Construction of a large-section long pedestrian underpass using pipe jacking in water-filled clay

Lishuai Wang¹, Chao Kong², Feng Peng²*, Baobao Zhang¹, Jiqing Deng², Song Gu³ and Quan Sun³

¹China Railway Construction Engineering Group North Engineering Co., Ltd., Tianjing, 300000, China
²School of Civil Engineering and Architecture, Southwest University of Science and Technology, Mianyang, Sichuan, 621010, China
³China Railway Development Investment Group Co., Ltd., Yunnan, Kunming, 650500, China

*Corresponding author’s e-mail: 928409600@qq.com

Abstract. This paper presents a design and construction schemes of a pipe jacking project in Kunming, China in detail. The underpass, having a width of 6.9 m and a height of 4.9 m, was jacked 46m in water-filled clay under a busy viaduct with 4.5 m overburden soil. Some adjustments have been made to the construction process due to the characteristics of the soil layer, the surrounding environment and the existing pipeline. During the whole construction process: the pipe jacking passes through the shallow confined aquifer with high water content and high void ratio, it is easy to produce rheology. In addition, the attitude control of whole tube is also a difficulty, and some adjustments have been made to this problem; the monitoring scheme has also been adjusted accordingly. In general, this project is completed successfully and the traffic on ground and viaduct runs well during the whole construction process.

1. Introduction

Underground space has become a critical development of modern cities. The partial arrangement of urban infrastructure in urban underground space can solve urban traffic pressure to a certain extent. Pipe jacking has many advantages such as economy, safety, efficiency and simplicity, and thus has been widely used in the construction of urban underground space. From the 1960s to the 1980s, pipe jacking technology was fully developed and advanced in countries such as Europe and Japan. The pipe jacking construction process has achieved remarkable results [1-5], particularly contain the distance of jacking is getting longer, the pipe diameter of the pipe jacking section is getting bigger, and the speed of jacking construction is getting faster. The regional differences in domestic pipe jacking technology are obvious, and the technical level of the construction team is still uneven. With the development of China's urbanization process, the scope of the applied industry is also expanding. The pipe jacking construction was mainly used for the construction of the sewer from the beginning. In recent years, it has been widely used in underground construction of many related projects such as urban underground passages and underground integrated pipe corridors. In order to ensure the safety of the pipe jacking in the underground construction process and ensure the smooth progress of the pipe jacking construction, we must carry out a more comprehensive study on the difficult technical problems existing in the pipe jacking construction [6-9]. Depends on the actual situation of construction and application of pipe
jacking technology in urban areas, through the research on the pipe jacking construction project of this project, it analyzes the difficult problems encountered during the construction process, the key technologies and the construction plan to solve the problems, and explores some theories that can be borrowed in the similar urban pipe jacking construction project in the future.

2. Project description

2.1. Pipe jacking project
Fig.1 and Fig.2 show the plan layout and section view of this pipe jacking project. There are several residential buildings around the construction site. The pedestrian underpass, being a municipal facility connecting the residential area to subway station district (shield tunnels of Kunming Metro Line 4), was designed to perpendicularly pass beneath the busy Caiyun North Road. The top of underpass is 4.5 m below the ground surface. To control the influence of construction on road traffic, non-invasive pipe jacking method was selected. Starting shaft and receiving shaft were constructed at the far ends of pipe jacking line. Each prefabricate reinforced concrete pipe segment is 1.5 m long, 6.9 m wide and 4.9 m high with thickness of 0.5 m.

2.2. Site condition
The construction site is located in Kunming City, Yunnan Province, which passes through the entire Kunming Fault Lake Basin from the northwest to the southeast, Meanwhile, this basin is located in the
watershed of the Jinsha River, Nanpan River and Honghe River Basin on the south of China. At this site, a total of 68 exploration holes were surveyed (including 24 replenishment holes), 50 soil samples and standard boreholes were drilled, 2 static penetration holes, 2 single hole pumping holes, and 2 wave velocity test holes. There are 2 soil resistivity test holes and 2 ground temperature observation holes. Limited by the site conditions, a total of 8 holes were not built in the building, and 60 holes were actually completed. The geological section obtained from geological drilling is shown in Fig. 2. The results show that the ground up to a depth of 28m mainly consists of New generation Quaternary Holocene artificial accumulation layer (Q4m1) and new deposits, including Prime fill, silty clay, clay, Fine sand, Peat soil, Silt from the top to down. The pipe segments were jacked in muddy silty clay layer.

3. Construction schemes

3.1. Schemes of starting and receiving shafts

The starting and receiving shafts would be finished firstly. The starting shaft with a length of 13.6 m, a width of 11.9 m and a depth of 11 m. Both the starting shaft and receiving shaft uses ø1000@1200 bored pile (24m length) + ø850@600 three-axis mixing pile water curtain (20m length). Both the reaction frame of starting shaft and receiving shaft are reinforced with ø850@600 three-axis mixing pile. The reinforcement range contains the back of the reaction frame and the main body of the station. The reinforcement area of the portal is 5.8m long. Meanwhile, the area of the receiving shaft is 6m. The reinforced soil own good homogeneity and self-supporting, which the unconfined compressive strength of the reinforced soil is not less than 1 MPa. The schematic diagram of pipe jacking construction is shown in Fig. 3.

3.2. Schemes of underpass

The machine (earth pressure balance), including front shield, back shield and screw conveyor, 6.9 m wide and 4.9 m high. The cutter head of the machine consists 6 large cutter arranged in a staggered manner, driven by six 30 kW motors. The pipe segment would be pre-manufactured, and excavate a vertical working well. After lifting the pipe joints into the starting shaft, the pipe joints are pressed by the large thrust provided by the hydraulic cylinders to the scheduled excavation face. Then, while excavating the soil layer in the pipe, the excavated earth is transported from the pipe to the ground, and then the pipe joint is pushed into the hollowed out soil layer by the large thrust provided by the hydraulic cylinder. After the first section of the pipe is pushed into the soil layer, the second section of the pipe is suspended into the working well to repeat the above process, and the excavation and jacking are sequentially performed until the hole is completed. The schematic diagram and field scene of pipe jacking construction are illustrated in Figs. 3 and 4. The first pipe segment was jacked into the ground on August 25th, 2019 and the whole underpass was completed on September 24th, 2019. It took 30 days for the whole pipe jacking process.
4. Field monitoring scheme

4.1. General idea of field monitoring
The geological conditions and environment along the excavation section are complex, which makes the construction difficult. During the construction period, monitor the deformation and other aspects of the structural engineering and the important underground and above ground buildings (structures), ground roads and primary supporting structures around the construction line, so as to provide timely and reliable information for units to assess the safety of the project during the construction period and the impact of the construction on the surrounding environment.

The whole hidden danger or accident shall be predicted timely and accurately, so as to take effective measures to eliminate hidden danger in time and avoid accidents. [Fig. 5]. illustrate the plan layout of tunnels monitoring sections.

4.2. content and purpose of field monitoring
According to the relevant design documents and construction drawings, determine the location and quantity of the monitoring arrangement of the excavation section. [Table.1]
Table 1. Monitoring point statistic

| Numbering | content                        | unit   | Quantity |
|-----------|--------------------------------|--------|----------|
| 1         | bench mark                     | point  | 4        |
| 2         | Surface subsidence             | point  | 59       |
| 3         | Segmental structure settlement | point  | -        |
| 4         | Building settlement            | point  | 19       |
| 5         | Crack width observation        | point  | -        |

From Table 1, it can be seen, specific requirements are made due to the construction progress and the requirements provided by the design. When it came conditions and data changed abnormally, the monitoring personnel shall firstly carry out inspection himself. After the retest is correct, they shall immediately report to the leader in charge and the supervisor of the project department. The project department shall convene relevant departments to hold a special meeting for safety assessment, determine the corresponding emergency response measures, such as increasing the frequency of monitoring and the specific frequency of monitoring, and form meeting minutes.

5. Monitoring data

According to the monitoring data. [Table 2 and Fig 6]. The monitoring points are normal during the whole construction period, and there is no warning.

Table 2. monitoring data of Surface subsidence

| Date       | Initial value (mm) | Final value (mm) | Settlement value (mm) | Rate (mm/d) | Cumulative value (mm) |
|------------|--------------------|------------------|-----------------------|-------------|-----------------------|
| DBC-A02-01 | 1892.84288         | 1892.84111       | -1.77                 | -0.06       | -10.59                |
| DBC-A02-03 | 1893.05204         | 1893.04806       | -3.98                 | -0.14       | -14.84                |
| DBC-A02-04 | 1892.94048         | 1892.93754       | -2.94                 | -0.14       | -20.66                |
| DBC-A03-01 | 1893.50924         | 1893.50992       | 0.68                  | 0.02        | -3.28                 |
| DBC-A03-02 | 1894.00622         | 1894.00503       | -1.19                 | -0.04       | -2.47                 |
| DBC-A05-01 | 1894.19774         | 1894.19813       | 0.39                  | 0.01        | -9.84                 |
| DBC-A05-02 | 1894.27748         | 1894.27875       | 1.27                  | 0.05        | -1.55                 |
| DBC-A05-03 | 1894.43895         | 1894.43638       | -2.57                 | -0.18       | 2.52                  |
Fig. 6. Surface settlement temporal curve

6. Conclusions
In this paper, a large section long rectangular pedestrian underpass constructed by pipe jacking is taken as an example, which passes under busy roadway and over existing viaduct. The design and construction scheme are introduced in detail. The project is successfully completed without any additional time and money consuming deformation control measures. Strict construction management and reasonable on-site monitoring are also considered to be very effective measures to control environmental deformation and ensure construction safety.

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