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STUDY ON THE MECHANICAL PROPERTIES OF LARGE DIAMETER AND LONG DISTANCE REINFORCED CONCRETE PIPE JACKING IN WEAK STRATUM

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ABSTRACT

In order to study the mechanical properties of large diameter and long distance reinforced concrete pipe jacking process in weak stratum, based on the Tangxun Lake sewage pipe jacking project in Wuhan, the jacking force, contact pressure, slurry pressure and pipeline strain were monitored on site, and their changes in the jacking process were analyzed, which provided reference significance for the similar projects in the future. The results showed that during the jacking process, the axial stress of the pipe was mainly compressive stress, and there are some areas of stress concentration. As the jacking distance increases, the axial stress of the pipe first increases and then remains relatively stable. The hoop strain of pipe is mainly compressive strain, which is mainly affected by earth pressure and axis deviation. Under the slurry pressure, the hoop strain at the top and bottom of the pipe increases, while the left and right sides decrease. The bottom of the pipe is in contact with the soil, and the contact pressure is the largest, while the left and right sides are in full or partial contact with the slurry. The crown of the pipe is in contact with the slurry and the contact pressure is affected by the mud pressure. In addition, the contact pressure is not directly related to the jacking distance.

KEYWORDS

Weak stratum, Large diameter reinforced concrete pipe jacking, Mechanical properties, Field testing

INTRODUCTION

As urbanization progresses towards a high-quality and sustainable stage, higher demands are being placed on urban underground space construction technology. Exploring construction technologies with low environmental impact, high efficiency, and low cost has become a common goal. The emergence of pipe jacking technology is a beneficial attempt, and now it has been widely used in underground engineering. The safety of pipe structure is a key factor to ensure the smooth progress of pipe jacking engineering.

In terms of field testing, Milligan and Norris [1-2] conducted tests on the angle deviation and stress distribution, longitudinal strain, axial strain, shear stress, and contact pressure between the pipeline contact surface and soil layer at the pipe connection through monitoring instruments arranged at the pipe jacking construction site. Zhang Peng [3-6] and others combined with the arch-shaped curtain jacking project in Gongbei Tunnel to conduct on-site monitoring of the axial and hoop strains and contact pressure of the pipe by installing monitoring instruments on the pipe, studying

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the distribution and variation of axial, hoop, and contact pressure of pipe jacking under deep burial conditions during the construction process. Zhang Yunlong [7] and others studied the change law of the pressure around the rectangular box and the contact state of the box-soil-lubricant through the field detection of Suzhou rectangular box pipe jacking project. Through the in-situ monitoring and direct shear test, Liu Kaixin[8] and others found that in the severe pipe sticking, the hoop strain of the pipe in contact with the blockages showed the tensile state, while the pipe in contact with the slurry or groundwater exhibited compressive strain. Based on the field monitoring of Hubei comprehensive pipe jacking project, Feng Xin [9] and others analyzed the change rules of contact pressure, mud pressure and pipe strain. Wei Gang [10] and others combined with a sewage interception project to investigate the compression size and state of the pipe by installing strain instruments on the inner and outer layers of the pipe jacking skeleton. Feng Jinyong [11] and others found through on-site monitoring that the hoop stress of the pipe was initially under compression and later turned to tension, and the longitudinal strain change was controlled by the deviation of the pipeline axis. Ji et al. [12] proposed a method to predict the jacking force of the pipe jacking through the particle model. By calibrating the microscopic parameters of the sand, the particle model can reproduce the macroscopic material behavior of the sand, so as to derive the contact pressure around the pipe. Then the interface friction coefficient is used to evaluate the friction resistance of the pipe jacking. Sheil[13] proposed a probabilistic observational approach for predicting microtunneling jacking forces.

In terms of numerical simulation, Zhou [14] analyzed the influence of different mechanical parameters of gaskets and different loads on the stress of pipes by using numerical simulation software,and found that pipeline deviation is an important reason for pipe tension and local compression, which can be improved by increasing prestressing belts. Zeng Qin [15] also used simulation methods to study the changes in internal forces, pipe-soil contact pressure, and pipe-soil contact resistance of rectangular pipe jacking during construction. Liu Xian [16] and others established a numerical model of longitudinal force changes with jacking distance in tunnel sections and verified it theoretically with the pipe jacking tunnel project at Jing'an Temple Station of Shanghai Metro Line 14. Yen et al. [17] used ABAQUS software to establish the jacking force of pipe jacking models under different contact areas and different slurry additives lubrication conditions,and obtained the effects of contact area and slurry additives on the jacking force of pipe jacking. Wen et al. [18] conducted a numerical and theoretical study on jacking force prediction in slurry pipe jacking traversing frozen ground.

In summary, existing research mainly focuses on the internal forces of pipes and the combined contact pressure, but there is little research on ultra-long distance and large diameter reinforced concrete pipe jacking in soft soil layers. Therefore, this paper combines the Tangxunhu sewage treatment plant tailwater drainage pipe jacking construction project in Wuhan City to conduct corresponding monitoring of the pipeline, study the stress characteristics during pipe jacking construction, and explore its distribution and variation rules, providing a reference for the safe design and construction of pipelines.

PROJECT PROFILE

The starting point of the Tailwater Discharge Project of Tangxun Lake Wastewater Treatment Plant is the Tangxun Lake Wastewater Treatment Plant, and the end point is Donggang, with a total length of about 10.8km. The pipeline is mainly divided into land and lake sections, and the pipeline construction is mainly carried out by the method of pipe jacking, with a small amount of open-cut sections in the land section. The land section adopts double-row DN1240×20mm welded steel pipes for jacking, with a total length of about 7.06km; the lake section adopts D4000 reinforced concrete pipes for jacking, with a total length of about 3.77km. The lake section includes three jacking sections, which are 1#~2# shaft, 3#~2# shaft, and 4#~3# shaft, and the general layout of the project is shown in Figure 1.

（a） （b）

Fig.1 - The general layout of the project

The on-site test was carried out on the 3#~2# shaft jacking section, which is about 1556.8m in total length. The geological profile of the construction area is shown in Figure 2, and the geological layers of this section are very complex, including loose fill, silt, clay, silt-clayey-fine sandy soil, fine sandy soil, fine sandy soil interbedded with silt-clay, clayey-medium sand with high plasticity, highly weathered mudstone, and moderately weathered mudstone from top to bottom, with the soil properties shown in Table 1. The jacking mainly passes through silt-clayey-fine sandy soil, fine sandy soil, clay, fine sandy soil interbedded with silt-clay, and highly weathered mudstone. Among them, silt-clayey-fine sandy soil is in a soft plastic to flowing state, with low strength, high compressibility, and high difficulty and risk in jacking construction.

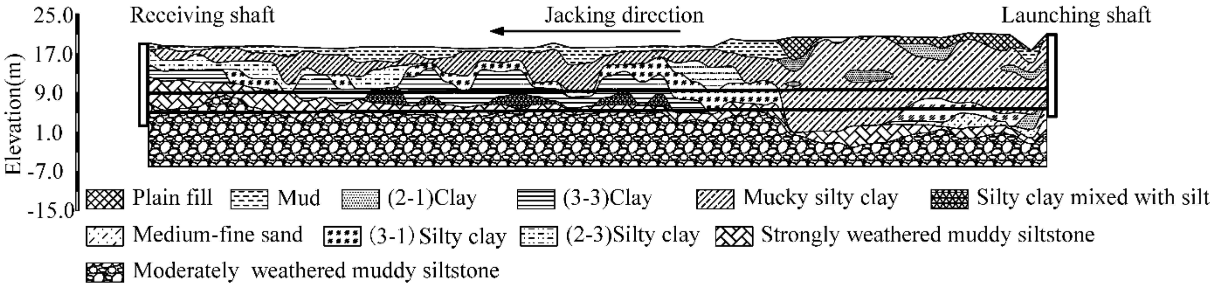


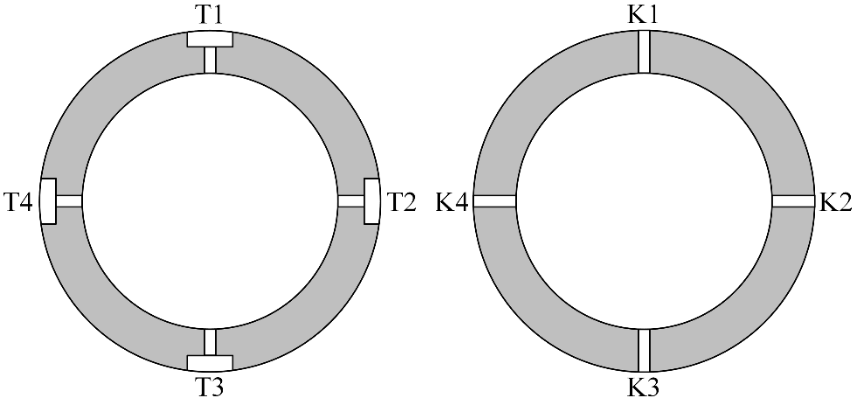
Fig.2 - Geological profile of pipe jacking

Tab. 1 - Summary of soil properties

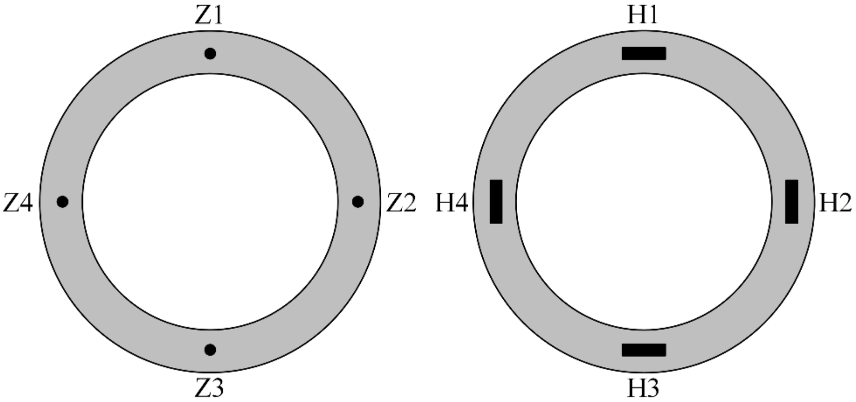
Soil	Density (g/cm3)	Internal friction angle (°)	Cohesion (kPa)	Elastic Modulus（MPa）	Poisson's ratio
Plain fill	1.85	8	10	8	0.3
Silt	1.67	4	9	6	0.35
Clay	1.76	6	16	10	0.32
Muddy silty clay	1.78	5	11	10	0.41
Silty clay	1.91	11	27	20	0.3
Silty clay with silt	1.97	10	20	24	0.28
Strongly weathered argillaceous siltstone	2.05	17	48	120	0.25
Moderately weathered argillaceous siltstone	2.16	22	70	210	0.22

MONITORING SCHEMES

During on-site testing, the contact pressure around the pipe, mud pressure, and steel bar strain were mainly monitored, and were measured using earth pressure cell, pore water pressure gauge, and steel bar strain gauge respectively. The 36th, 77th, 155th, 204th, 291st, 355th, 462nd, and 519th pipes were selected as test sections, among which the 36th, 291st, and 519th pipes were equipped with 4 earth pressure cells, 4 pore water pressure gauges, 4 hoop strain gauges, and 4 axial strain gauges, as shown in Figure 3. The remaining pipes were only equipped with 4 hoop strain gauges and 4 axial strain gauges. The technical parameters of the sensors used are shown in Table 2. The acquisition frequency was 1 time/10 minutes.



(a) Earth pressure cells *(b) Pore water pressure gauges*



(c) Axial stress gauges *(d) Hoop stress gauges*

Fig.3 - Schematic diagram for locations of monitoring points

Tab. 2 - Sensor Technical Parameters

sensor type	model	Range	precision
earth pressure gauge	JTM-V2000B	0~1MPa	2kPa
Pore water pressure gauge	JTM-V3000F	0~1MPa	2kPa
Rebar Strain Gauge	JMZX-416HAT	±1500με	1με

ANALYSIS OF MONITORING RESULTS

（1） Jacking force analysis

The variation curve of jacking force in the 3#~2# working well jacking section is shown in Fig.4. The jacking force generally increases with the increase of jacking distance, showing a stepwise rise, with a maximum of up to 26,000kN. However, there are irregular fluctuations in the rising trajectory. According to the changes in the geological layers, the variation of jacking force can be divided into three stages. When entering the fine sandy soil and clay layers from the silt-clayey-fine sandy soil layer, the jacking force increased significantly and then stabilized; when entering the highly weathered mudstone layer from the fine sandy soil and clay layers, the jacking force also increased significantly. Combined with the actual situation on site, the sharp rise and fall around 500m is due to the occurrence of floating phenomenon in the jacking trajectory, and the sudden increase in resistance in some pipes leads to the increase of jacking force. Then, the measure of activating relay station No.3 was taken to effectively alleviate the problem of abnormal increase of jacking force, resulting in the decrease of jacking force. At 670m, when the relay station was stopped, the frictional resistance increased and the jacking force rebounded; from 800m to 1200m, when the machine head entered the fine sandy clay layer, the frictional resistance was relatively small, and the jacking force fluctuated within a certain range. At 1300m, the jacking force reached its maximum value, because the synchronous grouting pressure decreased with the increase of distance, resulting in poor lubrication effect of the pipe outer wall and continuous increase of frictional resistance. After increasing the slurry injection pump, the external grouting of the pipe outer wall was strengthened, the frictional resistance of the pipe outer wall decreased, and the jacking force decreased and fluctuated within a certain range. The formula of the mud is shown in Table 3.

Tab. 3 - The formulation of the mud

Type of mud	Formulation of mud
Synchronous grouting mud	Bentonite : Na2CO3 : CMC = 8% : 0.4% : 0.1%~0.2% (The ratio of all the above formulation is the mass ratio to water)
Secondary grouting mud	Bentonite : Na2CO3 : CMC = 6% : 0.3% : 0.1%~0.2% (The ratio of all the above formulation is the mass ratio to water)

Note: CMC is a kind of additive, which can improve the viscosity of mud.

In the early stage of jacking, due to the initial lubrication grouting, the pipe circumference did not form a complete mud jacket, and the unit frictional resistance around the pipe was relatively high, about 26kPa. From 0m to 30m of jacking, the unit frictional resistance decreases linearly. From 30m to 300m of jacking, the rate of decrease in unit frictional resistance gradually slows down. After 300m, the unit frictional resistance basically stabilizes at around 1.2kPa. According to relevant engineering specifications and engineering cases, controlling the unit frictional resistance at around 1.2kPa in such geological layers is already a relatively low level, indicating that the grouting lubrication has achieved good results.

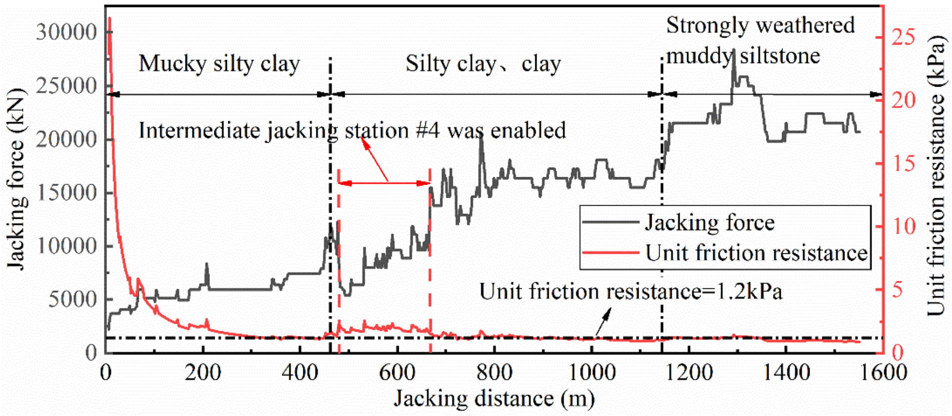


Fig.4 - Jacking force and unit frictional resistance

（2） Analysis of pipe circumference contact pressure and mud pressure

The test data of the 36th pipe at the jacking distance of 280~285m was selected for analysis, and the contact pressure around the pipe is shown in Figure 5. The contact pressure around the pipe is in the range of 160~270kPa, and the order of magnitude is bottom contact pressure > left and right contact pressure > top contact pressure. The reason may be that the gravity of the pipe is greater than the buoyancy, and the pipeline is in full contact with the soil. The gravity and the top soil pressure of the pipeline all act on the bottom soil, resulting in a larger bottom foundation reaction force and a larger contact pressure around the bottom pipe; while the strata where the left and right pipes are located are the same, the magnitude and direction of the strata soil pressure on the pipe are equal and opposite, and the pore water pressure also has basically the same effect on the pipe. Therefore, the contact pressure around the pipe on both sides is basically the same. For the contact pressure received at the top, it indicates that there is no annular clearance at the top, and it is also in a full contact state, but because the top only receives the vertical soil pressure of the overlying soil, the contact pressure is relatively small. At the same time, it can be seen that the contact pressure fluctuations of the four parts of the pipe during the jacking process are small overall, and the influence of jacking on the contact pressure around the pipe is relatively small.

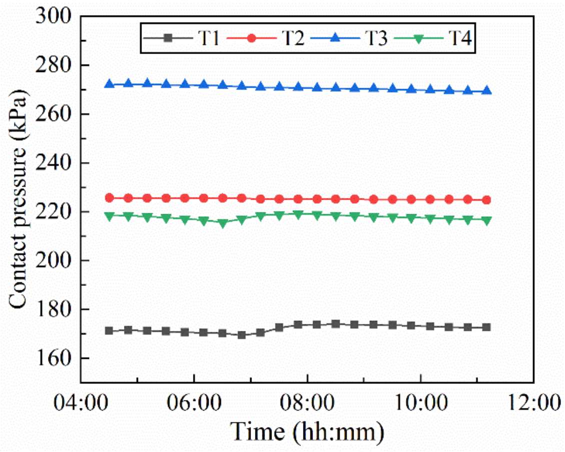


Fig.5 - No. 36 pipe contact pressure

During the on-site testing process, it was found that the pore water pressure gauge had poor testing results and did not reflect the actual grouting situation. The reason for this may be that the top hole of the pore water pressure gauge was filled with soil, preventing the slurry from entering. Therefore, the analysis of slurry pressure was no longer conducted.

To explore the effect of grouting on the contact pressure around the pipe, the changes in contact pressure of the 36th pipe during a certain grouting process were analyzed as an example. As shown in Figure 6, after opening the grouting valve, the bottom contact pressure around the pipe did not change significantly, while the other three areas rapidly increased and maintained stable contact pressure under the action of grouting pressure. The phenomenon of small changes in bottom pressure is firstly related to the arrangement of the grouting system inside the pipe. In order to make room for the drainage system and power system wiring inside the joint, and also facilitate personnel access, no grouting holes were arranged at the bottom, so the bottom was not directly affected by grouting pressure. Secondly, due to the close contact between the bottom of the pipe and the soil, it is difficult for the slurry injected from both sides to penetrate into the bottom, ultimately resulting in no change in the contact pressure around the bottom of the pipe with the change of grouting pressure. However, in the top, right, and left areas, after opening the grouting valve, the slurry invaded the outside of the pipe. Due to the formation of stable mud skin, it prevented the rapid dissipation of grouting pressure and acted on the pipe outer wall, increasing the contact pressure around the pipe. Further analysis of the changes in contact pressure showed that the top increased by 26 kPa, the right increased by 22 kPa, and the left increased by 28 kPa. The output pressure of the grouting pump was 250 kPa, indicating that the slurry pressure loss was significant during transportation and injection into the outer wall of the pipe. The slurry pressure actually acting on the pipe outer wall was about 1/10 of the output pressure of the grouting pump. After closing the grouting valve, the contact pressure around the top, left and right sides of the pipe rapidly decreased in a few minutes, and the slurry pressure rapidly dissipated outside the pipe, causing the contact pressure around the pipe to return to the level before grouting.

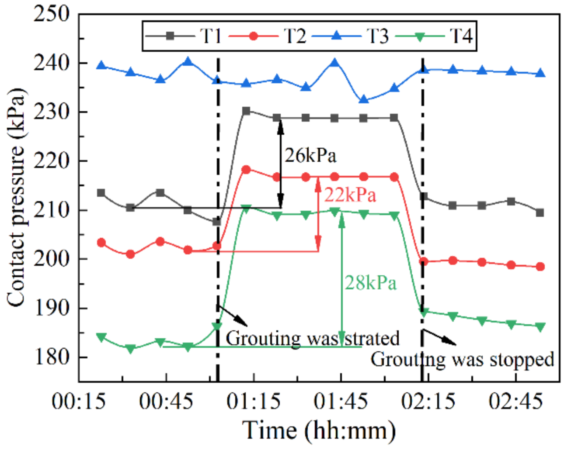


Fig.6 - Contact pressure of pipe No. 36 during grouting

During the stoppage of jacking, the contact pressure of the 36th pipe is shown in Figure 7. Since the bottom contact pressure is less affected by slurry pressure and the actual changes are relatively insignificant, only the pressure changes in the other three areas are studied. After the completion of jacking, the contact pressure gradually decreased overall. Stage I lasted for 9 hours and showed rapid decline, while Stage II lasted for 6 hours, with a gradually slowing decline rate, tending towards a stable state. This is because after the completion of jacking, the initial pressure of Stage I slurry was relatively high, so the slurry pressure dissipated quickly. At the same time, the soil was squeezed during the jacking process, and the release of deformation caused the contact pressure acting on the pipe to rapidly decrease after the stoppage of work. In Stage II, the rebound force of the soil basically dissipated, and the slurry pressure dissipated slowly, causing the contact pressure acting on the pipe to slowly decrease and reach a stable state at around 17 hours.

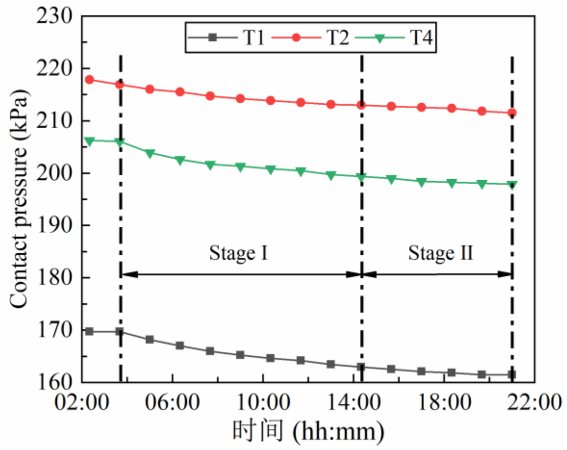


Fig.7 - Contact pressure of No. 36 pipe during jacking stop

（3） Axial strain analysis

Effect of construction stoppage on axial strain

At the jacking distance of 270-275m, the axial strain of the 36th pipe is shown in Figure 8. Throughout the monitoring period, the strains at the four positions, Z1 (top), Z2 (right), Z3 (bottom), and Z4 (left), were negative, indicating that the main stress on the pipe in the jacking process was compressive stress. During the jacking process, the strains of each part of the pipe remained stable. The strains on the left and right sides of the pipe were much greater than those at the bottom and top. The strain on the right side was greater than that on the left side, and the strains at the bottom and top remained basically the same. This indicates that the axial pressure received by the monitoring pipe was unevenly distributed during this jacking distance, mainly concentrated on the left and right sides, with relatively small pressure on the top and bottom. The right side was under greater stress than the left side, possibly due to a slight rightward tilt of the pipe, leading to more concentrated stress on the right side. After the stoppage of work, the strains on both sides decreased sharply, and except for the right side, the strains at other positions were basically the same, remaining within a certain range. This indicates that after the jack was unloaded, the axial stress of the pipe decreased, but a certain amount of strain was maintained, indicating that under the action of frictional resistance, the pipe maintained a certain amount of deformation. The axial stress of the pipe continued to be compressive, and the transmission of the jacking force was mainly completed by the left and right parts, with little change at the bottom and top. During the jacking process of the sections of the pipe at 270-272.5m and 272.5-275m, the strains remained basically unchanged, indicating that the increase in axial stress near the pipe was relatively small.

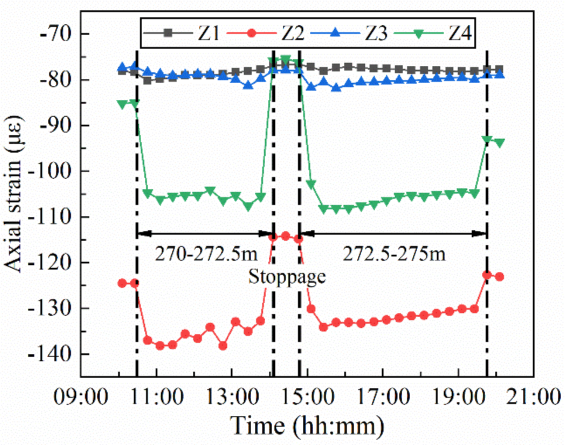
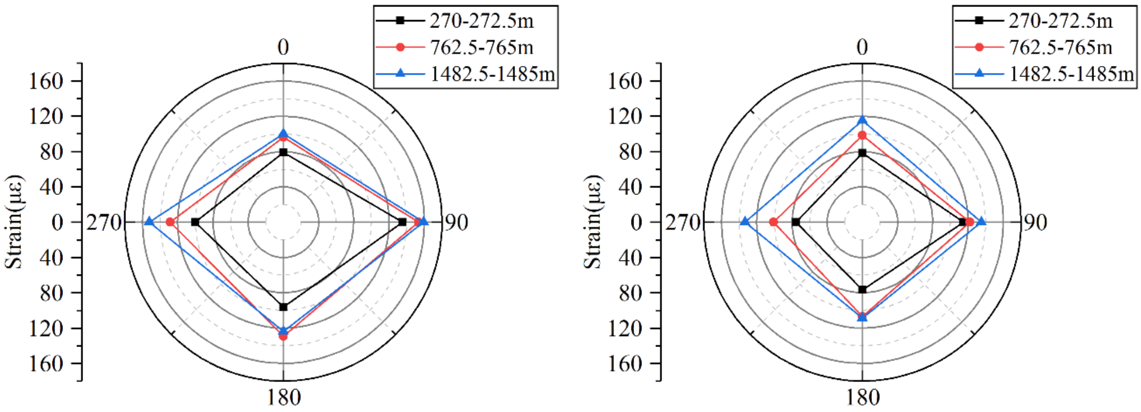


Fig.8 - Axial strain of No. 36 pipe when construction stops

Relationship between axial strain and jacking distance

To study the variation and distribution law of axial stress at the same pipe under different jacking distances, the 36th monitoring pipe was selected as the research object. The average strain values during the jacking process and stoppage period of the pipe at 270-272.5m, 762.5-765m, and 1482.5-1485m were selected as the research objects, as shown in Figure 9.



(a) During the jacking process (b) Shutdown phase

Fig.9 - Axial strain comparison diagram of No. 36 pipe with different jacking distances

Comparing the axial strain values of the three different jacking distances, it can be seen that the overall strain values of each part of the pipe in the last two jacking distances are slightly larger than that of the first jacking distance, and the strain changes of each part are relatively small, indicating that the axial strain of the pipe remains basically unchanged with the increase of jacking distance. At the same time, it can be observed that the strains on the left and right sides of the pipe are larger, and the strains at the bottom and top are smaller in all three jacking distances, indicating that the overall stress state of the pipe remains basically unchanged. With the increase of jacking distance, the stress on the left and right sides becomes more concentrated, and the transmission of the jacking force is mainly completed by the left and right sides. As shown in Figure 9(b), during the stoppage period, the axial strain of each part of the pipe gradually increases with the increase of jacking distance, indicating that the axial stress of the pipe in the stable state gradually increases after the jack is unloaded. The reason is that with the increase of jacking distance, the contact area between the pipe and the stratum continuously increases, resulting in an increase in frictional resistance. Under the action of frictional resistance, the rebound of the pipe gradually decreases, leading to an increase in axial stress in the stable state. At the same time, it can also be observed that with the increase of jacking distance, the distribution range of axial stress of the pipe during the stoppage period remains basically unchanged.

Effect of pipe deflection on axial strain

During the construction process of large-diameter reinforced concrete pipe jacking, after the relay station is activated, the maximum stroke inconsistency caused by the installation error of the relay station cylinder leads to non-uniform pushing in the pushing process, resulting in a large torque on the pipe and causing deviation of the pipe behind the relay station.

According to on-site records, after the 3rd relay station was activated, the pipe was deviated to a certain extent. The 77th pipe was just behind the 3rd relay station. In order to explore the influence of pipe deviation on the distribution law of axial stress, the axial stress monitoring data of the 77th pipe from April 4th to April 12th were selected as the research object, mainly studying the changes of axial stress under pushing state. As shown in Fig.10, the strain on both sides of the pipe remained basically between -100με and -200με during the entire monitoring period, while the strain at the bottom of the pipe gradually increased from -100με on April 5th to -500με. At the same time, the strain at the top decreased from -400με to around -200με, and then alternated between increase and decrease. It can be seen that the deviation of the pipe changes the distribution of axial stress, resulting in a negative correlation between the axial strain distribution of the top and bottom regions of this pipe. At the same time, it can also be seen that the left and right sides of the pipe do not show significant changes in stress. Based on the above analysis, the size of axial stress in the symmetrical part of the pipe shows a clear negative correlation.

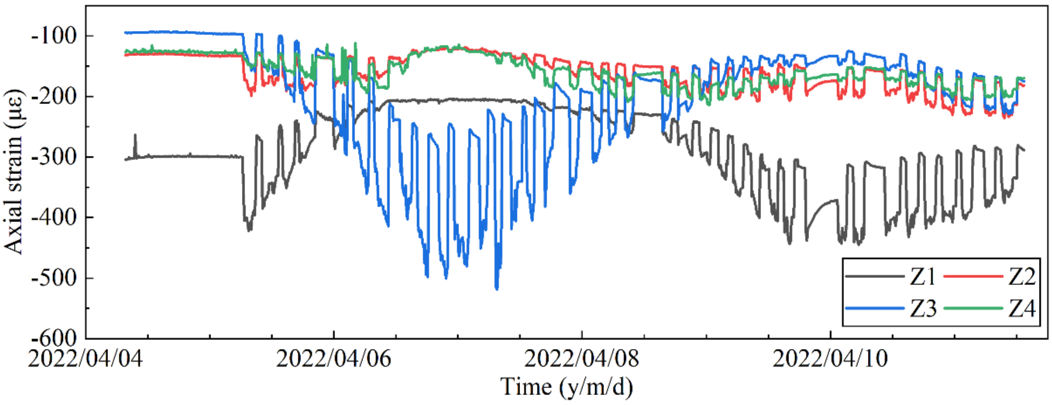


Fig.10 - Axial strain of pipe No. 77

Axial strain analysis of pipes at different positions

To study the variation law of axial stress at different positions of the pipe during the jacking process at the same time period, three consecutive axial strain monitoring sections arranged after the 3rd relay station (to avoid the influence of the relay station on axial stress) were selected as the research objects, namely the 77th, 122nd, and 155th pipes. Due to serious uplift in the later stage of jacking, an earlier jacking period was selected to avoid the influence of uplift. According to data comparison, axial stress of the pipe was mainly concentrated at the top and bottom during this period, with small changes on both sides. The variation law of the top and bottom was basically the same. Therefore, the variation law of axial stress was studied by focusing on the top of each pipe.

As shown in Figure11, the axial strain variation law of the three pipes was basically consistent during the jacking process, with the strain of the 155th pipe > the strain of the 122nd pipe > the strain of the 77th pipe. This is because as the jacking distance increases, the frictional resistance borne by the entire jacking pipe becomes greater, and the applied jacking force also increases accordingly. The pipe closer to the back end bears greater axial force, resulting in greater strain. During the stoppage period, after the unloading of the cylinder, the strain of the pipe decreased sharply, and the strain of the three pipes was basically the same, with the same axial stress borne.

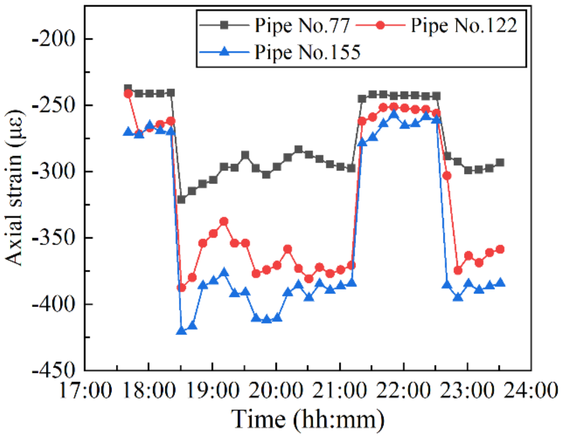


Fig.11 - Axial strain of different pipes in the same period

（4） Hoop strain analysis

Effect of jacking distance on hoop strain

During the jacking process at 285-300m, 859-874m, and 1514-1529m, the hoop strain of the 36th pipe is shown in Figure 12. The hoop strain of each part of the 36th pipe is relatively stable, with a fluctuation range of no more than 20με. From the comparison of strain magnitude, the strain at the bottom > the strain at the top > the strain on the left > the strain on the right, and the overall strain is compressive, indicating that the entire pipe has been under compressive stress as the jacking distance increases. At the same time, as the jacking distance increases, the magnitude relationship of hoop stress at each part of the pipe remains consistent, indicating that the hoop stress state of the pipe has not undergone significant changes. Under the interference of the external environment, the hoop stress is relatively stable as a whole, fluctuating within a small range, indicating that a complete mud jacket has been formed outside the pipe outer wall and the pipeline is evenly stressed in the hoop direction.

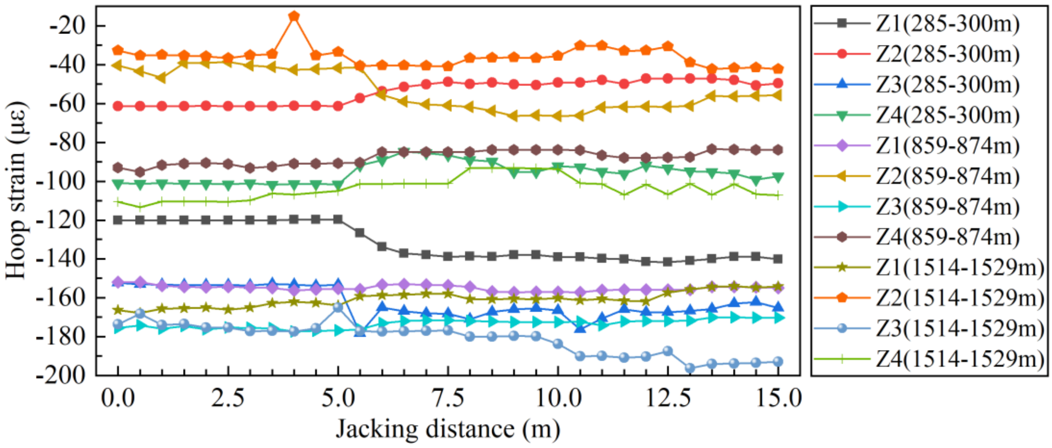


Fig.12 - Hoop strain of No. 36 pipe

Effect of grouting on hoop strain

During a grouting process, the hoop strain of the 36th pipe is shown in Figure 13. Before grouting, the hoop strain of the pipe was basically kept within a relatively stable range, with the strain at the bottom > the strain at the top > the strain on the left > the strain on the right, and the overall strain was compressive, indicating that the pipe was under compressive stress in the hoop direction during the jacking process. However, due to the influence of factors such as the deviation of the pipeline axis caused by the soil pressure of the formation, the distribution of hoop stress of the pipe was uneven, with the stress at the bottom and top much greater than the compressive stress on both sides. After grouting, the hoop strain at the four parts of the pipe fluctuated under the action of grouting pressure, but the overall magnitude relationship of strain did not change. The hoop strain at the top and bottom increased, while the hoop strain on both sides decreased. The reason for this may be that in the annular clearance on both sides, the mud pressure exerted a greater force on the pipe outer wall, squeezing the pipe outer wall on both sides and increasing the hoop stress at the top and bottom of the pipe, while releasing the hoop pressure on both sides of the pipe, resulting in an increase in hoop stress at the bottom and top, and a decrease in hoop stress on both sides.

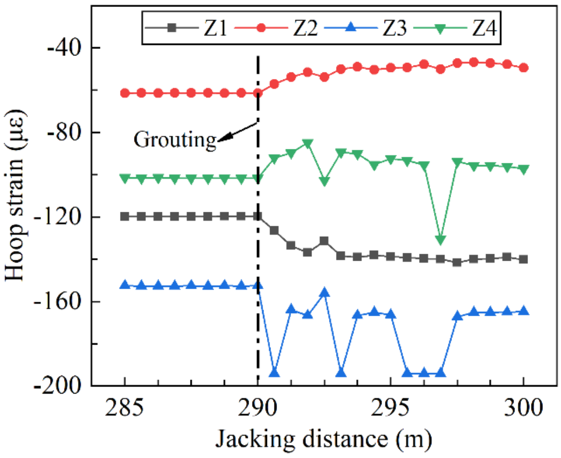


Fig.13 - Hoop strain of pipe No. 36 during grouting

CONCLUSION

This article studies the mechanical performance of large-diameter long-distance reinforced concrete pipe jacking construction in a weak stratum through on-site experiments. Based on monitoring data, the following conclusions were mainly obtained:

(1) The jacking force increases with the increase of the jacking distance, and the overall rise is stepped. The unit friction resistance around the pipe decreases linearly at the initial stage of jacking, and then the reduction rate gradually slows down until the unit friction resistance around the pipe tends to be stable. This is because the lubrication grouting is just started, and the complete mud sleeve is not formed around the pipe. The unit friction resistance around the pipe is large. After the complete mud sleeve is formed around the pipe, the unit friction resistance is reduced to 1.2 kPa, which is a lower level in this kind of stratum.

(2) During the jacking process, the axial compressive stress of the pipe is mainly compressive stress, and the distribution of compressive stress is not uniform. The compressive stress at the top and bottom of the pipe is relatively small, the compressive stress on the left and right sides is relatively large, and the compressive stress on the right side is greater than that on the left side. It is speculated that the pipe is slightly skewed to the right during the jacking process, resulting in a more concentrated stress on the right side; with the increase of the jacking distance, the axial stress of the pipeline increases first and then remains relatively stable. After the shutdown, the axial pressure of the pipe dissipates rapidly, but the overall performance is still in the axial compression state. This is because after the jack is unloaded, the friction resistance around the pipe makes the pipe unable to completely rebound, and a certain compressive strain is maintained in the axial direction, so the whole pipe is in the axial compression state. Under the influence of the deflection of the pipe, the axial stress of the symmetrical part of the pipe shows a significant negative correlation.

(3) During the jacking process, there is a full contact state between the pipe and the stratum, and the contact pressure around the pipe changes little, and the overall performance is the contact pressure around the bottom of the pipe > the contact pressure around the left of the pipe ≈ the contact pressure around the right of the pipe > the contact pressure around the top of the pipe. After grouting, the contact pressure at the top, left and right sides of the pipe increases rapidly, while the change of the contact pressure at the bottom is not obvious. This is because the bottom of the pipe is not placed with the grouting hole and the bottom of the pipe is in close contact with the soil. The mud injected on the left and right sides is difficult to penetrate to the bottom of the pipe, resulting in no significant change in the contact pressure at the bottom of the pipe after grouting.

(4) During the normal jacking process, the hoop strain of the pipe is mainly compressive strain. And the hoop strain of the pipe is relatively stable, basically fluctuating in a small range. This is because a complete mud sleeve is formed outside the pipe, and the pipe is evenly stressed in the hoop direction, so the hoop strain of the pipe does not change much; However, after grouting, the hoop strain at the top and bottom of the pipe increases, and the hoop strain on the left and right sides decreases. The reason may be that in the annular gap, the mud pressure on the left and right sides of the pipe is large, and the left and right sides of the pipe is squeezed, so that the hoop stress at the top and bottom of the pipe increases. At the same time, the hoop pressure on the left and right sides of the pipe is released, so that the hoop stress at the bottom and top of the pipe increases, and the hoop stress on the left and right sides decreases.

(5) Based on the study of the mechanical properties of large-diameter long-distance reinforced concrete pipe jacking construction in weak strata, this paper provides the basis for the setting of construction parameters for the subsequent pipe jacking project in the weak strata, which is of great significance for ensuring construction safety.

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