Abstract

Concrete structure is commonly used in the anchorages of a large cable-suspended pipeline crossing construction. With the increase of span and load, the stress on the concrete anchorages may rise rapidly. In case of traditional anchoring structure fixed by anchor rods, concrete cracking will occur, thereby reducing the anchorage life. To solve this problem, the pre-stressed structure was designed to effectively improve the efficiency of anchoring and reduce engineering cost. In the crossing construction of China–Myanmar Gas Pipeline, the pre-stressed technology was used to establish an effective pre-stressed anchoring system, which integrates the pre-stressed structures (e.g. tunnel anchorages in the anchors) and the optimization measures (e.g. positioning mode, anchorage structure, concrete placement, pre-stressed, and medium injection), in line with the crossing structure and load features of this project. The system can delay the occurrence of concrete cracking and enhance the stress durability of the structure and anchoring efficiency. This technology has been successfully applied in the crossing construction of China–Myanmar Gas Pipeline, with good economic and social benefits, indicating that this technology is a new effective solution to the optimization of suspended pipeline anchorage structures, providing technical support for the development of pipeline crossing structure.

Keywords: China–Myanmar gas pipeline; Pre-stress; Suspension cable; Pipeline crossing; Concrete; Optimization of anchorage structure; Durability of structure; Anchoring efficiency

In recent years, with the expanding construction of oil and gas pipelines, the requirements on pipeline crossing structures in the design of large-diameter pipelines and double pipelines laid in one ditch are getting higher. Both span and load of such structures are increasing. However, traditional cable-suspended pipeline crossing anchoring structure fixed by anchor rods can no longer meet the pipeline construction requirements because of its poor efficiency of anchoring and serious tensile stress on the concrete structure. Pre-stressed concrete structure with strong anchoring efficiency has been maturely used in highway and railway bridge engineering, so it can be used as the important part in pipeline cable-suspended system to bear the load by linking the cables and anchorages, delivering the stress from the former to the latter and then to the foundation [1]. For this pre-stressed system, cables are connected with pre-stressed rebar by fastenings so as to transmit stress to the anchorages. It is characterized by less steel amount, flexible pre-stressed rebar arrangement and simple construction [2], representing the trend of large cable-suspended pipeline crossing construction.

1. Overview of the project

The China–Myanmar Gas Pipeline, one of the key projects in China's energy strategy, is the main passage of energy imports in the southwestern China, which starts from Kyaukphyu off the west coast of Myanmar and enters China at Ruili City in Yunnan Province and ends at Guigang City in Guangxi Province.

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Suspension cable crossing mode is used at both the Nujiang River section and the Yangbiji River section of the China–Myanmar Gas Pipeline, the span length of which is 380 m and 230 m respectively. Specifically, the Nujiang River crossing is a suspension cable double-pipeline crossing with the longest span in China (Fig. 1). Steel structure tower and hinged steel structure tower are respectively used in these two crossing sections, and the tower height is up to 57 m. The cable system includes main cable, sling cable, wind cable, wind-resistance cable, and stabilizing cable. The main cable is made of braided cables and parallel steel wires prefabricated by PPWS. This project was completed and delivered into operation in May 2013.

2. Optimized application of pre-stressed technology in suspension cable crossing and its technical characteristics

As an important method of crossing, suspension cable crossing features graceful bridge structure, reasonable mechanical property and long history of application. Moreover, its structure is special and different from the traditional bridge crossing. It mainly consists of upper and lower parts. The lower structure includes stake foundation, anchorages and bearing platform, while the upper structure includes hinged steel structure tower, main cable, truss bridge, wind cable and pipeline [3,4]. Most suspension cable crossing structures are built for oil, gas or water pipelines. Their bearing loads are stable, except in wind and earthquake situations. In contrast, traditional suspension bridge suffers from dynamic loads (e.g. vehicles). A suspension cable crossing bridge is more of a flexible truss structure, which is different from the rigid bridge of a suspension bridge, so wind-resistance cable system is generally added in the suspension cable crossing structure to enhance its wind resistance. Conjugated cables and stabilizing cables are also added to prevent dynamic wind effect. Therefore, the suspension cable crossing bridge reflects more obvious nonlinearity than traditional suspension bridges.

As the crossing structure has experienced significant changes — increasingly larger and more bridge-like, traditional anchoring system fixed by anchor rods can no longer meet the engineering requirements.

The pre-stressed concrete structure can improve the stress state of the concrete's tensile region, and expand the tensile scope of the anchorages, so that the life of concrete can be prolonged and the total concrete quantity used can be reduced. It has been widely and maturely used in highway and railway bridges, and become the development trend of large-scale suspension cable crossing anchoring system. In current bridge construction, post-tensioned system is often used [5], with hinged steel cable as pre-stressed rebar. In the recent two years, the pre-stressed structure constructed by post-tensioned method has been gradually adopted in suspension cable crossing projects. The anchorages used in the post-tensioned pre-stressed concrete structure can be divided into mechanical anchorages and friction anchorages [6]. Friction anchorages are usually adopted in the crossing structures. In the Bailong River crossing of Lanzhou-Chengdu Gas Pipeline, CNPC adopted the pre-stressed structure for the first time. Likely, the tunnel anchor cable structure was firstly used in the Yangbiji River crossing of the China–Myanmar Gas Pipeline in China.

2.1. Introduction to pre-stressed structure

Anchoring structures in both the Nujiang River and Yangbiji River crossings of the China–Myanmar Gas Pipeline adopt a variety of pre-stressed structures (Table 1).

2.1.1. Main anchor system

1) In the Yangbiji River crossing section of the China–Myanmar Gas Pipeline, where the terrain structures on the east and west bank are different, two types of anchoring structures are employed respectively. Specifically, 32 bunches of M15DH low retraction anchors in pass-through layout are used at the east bank, namely, the front and back low retraction anchors are symmetrical, with the front anchor pressing tightly on the main anchor seat, and the back anchor pressing on the positioning steel plate. In contrast, because of the terrain restriction and fragmented surface rocks on the west bank, tunnel anchor structure is used.

2) Pre-stressed anchor cables mainly include cable material, anchoring apparatus, grouting material and anchor pier material [4]. Twenty four epoxy coated steel strands and eight-level bearing plates are used in the structure of tunnel anchor cable. The tunnel is 23 m long, and borehole of anchor cable section is 25 m deep. The

Table 1

<table>
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<th>Crossing section</th>
<th>Pre-stressed structure of main anchor</th>
<th>Pre-stressed structure of wind anchor</th>
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<td>Nujiang River</td>
<td>Replaceable pre-stressed system (12 bunches)</td>
<td>Low retraction anchor (4 bunches)</td>
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<td>Yangbiji River</td>
<td>Tunnel anchor cable (24 bunches), low retraction anchor (4 bunches)</td>
<td>Low retraction anchor (4 bunches)</td>
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Fig. 1. Nujiang River crossing of the China–Myanmar Gas Pipeline.
anchoring end on the west bank has eight sections of anchoring cables and one section of test anchoring cable. The bearing layer is sandstone with medium weathering, and the tunnel was filled with C30 concrete after completion.

3) In the Nujiang River crossing section of the China–Myanmar Gas Pipeline, the main cable is PPWS fabricated in air. Therefore, the anchoring system is distinct from the anchor seat structure. To prolong the service life of the crossing structure, replaceable epoxy coated steel strand and anti-corrosion grease are used, and steel strand can be replaced years later. On the east and west banks, fourteen bunches of M15-12 anchorages in front-back symmetrical arrangement are used respectively.

2.1.2. Wind anchor system

The wind anchor systems in the Nujiang River crossing and Yangbijiang River crossing are both M15DH pass-through front-back symmetrical anchoring system, the same as the main anchor used in the Yangbijiang River crossing on the east bank.

2.1.3. Pre-stressed system on the tower top

Since concrete towers are used in the Nujiang River crossing, the cross beam on the tower is where vertical load of the whole bridge concentrates. Therefore, 12 bunches of M15-12 anchorages are used to arrange pre-stressed force symmetrically at the this part, to improve the stress state and optimize the quantity of concrete and steel bar used.

2.2. Project features

Pre-stressed system is widely used in the Nujiang River crossing and the Yangbijiang River crossing. According to the anchoring requirements and the terrain of the crossing site, four types of pre-stressed structures are used, making them the crossings with the most pre-stressed structures in China.

All four types of pre-stressed structures are difficult to construct, with high positioning requirements and many construction steps, as well as higher construction requirements than pre-stressed construction in ordinary civil work. In particular, tunnel anchoring structure and unbonded pre-stressed structure are both used for the first time in crossing structures in China.

Due to different suspended cable crossing structure and mechanical conditions from those for suspension bridge, pre-stressed structure is different from bridge in selection, application and construction.

2.3. Technical features of construction and optimization measures

2.3.1. Positioning measures

Since pre-stressed is mainly used in the anchoring structure of China–Myanmar Gas Pipeline, and suspension cable crossing structure has very high requirement on the positioning of anchorage, anchoring accuracy would significantly affect the mechanical behavior of the crossing structure and the linearity of the completed bridge, or even lead to failure of the crossing.

In summary, in the crossings of China–Myanmar Gas Pipeline, according to the structure and positioning requirements of pre-stressed system, different positioning optimization measures are taken to ensure the accuracy of the anchoring position, and also provide favorable conditions for later pre-stressed construction.

2.3.1.1. Optimization of positioning support. Traditional crossing structures, which mostly use anchor rods, are relatively easy for positioning. In contrast, the positioning of pre-stressed structures must take into consideration the features of flexible steel strands and the design of pre-stressed grouting system, so the construction of pre-stressed positioning support is very difficult. Positioning steel support and the positioning plate on its holder are used jointly to realize the accurate positioning of the pre-stressed steel pipe, and the manufacture and installation precisions of steel support (especially holder) directly affect the positioning accuracy [7]. According to the position and angle requirements of the anchoring structure, steel skeleton and positioning steel plate are combined to calibrate the elevation of front and back anchoring surfaces, and support the pre-stressed grouting tendon duct. The application of positioning plates allows the visual and effective positioning of position, elevation and angle of the pre-stressed front and back anchoring position (Fig. 2).

2.3.1.2. Optimization of positioning method. The positioning method of traditional anchor pier embedded parts can only fix the position of the front and back anchor surfaces. However, each bunch of anchoring structure in the Nujiang River crossing is different in position and angle, so each bunch of anchoring structure should be positioned independently, and it is difficult to meet the required construction quality. Based on the experience of previous construction and special features of

Fig. 2. Schematic diagram of positioning support and plate.
In this project, the combined measuring and positioning measures are adopted.

1) The 3D model of the positioning device was established according to the design drawing. The position and angle of front and back positioning steel plates were simulated, and the position and angle of the front and back anchor plates for each pre-stressed bunch were acquired.

2) Based on the simulation, total station instrument and level gauge were used to determine the positions of front and back positioning steel plates. Then, the positioning steel plates were installed correctly and connected with embedded support skeleton.

3) Laser projection and total station were combined to mark out the position of each pre-stressed hole on the positioning steel plate, and total station instrument and GPS RTK were combined to recheck if the position of each hole was consistent with that simulated by the 3D model. With the infilling control piles as basic points, the total station instrument can control the position of each point in the local coordinate system precisely, whereas GPS RTK can make it convenient to recheck the position of pre-stressed bunch of anchor plate by establishing a whole bridge control system based on the basic control piles of the bridge. These measures can make the solid installation of the anchoring system possible, ensuring the position precision at about 10 mm and the angle precision below 0.5° (Fig. 3).

2.3.2. Optimization of anchoring structure

Traditional anchoring structures of suspension cable crossings are largely in the form of gravity anchorage and anchor rod, which is not conducive to the construction of crossings in different topographic and geologic conditions. In view of the anchoring features and requirements of the crossing structure, pre-stressed anchoring modes such as extruding anchor, grading anchor cable and symmetrical anchoring etc corresponding to inner anchorage structure, inner hole rock anchoring [8], and overall replaceable anchoring respectively, are used in the crossings of China–Myanmar Gas Pipeline, meeting the anchoring requirements of different crossing structures.

2.3.3. Optimization of concrete pouring

For pre-stressed structures, the anti-cracking performance of concrete is improved the mechanical behavior modification of concrete structure. Pre-stressed structures of post-tensioning method are used in the China–Myanmar Gas Pipeline crossings, so the quality of concrete pouring is the key to ensuring pre-stressed effect and pre-stress tensioning. For concrete pouring of traditional crossings, measures are only taken to keep temperature of the concrete. However, for large concrete structures like the Nujiang River crossing with a concrete pouring volume of 6300 m³, only temperature keeping is not enough, because the temperature stress of large volume concrete is sometimes higher than the stress caused by external load, causing temperature fractures to the structure [9]. Therefore, during the concrete pouring of the pre-stressed structure of the project, several measures were taken to ensure the quality of the concrete.

1) In line with the regional features and pouring volume, mixing by supplier and station mixing were adopted to ensure the quality of concrete pouring and the required pouring quantity.

2) In view of the features of large volume concrete of the anchoring structure, internal and external measures were taken to enhance the anti-cracking performance of the large concrete mass. Internal measures includes proper selection of fly ash dosage, optimization of mix proportion, reduction of cement quantity to lower hydration heat [10]. External measures: the cooling water plan for internal concrete was optimized, and a multiple layer cooling system was designed to reduce temperature for different layers of concrete continuously (Fig. 4). The surface was covered by gunny bags [10], and the surface concrete was covered by hot water circulating outside the internal concrete mass to keep the temperature difference inside and outside the concrete at less than 20 °C, which lowered the cracking risk of concrete effectively.

3) Layer pouring was taken to reduce the heat generated by large volume of concrete pouring. Measures such as laitance removal, chiseling the concrete interface rough, smearing cement, and planting bar in faying face were taken to ensure the quality of large pre-stressed concrete pouring.

2.3.4. Optimization of tensioning measures

The traditional tensioning of suspension cable crossing uses a winch system and tensiometer, and the anchor rod in the anchoring structure usually doesn't need tensioning. According to design and standard requirements, low retraction anchor, multiple levels of anchor cable and other pre-stressed
structures are adopted in the China—Myanmar Gas Pipeline crossings to ensure the pre-stressed effect of the entire structure. So, the pre-stressed structure needs to be pulled to meet the technical requirements. To enhance the effect of pre-stressed construction, several pertinent tensioning measures and processes were designed for the construction process, which not only ensured the tensioning effect but also reduced the crossing construction interference with civil work, and enhancing construction efficiency.

1) Several kinds of tensioning counterforce devices including fixed counterforce frame and flexible counterforce frame were designed to meet the demand of tensioning of different structures.

2) According to the features of anchors, requirements of pre-stressed tensioning, and standard requirements, multiple tensioning modes (such as single bunch tensioning, multiple bunch tensioning, and grading tensioning) [3] were employed, and tensioning force and elongation were taken as calibration indexes [11] to ensure the tensioning, meeting pre-stressed requirements. Class difference group tensioning method for pre-stressed system ensures the construction accuracy of cable plait, installation, anchoring and pre-stressed tensioning [12].

2.3.5. Optimization of anti-corrosion agent injection system for steel strands

Pre-stressed tendons are very susceptible to corrosion in high stress state. Therefore, the quality of filling is directly related to the anti-corrosion capacity of pre-stressed, safety and durability of pre-stressed structure. For all traditional pre-stressed structures, finished anchor plates are used in grouting injection and discharge. But the pre-stressed structure of the crossing takes anchor seat, on which the construction of grouting injection system is unsuitable. Therefore, the grouting injection system of the anchor pier's pre-stressed system must be modified to adapt to the anti-corrosion demand of pre-stressed anchoring system of the crossing. Considering the different anti-corrosion agents for the pre-stressed system, the appearance of anchorage and the protection requirements of steel strand in later stage, lines of grouting injection and
discharge system outside the anchorage are used in the China—Myanmar Gas Pipeline crossings, which optimized anti-corrosion agent injection route and enhance the construction efficiency of anti-corrosion agent significantly. It is fit for pre-stressed structure of the crossings, and ensures the anti-corrosion effect in later stage.

3. Conclusion

The successful application of pre-stressed structure in the pipeline crossings has improved the mechanical behavior of concrete, enhanced the anti-cracking capacity of cable anchor piers, and prolonged the service life of the crossings. So, pre-stressed structure represents the optimization direction of anchoring structure of large span suspension cable crossing. In the construction of Nujiang River and Yangbiji River crossings in the China—Myanmar Gas Pipeline, multiple pre-stressed structures met the anchoring demand of several suspension cable crossing structures, proving that the measures taken in the pre-stressed construction can meet the structure features of the crossings and provide technical support for the smooth construction of the project. The innovative pre-stressed anchoring system was not only successfully applied in this project, but also provides alternative technical options for the anchoring construction of similar crossing structures.

References


