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Effect of excavation blasting vibration on adjacent buried gas pipeline in a metro tunnel

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A B S T R A C T

To ensure the safety of gas pipeline during tunnel blasting excavation, it is crucial to investigate the dynamic response of gas pipeline to blast vibration under tunnel excavation. In this paper, the blasting excavation of Beijing metro line 16 was selected as a case, and the blasting vibrations in the field were monitored. Based on the field monitoring data, a mathematical model was established and proposed to describe the attenuation of peak particle velocity (PPV) of ground surface soils with respect to the depth of tunnel blasting. Next, a 3D numerical model was established to analyze the response characteristics of burial gas pipeline subjected to blasting vibration and its reliability was verified using the field monitoring data. The effects of metro tunnel blasting vibration on gas pipeline under different tunnel blasting conditions were further calculated, and the dynamic response characteristics of soil, pipe and pipe surrounding soil were discussed. At last, to better and more conveniently assess and predict the influence of blasting vibration, a PPV prediction model of gas pipeline under metro tunnel excavation blasting for this project was proposed.

1. Introduction

As of early 2017, China has 5636.5 km of urban rail transit lines under construction and plans to spend 4.7 trillion Yuan ($706 billion) on transport infrastructure in the next 3 years. With the carry out of the large-scale urban rail construction projects, a large number of metro tunnels passing through the existing buried city gas pipeline projects continue to emerge. During the excavation of metro tunnels, blasting, as a fast and efficient excavation method for hard rock mass has been widely used. To ensure the safety and stability of the gas pipeline during the tunnel blasting excavation, reasonably and properly evaluating the impact of the blasting vibration on the nearby gas pipeline and controlling the detrimental effect of blasting vibration are the key technical issues to realize the safe and efficient construction of metro tunneling projects.

At present, although many scholars have extensively studied the impact of blasting on pipeline, most of them focused on the influence of surface explosion of terrorism and military on pipeline (Ojdrovic et al., 2003; De et al., 2005; Gad et al., 2007; Rigas, 2009). For example, Kouretzis et al. introduced a robust methodology for analytical calculation of the strains in flexible buried pipelines due to surface point-source blast (Kouretzis et al., 2007). Yan et al. analyzed the dynamic responses of pipelines in soft soil to ground explosion (Yan et al., 2012). Won et al. examined the behavior of multilayered pipeline affected by blasting loads based on full-scale field test and numerical analysis (Won et al., 2014). Mokhtari and Nia numerically analyzed the response of API 5L grade X65 pipeline to nearby sever explosion due to sabotage or war (Mokhtari and Nia, 2015). Nourzadeh et al. discussed linear and nonlinear behaviors of buried pipelines under blast pressures induced by external explosion (Nourzadeh et al., 2011). Gospodarikov et al. proposed an approach to mathematical modeling the effect of blast waves on an underground oil pipeline (Gospodarikov et al., 2014). Abedi et al. presented a mathematical method to calculate the displacements of pipelines under an equivalent blast dynamic load (Abedi et al., 2016). In recent years, with the development of computer technology, numerical simulation methods are frequently adopted to study the influence of blast on pipelines (Provatidis et al., 2000; Maáachowski, 2008; Xu et al., 2013; Giannaros et al., 2016; Song et al., 2016).

In this paper, we focused on the construction of metro tunnels that pass through gas pipeline by blasting and selected the actual blasting engineering in section Xibeiwang-Malianwa (Xi-Ma) of the Beijing metro line 16 as a case (Section 2). First, based on the field blasting vibration monitoring and analysis, we established a mathematical model to describe the attenuation law of peak particle velocity (PPV) of surface soils affected by the depth of tunnel blasting (Section 3).

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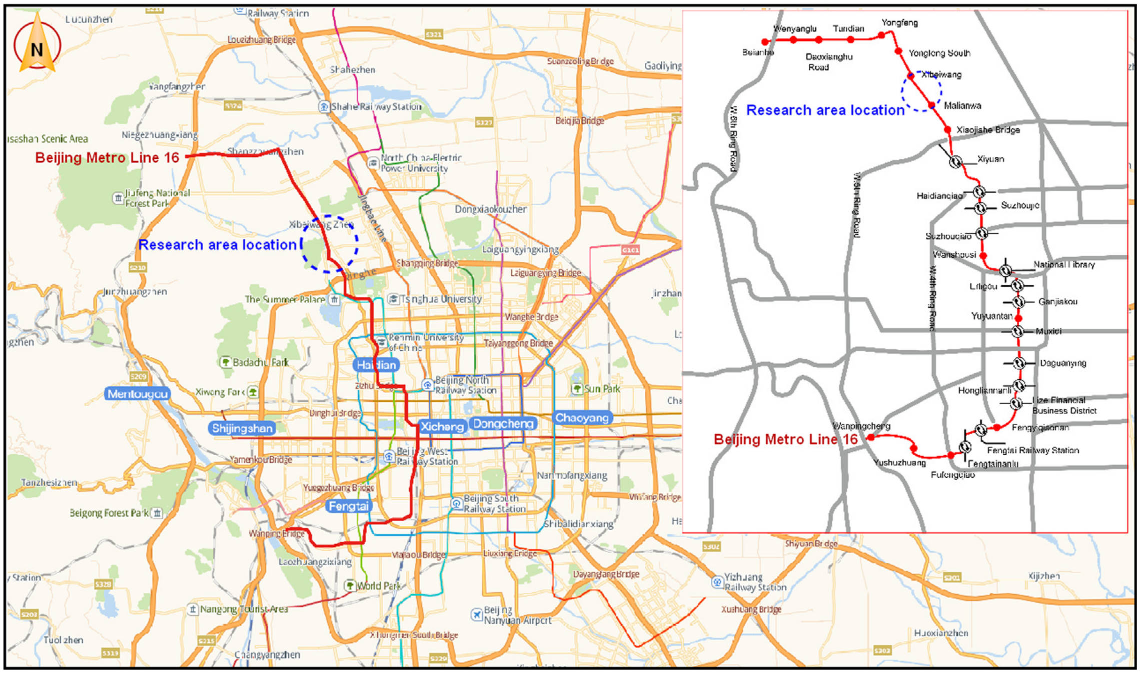

Fig. 1. Beijing Metro Line 16 layout.

Second, we established a 3D numerical model to analyze the response characteristics of buried gas pipeline subjected to blasting vibration by adopting the dynamic finite element software ANSYS/LS-DYNA and verified its reliability using the field monitoring data (Section 4). At last, based on these primary results, we calculated the effect of metro tunnel blasting vibration on gas pipeline under different working conditions, discussed the dynamic response characteristics of soil, pipeline and pipeline surrounding soil, and proposed the PPV prediction model of pipeline under metro tunnel blasting excavation (Section 5).

2. General information of the metro tunnel project

Beijing Metro Line 16 is a planned north-south trunk line of Beijing. It passes through three administrative districts: namely Fengtai, Xicheng and Haidian. The route starts from Wanping City Station in Fengtai District, passes through Beijing Lize Financial & Business District, Sanli Sanxi River, National Library, Suzhou Street, Yongfeng Science and Technology Park, Haidian Hill Area and ends at Haidian Beinan River. The line is a 49.8 km long underground line with 29 stations and two vehicle bases (Yushuzhuang parking and Beian River depot), as shown in Fig. 1.

The Xi-Ma section of the Beijing Metro Line 16 is chosen as the research area (Fig. 1). This section is relatively flat with the quaternary sedimentary soil distributed on the ground surface. The surrounding rocks under the soil layer are mainly quartz sandstones and bedded with poorly developed joints of better homogeneity, higher toughness and Protodyakonov coefficient of 8–10. Because the metro tunnel is surrounded with hard rocks, blasting method is adopted for its excavation.

According to the site engineering geological survey, the buried depth of the tunnel, which is the distance between the tunnel roof and ground surface, is 21 m. The tunnel in the Xi-Ma section is designed as a 6.4 m high and 6.3 m wide horseshoe-shaped tunnel, and constructed using the method of drilling and blasting of up-down short benches. Around the tunnel, there are large amount of residential quarters and a large amount of gas pipelines distributed in the overlying soil. The tunnel passes through and vertically intersects with a ductile iron gas pipeline. The distance between the tunnel vault and the cast iron gas pipe is 18.7 m. Fig. 2 shows the relative position of the tunnel and the pipeline. The pipe has a diameter of 500 m, wall thickness of 100 mm, and buried depth of 2.3 m. Analyzing and evaluating the effect of the tunnel blasting on the gas pipeline is one of the main purposes of this paper.

The tunnel is excavated by drilling-and-blasting method in two benches. Fig. 3 shows the arrangement of the blast holes and the design of delay detonators and Table 1 lists the parameters of the blast holes in the upper bench. These holes are oblique holes with diameter of 42 mm and circulating footage of 1.0–1.2 m in design. The cut holes are oblique holes and arranged in four rows with straight depth of 1.3 m. These holes are charged with 0.9 kg explosive each and blasted using smooth blasting method. The perimeter holes are vertical holes with depth of 1.2 m and outwardly inclined by $2-4^{\circ}$. The hole-by-hole delayed detonating network with electronic detonators is chosen with 2 ms difference for each cut and perimeter holes, and 4 ms difference for each relief and bottom holes.

In the lower bench, the blast holes include only relief holes, perimeter holes and bottom holes. They are horizontally drilled with depth of 1.2 m and arranges with row spacing of 0.8 m and hole distance of 0.9 m. Each hole is charged with 0.4 kg explosive. Except that the bottom hole pitch is set at 0.7 m, the other parameters of these holes are same with those in the upper bench.

3. Field blasting vibration test and analysis

According to the tunnel construction characteristics, to accurately evaluate the impact of blasting vibration on the gas pipeline under the existing blasting excavation method, the metro tunnel section (K14 + 494–K14 + 514) at a horizontal distance of 40–20 m from the pipeline is designated as the blasting vibration monitoring area to monitor and analyze the vibration of the blasting construction and the metro tunnel section (K14 + 514–K14 + 534) and the horizontal distance of 20–0 m from the pipeline is designated as the blasting vibration safety assessment area, as shown in both Figs. 2 and 4.

The Blastmate-III blasting vibrometer is used to monitor the vibration of tunnel blasting construction. The instrument has four channels (ultrasonic and three-dimensional vibration detector) with sampling frequency of 1024 samples per second, vibration pickup range of 254 mm/s, resolution of 0.0159 mm/s, and built-in preamplifier and