Overall Tensioning Construction Technology of Main Beam of PC Plate Stiffened Beam Suspension Bridge

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Abstract. In the construction of the main beam of the PC plate type stiffening beam suspension bridge, the problem of tensioning construction of super-long prestressed steel bundles, combined with the Moon Bay Bridge with the main span of 465m, introduces the whole process of prestressed steel beam piercing and tensioning of the main beam. And the problems existing in the tension construction were analyzed. The construction of the Moon Bay Bridge was successfully completed, and its construction method can provide reference for similar bridge construction, which has certain reference significance.

1. Introduction
The terrain in the southwestern mountainous areas of China is very high, and many traffic routes pass through the deep valley area, and a large number of suspension bridge projects will inevitably emerge. The southwest mountainous area is rich in stone resources. It is convenient to construct the PC plate type stiffening beam suspension bridge in the low-grade roads in the area, and reduce the engineering cost. According to the literature records, several PC plate stiffened beam suspension bridges have been built on the roads in the southwest mountainous area. They are the main span of Guiyang-Bijie secondary road of 278m, the bridge width of 14.5m and the main span of 338m, the bridge width of 14.5m Xixi Bridge; the Guanling-Xingren secondary road main span of 388m, the bridge width of 14.4m Beipanjiang Bridge; the Zhenshui secondary road spans 283m, the Ashihe Bridge with a bridge width of 15m [1], the main span of the Jinsha Highway 325m, and the bridge width of 13m Wujiang Bridge [2]. The Moon Bay Bridge, which is under construction on the fourth-class highway in Yongshan County, Zhaotong City, Yunnan Province, uses a PC-plate stiffened beam suspension bridge with a main span of 465m.

Tension construction is an important process in the construction of prestressed concrete bridges. Tao Jianshan et al. [3] studied the tension construction of prestressed concrete stiffened box girder with a span of 445 m. Lu Xiaoming et al. [4] studied the method of identifying the tensile force of steel strands by the acoustic-elastic effect through the tensile test of steel strands. Hu Yiliang et al. [5] analyzed the problem of elongation deviation during tensioning of prestressed steel strands. Wang Jinhai [6] introduced the construction technology of 405m ballast continuous bridge tensioning. Li Wei et al. [7] studied the construction of long prestressed bundles of box girder.

In summary, the research on the tension of prestressed bridges has yielded a lot of results, but the PC plate stiffened beam suspension bridges have been built less and the span is relatively small, so the tension of the main beam of the PC plate stiffened beam suspension bridge is still it is lacking and can not provide reference for similar construction. In order to guide the construction of such bridges, this
paper takes the Moon Bay Bridge as the research object, and introduces the process of the bridge construction and the analysis of the field measured tensile data to study the tension of the main beam of the super-long PC plate stiffened beam suspension bridge.

2. Project Overview
The Moon Bay Bridge crosses the Jinsha River and connects Daxing Town, Yongshan County, Yunnan Province, and Dexi Township, Jinyang County, Sichuan Province. The main bridge of the Moon Bay Bridge adopts a single-span 465m prestressed concrete slab stiffening beam suspension bridge design. The span is 130m, and the main cable side of the Yunnan shore is 140m. Considering the hoisting and erection of the main beam, the sling spacing is 6m, and the main bridge has a total of 78 prestressed concrete slab stiffening beams (Figure 1).

The prestressed concrete slab stiffening beam standard beam section is dumbbell type, the beam width is 1300cm, the axis beam height is 70cm, and the center spacing of the two main cables (suspensions) is 1150cm. The prestressed concrete stiffening beam has a total of 37 bundles of longitudinal prestressing beams. The N1 long beam is made of 15 pre-stressed steel beams with a diameter of 15.2mm and a length of 461.58m, a total of 21 bundles. The short bundle uses 12 pre-stressed steel bundles of 15.2mm, a total of 16 bundles, of which N2 has 8 bundles, and the length is 443.5m, N3 has 2 bundles, length is 335.5m, N4 has 2 bundles, length is 251.5m, N5 has 2 bundles, length is 167.5m, N6 has 2 bundles, length is 71.5m, (stiffened beam section view 2). The length of the longitudinal prestressed steel beam of the bridge is up to 461.58m, which is the longest prestressed beam at home and abroad.

3. Field tension test
3.1. Prestressed steel bundle blanking and braiding
It can only be cut after ensuring the inspection of each prestressed steel strand and the positioning of the bellows. When cutting the material, the steel wire is cut by a wheel saw, and the working length is 800mm at each end, and the tapered end is made by lengthening the pulling end by 200mm.
At the time of braiding, the steel stranded discs are arranged neatly and horizontally at the bridge deck position on the south bank of Yunnan. At the same time, the opening and unwinding is carried out, and a splitter frame is set at a position of about 1.8 m in front of the laying head, and each steel strand is twisted. The cable is straight and straight, and the wire dividing plate (using an anchor plate) + temporary corrugated pipe hoop (about 10cm long) is inserted at a position 5m away from the reserved hole for tightening the steel strands for lashing bundle. The steel stranded wire frame is 10.2m long and adopts 25a steel as the main beam, which is welded with Φ32mm round steel shaft and jacket Φ48×3.5mm steel tube, 2 sets of each set, used for restraining steel strands during laying. A total of 15 groups are set up with a spacing of 0.5 m. [25a steel main beam is anchored on the bridge deck by Φ25mm anchor. 

3.2. wearing a bundle
Firstly, the wire traction rope of the traction hoist Φ16 is inserted into one end of the prestressed tunnel of the Yunnan shore, and then taken out from the end of the Sichuan shore. Since the wire rope has a certain rigidity, it can be realized from one end of the tunnel through each beam section of 5.5 meters in length. The traction rope is connected to the conical head during the wearing process, and the butter is applied on the conical head to effectively reduce the friction of the pipeline, and the steel strand is sequentially pulled by the hoisting machine. After pulling to the Sichuan shore, the cone is cut off with a grinder.

3.3. pull
When the tensioning work is carried out, the strength of all wet joint concrete must be above 90% and the concrete strength is up to 7 days. Four 400t hydraulic jacks and matching cylinders and pressure gauges are arranged on site, and the two ends are symmetrically tensioned. When the tension is controlled, the control stress is 1395 MPa, and the increase value should be controlled to 5% of the tensile control stress. During the tensioning process, the tension and elongation are controlled by two times, and the tension is controlled by the tension and the elongation is checked. Due to the insufficient length of the top core of the tensioning jack, the tension is applied by means of inverted top, and the tensile elongation and tensile stress value of each tension are recorded during the process. Before pulling, I chose to pass the long bundle N1 to test the Zhang. When I tried to open the sheet, I first pulled the side of the Sichuan shore, and then pulled the side of the south bank of the cloud, and the part was single-ended. The test data is shown in Table 1:

Table 1. Test data

| Tension direction | 30%stress elongation (cm) | 60%stress elongation (cm) | 70%stress elongation (cm) | 75%stress elongation (cm) | 80%stress elongation (cm) | 90%stress elongation (cm) | 100%stress elongation (cm) | 103%stress elongation (cm) |
|------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|---------------------------|
| Sichuan side     | 45.5                     | 118                      | 150.4                    | /                        | 176.1                    | 212                      | 237.5                    | 251.7                     |
| Yunnan side      | 38.6                     | /                        | /                        | 41.6                     | /                        | 57.8                     | /                        | 74.6                      |

It is determined from the test results that the control stress of the long beam at the time of tension is 30%σcon→60%σcon→103%σcon (σcon is the control stress), and the corresponding tensile stress is respectively measured. The long bundle is over 3%, the short bundle is not over-tensioned, and the tensile force is mainly controlled during the tensioning process, and the elongation value is used for verification. The exposed length of the jack under each stress state is measured separately. The actual elongation valueΔL is calculated as follows:

\[ \Delta L = B + C - 2A \]  

(1)

Where: A is the actual elongation of the jack under 0-30%σcon; B is the actual elongation of the jack under 0-60%σcon; C is the actual elongation of the jack under 0-103%σcon.
4. Tensile analysis
The longitudinal prestressed steel beam tension is simultaneously tensioned at both ends in the order of the first long bundle and the short bundle (in order, N1, N2, N3, N4, N5, and N6). The tensile results of some of the long bundles and short bundles are shown in Tables 2 and 3.

Table 2  Long beam elongation test results

| Steel strand type | Tension direction | 30% stress elongation (cm) | 60% stress elongation (cm) | 103% stress elongation (cm) | Actual elongation (cm) | Theoretical elongation (cm) | Elongation deviation |
|-------------------|-------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------|---------------------------|--------------------|
| N1                | Sichuan side      | 30                          | 77.2                        | 153.2                       | 170.4                   | 139.6                     | 22.06%             |
|                   | Yunnan side       | 50.2                        | 100.2                       | 176.2                       | 176                     | 139.6                     | 26.07%             |
| N1                | Sichuan side      | 47.5                        | 103                         | 177.6                       | 185.6                   | 139.6                     | 32.87%             |
|                   | Yunnan side       | 34.1                        | 72.1                        | 148.1                       | 152.0                   | 139.6                     | 8.88%              |
| N1                | Sichuan side      | 49.5                        | 107.3                       | 184.3                       | 192.6                   | 139.6                     | 37.97%             |
|                   | Yunnan side       | 30                          | 69.2                        | 154.4                       | 163.6                   | 139.6                     | 17.19%             |
| N1                | Sichuan side      | 29.8                        | 67.4                        | 145.4                       | 153.2                   | 139.6                     | 9.74%              |
|                   | Yunnan side       | 30                          | 77.2                        | 151.2                       | 166.2                   | 139.6                     | 19.05%             |

Table 3 Prestressed steel strand short beam elongation test results

| Steel strand type | Tension direction | 30% stress elongation (cm) | 60% stress elongation (cm) | 100% stress elongation (cm) | Actual elongation (cm) | Theoretical elongation (cm) | Elongation deviation |
|-------------------|-------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------|---------------------------|--------------------|
| N2                | Sichuan side      | 45.1                        | 88.6                        | 160.8                       | 159.2                   | 135                       | 17.93%             |
|                   | Yunnan side       | 39.5                        | 86.2                        | 153.8                       | 161                     | 135                       | 19.26%             |
| N3                | Sichuan side      | 36                          | 72                          | 120.5                       | 120.5                   | 106.1                     | 13.57%             |
|                   | Yunnan side       | 32                          | 67.3                        | 119.7                       | 123                     | 106.1                     | 15.93%             |
| N4                | Sichuan side      | 25.7                        | 48.5                        | 88.5                        | 85.6                    | 82                        | 4.39%              |
|                   | Yunnan side       | 27.5                        | 58.8                        | 95.1                        | 98.9                    | 82                        | 20.61%             |
| N5                | Sichuan side      | 15.7                        | 33.3                        | 57.2                        | 59.1                    | 56.3                      | 4.97%              |
|                   | Yunnan side       | 15.8                        | 35.6                        | 65.5                        | 69.5                    | 56.3                      | 23.45%             |
| N6                | Sichuan side      | 6.5                         | 15.3                        | 24.3                        | 26.6                    | 24.9                      | 6.83%              |
|                   | Yunnan side       | 7.7                         | 15.5                        | 26.2                        | 26.3                    | 24.9                      | 5.62%              |

After analyzing the data of Table 2 and Table 3, the measured elongation of the prestressed steel beam in the full-bridge tension of the main beam of the Moon Bay Bridge is greater than the theoretical elongation. The deviation of the elongation is greater than the range of ±6% specified in the specification.

According to the actual construction situation at the site, the reasons for the deviation of the prestressed steel bundle elongation of the PC plate stiffener are more than 6%:

- The construction is limited by the site. During the prestressing steel beam blanking and piercing process, the strands are inevitably twisted and slackened, so there is some elongation...
under the non-stress state during the first tensioning process. This is the main reason why the actual elongation of the strand and the theoretical elongation exceed the specification.

- There is an error in the tension control process, and the error caused by the instability of the oil pressure gauge during the manual reading is unavoidable.
- It is not accurate enough to manually measure the tensile elongation of the prestressed steel bundle, and the elongation is inevitably inaccurate.
- The value of the elastic modulus of the prestressed steel strand in the calculation of the theoretical elongation is generally not measured in the field, and there is a certain error according to the standard value.

5. Conclusion

Prestress is the main force structure of PC plate stiffening beam. Prestressed steel beam tensioning is the key process for PC plate stiffening beam construction. All the links in the tensioning process must be strictly controlled, and the quality of the prestressed construction must be guaranteed to meet the design requirements. For the long-tensioning of the main beam of the PC plate type stiffening beam suspension bridge, it is necessary to control the tension and elongation, but it is not limited to the elongation. In the actual construction process of ultra-long prestressed steel bundles, there is steel strand slack. When the deviation of elongation exceeds 6%, do not stop stretching because the elongation exceeds the specification during construction, so as to avoid insufficient prestress and affect the bridge normal use.

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