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Technical Note

# Ground surface settlements due to construction of closely-spaced twin tunnels with different geometric arrangements

Qian Fang [a,*], Qimin Tai [a], Dingli Zhang [a], Louis Ngai Yuen Wong [b]

[a] *Key Laboratory for Urban Underground Engineering of the Education Ministry, Beijing Jiaotong University, Beijing 100044, China*
[b] *School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798, Singapore*

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ABSTRACT

This paper examines the ground surface settlement profiles due to the construction of closely-spaced twin tunnels using the shallow tunnelling method. In the concerned zone, where the twin-tunnelling was performed in stacked and offset arrangements, the ground surface settlements of in total 18 cross-sections were continually recorded during construction. To cater for different conditions of the twin tunnels in the concerned zone, partial face, full face and forepoling reinforcement schemes were adopted. The recorded surface settlements and settlement troughs of three typical sections are reported and illustrated. The surface settlement troughs induced by each of the twin tunnels are fitted by the Gaussian function. The parameters that characterize the surface settlement troughs induced by each of the twin tunnels, such as the maximum settlement, percentage of ground loss, trough width and empirical trough width parameter are presented and compared.



## 1. Introduction

Twin tunnels construction in close proximity to each other is common in urban subway construction. In many cases, the twin tunnels are shallowly buried in soft ground and adjacent to existing structures. Their construction would inevitably induce ground movements which may lead to damage to nearby surface and subsurface structures.

The ground movements induced by single tunnelling have been extensively studied by field observation (e.g., Peck, 1969; Cording and Hansmire, 1975; Attewell and Hurrell, 1985), analytical method (e.g., Loganathan and Poulos, 1998; Bobet, 2001), numerical modelling (e.g., Rowe et al., 1983; Addenbrooke, 1996; Franzius et al., 2005) and physical modelling (e.g., Mair, 1979; Taylor, 1984). Meanwhile, research has also been carried out to investigate the ground movements induced by multiple tunnelling. Some case studies have shown that the surface settlement troughs caused by twin tunnels have a variety of shapes (e.g., Cording and Hansmire, 1975; Cooper et al., 2002; Suwansawat and Einstein, 2007). Due to the lack of field data, researchers usually relied on numerical modelling (e.g., Addenbrooke, 1996; Addenbrooke and Potts, 2001; Hunt, 2005) and physical modelling (e.g., Chapman et al., 2006, 2007; Divall, 2013) to study the movements associated with multiple tunnelling. There is no doubt that valuable insight could be gained from both numerical and physical modelling. However, due to the inherent uncertainties in tunnel engineering, the settlement magnitudes obtained by such studies can hardly reproduce the actual magnitudes found in a real project. Moreover, most previously documented twin-tunnelling cases were using the shield method.

In this study, the ground surface settlements caused by twin tunnelling using the shallow tunnelling method are investigated. The twin tunnels, which link the Beihai North Station and the Nanluoguxiang Station of the Beijing Subway Line 6, are of various geometric arrangements such as stacked, offset and side-by-side. The geological conditions, geometric arrangements, construction measures and monitoring points layout of this project are introduced first. Then the surface settlements of some typical geometric arrangements of the twin tunnels are presented and discussed. Finally, the surface settlement characteristics of each of the twin tunnels are illustrated by using the Gaussian function with superposition technique.

## 2. Project overview

Line 6 of the Beijing Subway is a main artery crossing Beijing city from east to west. The Beihai North Station and the Nanluoguxiang Station are two adjacent stations of Line 6, which are linked by two horseshoe shape tunnels under the Di'anmen

* Corresponding author.
*E-mail address:* qfang@bjtu.edu.cn (Q. Fang).

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West Street (Fig. 1). They were excavated using the Shallow Tunnelling Method, which is particularly designed for shallowly-buried tunnels constructed in a densely built urban area relying on manpower-excavation (Fang et al., 2012). The total length of each tunnel is about 1166.8 m (from K9+794.7 to K10+961.5). The excavation width and height of a single tunnel are 6.2 m and 6.5 m respectively. Sprayed concrete primary lining and cast-in-place concrete secondary lining were adopted as tunnel support. Waterproofing membrane was sandwiched between the primary and secondary linings. The top heading (with support core)-bench-invert (with temporary invert) excavation sequence was adopted (Fig. 2). The twin tunnels run upwards side by side with each other from the Beihai North Station to Section K10+489.9. From K10+489.9 to K10+961.5, the north tunnel runs upwards continuously while the south tunnel runs downwards. Meanwhile the north tunnel runs close to the south tunnel. The cross-sectional layouts of the twin tunnels of this project thus are of different geometric arrangements from side-by-side, offset to stacked. The spatial relationships between the twin tunnels at some typical cross-sections are shown in Fig. 3. The geological profile along the south tunnel and the twin tunnels alignment are shown in Fig. 4. It reveals that the ground is typically composed of backfill soil, silty sand, silt, silty clay, gravel, etc. The confined water table varies from 21.8 m to 24.9 m below the surface. The typical physical and mechanical properties of soils are shown in Table 1.

In this research, the ground surface settlement data of closely-spaced twin tunnels from K10+730.9 to K10+940.5 (concerned zone shown in Fig. 3), which have been systematically recorded, are investigated. In this part of project, the overburden thickness varies from 13.1 m to 14.5 m above the north tunnel and varies from 18.8 m to 21.1 m above the south tunnel. The south tunnel was first excavated from both the west side and east side of the No. 1 shaft at K10+934.4 (Fig. 4), which was followed by the north tunnel with certain lags. From K10+885.0 to K10+940.5, grouting was adopted to reinforce the ground above the twin tunnels. A 1.5 m thick zone outside the top heading and the upper part of the bench was reinforced for the north tunnel. And a 1.95 m thick zone above the top heading with an angle of 120° was reinforced for the south tunnel (Fig. 5). From K10+875.0 to K10+885.0, the twin tunnels were constructed beneath a rectangular cross-section water tunnel, which is approximately 4 m wide and 2 m high. The minimum vertical clearance between the newly built upper tunnel and the existing water tunnel is about 8.5 m. Full face grouting was adopted to reinforce both the excavated ground and the surrounding ground with a thickness of 2.0 m around the circumference of each of the twin tunnels (Fig. 6). From K10+875.0 to K10+730.9, grouting type forepoling was adopted to reinforce the ground above the top heading. Forepoling pipes, steel, 42 mm diameter (25 mm diameter used in gravel), 2.8 m length, were driven at an angle of 10° to 15° with the tunnel longitudinal axis into the ground above the top heading arch ahead of the cutting face.

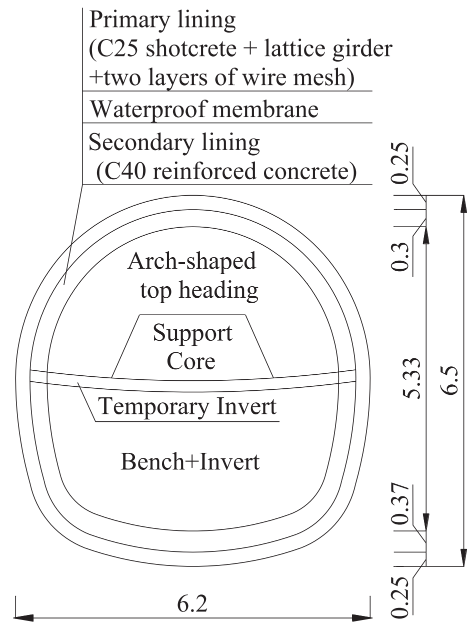


**Fig. 2.** Dimensions and support parameters of a single tunnel (unit: m).

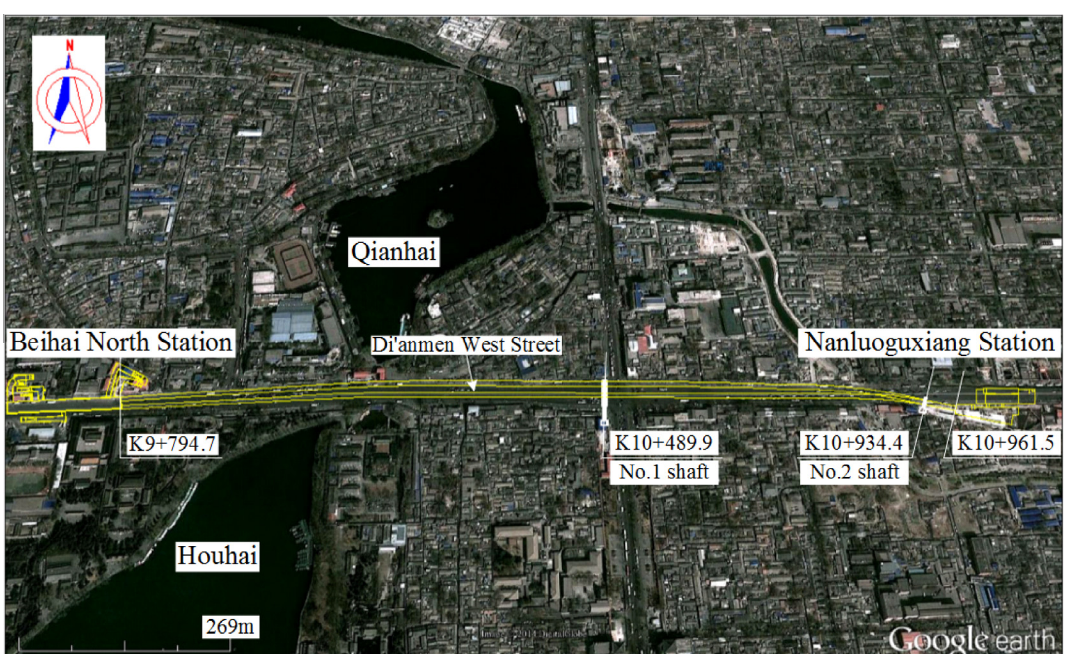


**Fig. 1.** Aerial photo of the project area (Google Earth).