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The Application of Trenchless Piping in Sandbar Drainage Network Renovation Projects

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Abstract: In this study, the research progress of trenchless piping technology for pipes with a large diameter was reviewed. The geological conditions of the sandbar in Xiangyang were taken into account in this study. This paper highlights the construction process management of the pipeline network project in Yuliangzhou Starting Area of Xiangyang City. Research was carried out in the aspects of optimizing mud ratio, controlling pipeline elevations, pipeline welding, and trenchless pipeline construction in limited spaces, stable support during pit excavation, and controlling the spacing between the junctions of two pipe segments. The research resulted in excellent outcomes and ensured safe construction, and the quality requirements were also met.

Keywords: High water level; Sandbar; Trenchless piping

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1. Introduction

Despite the rapid development of cities, many sewer systems in the old urban areas are still combined sewer systems [1]. As the city progressed, the sewage pressure increased sharply. Besides, many old pipelines did not undergo regular maintenance, which resulted in many problems like misalignment, disconnection, water seepage, rupture, root infiltration, and pockmarked surface. This led to poor drainage, which caused water accumulation and flooding. Environmental pollution, noise pollution, traffic congestion, and adjacent pipeline damage caused by excavation have also been major issues in this city. Therefore, there is an urgent need to employ non-excavation trenchless construction methods for the construction of such large-diameter, well-sealed pipeline projects. This article takes the Xiangyang Yuliangzhou starter district pipeline network project as an example and discusses the research and application of non-excavation large-diameter pipeline construction technology. It also provides insights and references for similar projects in the future.

2. Project overview

The Phase I renovation project of the drainage pipeline network in Yuliangzhou Starting Area, Xiangyang City, was located on the western side of Yuliangzhou, extending from the west to the Han River, east to Haoran Road, north to First Road, and south to Oasis Avenue. The total area covered approximately 2.4 square kilometers. This project involved converting the original combined sewage system into a separated sewage system. The new sewage pipeline network had a total length of 15.233 km, with pipe diameters ranging from 600 mm to 400 mm. Additionally, a new integrated sewage lift pump station with a capacity of 0.2 m^3/s was constructed [2].

The geological structure of Yuliangzhou belongs to the Quaternary Holocene formation (Q4al+pl), characterized by layers of sand, gravel, and silt deposits, with an upper section of marl on the bedrock [2]. The geological drilling data showed that at depths of 5 to 12.8 meters, there was fine sand (classified as type III), and at depths of 12.8 to 14.2 meters, there were rounded gravels (classified as type V to VI). Below 35 meters, there was tertiary clay, marl, and sandstone (classified as type V). The non-rock soil cover layer was not very deep, and there were no severe soft layers encountered. The underground utility networks crossed at depths ranging from 5 to 12.8 meters within the fine sand layer (**Figure 1**).

Figure 1. Overview of Yuliangzhou

3. Important and difficult points in the construction of trenchless pipelines at sandbars

3.1. Difficulties in controlling pipeline elevation

Due to the layered composition of sand and silt in the underground soil at this project site, coupled with a high water table, the pipeline, which had a lower density than the slurry, consistently remained suspended near the upper part of the borehole. This resulted in excessive drag forces and elevation deviations that exceeded regulatory requirements.

3.2. Difficulties in foundation pit support and dewatering

According to the design specifications, this project utilized wellpoint dewatering and FSP-IV Larson steel sheet pile support for the excavation and receiving pits in the pipeline installation area. However, due to the project’s location in the Yuliangzhou Economic Development Zone, surrounded by the Han River, and with a high water table and challenging geological conditions, the excavation support and dewatering were particularly difficult (**Figure 2**).

Figure 2. Support and groundwater level diagram

3.3. Serious pipe scratches

The project was located near a residential area, which is densely populated. The long-distance pipeline dragging process could significantly disrupt traffic. Additionally, limited space for welding and transportation will result in considerable bending and abrasion damage to the pipeline during transfer (**Figure 3**).

Figure 3. Construction process

3.4. Borehole collapse during the dragging process

The construction area had soil composed of silty clay, which made it challenging to control the pipeline dragging process manually. This difficulty in maintaining a stable mud wall during dragging resulted in borehole collapses, generated pressure, and subsequently led to road surface subsidence (**Figure 4**)

Figure 4. Collapse and grouting

3.5. Pipeline fracture

After the mud wall was damaged, borehole collapses occurred. This was followed by direct contact between the dragged pipes and the underground sandy soil, causing an increase in friction during the dragging process. The frictional forces exceeded the maximum dragging capacity of the original pipes, resulting in pipeline fractures and subsequently causing an interruption in the dragging process, which had an impact on the project's progress.

3.6. Challenges in controlling pipe end misalignment

After dragging and connecting two adjacent pipe sections, significant eccentricity, and misalignment issues occurred at the horizontal joint due to the interference from inclined sections. This necessitated the expansion of the well chamber, which further complicated well support and dewatering efforts. As a result, it exacerbated the damage to the existing road surface (**Figure 5**).

Figure 5. Pipe end misalignment

4. Countermeasures

4.1. Construction scheme of well chamber support structure

To support the well chamber during pipe dragging, a closed support system is employed [3]. This system included cement mixing piles installed at the pipe ends, aligned along the width of the two sidewalls of the well chamber where the pipe passed through. These cement mixing piles served to solidify loose sandy soil. Additionally, surrounding the well chamber except for the pipe's location, several Larson steel sheet piles were placed in a radial arrangement. The two types of support structures intersected to create a closed support system, forming a watertight enclosure that effectively prevented water ingress, reduced the risk of well chamber collapse, and avoided roadbed erosion. In the cement mixing pile components, a pair of parallel transverse struts was placed above or below the pipe, with their ends securely fixed to the side walls of the cement mixing pile components using positioning bar clips. The ends of the transverse struts were secured in grooves on the ends of the Larson steel sheet piles on either side of the pipe. This enhanced the safety and stability of the cement mixing pile components, ensuring the safety and stability of the overall support structure. The cement mixing piles in the well chamber support structure not only formed a stable closed structure but also effectively controlled the elevation of the pipe ends and prevented damage to the overlapping panel beams of the roadbed (**Figure 6**).

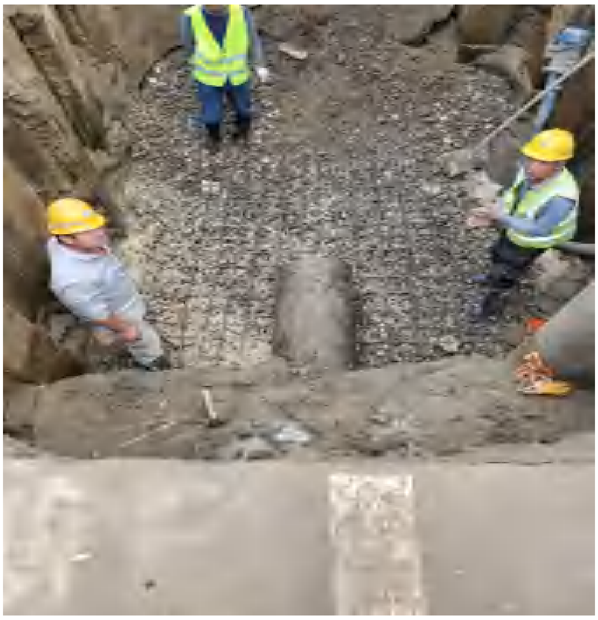


Figure 6. Closed support system of the foundation pit

For longer pipe sections with significant resistance where pipeline breakage was a concern, a well chamber support structure that facilitated pushing was employed. This structure utilized non-excavation, top-supported, and pipe-dragging well chamber support structures. The end-pulling groove piles were positioned on both sides of the well chamber support structure at the pipe ends, with both ends connecting to the steel sheet pile support structure. The groove-type blade feet were oriented downward, with the groove openings facing upward, and were placed horizontally between the end-pulling groove piles. The H-shaped joint groove slots were secured at the upper and lower edges of the prefabricated stopboard and were placed horizontally between the end-pulling groove piles. The prefabricated stopboard consisted of endplate boards and fixed boards, with the endplate boards situated at the pipe end openings, and the prefabricated stopboard positioned between the H-shaped joint groove slots and groove-type blade feet, and between the H-shaped joint groove slots. The open side of the endplate board was fitted with sealing membranes facing the soil, and the well chamber surface was fitted with locking covers. The T-shaped clip bars were inserted at the joints of the prefabricated stop boards and the soil. Grouting was used to strengthen the gaps between the prefabricated stopboard and the soil, forming a stable support structure that allowed the use of pushing equipment for assistance. This effectively addressed issues related to non-excavation, top-supported, and pipe-dragging well chamber support, including the inability to seal the openings, the instability of the soil around the pipe openings, the failure to form a stable backrest surface, and the non-standardized recycling of support structure measures. This approach offered distinct advantages, including evident hole-locking effects, structural stability, simple construction procedures, and cost-effectiveness (**Figure 7**).

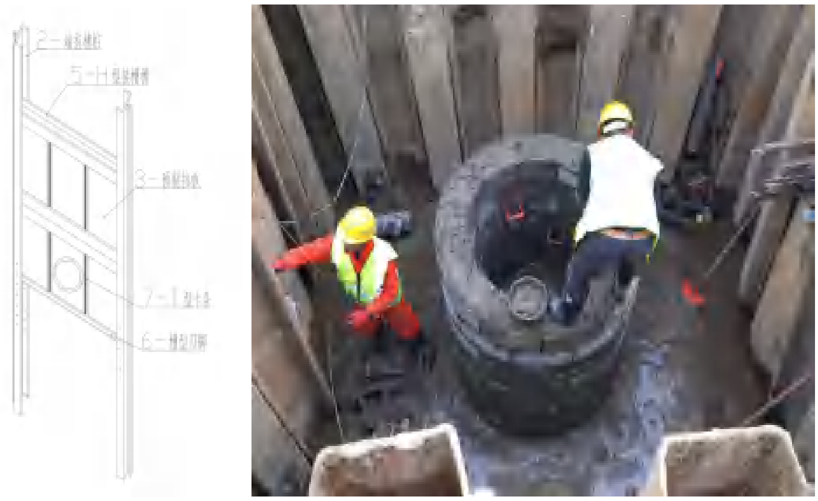


Figure 7. Schematic diagram of well chamber support structure

4.2. Pipe body reinforcement scheme

The slurry involved adjusting the amount of bentonite to be 2.5 to 3 times the original soil quantity. Additionally, inorganic water-hardening agents, primarily consisting of CaO, active Al_2O_3, and SiO_2, were added. The recommended additive blending ratio for bentonite ranged from 2% to 8%. The technical process involved a composite mineral design and chemical activation. The basic composition included 50% cement, 25% to 40% industrial waste materials rich in active Al_2O_3 and SiO_2 (such as slag, steel slag, fly ash, etc.), 1% to 5% surface modifiers (to enhance the surface activity and charge of soil particles), and 5% to 10% active activators (to promote the hydration reactions of cement and other minerals) [4].

The solidifier was mixed thoroughly with the soil and water. Through physical and chemical reactions between its components and the soil, this process significantly improved the soil's physical and mechanical properties, strength, water stability, and long-term volume stability. An experiment was conducted to determine the appropriate solidifier dosage, where comparative tests were performed with different types of solidifiers, varying dosages, and different slumps at the test site.

Simultaneously, during the pipe dragging process, further grouting and reinforcing of the pipe was achieved by installing grout ports on the pipe head. Alternatively, grout pipes were fixed around the pipe's circumference, and after the pipe dragging was completed, the secondary grouting was carried out by dragging the grout pipes. By combining these two methods, the stability of the sandy soil during the borehole expansion phase was ensured, and the pipeline was doubly reinforced by enveloping it with grout through these two reinforcing measures (**Figure 8**).

Figure 4.2 Mud ratio and construction drawing of tractor pipe

4.3. Dewatering and anti-floating plan for well chamber excavation

During the renovation work, external dewatering would have caused additional damage to the ground, leading to an expansion of the construction area for maintenance. Additionally, the residual dewatering piles would have resulted in wastage and left behind subsidence holes. Therefore, after some research a solution involving post-grouting piles, thus combining dewatering and anti-floating measures was implemented.

In the well chamber base, grout piles were installed, serving the purpose of dewatering in the initial phase and anti-floating measures in the later phase. The pile structure was established through mud wall drilling or borehole drilling using a jet grouting machine. An outer tube (permeable cement pipe) was placed into the borehole after drilling, and a certain amount of concrete was poured into the outer tube to seal the bottom. The reinforcement cage was constructed using grouting tubes as the main reinforcement, and an inner tube was securely positioned with inner supporting bars. After placing the outer tube, the reinforcement cage with the connected inner tube was centrally positioned. Then, the gap between the inner and outer tubes was filled with well-graded aggregate, sieving out particles smaller than 0.3 mm. Finally, using the grouting tube within the reinforcement cage as the main reinforcement, grouting was performed to form the pile structure. Throughout this process, it could be utilized as a dewatering well, and the grouting volume was easy to control. The resulting pile featured stability, a well-controlled steel reinforcement cover, a compact and stable structure formed through grouting, easy construction procedures, and cost-effectiveness (**Figure 9**).

Figure 9. Construction drawing of grouting pipe pile

4.4. Pipeline elevation control strategy

In addition to adding control points for pipeline elevation on the well chamber support structure, a pipeline elevation control device was utilized for backpressure at the pressure relief well. The well chamber's position was controlled using support piles formed with cement mixed piles, achieving multi-node elevation control.

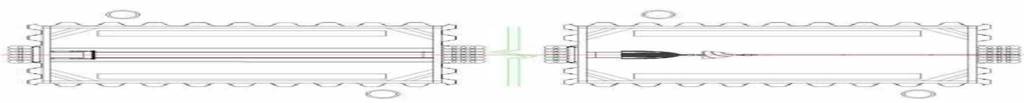
The sandbar pipeline terminal elevation control device consisted of a semicircular limit steel cover plate with a straight section in the middle and flared curved sections at both ends. The cover plate included pulleys or elastic protective strips. The support truss was a combination of upper truss, standard section truss, and lower truss. The upper truss was connected to the top frame, and the standard section truss was connected to the upper and lower trusses to adjust the height. The lower truss was connected to the cover plate and the standard section truss using bolt connections. All trusses were welded using angle steel, and the top frame's main beam was made of shaped steel. The sleepers could be square timber or shaped steel with wedges (bricks or wooden blocks) underneath for adjusting the truss structure's height. The cushion plate could be made of steel or wood and served to cover the top frame, facilitating the loading of upper counter-pressure items. These counter-pressure items could include construction shovels, sandbags, concrete blocks, and so on. The use of this device increased the vertical pressure at the pipe end, reducing the risk of slope changes, difficulties in controlling the pipe end elevation, and the danger of the pipeline moving upwards due to buoyancy during pipeline dragging construction (**Figure 10**).

Figure 10. Sandbar pipeline dragging terminal elevation control device

4.5. Anti-scraping and anti-collapse roof and dragging scheme

The main construction process includes several steps: construction preparation → surveying and layout → excavation and construction of the well chamber foundation pit → equipment positioning and directional drilling → hole expansion and mud circulation → secondary hole expansion and hole cleaning → welding of pipes → auxiliary support and pipe-dragging → high-pressure grouting during pipe-dragging→ mud clearance → cutting pipes at the well entry point → transferring equipment → well chamber construction and pit backfilling [5].

The construction sequence followed the "upstream to downstream, mainline before lateral line" approach. In the upper end of the well chamber, a non-excavation top and towing pipe pit support structure were utilized. At the lower end, a cement mixing pile support structure was employed for sealing. This strategy enabled the construction of pipeline sections with a sequence of jacking from the upstream well chamber, followed by towing from the downstream well chamber. The welding of pipe segments occurred inside the pit, while jacking and assistance took place simultaneously to prevent damage from friction during the dragging process on the road. Dual reaming was employed to stabilize the loose sandy soil into a cylindrical soil body in the first reaming, and the second reaming was used to remove the relatively moist core soil to create a stable borehole. The first reaming process compacted larger gravel and pebbles toward the outer layer, avoiding disturbance to the soil during the second reaming and cleaning processes, ensuring high construction quality. The grout pipe during dragging evenly injected slurry into the gap around the pipeline. The high pressure formed within the borehole due to the two reaming processes helped fill the gaps effectively. The slurry created a suspended pressure during the pipeline's dragging process and generated forward thrust using a reversed bending nozzle, reducing friction. Subsequently, the slurry solidified, reinforcing the pipeline body and enhancing its deformation resistance. This process formed a double-layer protection and reinforcement around the pipeline, effectively addressing the impact of temporary rising water levels on the pipeline's buoyancy and deformation resistance (**Figure 11**).



Jacking end Dragging end

Figure 11. Construction drawing of top and tow pipe

5. Implementation effect

The application of conventional non-excavation techniques, such as jacking construction, has been relatively slow to develop [1]. There is a lack of their application in the construction of long-distance, large-diameter sewage networks. Particularly in the sandy island environment, non-excavation construction methods have been scarce. Effective measures for controlling pipeline elevations, sealing support structures, and achieving precise and non-destructive pipeline connections have not been established, making it challenging to meet the on-site requirements.

Through research and exploration, the experience of drainage network jacking construction in favorable geological environments has been leveraged. A combination of conventional techniques related to welding, slurry treatment, soil improvement, and support and dewatering methods has been utilized for research into jacking construction techniques for large-diameter pipelines in high-water sandy soil areas. This approach has successfully tackled the challenges of jacking construction for drainage networks in sandy island environments, resulting in favorable results and practical application.

Through on-site experiments, applications, and inspections, all indicators met the design and drawing requirements. This method achieved significant savings in terms of labor, machinery, materials, and more, including a 45% reduction in the construction period, a 25% decrease in labor costs, a 20% reduction in material expenses, and a 47% cut in equipment costs. It effectively addressed various challenges such as unstable mud walls due to a high groundwater level leading to hole collapse issues, difficulties in controlling pipeline elevation, serious damage during pipeline welding, and significant pipeline undulation. Non-excavation construction technology was more convenient and flexible, enabling the completion of pipeline installation in urban areas where traditional excavation techniques faced challenges. It allowed avoiding underground pipelines and obstacles and ensured precise pipeline installation at designated locations. This approach reduced the impact on urban traffic, shortened construction periods, minimized repeated road excavation, and delivered significant social and environmental benefits, contributing to an enhanced urban image and quality.

6. Conclusion

The article, using the Xiangyang Yuliangzhou project as an example, discusses the research and application of non-excavation large-diameter pipe-pulling construction technology in upgrading and renovating pipelines in high-water-level sandy areas. This technology effectively changes the traditional excavation and road construction methods, reducing the environmental impact around the construction site. It ensures stable and reliable operation of the pipeline network, contributes to resource conservation, and prevents secondary environmental pollution, aligning with national requirements for energy efficiency, environmental protection, and a low-carbon “ecological civilization.” This approach has received recognition from various parties. It ensures the economic and safety aspects of project construction, reduces construction time, and significantly enhances the efficiency and results of pipeline network renovation, providing technical parameters and solution data for similar projects in the ecological construction of the Han River Basin, with wide prospects for application in domestic ecological civilization construction and related projects.

Disclosure statement

The author declares no conflict of interest.

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