Research on Construction Control of Semi Hybrid Steel-concrete Composite Cable-stayed Bridge

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Abstract: Hong-shui river especially big bridge is a kind of semi hybrid steel-concrete composite cable-stayed bridge. The erection of Guizhou side span adopt the incremental launching construction method, which was composite beam; The erection of midspan adopt cable-stayed buckled method, which was composite beam; The erection of Guangxi side span adopt support frame casting in situ construction method, which was concrete π type girder. The paper focus on the characteristics of the asymmetrical structure forma and asymmetric construction method of Hong-shui river especially big bridge, discussing the key contents of construction monitoring, which can offer reference and consulting for related engineering.

1. Preface
Hybrid steel-concrete composite cable-stayed bridge simultaneously has characteristic of hybrid girder cable-stayed bridge and composite beam cable-stayed bridge, that is to say, by using concrete girder with the larger dead weight and stiffness on side span, anchorage effect of side span and span ability of midspan can be improved, steel-concrete composite beam is adopted in midspan. The combination of steel and concrete can give full play to their material properties and then the mechanical properties were improved, project cost was reduced. But hybrid steel-concrete composite cable-stayed bridge is of a complicated structure with multiple construction processes. The internal force state of structure parameters and the alignment and the construction technology is closely related[1].

2. Engineering Situation
Hong-shui river especially big bridge is the first long-span cable-stayed bridge using hybrid steel-concrete composite beam in Guizhou province, which is asymmetrical in span arrangement and structural forms of main girder, due to the limitations of damsite topographical conditions. Hong-shui river especially big bridge is a half floating cable-stayed bridge with double towers, double cable plane, and the main span (150+270+150) m. Guizhou side span and midspan adopt composite beam with steel girder and associativity with concrete slab, guangxi side span adopt prestressed concrete π type girder. Main tower adopt thin-wall voided vase-shaped cable tower with group piles foundation, the assistant piers are hollow piers with thin wall and group piles foundation. The arrangement of stay
cable is double cable planes with sector multi-cable systems, 21 pairs of plane cable for every main tower. Longitudinal semi floating system was adopted, between tower and beam at main tower. Vertical sphericity bearing were installed in main tower, transition pier and assistant pier, with lateral anti-wind and anti-earthquake support between tower and beam, as shown in Fig. 1- Fig. 3 below.

3. Construction Situation
The construction technologies of Hong-shui river especially big bridge are complex, due to the limitations of damsite topographical conditions, with different construction scheme adopt to the Guizhou side span, the midspan and the Guangxi side span.

Installation of main steel girders adopt multi-point synchronous incremental launching method, using multiple buttress as load-points, horizontal hoisting jacks were installed, the line of force applied on jack of each pier depends on the line of the sliding friction that the pier’s top bears from the girder body, with the force applied on jack balanced against the sliding friction on the whole, beam body can slide on the slideway fitted by slide plate and stainless steel slide way plate with low friction factor, so that flexible piers can bear nearly no nor less horizontal force. Horizontal jacking force was distributed to every pier and abutment, the line of force of jack was slowly applied on beam body step by step depend on the change range of the line of the friction. All hoisting jack work together. Bridge deck was installed step by step after the beam body was Incrementally Launched to the position, as shown in Fig. 4 below.

Figure 1. Elevation Drawing and planar graph of Hong-shui river big bridge(unit:cm)
Figure 2. Standard Drawing of Guangxi Side Bank Concrete Girder(unit:mm)
Figure 3. Standard Lateral Heterogeneity Profile of Composite beam(unit:mm)

Figure 4. Schematic Diagram of Guizhou Side Span Steel Girder Incremental Launching

The steel girder of midspan was transported to site in terms of KD(Knock-Down) according to main girder, cross beam and small longitudinal beam. They were assembled into entire augment on
subgrade posterior to Guizhou side approach bridge, and then transported to the main tower of the Guizhou side based railway trailer pass by approach bridge and side span, with cable-hanging vehicle slinging, adopt by steel girder cantilever erection. They were installed when stay cable and bridge desk were installed according to monitor demand, and steel girder cantilever erection, stay cable and bridge desk installation were carried out alternately. The steel girder of tow bank were carried out alternately, the steel box girder continue cantilever erection to shut. Three-direction positive stop was set on main tower to ensure the safety of the cantilever erection, and the bridge desk of the midspan was also installed by cable-hanging vehicle, as shown in Fig. 5 below.

Concrete π type girder of Guangxi side span adopt steel pipe pile support frame casting in situ construction, bridge in longitudinal direction was divided in 4 pouring segment, concrete was symmetrically poured in layers from middle to two side, as shown in Fig. 6 below.

4. Construction Control
Hong-shui river especially big bridge is asymmetric in structure, guizhou side span, guangxi side span and midspan adopt diggerent construction scheme, in construction, order of the tension and line of stay cable, installation elevation of construction segment, material properties and the temperature and humidity of atmosphere around bridge in the process of construction would infact the internal force state and liner of structure parameters. Because of the big stiffness difference between main beam, tower pier and stay cable, and affected by the factors of temporary load of construction and change of temperature, it's very complicated between and. The liner and internal force state of
structure parameters have a close relationship with construction method and installation order adopted, and there are a lot of differences between the structure system and load condition of each condition, with the structural internal force and liner changing with it. So, it is the key problem for the construction control of Hong-shui river especially big bridge that how to get the stress state and the geometric liner designed in advance through adjusting construction cable force and setting each segmental elevation.

4.1. Steel Main Girder Incremental Launching Construction Control of Guizhou side span

Monitoring calculation of Guizhou side span steel main girder incremental launching construction adopt activating and inactivating the point of model to model the procedure of incremental launching. The model can be seen Fig. 7.

During the procedure of incremental launching construction of steel girder, the maximum stress value of guiding beam and steel girder is 116.7MPa (Subjected to Tension), the maximum deflection of guiding beam and steel girder is 109mm, as shown in Fig. 8- Fig. 11 below.

In the procedure of the Guizhou side span steel main girder incremental launching, dissymmetry of assistant pier top, settlement of temporary pier, dissymmetry of temporary pier, stress of temporary pier, liner of guiding beam and steel girder, stress of steel girder and so on.

**Figure 7.** Construction Monitoring Calculation Model of Guizhou Side Bank Steel Girder Incremental Launching

**Figure 8.** Tensile Stress Envelope of Guiding Beam and Steel Girder (unit: MPa)

**Figure 9.** Compressive Stress Envelope of Guiding Beam and Steel Girder (unit: MPa)
Dissymmetry of assistant pier top adopt prism setted on the top of pier cooperate with total station to measure. Stress of temporary pier adopt Stress Sensor setted in the piers to measure. Dissymmetry of temporary pier adopt prism setted under the pier cooperate with total station to measure. Stress measure point of steel girder was setted at the cross section of maximum sagging moment and maximum negative moment during the procedure of incremental launching construction. The monitoring of the liner of giding beam and steel girder include the axes dissymmetry and deflection of the steel girder. During the procedure of ncremental launching, the axes dissymmetry of the giding beam the steel girder should be monitored at all time, if horizontal dissymmetry exceed 5cm, rectification notice should be issued immediately. During the rectification, stop the incremental launching hoisting jack first, then set screw jack on the side offsetted to jack tight the steel girder, and then start hoisting jack, along with the moving of beam body, apply a horizontal force to contral the dissymmetry of beam body less then 5cm.

4.2. Steel-Concrete Composite Segment Construction Control of Guangxi side span

Pinpoint of the 0# steel-concrete composite segment in the main tower position of Guangxi side bank is the key work of monitor, exact pouring and field installation of steel-concrete composite segment is the key to ensure the successfull hoisting midspan composite beam. Location of steel-concrete composite segment should comply with: (1) End-plate side should be vertical against the axis of the bridge. (2) Elevation angle of the end of main girder should be anastomosed to the slinging of steel girder. Before steel-concrete composite steel girder site connecting piece construction, 24-hourly measure the deformation of the performed concrete cast-in-situ section, frequency of every 2 hours. Measure the end face, setting 3 measuring point on the top and 2 underside of the end face. The measurement of the vertical and elevation angle of the steel beam end surface before and after installation of the steel mixing and combining segment is measured directly by the full station instrument, deformation measurement in the process of lifting medium-span steel beams, including spatial coordinates, end corners, etc.

4.3. Midspan composites beam cable suspension construction control

After the Guizhou side span steel main girder incremental launching, install all bridge panels of the Guizhou side span. Concrete π type girder of Guangxi side span support frame casting in situ construction segment was divided in 4 segment, after the completion of supported frame casting in situ construction, carry on the hoisting of midspan steel girder and the tension of stay cable of side span and midspan. The calculation model of construction monitoring can be seen Fig.12.
Figure 12. Construction Monitoring Calculation Model of Hong-shui River Especially Big Bridge

Hong-shui river especially big bridge midspan construction adopt twice-tension stay cable technology, that is to say, hoisting beam segment-first tension of stay cable, hoisting bridge plate and pouring wet-joint-second tension of stay cable. Calculation of construction monitoring is one of the important work of construction monitoring, based on the calculation of the whole construction procedure [4], get the liner of steel girder manufacture which can be seen Fig. 13.

Figure 13. Manufacturing Alignment of Hong-shui River Especially Big Bridge Steel Girder (unit:mm)

Transverse pre-camber of cross beam can be seen in Table 1.

Table 1 pre-camber of cross beam

| Number of Segment | Pre-camber(mm) | Remark |
|-------------------|----------------|--------|
| All cross beam of ZL3, ZL4, ZL5, ZL7 segment | 18 | This pre-camber is the pre-up values of the centre point of the cross beam top, with no pre-camber setted at both end of cross beam, and the pre-camber of point left is valued depend on the change of line. |
| HL1, HL2, HL3    | 8              |        |
| HL4, HL6, HL7    | 15             |        |
| HL5              | 21             |        |

Hong-shui river especially big bridge midspan adopt cable-hoisting cantilever construction technology, cable was suspended on the main tower and cross beam, so it would infact the dissymmetry of main tower and liner of main girder while hoisting steel beam segment on cable, as shown in Fig. 14 and Fig. 15 below.
It can be seen from the results, the maximum influence quantity of the cable hoisting construction against the dissymmetry of number 5,6 tower are 1.3mm,2.0mm(midspan direction), the maximum influence quantity against the deflection of the cantilever end of main girder(depend on specific construction stage) is 1.6mm(downward). So, cable hoisting construction have little influence quantity to the dissymmetry of the top of main tower and the liner of main girder.

Composite beam closure is one of the important work of construction monitoring\cite{5}\cite{6}. Composite beam closure is in “dynamic closure”, adopt the “ex ante forecast, monitoring in matters” method. Before hoisting composite beam, make sure the state of stability of closure face, and construction monitoring unit monitor the environment temperature and beam temperature non-stoply in 48 hours, select the time when it is lower temperature and less range change of temperature one day to close and lock, 24-hourly measure the elevation of the cantilever end monitor point in succession, monitoring every 2 hours, and record the curve of the elevation of the cantilever end variation over time.

Try to keep the hoisting of closure segment and the connecting temporary connection simultaneous and staggered, when the temporary connection were finished and form structural continuity, temporary consolidation constraints should be rescinded timely, to avoid that steel girder temporary connection bear too much axial force because of the change of temperature, bring about high strength bolt sliding, infecting attrition surface.

Principle of closure: (1) Closure must follow the principle of low temperature closure, designed closure temperature is 18℃. (2) Tensioning of steel wires of closure segment concrete slab should be in progress according to designed demand after construction of closure segment steel girder, to ensure no cracking in slab. (3) Closure pore should be precisely measured and control before and after the midspan closure.

The error of shut port have three directions: the error of longitudinal bridge, the error of cross bridge, the error of elevation. Because of the difficulty of measuring the error of angle, it should be calculated according to the elevation of the front internode closure pore, sort as the error of elevation. The reason of error produce of each direction and adjust measures as shown in Table 2.

Actual operation on site, each cable force shall be measured first, spatial coordinates of main girder (especially the coordinates at the closure). Combined with the test and analysis results of temperature field, a reasonable time period is selected for closure, specific closing steps:(1) The deviation of the transverse direction of the bridge shall be adjusted first, and the upstream and downstream pull guide chains shall be used to realize the precise adjustment of the guide chain tension required by the displacement. (2) Adjust the cable force, combined with the counterweight, adjust the vertical displacement error, adjust the height difference and angle difference of the closure. (3) By pushing the pier top or pulling the guide chain at both ends of the closure, the error of the longitudinal bridge direction can be adjusted.
Table 2 Error analysis of the closure

| Error direction | Reason of Error                                                                 | Adjust Measures                                                                 |
|-----------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Direction       | Length Deviation of Composite Beam Manufacture                                 | Jack of Incremental Launching with Jack on the Top of the piers; Make Use of Temperature Effect; |
| Longitudinal    | Temperature Effect                                                              | Make Use of Temperature Effect;                                                 |
| Bridge          | Cable Force Compression Effect                                                  | Make Use of Temperature Effect;                                                 |
|                 | Installation error                                                              | Make Use of Temperature Effect;                                                 |
|                 | Sunshine Temperature Gradient                                                   | Make Use of Temperature Effect;                                                 |
| Direction       | Unbalance Cable Force Upstream and Downstream                                   | Cable force Adjustment; Make Use of Temperature Effect; Temporary Load;          |
| Across          | Torsion due to Unsynchronized Installation of Upstream and Downstream           | Temporary Cable; Temporary Load;                                               |
| Bridge          | Load Unsynchronized Stacking of Temporary                                       | Temporary Loading; Hoisting up of pier top;                                    |
| Direction       | Magnitude and position of constructing load                                     |                                                                                  |
| Vertical        | Sunshine Vertical Temperature Gradient                                          |                                                                                  |
| Direction       | Sunshine Overall Warming Cooling                                                |                                                                                  |
| Vertical        | Error of Cable force                                                            |                                                                                  |

5. Conclusions
Hong-shui river especially big bridge is kind of hybrid steel-concrete composite cable-stayed bridge. Main girder Guizhou side span and midspan adopt composite beam with steel girder and associativity with concrete slab, guangxi side span adopt prestressed concrete π type girder, guizhou side span steel girder adopt incremental launching, guangxi side span main girder adopt supported frame casting in situ construction, midspan steel girder adopt cable hoisting construction. This paper discusses different monitoring strategies in accordance with different structure form and different construction scheme, which can provide reference experience for similar projects.

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