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Short-Segment Jacking of Water Main for Realignment under Limited Space in Urban Area

Huanying Fan [1], Shihchi Wu [2]

1 Superintendent, Taipei Water Department, Taiwan
2 Subsection Chief, Taipei Water Department, Taiwan

ABSTRACT: The underground pipelines of various utilities crossing each other is inevitable due to limited beneath space in urban area such as Taipei city. Among this circumstance, the existing large-diameter water main penetrating through drainage become a major concerning issue. The water mains passing through drainages not only causing breach that affect the drainage structural stability, but also occupy the interior space that might obstruct the draining water flow. Therefore, such situation can lead to catastrophic consequence to general public and utilities in terms of public safety as well as property damage. Thus Taipei Water Department plans to remove all the penetrating water main pipes inside the drainages in time. Considering the complexity of various underground circumstance, traditional open-cut method is not capable to complete the water main realignment of crossing drainage. Therefore micro-tunneling pipe jacking method has been implemented in such kinds of water main realignment project. In addition, indispensable adjustment and innovation of the trenchless method coordinated to the site conditions had been carried out repeatedly, including minimize the size of jacking shaft as well as the length of pipe unit in order to fit the congested circumstance. Eventully the improved method regarded as short-segment jacking of water main had become a reliable approach in the waterline realignment project. Until now several cases had been successfully realigned by this technique, therefore become a trenchless resolution for the drainage trouble. The technique might be applicable for other urban areas with complex underground in the future. This paper will elaborate the application of short-segment jacking method and the adjustment as well as innovation adopted during the process. Furthermore, § 700mm water main realignment case study will be discussed considerably in this paper.

Key words: short-segment jacking, water main, realignment, drainage, innovation

1. INTRODUCTION

Being a densely populated metropolitan, there are various kinds of underground lifelines such as: electricity, telecommunication, water, drainage, gas, sewage etc. squeezed in very limited space underneath the road of Taipei city. The quantity as well as volume of the underground infrastructures in urban area are relatively large therefore resulting an crowded and orderless underneath circumstance. Moreover, situated in subtropical area, the annual rainfall of Taipei is approximately three times than the rest of the world. In response to frequently thundershower and rainstorm bombard, enormous drainage system occupied the majority of the underground buried space in Taipei. The burial space of underground lifelines is even scarcer, consequently all kinds of pipelines crossing each other become inevitable situation within such circumstance. The widespread drain systems had become the main obstructions for the rest of the lifelines underneath roadway. Eventually pipes penetrating through drain structures or pipes occupied the inner space that might hinder the drain flow in case of storm rain become more concerning for the administration. Of the major obstacles that water main pipelines are

significant one(Figure 1,2), thus water main realignment project aim to remove the pipes section wrapped inside drain structures had been demanded according to the administration. Due to the complexity of underground in such urban area, the water main realignment works by open-cut method is not feasible. The trenchless technique became the only approach in such harsh circumstance to achieve the task. In response to the occupied underground space and difficulties, conventional trenchless such as pipe jacking method had been improved and adjusted into short-segmant pipe jacking method which characterized with a relatively small shaft as well as short pipe in coordinate with limited urban area.

Fig.1 ϕ900mm water main penetrate pipe drain

Fig.2 ϕ700mm water main penetrate box culvert

2. DIFFICULTIES OF CONVENTIONAL WATER PIPEJACKING

Ductile iron pipe (DIP) is the major pipe material of water distribution system in Taipei city, therefore DIP pipe jacking method for water mains installation as well as aging pipes replacement is adopted once necessary. The diameter of water mains which need to be realigned due to the drainage penetration cases mostly between DN 700mm~ DN 1000mm. The DIP jacking pipe joints include two type, type U for diameter more than DN 800mm and type T(push-on) for less than DN 700mm respectively. In general the standard length of DIP jacking pipe is 6 meters per unit(Fig.3), therefore the jacking shaft size should be able to set up the pipe unit inside(Fig.4).

Fig.3 normal jacking water pipe (DIP U type)

Fig.4 jacking pipe settlement of start shaft

Thus the water main pipe jacking method is possible only for spacious construction site, in practical the minimum pipe jacking shaft size is no less than approximately 8X4 meters in length and width. In addition to the shaft size, extra space surrounding the shaft is needed for the stacking of various machineries and materials such as generator and pipes. Therefore the overall range of the constructed site will be extended more than jacking shaft merely(Fig.5). Even though it is trenchless with lowest disturbance, but this kind of significant construction site is still increasingly difficult to be setting along a congested roadway in urban area. Furthermore, the end connections with existing water main pipes are also a big challenge whereas numerous obstacals might

hinder between the two ends of connection pipes. In reponse to the severe circumstance, the only solution is to shrink the standard size of shaft as well as pipes' unit length.

In the meanwhile, the sewer pipe jacking method characterized with relatively smaller shaft and pipe had been successfully implemented throughout the urban city of Taiwan for years. The circular starting shaft with a specified size less than 2.6 meters in diameter, while the arrival shaft is less than 2.1 meters(Fig.6). The unit length of jacking pipe shrink to 1 meter to fit inside the starting shaft. As a result, the essential area for shaft of sewer pipe jacking is extremely reduced compare to water pipe jacking(Fig.7), therefore leading to a superior approach for the installation of sewer trunk system. Consequently the sewer pipe jacking method became a prototype of trenchless to conquer the congested urban area of Taipei city.

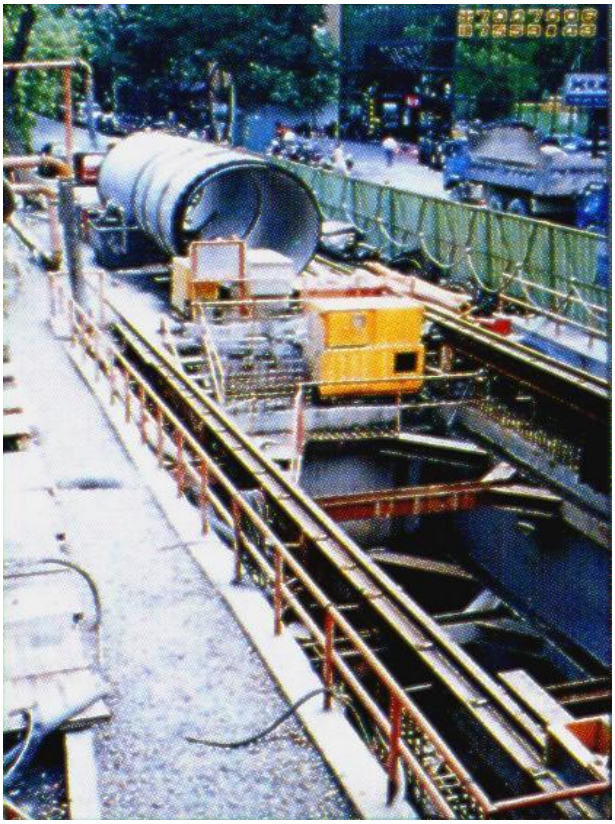

Fig.5 construction site of water main jacking

Fig.6 ∮ 2.1M arrival shaft covered by plate

Fig.7 construction site of sewer jacking

However, the fundamental divergence between water and sewer system is pressure. As a pressurized system, water supply pipelines suffer higher pressure than the sewers in which sewage are normally by gravity flow. Precast reinforced concrete pipe(RCP) is used as standard sewer jacking pipe whereas the pressure rating of the RCP joint is as low as 0.5kg/cm^2(0.05 Mpa) which is capable enough for the gravity flow of sewage(Fig.8), but not for pressurized waterlines. The water distribution systems endure much higher pressure than sewer's, therefore pipe pressure rating should be considered thoroughly. The minimum DIP pressure rating of Taiwan national standard is more than 10 kg/cm^2(1Mpa) which suffer normally pressure of average 1.5~3 kg/cm^2(0.15~0.3 Mpa) among water distribution systems. It is undoubted to adopt DIP as pipe jacking material for water system, whereas the ordinary DIP pipe length as well as the joint should be modified and adjusted to become short-segment pipe jacking method for water main.

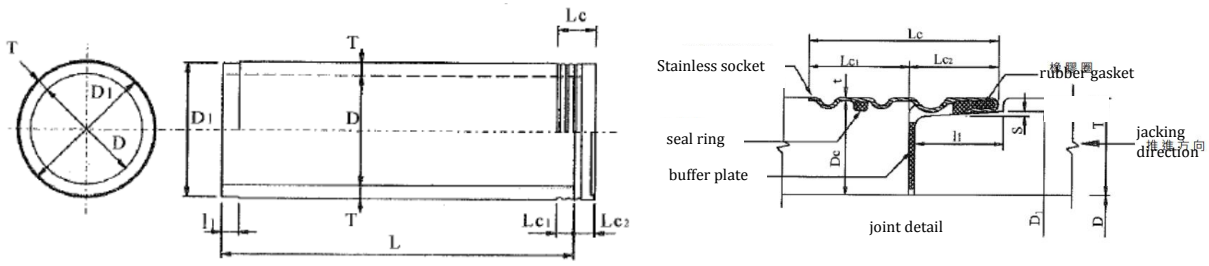

Fig.8 sewer RCP jacking pipe and joint detail

3. SHORT SEGMENT PIPEJACKING

Regard to the jacking pipe joint of DIP, according to the Ductile Iron Pipe Research Association from US, DIP's T type (push-on) joint systems have been proven effective in actual tests with up to 1,000 psi(70kg/cm^2) internal pressure, 430 psi(30kg/cm^2) external pressure, and 14 psi(1kg/cm^2) negative internal air pressure without leakage or infiltration. Even though it is rated for a maximum water working pressure of 350psi(25 kg/cm^2); however, for specific conditions the T type joint has been approved for much higher pressure ratings(Fig.9). The joint is designed and manufactured to close tolerances so that the gasket is self-centered, securely confined, and firmly compressed for a permanent, tight, trouble-free connection. It is bottle tight under vacuum and external pressure and becomes even tighter with the application of internal pressure. The design ensures effective sealing at low or high pressures and in straight or deflected joint alignment. It also eliminates any concerns of infiltration or root intrusion. The design also ensures positive sealing against negative pressure, thus preventing gasket "pullout" should a vacuum be created in the line.

Therefore T type(push-on) joint had been standardized as water main jacking pipe with diameter less than ϕ700mm, and had performed excellent water tightness for years. In order to fit the smaller circular starting shaft with diameter of 2.6M, the T type joint DIP jacking pipe length should shrink into one meter or less. With numerous trial and error for manufacturing the one meter short segment jacking water main pipe, as well as the practical implementing in site. During the beginning for site implementing of short segment jacking method, failure occurred frequently due to the joint leakage in which the joint number increase six times than original jacking pipe. By means of modification for the material manufacturing precision of T joint DIP jacking pipe as well as the revision of jacking process, finally both the material and jacking process of the innovative short segment pipe jacking method had been successfully developed and standarized(Fig.10).

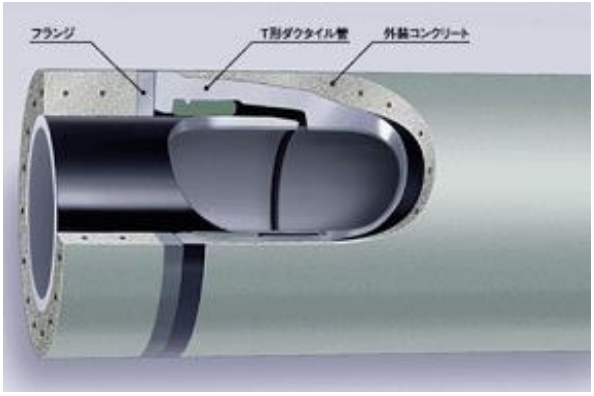

Fig.9 T(push on) joint withstand high pressure

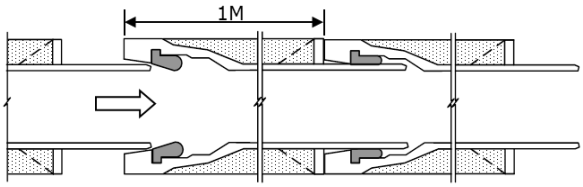

Fig.10 model of short segment jacking pipe

The dilemma of water pipes penetrating through drainages had been dragged on for years since the drain administration claim for the removal of all obstacles. According to the investigation throughout the drain system by administration, over 120 water pipes had been spotted and recorded inside the drainage. Among which more than 30 cases belong to water mains with diameter over DN500mm were regarded as the paramount priority and to be scheduled for realignment. Being responsible utility, Taipei Water Department devoted to overcome the imperative challenge, and therefore blend the advantages of sewer and water pipe jacking method. Step by step, these problems were finally moving forward to a feasible solution until the new short segment pipe jacking technique growing maturely and became more reliable. Soon after the innovated short segment pipe jacking technique implementing on site, several cases of water main realignment had been completed successfully. Therefore the method had been promoted and adopted not only for water main realignment due to the drainage problem, but also for new water main installation as well as aged pipes replacement respectively(Fig.11). As a result, the short segment water main pipe jacking had become a prevailing and effective approaches throughout the urban area of Taipei city for Taipei Water Department.

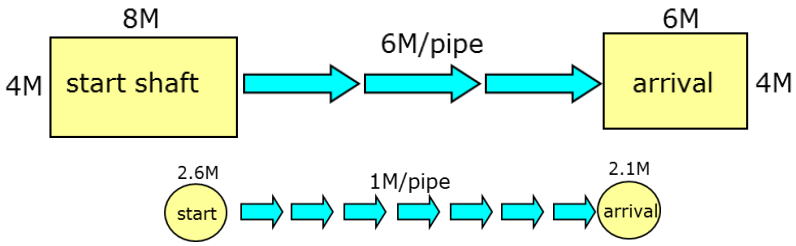

Fig.11 conventional jacking water pipe v.s short segment jacking pipe

4. CASE STUDY OF WATER MAIN REALIGNMENT

Of the water main realignment cases, the DN500mm water main of Chungcheng-Jiher Road intersection was one of the prior objectives should be realigned in order to remove the pipe section wrapped inside the drainage(Fig.12). The existing duo DN500mm DIP pipes installed in 1986 along both side of Chungcheng Road, the entire pipe crossing through upper space of drainage along Jiher Road(Fig.13). The Jiher Road drainage structural type is two-5.8MX2.4M box culverts which sustained the major draining of the region where suffered frequent overflow. The project outline as below:

(1)Project: Chungcheng-Jiher Road DN500mm water main realignment by short-segment pipe jacking method
(2)Main Content: 2-start shaft, 2- arrival shaft, 2-DN700mm DIP jacking pipe (T joint, 1M/unit)-30M
(3)Cost: US 300,000(EU 260,000)
(4)Duration:120 days

Fig.12 ∮ 500mm DIP water main inside drain

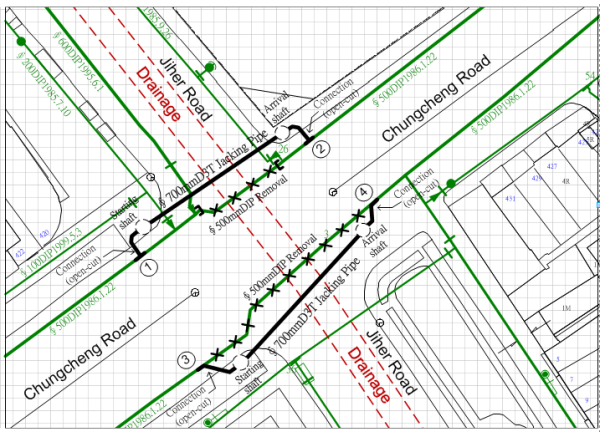

Fig.13 design layout for water main realignment

Geotechnical investigation was conducted before design and planning period, although adjacent site drilling information could be also referenced. The mixture of clay and silt was expected as well as high ground water level. According to the loose earth condition, soil improvement surrounding the shaft was carried out by jet grouting to ensure the waterproof during the process of shaft sinking as well as pipe jacking. The jacking construction compound consists of driven shaft and materials as well as equipment which occupied larger area for a jacking process duration, usually more than three months. The traffic maintaining plan in order to alleviate the impact due to the jacking compound should be conducted in advance of applying for excavation permission. To minimize the traffic impact of construction compound around the intersection, the compound area which include jacking shaft, pipes, power generator, hydraulic machine, cooling equipment as well as lubricant etc. should be arranged compactly within a confined area(Fig.14).

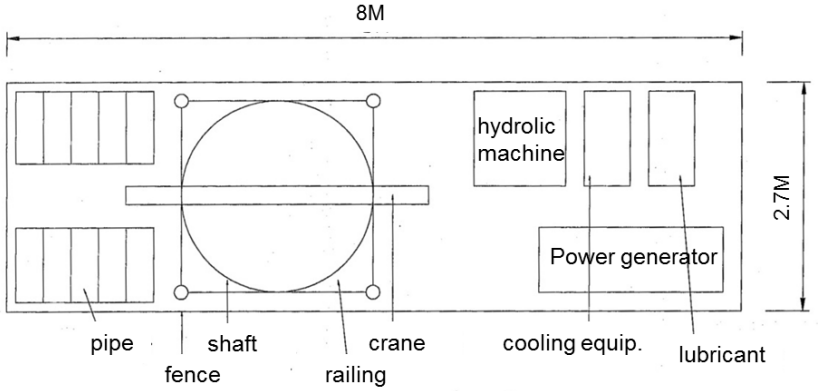

Fig.14 site configuration for start jacking compound

During the pipe jacking process, boring machine is setting to advance for the direction of reception shaft(Fig15). Auger and screw conveyor are installed in leading head. Auger and screw conveyor rotates in order to excavate and the spoil is removed to the start shaft. In addition, the surface of short jacking pipe is coated by reinforcing cement, which keep the surface and joint smooth in order to pass through underground(Fig16). The jacking alignment should keep straight due to the numerous joints that increasing for short pipe, while curve jacking is not allowable for the strict waterproof standard. The DIP T type(push-on) joint is designed and manufactured to close tolerances so that the rubber gasket is self-centered, securely confined, and firmly compressed for a permanent tight connection. The push-on joint consists of a special socket, plain end, and rubber gasket. The socket is provided with an internal groove in which the appropriate gasket is seated. The plain end is beveled, and the joint is assembled by pushing the plain end into the socket, which compresses

the gasket and forms a watertight seal. However, the push on process should be considerably cautious. The standard procedure of joint connection start with thoroughly clean the groove and the socket of the pipe as well as the plain end of the mating pipe. Then apply lubricant to the exposed surface of the gasket and plain end of the pipe, do not apply lubricant to the socket or the surface of the gasket in contact with the socket. Because of the annulus gasket inside the socket might be dislodged or damaged during the push-on process, leading to the joint failure, therefore devise such as gauge should be adopted to assist the joint assembling(Fig.17,18).

Fig.15 boring auger machine for pipe jacking

Fig.16 short segment pipe with cement coating

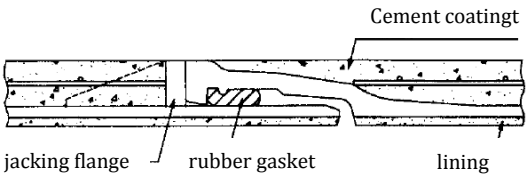

Fig.17 T(push on) joint assembly of jacking pipe

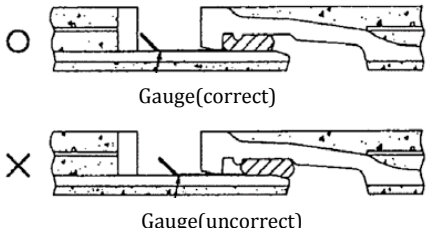

Fig.18 joint assembly gauge for gasket fixed

For the jacking capacity of short pipe, in practical the average jacking distance for one section is approximately 50 meters, for more than 70 meters the intermediate jacking device should be implemented. However the exact limitation of jacking distance mainly depend on the geotechnical condition as well as the lubricant usage. In this case the design jacking distance is about 30 meters, far less than the average distance, so the jacking process is relatively straightforward. The pressure test up to 0.7Mpa(7kg/cm2) should be conducted once pipe jacking is completed. Connection work between existing and new pipe will continued only if the pressure test is qualified. Regarding to the shaft construction, instead of sheet pile wall method or caisson which occupied large area of roadway, steel-pipe made shaft with diameter of 2.6M is the only approach to minimize the jacking compound settlement that the traffic administration would be possibly agree with. Only if the traffic maintaining plan is approved, then excavation application would be proceed afterward. The steel-pipe made shaft installation period lasting only about one week(Fig.19), far more shorter than other types, consequently become prevailing design throughout the urban area for pipe jacking construction. Jacking thrustblock is also unnecessary due to the circular confined of shaft which provide resistant force for the jacking process(Fig.20).

Fig. 19 excavation for steel shaft sinking

Fig. 20 circular steel-pipe made shaft

The arrival shaft with diameter less than 2.1 meters, with very limited working room inside the shaft during the breakthrough works of boring machine. A reception shaft of sufficient size for removal of the boring auger machine is normally required after the completion of jacking work(Fig.21). The initial alignment of the pipe jack was controlled by accurately positioning guide rails within the thrust shaft on which the pipes were laid. To maintain accuracy of alignment during pipe jacking, it is necessary to frequently checked for line and level from a fixed reference. For short pipe jacks, these checks was carried out using traditional surveying equipment. Rapid excavation and remote control techniques require sophisticated electronic guidance systems using a combination of lasers and screen based computer techniques. With the jacking pipes works finished, pipes fittings was connected with jacking pipe inside the shaft and soon afterward the pressure test was conducted in order to confirm the joints watertight(Fig.22).

Fig.21 boring auger breakthrough arrival shaft

Fig.22 pipes fitting installed before pressure test

5. CONCLUSION

This paper presents an effective trenchless approach for water main realignment among congested urban area. However, various kinds of unexpected difficulties occasionally occurred during the pipe jacking works. Even though with innovated trenchless such as short-segment pipe jacking method, it is still not almighty technique which able to overcome all the difficulties encountered underground. Therefore, constant innovation and adjustment are also indispensable during the design and construction process. This kinds of experiences in Taipei urban area might be similar to other place of the world, although the resolution which Taipei Water Department adopted might not exactly suitable for the other city of the world. Nevertheless lots of practical experience in site which lead to failure can be referenced in order to prevent and consider in advance. Based on the experience of jacking projects, the major factors that might hinder the pipe jacking works are summarized as follows:(1)Difficulties to find areas to install jacking shaft. (2)Connection between new jacking pipes and existed pipes. (3)Push-on joint installation failure of jacking pipes. According to the factors above shown that there are still challenges to the short-segment pipe jacking method. Whereas the improvement as well as re-innovation for this pipe jacking technique is still essential and continuing, and nowadays it is still at the midway of further accomplishment for water main pipe trenchless construction. Hopefully in the near future, further improvement for the innovative technique will be achieved.

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