Research on the Application of Small Caliber Pilot Jacking Method Under Silt Geology

Qixing Wu, Jieming Huang, Qijun Li, and Haoran Liu

Abstract With the rapid development of urban scale in China, the number of drainage pipes and new construction has also increased rapidly, and pipeline maintenance and new not suitable for excavation construction and silt formation construction due to limited space, and introduce the working principle, construction design, construct construction are facing problems such as environmental protection and narrow construction sites. The use of small-diameter pilot top pulling method can effectively overcome the difficulties of drainage pipeline projects in bustling urban areas that areion process and process of the construction method. Combined with the construction example of a small-caliber pilot top pull method of a drainage pipeline project in Zhongshan City, it shows that the construction technology has the advantages of high precision, space saving, small environmental impact and can be constructed on narrow roads, which can provide reference for similar projects and has greater promotion and application significance.

Keywords Pilot Jacking Method · Small Diameter Pipe · Silt Formations · Drainage Works · Trenchless Technology

1 Introduction

In China, local public infrastructure building has grown substantially since the dawn of the twentieth century [1]. According to the "2020 Urban and Rural Construction

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Statistical Yearbook" [2], there will be 687 cities in the nation in 2020, and investment in fixed assets of urban municipal public amenities will be $2 billion. Medium drainage contributes 9%, gas accounts for 1%, and water supply accounts for 3%; by 2020, annual urban sewage discharge will total 57,136,330,000 cubic meters, with drainage pipes totaling 802,721 km in length. As a result of the fast growth of the national economy and the extension of the city size, the demand and quantity of urban pipes are expanding, and their laying and maintenance are being hampered by environmental protection pressure and limited building sites. Pipes with small diameters. Traditional excavation construction affects traffic and the environment and is not conducive to people's desire for a better life. At the same time, the most wealthy cities are found around the coasts and rivers. Pipeline construction frequently confronts weak stratum such as silt. Pipeline construction is prone to engineering issues such as difficult height control, trajectory variation, and ground collapse [3].

As a function, for the laying, renewal, and maintenance of the pipeline network when the construction site of the small-diameter pipeline is restricted and unsuitable for excavation and the ground conditions are adequate, the trenchless construction technology of the pilot top pulling technique is proposed. This study will conduct important analysis and research on the construction technology and application of the small-diameter pilot top-pull method.

2 Principle of Micro-slit Pilot Roof

The pilot jacking technique is a small-diameter mixed pipe jacking construction method that was developed by refining the combination of directional drilling and mud-water balancing pipe jacking construction technology for the common construction circumstances of sewage pipe networks. The pipe diameter is typically DN300-600, which not only has the geological flexibility of directional drilling, strong obstacle management ability, and minor secondary disasters, but also the benefits of standard pipe jacking elevation control. The procedure works in tandem with the self-sealing socket and the socket interface short tube [4]. The conventional pipeline back-drag technique can be replaced with a top-pull process in which the pipe section is inserted downhole at the end, the drill pipe is utilized to pass through the center of the pipeline, and the pipe section is top-pulled at the pipeline's end. The mud is allowed to enter the inside of the pipeline during the top-pulling step, which reduces weight and resistance. Since this end hole's necessary diameter is near to the pipeline's outer diameter, the annular gap is tiny or non-existent.

Following the completion of the well, the small-diameter pilot jacking method employs the procedure of directional drilling and jacking. The wellbore height is readily regulated, and the steel drill pipe is straightened and penetrated, as well as the pipeline elevation. Figure 1. depicts the small-diameter pilot top pull method.

Since 2017, the small-diameter pilot top-drawing method and accompanying pipes have been increasingly popular in towns and regions throughout Guangdong Province, including Foshan, Zhongshan, Dongguan, Shantou, Shenzhen, and

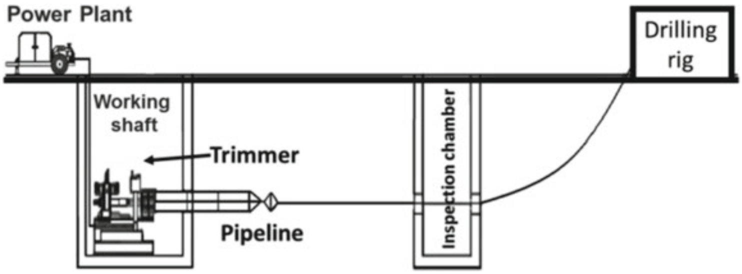

Fig. 1 Small-caliber pilot top pulling is indicated

Guangzhou. The total length of the single design and construction has topped 100 km, and it has also been expanded to Fujian, Hunan, Jiangxi, Anhui, Zhejiang, Shanghai, Jiangsu, and other locations. It is also being used to replace aged pipes as part of pipe network maintenance [5].

3 Construction Design of Small Diameter Pilot Top Pulling Method

3.1 Selection of Key Technical Parameters

The maximum mud pressure and nose pulling force are important technical elements of the small-diameter pilot top pulling technique.

Maximum Mud Pressure Analysis and Calculation. The mud circulation system must be utilized to discharge the created soil slag during the pipeline jacking operation under silt geology. To lessen the resistance between the pipeline, the machine head, the soil layer and clear water plus hydrolyzed polyacrylamide is used in the mud solution for reducing grouting drag in silt geology (HPAM).

The building hole wall formed by silt has weak stability, low shear strength, and high compressibility when compared to other soils. The pressure of the mud pump in the mud circulation system is too high, causing the mud to flow too quickly, resulting in formation damage and ground escape, which is easy to cause ground collapse and impairs the stability of nearby building foundations. As a result, determining the maximum mud pressure before construction is crucial to assure the formation's stability throughout construction. The maximum mud pressure is the sum of the mud pressure at the bottom of the hole and the head loss, and the maximum mud pressure at the bottom of the hole may be calculated using the Delft formula [6, 7].

$$P_{\max} = (p_{\mathrm{f}}' + c\cot\varphi)\left[\left(\frac{R_0}{R_{\mathrm{pmax}}}\right)^2 + Q\right]^{\frac{-\sin\varphi}{1+\sin\varphi}} - c\cot\varphi \tag{1}$$

$$p_f' = \sigma_0'(1 + \sin\varphi) + c\cot\varphi \tag{2}$$

$$Q = \frac{\sigma'_0\sin\varphi + c\cot\varphi}{G} \tag{3}$$

where: σ'_0 is the initial effective stress (kPa); φ is the internal friction angle (°); c is the cohesive force (kPa); R_0 is the initial aperture (m); $R_{p,max}$ is the maximum allowable The radius of the plastic zone is generally 2/3 of the height of the hole axis from the surface (m); G is the shear modulus of the formation (kPa).

Analysis and Calculation of the Pulling Force of the Nose. To carry out the pilot top pulling technique under silt stratum conditions, to construct securely and prevent ground damage, the maximum value of the back drag force (top pull force) of the pipeline crossing must first be determined.

The maximum pulling force of the nose during pipe jacking may be determined using the unloading arch algorithm [7, 8] as shown in Eq. (4). For silty strata, Eq. (5) can also be used to estimate the maximum top tensile force in engineering practice [7, 8].

$$T_{max} = [2P(1 + K_a) + P_0]f_e L \tag{4}$$

where: T_{max} is the maximum value of the return drag force of the pipeline crossing (kN); P is the earth pressure of the crossing pipeline per unit length (kN/m); K_a is the active earth pressure coefficient of the crossing soil layer, generally taken as 0.3; P_0 is the dead weight of the crossing pipe per unit length (kN/m); f_e is the friction coefficient between the pipe and soil, generally taken as 0.2 ~ 0.3; L is the length of the crossing pipe (m).

$$T_{max} = f_e L(4D_0 D_e + P_0) \tag{5}$$

where D_0 is the outer diameter of the crossing pipe (m); D_e is the maximum reaming diameter (m); the meaning of other parameters is shown above in Eq. (4).

3.2 Construction Process of Pilot Top Pulling Method

The underground pipeline survey, engineering design, well site construction, pilot hole construction, pipeline jacking and laying, landform restoration, and engineering acceptance are the primary construction operations of the small-diameter pilot jacking technique, as illustrated in Fig. 2.

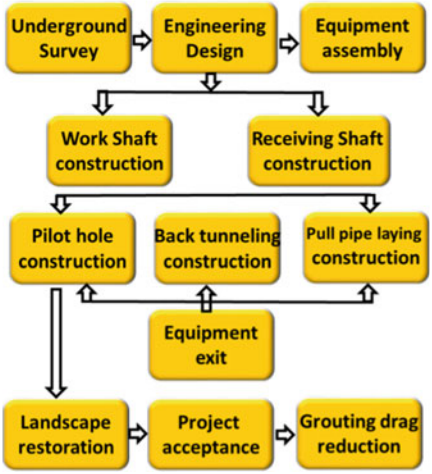

Fig. 2 Construction process of small-diameter pilot jacking pipe

3.3 *The Primary Process Design*

The key processes of the pilot jack-up construction include well site construction, pilot hole construction and jack-up construction.

Well Construction. Working well construction and receiving well construction are both aspects of well construction. Wells are classified as circular, square, or round pits. The inner diameter of a circular working well should not be less than 2.0 m in general, but it should not be less than 1.8 m if the layout site is constrained. The inner diameter of the pit-type circular working well is not less than 2.8 m and the inner diameter of the pit-type square working well is not less than 2.8 m (length) 2.2 m (width). The inner diameter of the receiving well must be at least 2.0 m and, in severe instances, no less than 1.8 m. The well wall is often composed of the prefabricated wellbore, with caisson construction. Before constructing working wells and receiving wells, the site must be enclosed and the road and water elevation must be remeasured, and the road must be reduced to the minimal size necessary for construction. After cutting and fracturing the road surface, dig the soil using the telescopic boom excavator, then cycle to excavate and sink to the lower side in turn. Frequent inspections and measurements are performed during the excavation process to avoid over-excavation and disturbing the undisturbed soil, and the construction is strictly per the design and construction, and the wellbore and wellbore overlap are well waterproofed to ensure safety and quality.

Pilot Hole Construction. After the pipe jacking working well and receiving well are completed, the installation of the pipe jacking machine and horizontal directional drilling may begin, and the directional drilling equipment can be placed following the pilot hole trajectory design.

At the back end of the directional drilling bit, an electronic direction finder is installed in the drill pipe. During the drilling process, it continually measures the parameters of the drill bit's precise location, apex angle, and depth, and modifies the drill rig settings at any moment to regulate the drill bit to drill according to the specified trajectory. Drilling begins once all of the equipment is in place. The walking tracking technique is used to regulate the drilling according to the intended drilling curve, monitor the drilling direction, depth, drill bit plate status, and signal rod temperature, and connect with the driller. When drawing back, it is explicitly prohibited unsuitable to rotate the drill pipe counterclockwise. The incidence angle of the build-up section is less than 13 degrees, the build-up curvature fits the drill pipe's 1500D (drill stem diameter), and the curved drill pipe is not employed.

The design axis determines the direction and slope of steerable jacking. When jacking deviation occurs, it may be corrected using the center coordinate and elevation of the pipe jacking well hole. Also, The side station must oversee the pilot hole drilling procedure, and the drilling trajectory must be approved.

Back Towing Excavation, Mud-water Pressure Balance Construction. After the pilot hole is completed, the drill bit is withdrawn, and the back towed road-head, connecting piece, mud discharger head, connecting back drill pipe, pipe, roof plate, and hydraulic jack are placed in sequence. When the pipe section passes through the reinforcing region of the hole, the operator begins to pull the top into the hole whilst performing the anti-twist measures with the speed controlled at 0 ~ 10 mm/min. The viscosity of the mud should be monitored often during the jacking operation, and the value should be regulated between 40-60 s, and the soil should be drained in time according to the pulling power of the drill pipe. Every time a portion is jacked, the pipe jacking machine's oil cylinder is pushed backwards, and another segment of the pilot pipe is inserted to continue jacking up until the receiving well is reached. When both the machine head and the pipe section enter the receiving well, the space between the pipe and the hole wall should be filled with water-stop sealing treatment and the water-stop sealing steel plate placed, as illustrated in Fig. 3.

3.4 Quality, Safety and Environmental Measures

In an attempt to adapt to the sustainable development of the city, reduce the degree of pollution to the environment, and reduce the damage to surrounding or adjacent buildings, the construction of the small-diameter drainage pipe top-drawing method should include: "Safety Inspection Standards for Municipal Engineering Construction" (CJJ/T275), "Technical Specifications for Temporary Electricity Safety at Construction Sites" (JGJ46), "Safety Technical Regulations for the Use of Construction Machinery" (JGJ33), "Technical Regulations for Pipe Jacking of Water Supply and Drainage Engineering" (CECS246: 2008), "Technical Specifications for Horizontal Directional Drilling Pipeline Crossing Engineering" (CECS382: 2014), "Flexible Sealed Self-locking Interface Polyethylene Wound Solid Wall Drainage Pipe and

Fig. 3 Schematic diagram of water-blocking steel plate

Fittings" (T/GDSTT 1–2021), "Expansion Lock" Sealing and connecting polyethylene solid wall drainage pipes and accessories" (Q/STXM 1–2021), "ductile iron castings" (GB/T 1348) and other national and industry standards to formulate construction quality, safety and environmental protection measures and other plans, and in accordance with "The project acceptance shall be carried out according to the standards for the construction and acceptance of water supply and drainage pipeline engineering (GB/T 50,268–2008).

3.5 Process Characteristics

When compared to typical pipe network excavation methods, small-diameter pilot pipe jacking construction technology offers the following important benefits:

(1) It offers a wide range of applications and uses a socket-type connecting mechanism that can be used with water and has no risk of leaking. Multiple winding and braiding extrusion form the HDPE solid wall winding pipe, which has high performance and is suited for most applications.
(2) High controllability, the pilot jacking method uses an electronic direction finder placed in the drill pipe at the rear end of the drill bit to continuously measure the parameters of the drill bit's position, apex angle, and depth, and adjust the drilling rig parameters at any time through the drilling rig to control the drill bit to drill according to the design trajectory, which can ensure drainage pipe elevation with high precision.

(3) The economic benefits are good. Only small equipment can be used for the laying of pipelines. The amount of soil and road restoration works produced is small, and a lot of operational costs are reduced.
(4) The environmental impact is minimal, the influence on ground traffic and nearby buildings is also minimal, the operating noise is relatively low, and inhabitants' daily traffic and lives are unaffected [9].
(5) Construction may be carried out on restricted site areas, narrow roadways, and densely packed urban settlements.
(6) The building efficiency is good, and no extensive excavation is required. A good positioning and deviation correction system may ensure that the pipeline trajectory is exact, saving time.

4 Engineering Case Study

4.1 Project Overview

A drainage pipeline project in Zhongshan City, Guangdong Province is located in an affluent region of the city [10]. According to the geological survey data, the strata inside the pipeline's buried depth range include plain fill, silty clay, silt, and medium sand from top to bottom. Following the technological demonstration, this area adopts the construction method of small-diameter pilot top-pulling pipe, the pipe buried depth is around 5 m, the pipe diameter is DN400500, and the pipe material is socket type HDPE solid wall winding pipe. The distance between functioning wells is between 22 and 31 m. Figure 4 depicts the pipeline's configuration.

Fig. 4 Schematic diagram of the project

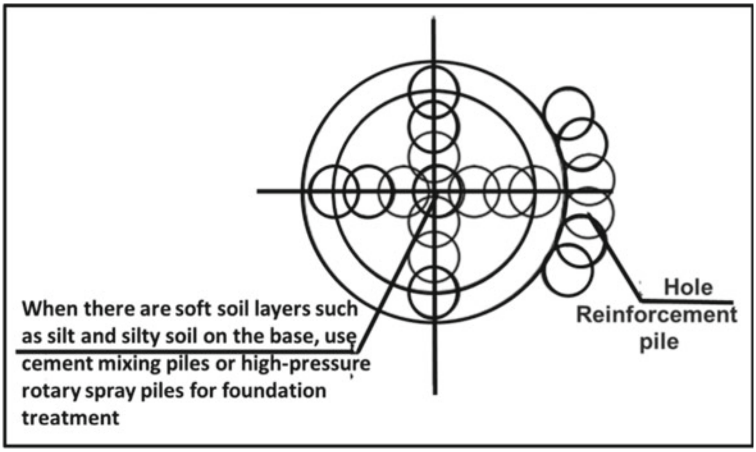

Fig. 5 Work well plan

Since the pipeline is placed in the silt stratum and the foundation's bearing capacity is low, the foundation of the working well is strengthened with cement mixing piles or high-pressure rotary jetting piles, and reinforcement piles are installed at the hole's entrance, as shown in Fig. 5.

4.2 Calculation of Maximum Mud Pressure and Nose Pulling Force

Using the DN400-29 section of the pipeline as an example, where the pipe length is L = 29.0 m and D 0 = 0.4 m, the maximum mud pressure during the pilot jacking method construction process is calculated using Eq. (1), (4), or (5) and the pulling force of the machine head, and the calculation results are shown in Table 1.

The viscosity of the mud was monitored and regulated on a regular basis by a Marsh funnel during the construction phase. The maximum mud pressure at the bottom of the hole was set at around 50 kPa, while the machine head's pulling force was set to around 8.5 kN. A compact directional drilling rig may be chosen for the top pulling equipment, and the machine's rated feed force and maximum pullback force can match the pipeline laying load requirements.

Table 1 The result of the calculation results in maximum mud pressure and nose pulling force

Maximum mud pressure at the bottom /kPa	Pulling force /kN
50.17	8.53

Table 2 Comparison of economic benefits of different construction methods

Construction method	Pipe laying material cost/(RMB/m)	Equipment fee for pipe laying personnel/(RMB/m)	Material cost of working well/(RMB/m)	Staff and equipment costs for working wells(RMB/m)	Work efficiency/(m/day)	Comprehensive unit price/(RMB/m)
Pilot top pull method	2847	748	1250	1627	28	6472
Pipe jacking	985	2214	3058	3702	16	9961

4.3 Analysis of Economic Benefits

The economic benefits of the small-diameter pilot jacking method and the regular pipe jacking method are contrasted using the pipe jacking project as an example. The costs are based on the "Guangdong Provincial Municipal Engineering Comprehensive Quota 2018" and the "Guangdong Provincial Drainage Pipeline Trenchless Repair and Renewal Project Budget Quota 2019." Table 2 shows the cost estimate comparison findings for the two building approaches.

The above table shows that the comprehensive cost of the pilot top pulling method is the lowest, and when considering factors such as construction period, quality and safety, and environmental protection, it is clear that this method has significant advantages in the construction of small-diameter pipelines.

5 Conclusions

The principle of the small-diameter pilot jacking method is analyzed, and the calculation methods of the maximum mud pressure and the maximum pulling force of the machine head in the pipe jacking construction process under silt formation are given, as well as the construction scheme design of the small-diameter pilot jacking method. The advantages of small-diameter pilot top-pull construction include a compact footprint, broad application, high efficiency, construction safety, environmental protection, and resource conservation. This approach has a wide range of applications and is particularly well suited for trenchless installation and maintenance of small-diameter pipes in densely populated metropolitan areas.

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References

1. Chao W (2018) Study on collapse mechanism of municipal buried pipeline. Jinan University
2. Ministry of Housing and Urban-Rural Development of the People's Statistical Yearbook of Urban and Rural Construction in 2020 (2020)
3. Kun G, Qijun L (2018) Discussion on the improvement of gravity flow drainage pipe directional drilling technology. Water Supply Drainage 54(06):102–105
4. T/GDSTT 1—2021 Flexible Sealing Self-Locking Interface Polyethylene Wound Solid Wall Drain Pipe and Fittings. Guangdong Trenchless Technology Association
5. Qijun L (2022) Technical reference for the design and construction of small diameter drainage pipe pulling
6. Shu-li L, Kai L, Shuning W (2018) Selection and control of key technical parameters of directional drilling process pipeline through Qin construction. People's Yellow River 40(07):124–128
7. Huijin C (2020) Research on the key technology of pilot top pipe drawing process. Jinan University
8. Jinlong A (2008) Calculation method and analysis of cross-return drag force of horizontal directional drilling. Petroleum Eng Constr 01: 21–26
9. Xinmin Z, Kun G, Zilin F (2014) Application of secondary pipe jacking method in laying small diameter drainage pipe. Water Supply Drainage 50(05):92–95
10. Tianjin Urban Construction Design Institute. Zhongshan City Center Group Black odorous (substandard) water remediation and upgrading project (project 3) Tugua Chung, Xiao Chung remediation and upgrading project construction drawing design (2020)