blasting vibrations, velocity response, vibration attenuation, and acceleration response and its dominant frequency of the tunnel structure are obtained and analyzed. A thorough understanding of the safety criterion of the blasting vibrations for the tunnel is realized by establishing a 3D numerical model using ABAQUS. The numerical simulation results are compared with field monitoring data.

2. A brief description of the tunnel

The Fuxing East Road Tunnel is the first twin-line and two-layer shield tunnel used for highway transportation in the city of Shanghai, China. The tunnel has a total length of 2785 m. Its layout can be divided into three segments: cross-river segment, nearshore buried segment and Puxi terminal segment. The tunnel liner of the Puxi terminal segment is made of 600 mm thick concrete. It is 13.95 m high, 19.5 m wide, and the shape of its cross-section is rectangular. The elevation of the bottom plate of the Puxi terminal segment is −8.641 m, and the diaphragm wall is adopted as the retaining structure. Below the elevation of −13.675 m, the diaphragm wall made of C10 fiberglass concrete is reserved for the subsequent shield tunneling of the other planned tunnel used for rail transit. The C10 fiberglass concrete, i.e. fiberglass used as a reinforcing agent for C10-grade concrete (the grade is consistent with the Chinese code for design of concrete structures 2010), is used instead of the traditional reinforced concrete, mainly due to the fact that compared to the reinforcement the fiberglass is much easier to be cut by the shield machine. The general plan and location of both the Fuxing East Road Tunnel and the planned subway tunnel are shown in Fig. 1. In order to guarantee shield tunneling successfully and accelerate construction schedule, the blasting construction scheme is employed on the diaphragm wall firstly, and then followed by the penetration of shield tunneling through the blasting zone. In the explosion, four sections of diaphragm wall are expected to be exploded, including two sections for the uplink and downlink of the planned tunnel respectively (Fig. 1). According to the geological exploration data following the geological exploration report of the Fuxing East Road Tunnel (2007), the soil through which the planned subway tunnel is excavated is mainly composed of the silty clay, as shown in Fig. 2.

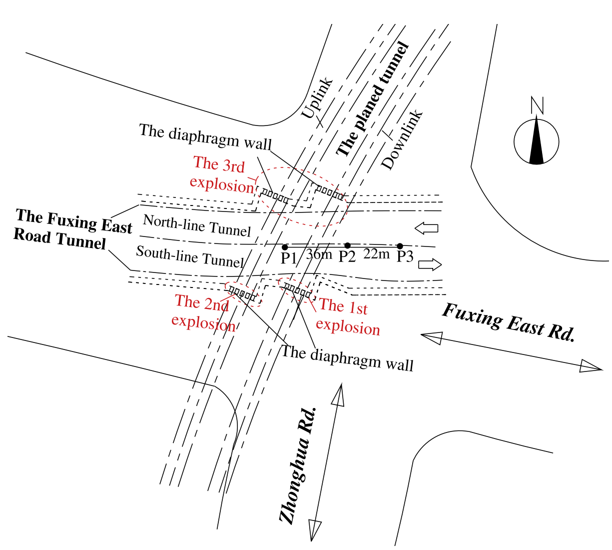

Fig. 1. Plane view of the Fuxing East Road Tunnel and the planned subway tunnel.

3. Blasting construction and field monitoring

3.1. Blasting scheme and its implementation

In the blasting construction, four sections of diaphragm wall are divided to be exploded in three groups, i.e. the first and second blasting constructions for the east and west sections of diaphragm wall close to the south-line tunnel, respectively, while the third blasting construction for both sections of diaphragm wall close to the north-line tunnel simultaneously, as shown in Fig. 1. In relation to tunnel construction, Peck (1969) stated three issues, which are: (1) maintaining stability and safety during construction; (2) minimizing unfavorable impact on third parties; (3) performing the intended function over the life of a project. Among the issues, the first and second ones are directly related to the appropriate construction of tunnels.

To maintain safety and minimize effects of blasting vibration on the existing tunnel structure, the reasonable controlled blasting technique is selected with consideration of the geological conditions and the surrounding environment. The blasting scheme of vertical drilling along the center line of the diaphragm wall is adopted. The vertical drilling starts from the center of the top surface of the diaphragm wall. The drilling depth and diameter are 27.2 m and 110 mm respectively, and the distance between each two adjacent drilling holes is 0.8 m, which equals to the width of the diaphragm wall. The vertical view of drilling holes in the diaphragm wall is shown in Fig. 3. The emulsion explosive equipped with RDX detonator is employed in the explosion, and the millisecond blasting technique is adopted as the detonation. The detailed blasting scheme for each section of diaphragm wall is arranged as followed: firstly, the No. 6 drilling hole (Fig. 3) in the middle of each section of diaphragm wall is blasted; then the next explosion is followed by the two adjacent drilling holes, i.e. Nos. 5 and 7 (Fig. 3); and the followed explosions spread continuously in the same way and finally end with the drilling holes of Nos. 1 and 11. The time interval for each adjacent explosion of drilling holes

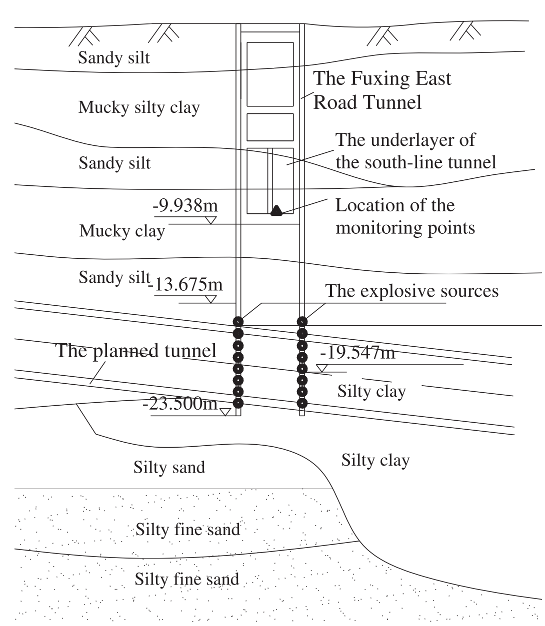

Fig. 2. Typical cross section of the Puxi terminal segment of the Fuxing East Road Tunnel.