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Key aspects of a DN4000 steel pipe jacking project in China: A case study of a water pipeline in the Shanghai Huangpu River

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ABSTRACT

Pipe Jacking is one of the most popular method to construct new pipelines below the ground surface in the area of oil & gas, water supply, sewage, communication and electricity pipelines, and pipe-roof projects. The common jacked pipes are concrete pipes, steel pipes, glass Fiber Reinforced plastic Mortar Pipes (FRMP), cast ductile iron pipes and clay pipes. The key technologies involved includes but not limited to: selection of the jacking machine, jacking force prediction and reduction, trajectory deviation control and corrosion protection. Moreover, the key technologies may changes from one jacking project to another one, as the geological conditions and the size of the jacking projects changes. These key aspects are crucial importance especially for the large diameter pipe jacking, because out of control of theses aspects will remarkably increase of the failure risks. In this paper, these key aspects were introduced and discussed based on the largest diameter steel pipe jacking project, called C3 pipe jacking project. This projects involved nine sections of a DN4000 mm and totally 5221 m jacking length in soft soil strata. The largest single jacking length between two shafts is 970 m. An earth-pressure-balance pipe-jacking machine (EPB) with a large spoke-type cutter face was employed to excavate the soil. A highly viscous bentonite slurry mixed with polymer was used to reduce the friction resistance. Close control of the pipe welding and use of corrosion protection technology has ensured the efficiency and quality of the project.

1. Introduction

In the past century, many large pipe jacking projects have been constructed around the world. In recent years, notable projects include a 2.4 m diameter and 1040 m long drainage tunnel constructed in Canada in April 2012 (Shen et al., 2012). A 7.8 km (4.9 miles) project with 1.37 m or 1.52 m diameter was implemented in America (Smith et al., 2001). A 3.13 m diameter steel pipe was constructed in South Africa (Trebicki et al., 2002). Approximately 48.3 km (30 miles) of pipe was jacked with fourteen tunnel crossings in America (Shirk, 2016). In China, many large diameter and long distance pipe jacking projects were also constructed in recent years. Some of the projects are: Guangzhou Xijiang project with 5.14 km jacking distance and 2.4 m or 3.6 m diameter (Zhong et al., 2011), Shanghai Qingcaosha project with 27 km jacking distance and 3.6 m diameter (Gu, 2012), Shanghai Hongqiao energy center pipeline project with 4.2 m outside diameter steel pipe and 4.7 m outside diameter concrete pipe (Zhou et al., 2014), Kunming sewage treatment plant drainage project with 4 m inner diameter concrete pipe and 1188 m jacking length (Tunnel Construction, 2014), Shanghai West Beijing Road-West Huaxia Road electrical cable tunnel project with 3.5 m diameter and 6.22 km jacking distance (Ding et al., 2010).

From the cases listed above, most of the projects which has more than 4 m diameter are concrete pipe jacking while most steel pipe jacking projects are less than 3 m diameter. C3 section of Huangpu River water pipelines project is both large and long in diameter and distance without precedent in China before. Compared to small diameter pipe jacking, the large diameter projects are likely to experience more risks. Such as excessive jacking path deviation and jacking force, difficulty of lubrication mud grouting and steel pipe buckling. To avoid or minimize the failure risk, successful use of the key technologies involved is particularly important. In this paper, the key aspects of the pipe jacking are analyzed based on the Section C3 of the overall pipe jacking project.

2. Background of the C3 section of the pipe jacking project

2.1. Project background

The connecting pipe project in the upstream water source area of Huangpu River includes the water transmission line, the Songjiang pump station and three water delivery branch points at Qingpu, Jinshan

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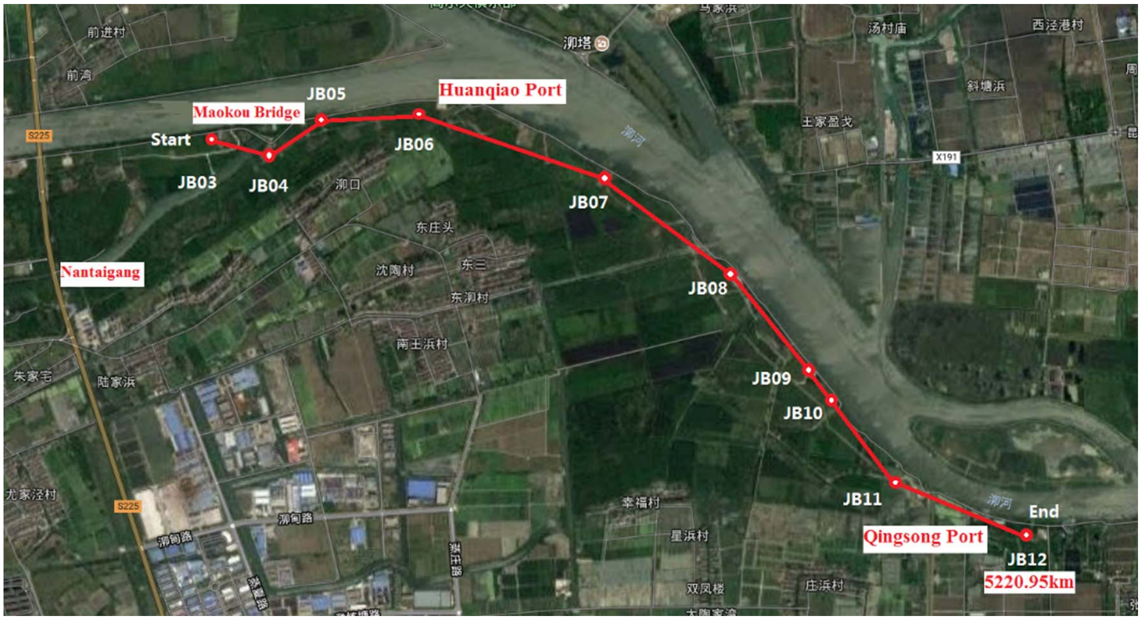

Fig. 1. Construction schematic plan of C3 section.

and Minfeng. The project starts from a shaft in the pump station of Jinze Reservoir, and terminates at the Minfeng water point. The water transmission line is constructed using steel pipes with 4 m or 3.6 m inner diameter, and pipe jacked segments are connected using 70 working shafts. As steel pipe has a good sealing performance, a high inner pressure capacity and little impact on the environment, it is widely applied in urban drainage pipe construction (Chen, 2012). The project is being used to transport 3.51 million cubic meters of water every day (m^3/d) through the 42 km transmission line. The success of this project will improve the ability to face a sudden water pollution incident, will enhance the safety of the raw water supply and promote the economic, social and environmental development of Shanghai.

This paper focus on the C3 section of the project which runs from the JB03 shaft in Qingpu to the JB12 shaft in the Songjiang pump station with a length of 5220.95 m, including 8 working shafts and 9 jacking sections (Fig. 1, Table 1). The steel pipes used in the C3 section are constructed with 4 m inner diameter and two different wall thickness (40 mm and 38 mm). Such kind of large diameter and length steel pipe jacking project is firstly constructed in China with no construction precedent.

The C3 section crosses various types of terrain, including woodland, fishponds, river channels and sluices. The geomorphic type along the project line is a limnetic plain and slightly undulating. The surrounding environment of the project is relatively complicated requiring jacking through areas containing multiple important watercourses and ports such as Nandagang, Huanqiao port, Dongtang port, Qingsong port and Zhongxin river and including obstacles such as high-voltage towers and communication lines. The range of single jacking distances is between 600 and 1000 m. Some wells, especially JB07 and JB08, are in a confined aquifer, so sudden water ingress or other conditions were of concern. Because of the long construction distance as well as the large diameter steel pipe, which lead to the lubrication mud difficult to surround the pipes entirely and the pipe-soil friction resistance increase. Additionally, the large diameter steel pipes with high stiffness are hard to adjust trajectory and need more stoppage time to welding. So it is more difficult to control jacking force, trajectory and improve jacking efficiency, etc. than in typical smaller diameter and shorter jacking distance projects. This paper focuses on those problems and difficulties.

Table 1
Information of all jacking periods of C3 section.

Jacking period	Diameter-wall thickness (mm)	Pipe length (m)	Buried depth of pipe center (m)
JB04 ~ JB03	DN4000-38	253.05	−7.50 to −7.50
JB04 ~ JB05	DN4000-38	289.06	−7.50 to −7.50
JB06 ~ JB05	DN4000-38	763.30	−9.00 to −7.50
JB07 ~ JB06	DN4000-40	969.94	−12.50 to −9.00
JB08 ~ JB07	DN4000-40	926.02	−12.50 to −12.50
JB08 ~ JB09	DN4000-40	637.61	−12.50 to −8.00
JB09 ~ JB10	DN4000-38	247.60	−8.00 to −8.00
JB11 ~ JB10	DN4000-38	689.30	−9.00 to −8.00
JB11 ~ JB12	DN4000-38	433.84	−9.00 to −9.00
Total		5220.95	

2.2. Geological conditions

The strata of the C3 section consist of artificial fill, silty soil, mucky soil, clay and sandy soil, as shown in Table 2 and Fig. 2. Fig. 2 shows the strata condition of the JB06-JB07 jacking section which is noteworthy because it has the longest jacking length and deepest depth of pipe. The pipe jacking passes through mucky silty clay, silty clay and sandy soil at

Table 2
Summary of soil properties.

Layer	Soil	P_s of CPT (MPa)	Density (kN/m^3)	Cohesion (kPa)	Internal friction angle (°)
②1	Silty clay	0.70	18.5	19	20.5
②3	Silty clay	1.35	18.7	6	30.5
③1	Mucky silty clay	0.41	17.6	13	18.0
③1-inter	Sandy silt	4.56	18.4	7	29.5
③3	Clay	0.51	17.6	14	16.5
⑥1-1	Silty clay	2.22	19.4	33	19.0
⑥1-2	Silty clay	1.38	18.9	29	19.0
⑥2-1	Sandy silt	3.41	18.7	5	31.0
⑥2-2	Sandy silt	5.96	19.0	5	32.0
⑥3	Silty clayey soil	0.96	18.4	19	19.5
⑥3-inter	Sandy silt	3.18	18.5	26	31.0
⑥4-1	Silty clay	2.22	19.6	40	19.5

CPT: Cone penetration test. P_s: specific penetration resistance.