The Application of Mud-water Balance Method Pipe Jacking in Jinzhong Road ((Amoy Circular Road (ACR) Main Road—ACR Eastern Section)) Reconstruction Project

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Abstract. In the Jinzhong Road (ACR Main Road - ACR Eastern Section) Reconstruction Project in start up area of Xiamen Cross-strait Financial Centre, mud-water balance method was adopted and successfully jacked 2.4m diameter double-hole jacking pipes for 558m. This essay demonstrates the design of pipe jacking in this project and key points of construction and management, which accrues experience for large-diameter pipe jacking under Xiamen specific geological condition in the future.

Introduction

Pipe jacking construction is a process that, with the support of back, pipe jacking machine and tool head are pushed from working pit to receiving pit by main jack and rely station jacks, then pipes are left underground but pipe jacking machine and tool head are collected\textsuperscript{[1]}. According to types of pipe jacking machine, pipe jacking is classified as: manually artificial pipe jacking, squeeze pipe jacking, water jet pipe jacking and mechanical pipe jacking. Mechanical pipe jacking is consisted of mud type, slurry type, earth pressure type, rock type and etc. Widely use of mud-water balance method pipe jacking construction is because that can be applied to more geological conditions; that has little impact on soil nearby; that results in slight land subsidence after construction; that has better work environment in working pits; that is able to continues unearthed; and that has high movement speed. It is the most appropriate approach for granule and hard bottom as its short cutting moment of force. Key feature of mud-water balance pipe jacking construction is that, during the process, using mud pressure in jacking drilling machine’s mud tank caused by water inlet pipe to balance earth pressure and groundwater pressure in front of jacking drilling machine, and dispose soil through mud pump. This essay illustrates pipe jacking construction in Jinzhong Road (ACR Main Road - ACR Eastern Section) in Xiamen Cross-strait Financial Centre start up area to explain the design of pipe jacking in this project and key points of construction and administration.

Engineering Condition

Project Background

Jinzhong road (ACR Main Road - ACR Eastern Section) reconstruction project is located in Nijin Community and Pukou Community in Huli District in Xiamen, road starting point across ACR Main Road and ending point across ACR East Road. It is main road of the city with 673, 301m in length and 40m in width.

Storm sewer in Jinzhong Road mainly collects local and surrounding region’s rainfall. Total catchment area is 245 hectare. Rainwater tank culvert is located in road skate mark K0+000～
K0+622. As skate mark K0+622～B0+245 across ACR East Road, two 2.4m diameter pipes are adopted. Two 2.4m diameter rain pipes are used in skate mark B0+245～B0+382, then access to sea.

**Geological Condition**

The pipe jacking project in such area mostly involves silty clay. Silty clay is, around ACR, mainly consisted of particle and cosmid with 10~15% sand content, in brown colour, able to be made into hard plastic, and silty clay has no reaction when shaking and vibrating, has more smooth cutting surface, has higher dry strength, has medium toughness, which belongs to dry type of soil. The standard value of modified below count of standard penetration test (SPT) is approximately 13 counts. In conclusion, mud-water balance method pipe jacking is adopted.

**Pipe and Sink**

Round reinforced concrete three-stage drainage pipes are used, which inner diameter is 2.4m, which strength is C50, and which joint is in A shape. Rectangular sections are applied to working pits Y15, Y17 and receiving pits Y16, Y18. C40 waterproof concrete, in P8 impervious level, is used to build sink body. The construction in Y16 uses open cut technology and in Y15, Y17 and Y18 sink technology is used and pipes are divided in to two parts. Expansive concrete is poured on to sink baseboard. The first pipe is from working pit to receiving pit, the second pipe is from working pit to Y16 receiving pit, the last one is from Y17 working pit to Y18 receiving pit. Pipe jacking construction site is as shown in picture 1.

**Design of Pipe Jacking**

The most vital design in pipe jacking construction is calculation of jacking force and the calculation helps to ensure the ability of jacking equipment, to check the jacking force capacity of pipes, to arrange jacking equipment, to estimate the capacity of back and to choose appropriate back form and etc. [2].

![Figure 1. Pipe jacking construction site.](image1)

![Figure 2. Structure of mud-water balance machine.](image2)

**Calculation of Jacking Force**

To ensure pipes can be pushed forward smoothly underground, jacking force needs to overcome external force acts on pipeline, also known as jacking resistance, including penetration resistance, frictional resistance, and pipes’ gravity frictional resistance.

The formula of jacking force [3] is: \( F_p = \pi D_0 L f_k + N_F \), \( \pi D_0 L f_k \) represents for frictional resistance, \( N_F \) represents for penetration resistance, \( N_F = \pi / 4 \cdot D_g^2 P \).

Meanings of factors in the formula are listed below: \( D_0 \) is external diameter, 2.9m in the project; \( L \) is designed pipe jacking length, 139.4m in the project; \( f_k \) is average frictional resistance between pipes and soil per unit area, which is made at 4 KN/m²; \( D_g \) is external diameter, 2.9m in the project; \( P \) is control earth pressure, which is made to be equal to passive earth pressure at 1/3\( D_g \) of tool head.
(KN/m²), $P=γ(H+2/3D_p)\tan(45°+\varphi/2)$. γ is gravity density of soil where pipes located, the figure for silty clay is 18.6 KN/m³; $\varphi$ is internal friction angle of soil where pipes are, 20.8° in the project; H is height from top of pipe to the ground (m), 5.2m in the project. By calculation:

$$\pi D_0 L f_c = \pi \times 2.9 \times 4 \times 139.4 = 5077.5 \text{KN};$$

$$P = 18.6 \times (5.2 + 2/3 \times 2.9) \tan(45° + 20.8°/2) = 18.6 \times (5.2 + 1.93) \times 1.45 = 192.3 \text{kN/m}^2;$$

$$N_t = \pi \times 2.9 \times 2.9/4 \times 192.3 = 1269.5 \text{kN}; \quad F_p = 5077.5 + 1269.5 = 6347 \text{kN}.$$

**The Jacking Force Capacity of Sink Body at Back of Jack**

Back structure design can be made after the maximum jacking force is determined. Structure and size of back are mainly determined by pipe diameters and passive earth pressure of back soil, which is also known as earth resistance. Calculating earth resistance is aimed to protect back soil under the maximum jacking force, so that natural back soil can be taken full advantage during jacking process. Taking working pit Y18 to working pit Y17 as an example to estimate the maximum jacking force that sink body can take, the formula $[2]$ is

$$R_c = K_r \cdot B \cdot H \cdot (h + H/2) \gamma \cdot K_p.$$  

In the formula, $R_c$ is the capacity of back soil; $K_r$ is earth resistance coefficient of back, as to site without pile plank, $K_r$ is made at 0.85; $B$ is width of back body (m), which is 10m in the project; $H$ is height of back body (m), total height of twice pouring in the project is 9.9m; $h$ is distance between the top of back body and the ground, which is 3.5m in the project; $\gamma$ is volume weight of soil, 18.6 KN/m³ for silty clay; $K_p$ is coefficient of passive earth pressure, $K_p = \tan^2(45° + \varphi/2)$. By calculating:

$$R_c = 0.85 \times 10 \times 9.9 \times (3.5 + 9.9/2) \times 18.6 \times \tan^2(45° + 20.8°/2) = 65566.78 \text{ KN},$$

the force is bigger than jacking resistance $F_p = 6347 \text{ KN}$.

**Pipe Jacking Equipment**

Full cross-section drilling machine is used in the mud-water balance method pipe jacking and it is divided into two parts. Soil cutter is installed in the front of forepart of the drilling machine, followed by clapboard which divides forepart into two sections. Mud tank is located in front of the clapboard to sustain force from mud, while engine compartment is located behind the clapboard at atmosphere pressure. Back part of the drilling machine is connected with jacking pipes. When pipes are pushed forward, six 30KW electric machine motivate polygon cutter, installed at principle axis, to spin. With movement of pipes, cutter continues spin to cut soil, so that mud tank forms between cutter and polygon shell. After crushed by cutter, major soil block and stone turned into smaller pieces, so that they go into mud tank through grid plate. One water inlet and one mud outlet are located under the mud tank; earth pressure and groundwater pressure are balanced by water inflowing through water inlet. Meanwhile, muddy water is considered as a medium to transport soil, it is disposed out of mud tank through mud outlet. To achieve a better balance between groundwater pressure and earth pressure where pipes are located at, the project pays attention to control water pressure in mud tank and earth pressure in soil tank. Pipe jacking drilling machine is shown in picture 2. Symbol in picture represents: 1-cutter; 2-soil tank; 3-mud tank; 4-rectification oil cylinder; 5-principle axis box; 6-front shell; 7-back shell; 8-electronic machine cabinet; 9-grid plate

Each main device has six jacks in two lines. The main jack is single stroke jack, which traveling distance is 1.5m and its max jacking force is 2000 KN. Max jacking force for main devices can be 12000 KN. Each oil cylinder has independent oil circuit control system; the project achieved supplementary rectification by adjusting central joint force of main devices.
Key Technologies to Construct

Measurement and Rectification

As demonstrated before, skate mark K0+622~B0+245 across ACR East Road. ACR is a high standard set of road traffic, scenic tourism, coastal environmental remediation as one of the city landscape road, which is a secondary road in the city. During construction, traffic in the road must always be kept smoothly. To prevent the road from subsidence, during the construction, measurements of axis and height and pipe rectification become key control technologies.

In the project, T2 theodolite and its supporting distance measurement machine are applied to axis measurement, while S3 level is applied to height control. After construction in working pits, jacking axis will be determined by measuring centre of prepared hole in working pits and that in receiving pits, then jacking axis will be put into measuring platform in working pits and tank body, which nearby pipe launcher in the tank. Surveying control network is established in tank and each control point will be reviewed regularly. Putting through pipe measurement starting point and two back sight points, starting point is on special measurement platform at back of jack, back sight point is on sink body upper the wall hole, and check each other regularly. To guarantee little deviation of jacking axis, manual measurement is used in the last 5m to double check the whole pipe line. When jacking, set up a light target at tool head so that head’s direction can be known anytime according to the reading reflected by the light target.

Jacking measurement and direction control mainly rely on total station, accompanied by laser theodolite and level. At spots that hard to observe, automatic tracking machine and gyroscope are used. Rectification by oil cylinder during measurement follows rules that direction up-and-down goes first followed by direction left-and-right.

Pipe jacking machine in the project has the function that can rectify automatically; rectification equipment used is total station (GTS-800A type). The operating principle of rectification is: total station sends invisible light to central light target at tool head, and then light target reflects deviant value to the computer, so that jacks controlled by the computer make rectification. Max error of total station measuring height and jacking axis is 2 parts per million (ppm); rectification error of jacking machine is within 2 cm.

Rectification methods are used during process of pipe jacking in the project: (1) External diameter of tool head is 60mm wide than pipe diameter, which leave enough space to form 30mm thixotropic fluids between pipe and soil to reduce the constraining force of undisturbed soil and to make it easier to rectify. (2) Spinning cutter located on the pipe works at opposite direction when rectifying, that enlarge cut soil volume at opposite direction of rectification.

Pipe Locked and Solutions

Using mud to reduce resistance is one of the important strategies in long distance pipe jacking. During construction, added lubricating mud forms a more complete mud cover outside pipes, generally, friction resistance can be reduced from 12~20 KN/m² to 3~5 KN/m². The project adds mud into tail end of pipe jacking drilling machine simultaneously to reduce resistance.

However, in process of pipes pushed from working pit Y17 to receiving pit Y16, when 8 joints which has 20m in length, were pushed underground from south, the procedure delayed for one day because of power off in ACR. After that, effects of reducing friction resistance by mud disappeared, and was replaced by friction resistance caused by surrounding soil. When restarted construction, jacking force increased continuously, pipes went broken during movement because resistance was too big, though thixotropic fluids solution was taken to reduce resistance. Finally, the whole pipe locked.

There are normally 2 solutions when pipe locked: (1) Pushing pipes underground from its opposite direction and then it can be connected with locked pipe; (2) Manually excavating out locked pipes. As to this project, receiving pit Y16 could not be treated as back without enough resistance force, so that connection was not practical. As soil cover on locked pipes was only 3~4m and most of its was plain fill, if manually excavating out, large area collapse might happen and it could be in great difficult.
Therefore, neither of these two solutions could be used in this project. After carefully demonstration, a brand new solution was put up: leave locked pipes underground and push steel pipes along previous jacking axis from working pit. The steel pipes would cover and pass through locked pipes and keep moving until the whole pipe jacking operation completed.

Mud-water balance method was still applied to steel pipes with its external diameter 2.36m in length and 22mm in thickness and Q345B in strength. Each steel pipe was 4m in length, each joint was butt weld. Total length of steel pipe was 72.1m. After shaped up and rust removal, epoxy asphalt corrosion prevention materials were used onto both internal and external body of the steel pipe. Construction sites before and after steel pipe enter into locked pipe are shown as follow.

Administration and Recommendations

Pipe jacking project is a system engineering, which always influenced by various factors. This essay summarises experience in Jinzhong Road (ACR main road – ACR east road) reconstruction project, and gives recommendations on large diameter pipe jacking in the future as follows:

(1) Pay attention to pipe jacking construction project approachment. According to soil that pipes located in and judging advantages and disadvantages of various pipe jacking strategies, to determine the construction method that is the most suitable for specific geological condition.

(2) Pay attention to measurement and rectification during construction. In the process, measurement should be enhanced, rectification should be made whenever deviation happens, requirements of tracking should be met, and pipe instable should be prevented. Equipments should be arranged well-balanced to control pipe reverse. Collecting ground monitoring, tool head deviation, earth pressure situation, rectification situation and etc. in time to disclose and explain to operators before they work, and to supervise and administrate all positions.

(3) Pay attention to resistance reducing systems. Input and output of thixotropic fluids are operated at the same time, so mud should be made according to experiments and adjusted according to different geological condition. Meanwhile, mud should be added to pipes to ensure the form of mud cover so that effects of reducing friction resistance can be achieved.

(4) Preparation should be fully completed before pipes are pushed into soil. Ensuring all equipment is ready to work and jacking can be operated as soon as closing plate of doorway opens. Tool head should be jacked into soil at once after closing plate opens and sealing up should be made to prevent high volume of water leaking which could result in collapse.

(5) Emergency plan should be made before construction. For example, emergency plans for boulder and other barriers, and for pipe locked situation and etc.

(6) Administration of technicians should be enhanced. Technicians should turn for duty on a regular shift and it has to be ensured that there is at least one technician during each shift to solve potential problems that could happen by chance. Each shift should make records that accurate and authentic to analyse and mastery various situation during the process so that correct decision could be made to guide the jacking construction.
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