Zhoushan City Mainland Water Diversion Phase III Project
Key Technologies of Cross-sea Pipeline Laying Construction

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Abstract: This paper introduces the cross-sea water transmission pipeline project from Zhenhai to Mamu section of Zhoushan Continental Water Diversion Project Phase III, and summarizes the towing method of the nearshore section of the pipeline laying, the S-Lay, Post-trenching technology and concrete chain row installation construction techniques. Through the summary of the paper, it is expected to provide help for the construction of the sea bottom pipeline for island water supply in the future.

1. Introduction
The natural condition that there are large amount of islands whereas there is insufficient fresh water supply restricts the socio-economic development in China's South-East coastal area. One of effective solutions is to transmit mainland fresh water to islands through cross-sea pipeline. However, domestic application of this method is limited currently as a result of high cost, high demanding quality control and construction difficulties[1]. Pipelaying vessel method is applied in Zhoushan City Mainland Water Diversion Phase III project, which is based on sophisticate technology in oil gas pipeline construction. In this project, high construction quality, shortened duration and lower cost are achieved. This paper would provide a reference for island water supply projects by introduction and analysis of key technology in the cross-sea pipeline construction.

2. Introduction of project
Cross-sea water transmission pipeline project from Zhenhai to Mamu section of Zhoushan Continental Water Diversion Project Phase III is a component of the cross-sea pipeline project subordinating to Ningbo to Zhoushan Huang jin wan Reserioir Water Diversion Phase III. The pipeline passes through Huibie sea, from Dongshun shore (Zhenhai, Ningbo) to Mamu (Zhoushan). In this area, uneven distribution of water depth varies from 0-20m (National Height Datum 1985 ).According to the shallow strata cross section analysis and offshore drilling data, the shallow Holocene Marine sediments at the bottom of the sea area are mainly silty clay and grey silt-like soft clay at 15.0 - 18.0m. The pipeline is made up of Q345B steel, double-sided spiral welded, with a length of 33 km, inner diameter of 1200mm and wall thickness of 14mm. The project is aiming to provide water in daily life and industrial use for residents in Zhoushan and its surrounding islands.
The duration of project is from September 22, 2016 to September 30, 2017. On August 23, 2017, the hydraulic test on the whole offshore pipeline at depth of 33 km has been completed, which shows no leakage and no pressure drop, meeting the criteria.

3. Technology
Pipeline laying is applied in the project as a result of time limiting and site conditions. The pipeline is non-counterweight and floating after entering water. Therefore, water is injected into the pipeline during the laying process to make the pipeline sink to the bottom of the sea to ensure the stability[2].

3.1 Construction of nearshore pipeline
Since the general water depth in the nearshore section of Zhenhai (landing point) and Mamu (landing point) is relatively shallow and located in the tidal flat section, there is no access to this area for pipelaying vessels. Therefore, the towing laying method is adopted in this section.

3.1.1 Pre-trenching
According to the distribution of water depth, the pre-trenching is completed with joint grab boat, land and water excavator and excavator. To maintain high quality and progress control, the DGPS positioning in applied to set a positioning pole every 20 or 30 meters, along the pipeline, as the pre-trenching benchmark for excavator/land and water excavator. The pre-trenching operation is mainly based on positioning and navigation equipment on the trenching ship. The edge line, center line and control points are set with positioning equipment and measuring software which guarantees trenching within the designed ditch width. In the process, dredgers trench from deep water to shallow water, while constructing channel for itself which leads to proper navigation and operation[3].

3.1.2 Towing and laying method
After the pre-trenching is completed, the towing and laying method is immediately adopted to start the pipeline hauling. The laying vessels anchor at the predetermined location of the high tide, with the stern facing the landing end, and the laying line adjusted above the designed pipeline route guided by
DPGS. The towing cable is connected with the pipe end on the vessel, and each connected pipe is pulled towards land by the cable. On laying vessels, alignment, welding, integrity detection, internal and external corrosion prevention and anodic installation are conducted. After the whole process is completed, the winch pulls up the cable and pulls one pipeline toward the landing point. This cycle restarts until all subsea pipeline are positioned.

3.1.3 Trench backfill
According to the water depth, combination of excavator and shallow-draft barge excavator are adopted to backfill the riprap and raw soil.

3.2 Normal subsea pipeline laying
Pipe laying in deep water is completed by S-Lay method. Pipe-laying vessel is one of the common methods for laying pipelines in deep water. In S-lay, the pipeline is installed with anti-corrosion insulation layer of welding and welds in the deck or cabin, and then enters the water through the frame suspended outside the hull.

3.2.1 Pipe laying vessels S-lay method
The pipeline contains double or single node (about 24m/pipe or 12m/pipe). Multiple workstations are set up on the dedicated pipelaying vessel for pipeline alignment, welding, inspection and corrosion prevention. The cooperative labor division in workstations forming flow of automatic operation helps realize 24h continuous and uninterrupted construction and improves efficiency[4].

After the completion of a double/single node pipeline, the pipelaying vessel moves forward one pipe length under the guidance of DPGS, and the shift of the vessel is completely achieved by the retraction and retraction cable of the vessel's eight shifting winches. The pipe tensioner keeps the tension of the pipe section within allowable limits and relieves the stress transmitted to the pipe by the waves through the hull to ensure the stability and routing of the pipeline.

A large number of mature oil and gas pipeline construction technologies have been applied in the process of steel pipelaying, which has greatly improved the technology level. The technologies involve the following parts. The pipelines are effectively coupled by automatic hydraulic internal alignment device. Backing, filling and cover welding, are involved in welding process. During backing, STT (surface tension transition) semi-automatic welding technology is adopted, where the V-shaped weld groove is flat state, with high welding forming quality. In cover surface filling, FCAW (flux cored wire gas shielded welding) semi-automatic welding technology is adopted, which lead to high filling welding speed and quality. In weld inspection, PAUT (Phased Array Ultrasonic Testing Technology) is adopted, which is widely used in the weld inspection of oil and gas pipelines. It has characteristics such as high defect detection rate, accurate quantitative detection and traceability of data. In outer anti-corrosion patch, radiation cross-linked polyethylene heat-shrinkable belt is used, which is well matched with the outer anti-corrosion 3PE of steel pipe to maintain the quality of it. Special internal anti-corrosion patching trolley sprays wet curing solvent free epoxy with controllable quality. The internal anti-corrosion coating is sprayed well with underwater curing ability, maintaining high anti-corrosion effect.

3.2.2 Receiving and abandoning pipeline
Under the influence of weather or other environment, or the completion of laying construction, the pipe abandoning operation is conducted. In the welding station of the pipelaying vessels, the pipe abandoning traction head is welded to the last one, and connected to the A/R winch (pipe abandoning winch). The vessels are moved forward slowly, while the other stations continue with the pipeline welding, inspection and anti-corrosion. Tension conversion is carried out after the pipe head reaches the position of the tensioner. After the A/R winch obtains the tension of the pipeline, it continues to move the vessel, and the float is tied when the pipe head reaches the trusteeship frame. It continues to move the vessel until the pipe head falls to the sea bed, and the diver hydrolyzes the rope.
Under suitable sea conditions, or laying is required to continue, the stern of the pipelaying vessel are located at the abandonment point of the pipe head and the divers go down to connect the A/R winch cable to the pipe head. Pipelaying vessels move to the designed position, with A/R winch steel cable to the set tension. Afterwards pipelaying vessels move back, the pipe head is pulled to the first welding station, and then the tension conversion between the tensioner and A/R winch is carried out. Finally, The pipe head is cut and resume normal pipe laying.

3.3 Post-trenching
At present, the main technology of submarine pipeline ditching in China is the combination of machinery and water conservancy ditching method of hinge suction and water injection. The deep-water pipe burying in this project is carried out by the water-jet back-trenching method, to be specific, the back-trenching ship is equipped with H-type submersible jet trenching machine. H-type submersible jet trencher is equipped with power station, water pump, air compressor and other supporting equipment. With the guidance of DPGS, the buried pipe engineering ship is in place, and the trencher is lowered to direct above the pipeline. High-pressure water flow is pumped into the ship through the high-pressure pump to break the soil layer, and then a large amount of water flow is pumped into the low-pressure pump to take away the broken soil and ensure the effect of mud blowing. After a certain length of trench is formed, the water-filled pipe sinks to the bottom of the trench by its own weight

The major equipment and ship consist of the main working ship, the trencher and the monitoring equipment. After the trenching machine is started, the main working ship will drag through the traction cable to carry out post-trenching. The trenching quality and process control are mainly maintained by monitoring equipment[5].

In this process, the position of the ship relative to the pipe line is determined by the DGPS positioning system, and the position of the working ship is adjusted by operating 8 positioning windlass. The post-trenching should also consider the transition area at the beginning and end of pipeline construction to avoid the concentration of pipeline stress caused by the height difference between excavated and unexcavated sections. To ensure the safety and stability of the pipeline, the smooth transition is adopted, and the slope is constructed at the junction (trenching treatment in the transition section).

The designed depth of the buried pipeline will be reached through multiple trenches dug in post-trenching. There is no overlap of starting nodes and ending nodes to reserve enough length as the transition of each trench. Trenching speed and parameters of the trenching machine system are adjusted at end point or starting point according to the state of trenching depth monitored by sonar. The distance between each ditch and the starting/ending node of the previous ditch is strictly
controlled based on design requirements. Finally, the original state is gently transferred to the state after the immersed pipe through a step-by-step transition.

In the post-trenching process, the positioning of trenching machine, the judgment of trenching section and depth, and the record of trenching shape are all obtained by sonar. And sonar observer will track and check the whole process, including trench shape and trench depth, pipeline status and guide wheel status. At the same time, the connected computer record information from sonar automatically. The professional survey engineer records the DGPS positioning survey data regularly.

3.4 Installation of concrete chain row
The floating of pipeline during the natural silting in the groove can be analyzed based on the static calculation results. In the natural back-silting process, the soil depth the upper part of the pipeline increases. With the decrease of the moisture content in the soil, the higher buoyancy of the pipeline increases in the risk of floating and the lateral shear force on the pipeline is increased as a result of back-silting soil. Based on experience of phase II of the pipeline and the detection data, the overall trenching is a success, but the pipeline is exposed to the sea bed in certain area. The exposed area of the pipeline is mainly on the side near Zhenhai. In order to reduce the floating risk of the pipeline in this area, concrete interlocking drainage ballast are set as protective measure at 50m intervals. As a measure of pipe ballast, the soft concrete interlocking block row has the advantages of flexibility, high strength, good overall stability and low engineering cost. The dimensions of the single block interlocking row in this project are (width × length × thickness =4m×3m×0.3m). The dry weight is 8693kg/block. The underwater weight is 4980kg/block, and the equivalent underwater specific gravity is 1.34.

As the construction conditions on the offshore are limited, DPGS is selected for measuring and positioning. With the guidance of DPGS, the interlocking row installation ship is located above the pipeline route. Through automatic decoupling installation equipment, the interlocking row is hoisted and lowered to the top of the pipeline. The installation process is monitored by sonar. In this process, the relative position of the concrete compaction to the pipeline and the height of the concrete compaction to the seabed are detected. The installation and layout position of the concrete compaction are monitored and the data are recorded.

![Figure 3 Installation of concrete interlocking row](image)

3.5 Hydrostatic test
After pipeline laying, the 33km cross-sea pipeline is tested for overall pressure by fresh water injection with 1.3 MPa. After installation, leak detection and debugging of the water tank, pressure test pump, manifold, hose, valve, flow meter and pressure gauge, the test starts.
Pressure test consist of two stages: pre-test and main test. In the pre-pressure test stage, when the pressure in the pipeline increases to 1.3MPa, the pressure is maintained for 30min without leakage and pressure drop, and then main pressure test stage is entered. The main test pressure is maintained at the test pressure of 1.3MPa for 15min, then pipeline pressure is reduced to the working pressure of 0.8MPa, maintained for 24h without leakage and pressure drop. These indicate that the hydraulic test is qualified and the pipeline meet the design requirements.

4. Conclusion
The cross-sea water transmission pipeline project from Zhenhai to Mamu section of Zhoushan Continental Water Diversion Project Phase III has been completed, within which the pipelines are in stable operation. There is no pipeline drift and free suspension. The self-burying of pipeline basically achieves the expectations. By summarizing some key construction techniques of this project, a reference for similar projects is provided.

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