DOI 10.15302/J-SSCAE-2017.06.018

Mobile Support Technology and Its Application Prospects in Urban Underground Engineering

Wang Xiuying[1], Tan Zhongsheng[1], Yang Jikai[2], Zheng Weihan[1]

1. School of Civil Engineering, Beijing Jiaotong University, Beijing 100044, China
2. Beijing SHOUER Engineering Co., Ltd., Beijing 100192, China

Abstract: The intensive development of urban space provides a good opportunity for the development of underground engineering while simultaneously demanding stringent requirements in terms of underground construction technology. Herein, combined with the advantages of the shield method and shallow tunneling method, a mobile support technology suitable for soft soil tunneling is proposed, and its control effect on ground deformation is studied. Numerical analyses and field tests show that the technique we proposed is capable of controlling ground deformation. This technique has remarkable advantages in urban short-distance crossing engineering and tunnel construction in districts where a strict surface subsidence demand exists; therefore, this technique is worth applying and popularizing.

Keywords: mobile support; ground deformation; application prospect; numerical simulation; site monitoring

1 Introduction

Currently, the construction of China's urban underground space has entered a period of great development. Major cities in the country have begun to build and plan subways. Additionally, urban municipal facilities, civil air defence works, and underground pipe networks need to be constantly transformed and constructed. Most cities in China are in the quaternary strata, with weak strata and complicated ground environment. Owing to the planned depth, size, structure, and function of the underground engineering, the differences in the ground environment, underground geological conditions, and control requirements for the construction in contrast, tunnel builders have studied diversified underground construction methods. China has achieved significant heights in the construction of underground projects [1,2]. However, with the requirement for further development of underground space in China, the complex geological conditions and ground environmental problems encountered in tunnel construction have become increasingly prominent. Further, the problem of labor shortage has gradually emerged. In response to the current tunnel construction difficulties, the development of a variety of weak surrounding rock tunnel mechanization construction methods has become an urgent need [3]. In this paper, we present a mobile support technology for the construction of weak surrounding rock tunnels, study its role in controlling formation deformation, and discuss its application prospects in urban underground engineering.

2 Introduction of mobile support technology

The mobile support technology is a mechanized construction technology developed for the construction of weak surrounding rock tunnels, combined with the concept of shield construction under the protection of shields and shells, and the shallow buried excavation method to freely and flexibly deal with the characteristics of complex and variable geology. With the idea of a

Received date: November 18, 2017; **Revised date:** December 20, 2017

Corresponding author: Wang Xiuying, School of Civil Engineering, Beijing Jiaotong University, Associate Professor. Major research field is tunnel and underground construction. E-mail: xywangl@bjtu.edu.cn

Funding program: CAE Advisory Project "Development Strategy for Urban Underground Space Planning in China" (2015-XZ-16)

Chinese version: Strategic Study of CAE 2017, 19 (6): 124–130

Cited item: Wang Xiuying et al. Mobile Support Technology and Its Application Prospect in Urban Underground Engineering. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2017.06.018

foreign pre-groove method, and based on its innovative R&D technology, a full-face excavation in a weak formation can be achieved by forming a closed advance pre-support in front of the excavation face. This technology overcomes the defects of the pre-grooving method that causes transverse discontinuity in the trough section. Through the excavation of the box, a pre-supporting structure with sufficient rigidity and good lateral connection can be formed in front of the excavation face, and the lower soil excavation can be performed under the pre-support protection. The excavation of a large-section machinery not only improves the safety of construction but also significantly improves the construction efficiency. The schematic of the mobile support equipment is shown in Fig. 1. The construction process of the mobile support is shown in Fig. 2.

The basic unit of the structure of the mobile support equipment is the self-digging box body and the guard plate connected to the rear of the box body. Each boring box body and rear guard plate are meshed with each other to form an arch structure, and the structure has a movable support arch frame. The interlocking box group penetrates into the face of the tunnel and provides protection for tunnel excavation. The lining support of the tunnel is performed under the interlocking rear guard. Hence, tunnel construction under the protection of mobile support can be easily

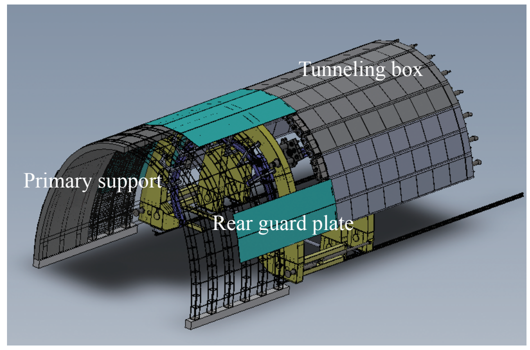


Fig. 1. Schematic of mobile support equipment.

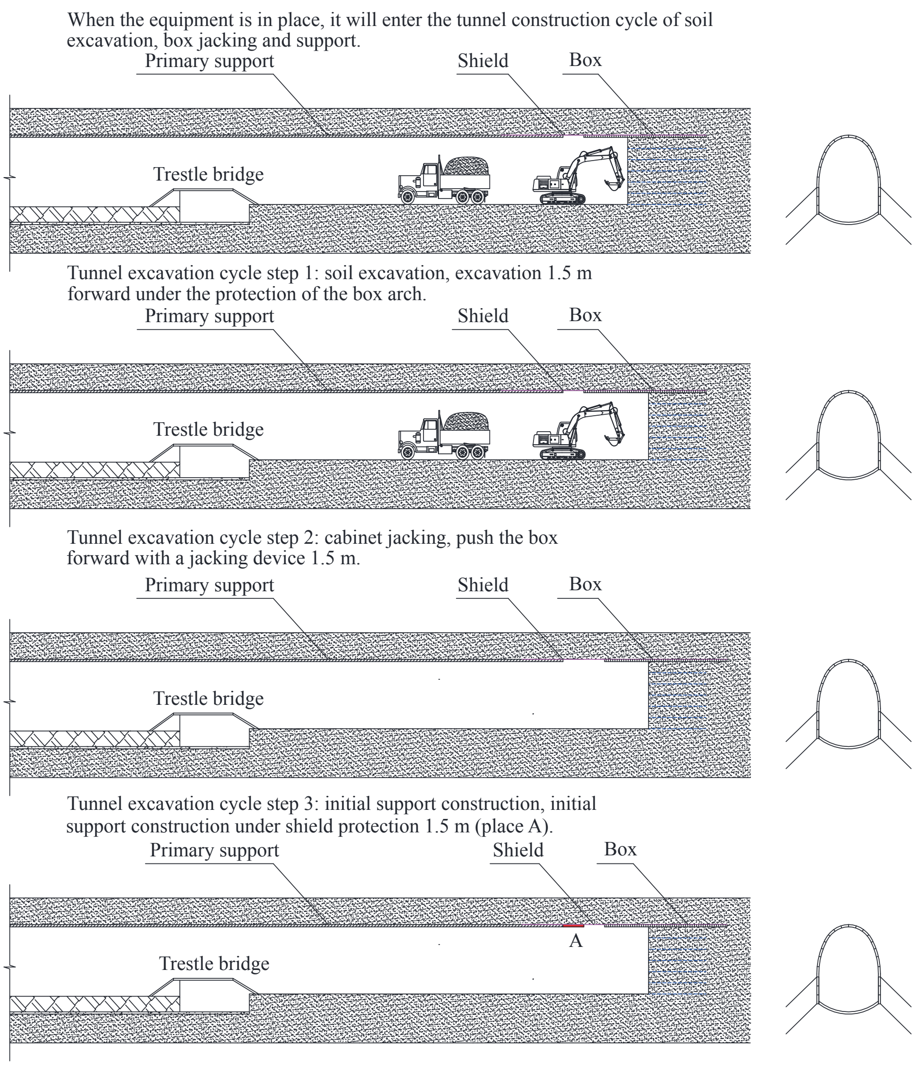


Fig. 2. Schematic of construction process of mobile support.

divided into three steps: box drilling, soil excavation, and lining support. The three processes are continuously repeated until the completion of the tunnel construction. Fig. 3 shows the construction process of excavating the tunnels for the mobile support equipment.

3 Analysis of formation deformation caused by mobile support method

3.1 Test overview of mobile support method

The mobile support structure used in this test consisted of 13 excavation boxes with a length, width, and height of 8800 mm, 1000 mm, and 350 mm, respectively. The interlocking structure is of a simple slotted steel pipe and connected shaft. Thirteen excavation boxes form the protection in the tunnel arch. The geological conditions of the test site are the original cultivated land, the construction site is 0–3 m below the surface, the construction length is approximately 30 m, the depth of the import position is 0 m, and the depth of the exit location is 3 m. Owing to the small overburden, an inverted arch has not been planned. The on-site construction is shown in Fig. 4.

The assembled steel corrugated plate support structure was used as the initial support of this experiment. The assembled steel corrugated plate is a space-thin-shell flexible load-bearing structure formed by the rapid splicing of factory-prefabricated corrugated steel plates at the construction site [4]. The joints between the segments are connected by high-strength bolts. The surface of the steel plate is often treated with hot-dip galvanized aluminum. After the assembly is completed, the splicing seams and bolts are treated with a sealant and the internal and external surfaces are coated with asphalt. Hot-dip galvanizing and asphalt spraying on the external surface can be used for anti-corrosion. Sealant treatment for welding and asphalt spraying can be used for waterproofing, as shown in Fig. 5.

3.2 Analysis of formation deformation caused by mobile support construction

3.2.1 Calculation model and parameter selection

The MIDAS/GTS numerical simulation software was used to simulate the arch excavation, arch support, and core soil ex-

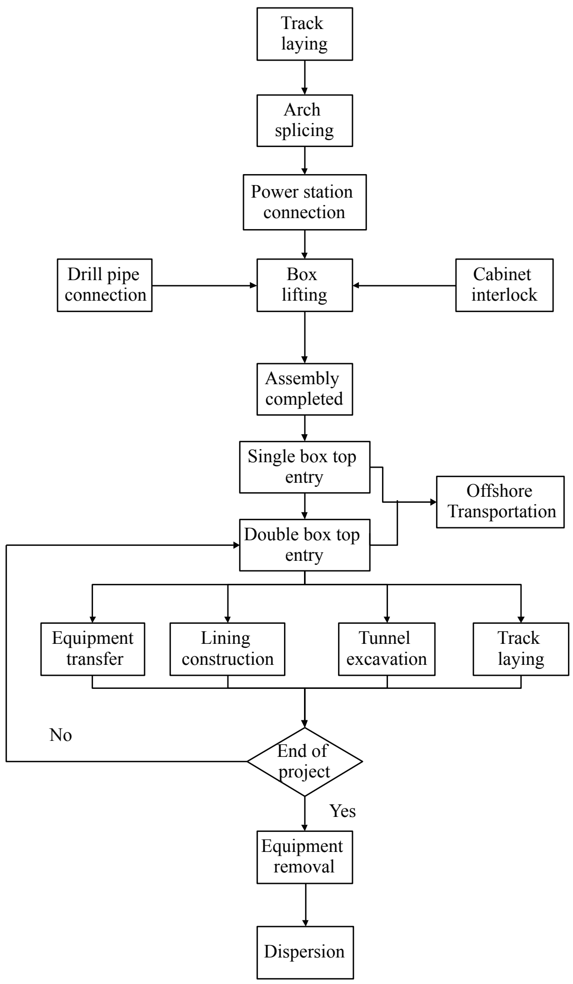


Fig. 3. Flow chart of pre-lining tunnel construction.

Fig. 4. Site construction of mobile supports.

Fig. 5. Corrugated steel plate assembling picture.

cavation. The model was composed of a lateral length of 58 m, a height of 37 m, a burial depth of 0–3 m, and a longitudinal length of 30 m. At each step, 2 m was excavated. A Mohr-Coulomb constitutive model was adopted for the soil layer, and an elastic constitutive model was adopted for the post-guard support and the initial branch of the steel corrugated plate to analyze the surface settlement, arch settlement, and perimeter convergence [5]. The model is shown in Fig. 6.

According to the measured ground conditions of the site, the surrounding rock is classified as grade V according to the China's code for railway tunnel design; the parameters are as shown in Table 1.

3.2.2 Computational simulation and analysis scheme

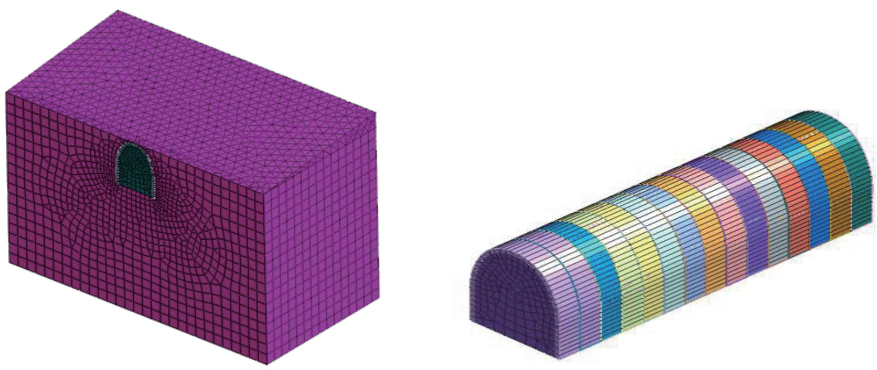
To produce a numerical simulation that is consistent with the actual sequence of the on-site execution, the entire process was divided into 34 steps, in which the box was excavated 2 m. After the box was excavated 10 m, the core soil was excavated. Under the protection of the rear guard plate for the installation of the steel initial support, 2 m was excavated each time.

We focused on the measurement points on the y=8, y=15, and y=22 sections, respectively, and monitored the surface settlement, arch settlement, and perimeter convergence of the three sections as the construction progresses. The layout of the measurement points is shown in Figs.7 and 8.

3.2.3 Analysis of calculation results

(1) Surface settlement analysis

After the simulation calculation, the surface settlement cloud chart after the construction of the mobile support structure method is completed, as shown in Fig. 9.



(a) Model perspective (b) Partial enlargement of the model

Fig. 6. Calculation model.

Table 1. Table of parameters for the calculation model.

Material category	Modulus of elasticity, E (MPa)	Poisson ratio, μ	Unit weight, γ (KN·m^{-3})	Cohesion, c (kPa)	Angle of internal friction, φ (°)
Soil layer	200	0.35	16.5	200	25
Rear guard plate	320 600	0.3	78.9	–	–
Initial support of steel corrugated plate	309 000	0.3	88	–	–

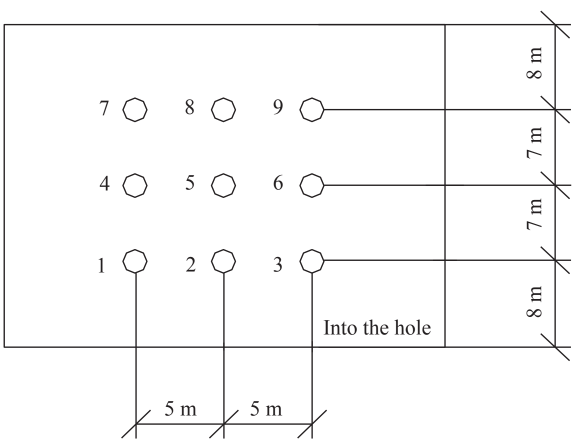


Fig. 7. Ground measurement point map.

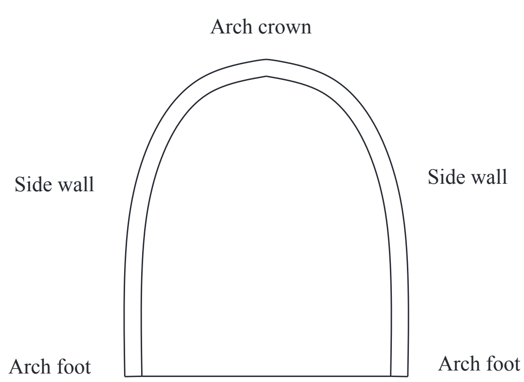


Fig. 8. Topography of the arch settlement and surrounding convergence measure points.

The simulation of the settlement changes of nine surface subsidence points with the construction sequence is shown in Figs. 10 to 12, where construction steps 1 to 5 correspond to the box advancement, steps 5 to 30 are the core soil excavation, and beyond step 30 are the assembling of the steel corrugated plate. The sedimentation effects at the nine site points on the surface are shown in Table 2.

Figs. 10 to 12 and Table 2 show that during tunnel excavation, the ground surface settlement gradually increases with the construction process and that the settlement value of the surface settlement point above the arch is significantly larger than the surface measurement points on both sides. When the core soil is excavated, the surface settlement increases, and when the assembled steel plate is initially installed, the settlement decreases. In the excavation using the mobile support structure method, the three middlemost measuring points (No. 2, 5, and 8) have larger settlement values, and the maximum settlement value (No. 2 measuring point) can reach 2.22 mm. The settlement values at the two sides of the measuring point are smaller, which are approximately 1.38–1.63 mm; the settlement values of the shallower depth of the No. 1, 2, and 3 measuring points are larger; the settlement values of the No. 7, 8, and 9 measuring points with the deeper depths are smaller. Further, Table 2 shows that the settlement of the arch caused by the excavation of the core soil is large and that the initial installation of the assembled steel plate significantly inhibits the settlement of the ground surface. Table 3 shows the settlement values measured at the test site.

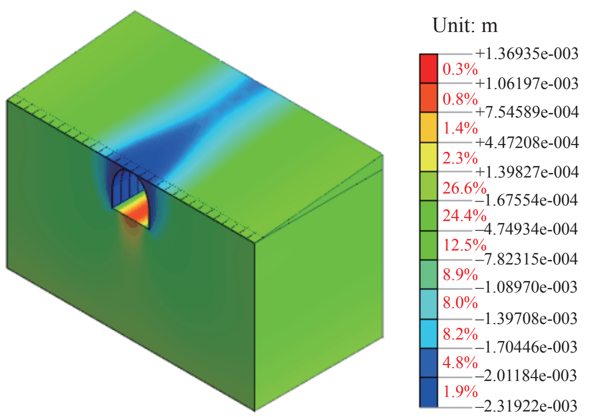


Fig. 9. Stereoscopic cloud chart of settlement when the excavation is completed by the mobile support structure method.

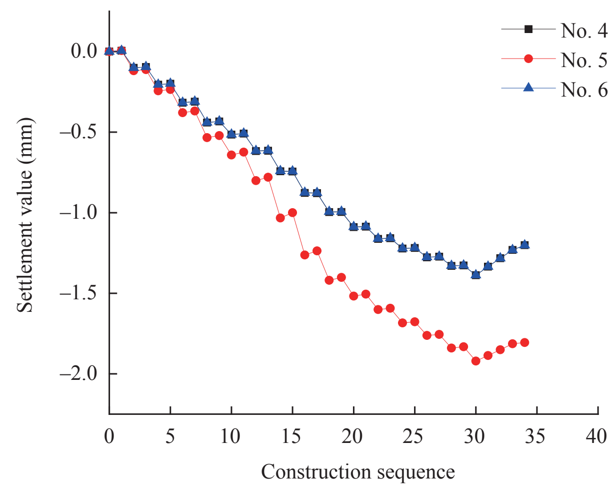


Fig. 11. Settlement maps of measuring points 4–6 of the mobile support structure method with construction progress.

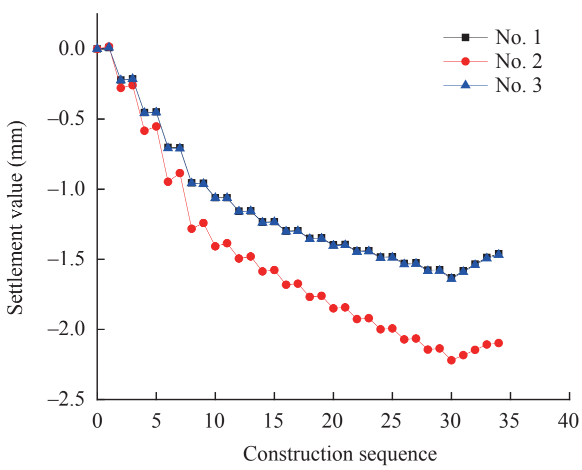


Fig. 10. Settlement maps of measuring points 1–3 of the mobile support structure method with construction progress.

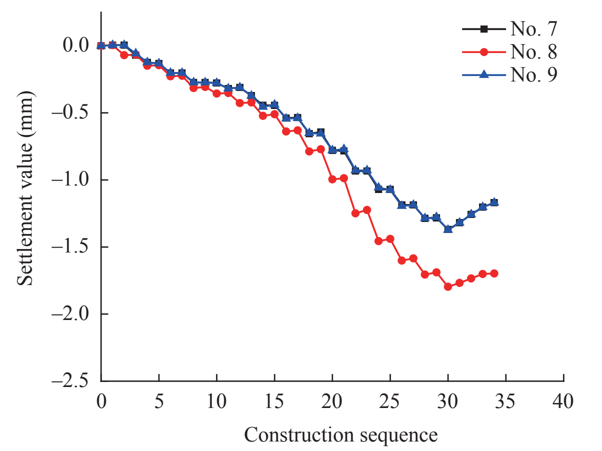


Fig. 12. Settlement maps of measuring points 7–9 of the mobile support structure method with construction progress.

Table 2. Surface settlement values.

Measuring point	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
Settlement value (mm)	1.63	2.22	1.64	1.39	1.92	1.39	1.38	1.79	1.38

As shown in Table 3, the maximum measured surface settlement at each point on the surface is 5 mm. Additionally, the surface settlement caused by the mobile support method in the shallow depth case is very small.

4 Application prospects of mobile support technology in urban underground engineering

4.1 Characteristics of mobile support method

4.1.1 Strong adaptability to tunnel sections

The mobile support is primarily the effect of the box supported by the arch support to advance the support, and the box can be flexibly adjusted and combined to adapt to various shapes of tunnel sections such as a square, round, oval, horseshoe, etc., which enhances its section adaptability.

4.1.2 High degree of automation

With the automatic control system, sensors such as travel, pressure, and speed collect the real-time status of the equipment. After the controller processes the control, the controller controls the power head to drill automatically according to the set parameters of the site. It can increase the degree of equipment automation and improve the construction efficiency.

4.1.3 Tail shield protection

Exploiting the shield machine's function of assembling segments in the tail of the shield, the mobile support equipment is provided with a tail shield, which is lapped on the concrete structure at the rear of the cabinet and equipment. The construction of concrete structures under the protection of the tail shields has significantly improved the construction safety compared with traditional mine construction.

The arch shell formed by the box body can fully ensure the excavation safety of the face of the hand, thereby achieving mechanical excavation. The construction equipment is simple in structure, easy to operate, small, low in energy consumption, and has little impact on the follow-up, crossover, and parallel constructions of the tunnel. Compared with the shield method, the mobile support method is more flexible in cross-section, low in construction cost, and can be tilted into a hole without a shaft under complex conditions.

4.2 Application prospects of mobile support method

According to statistics, the cities that have been approved for rail transit construction has reached 45 in China, according to the statistics of the Ministry of Housing and Urban–Rural Development of the People's Republic of China. By the end of December 20, 2016, 147 cities and 28 counties across the country have started to build underground integrated pipe corridors of approximately 2005 km, and the construction of urban underground space has entered a period of significant development.

Simultaneously, the intensive development of the city has also put forth higher requirements for the construction of underground projects. In recent years, the construction sites available for the construction of urban underground projects are continuously decreasing. This is particularly prominent in urban built-up areas [6]. The cost of site occupation and the difficulty of demolition increase, traffic guidance and pipeline relocations become more difficult, and the construction noise and dust are strictly limited. In addition, many underground construction projects involve crossing the existing structures at a close range. The mobile support method advances the box through the front of the excavation face before a large-scale excavation and forms a ring-shaped protection zone on the outer contour of the tunnel. Therefore, it has significant advantages in the near-distance crossing project and can significantly reduce the influence of excavation on the surrounding strata and buildings. Additionally, the mobile support method has a high degree of mechanization, which can significantly reduce the labor intensity of the construction workers, and can be adopted in the relatively short tunnels where

Table 3. Settlement values of each measuring point.

Time	Settlement value (mm)								
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
2016-12-06	0	0	0	0	0	0	0	0	0
2016-12-07	0	1	0	0	0	0	1	0	1
2016-12-09	−1	1	1	−2	−2	−1	0	−1	0
2016-12-12	0	0	1	−2	−3	−1	−3	−2	−1
2016-12-13	0	1	0	−2	−3	−1	−2	−2	0
2016-12-14	0	1	0	−3	−3	−2	−3	−1	−1
2016-12-16	0	0	0	−3	−3	−1	−3	−3	−2
2016-12-23	−1	0	−1	−5	−2	−2	−3	−3	−2
2016-12-25	−1	0	−2	−4	−4	−2	−4	−3	−2
2016-12-29	0	−1	−2	−5	−4	−2	−4	−3	−2
2016-12-30	0	−2	3	−5	−3	−2	−5	−2	−2

using shield machines are not economical. In addition, the section of mobile support method is flexible and has unique advantages in the construction of comprehensive urban corridors, because the integrated pipeline corridors are primarily flat and straight walls with shallow depths. The mobile support method can be adapted to the demands of section changes in underground pipe corridors in cities; additionally, it can be inclined into the hole to meet the construction of underground works under limited space conditions.

5 Conclusions

Herein, numerical control and field measurements were used to study the control effect of the mobile support technology on the ground deformation, and the characteristics of the mobile support technology are analyzed. Based on our research, the following conclusions were reached:

(1) The surface settlement caused by the mobile support technology even in the case of shallow depths is relatively small; therefore, this technology is capable of controlling the ground deformation.

(2) The mobile supports technology section has strong adaptability and high construction safety. It can be adapted to the demand of section changes in underground pipe corridors in cities and can be inclined into the hole, thereby allowing the construction of underground engineering under the condition of limited space. Therefore, this technology is of feasibility and it is necessary to promote this technology.

(3) As the current mobile support technology has only achieved success in industrialization tests and a series of construction methods is yet to be formulated, it is necessary to conduct research on the applicability, structure stress mechanism, and mechanical matching and select the suitable work sites for the pre-design and construction tests. We believe that by continuous efforts, a complete mobile support construction method can be developed.

References

[1] Wang M S. General theory on shallow buried excavation technology of underground engineering [M]. Hefei: Anhui Education Press, 2005. Chinese.

[2] Wang M S. Tunneling by TBM/shield in China: State-of-art，problems and proposals [J]. Tunnel Construction. 2014, 34 (3): 179–187. Chinese.

[3] Wang X Y, Liu W N, Zhao B M, et al. Pre-cutting method and its key techniques in application [J]. Modern Tunnelling Technology. 2011 (3): 22–27. Chinese.

[4] Feng Z M. Soil-structure interaction analysis and design method study of buried corrugated steel bridges (Master’s thesis) [D]. Beijing: Beijing Jiaotong University, 2009. Chinese.

[5] Wang X Y. Analysis of ground deformation caused by mobile support technology [R]. Beijing: Beijing Jiaotong University, 2017. Chinese.

[6] Li H A. Application and prospect analysis of large-diameter shield driven tunnels combined with enlarged metro stations [J]. Modern Tunneling Technology, 2015, 52 (5): 16–23. Chinese.