The New Incremental Launching Construction Technology of Jiubao Bridge Long-span Hybrid Arch-girder Structure

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***Abstract*-Hangzhou Jiubao Bridge crosses the Qiantang River with full length of 1855 m, which is the first large river crossing project completely using composite structure in China. The main navigation span, of span arrangement of 3x210 m, uses the continuous hybrid arch-girder structure, with multi-point simultaneously incremental launching construction method. The design scheme comes out an integrated consideration of both structure and construction technology. For the purpose of safe, reliable, efficient and economical construction, tracked incremental launching equipment is especially developed with only one temporary pier considered for the 210 m main arch span during the launching construction. Design scheme of this bridge presents new design philosophy, technology and creativity.**

Keywords- Hybrid Arch-Girder Bridge; Design Scheme; Tracked Incremental Launching Equipment; Incremental Launching Construction

I. INTRODUCTION

Jiubao Bridge is one of the most important Qiantang River crossings in Hangzhou, China. The design speed of the bridge is 80 km/h, 2-way 6 lines structure with 3 m wide pedestrian lane in both sides, and the deck total width is 31.5 m for standard section and 37.7 m for structurally extended main bridge. The tidal force of Qiangtang River is extremely strong, with maximum tidal height up to 2.5 m and corresponding tidal speed up to 6～9 m/s. The bridge is designed with the capacity to pass 1,000-ton vessel.

The bridge main navigation span uses long span continuous hybrid arch-girder structure, with the incremental launching construction method used. The overall length of the bridge is 1855 m, with the span arrangement of 55+2×85 m +90 (north approach span +3×210 m (main navigation span) +90+9×85+55 m (south approach span) as shown in Fig. 1 [1].

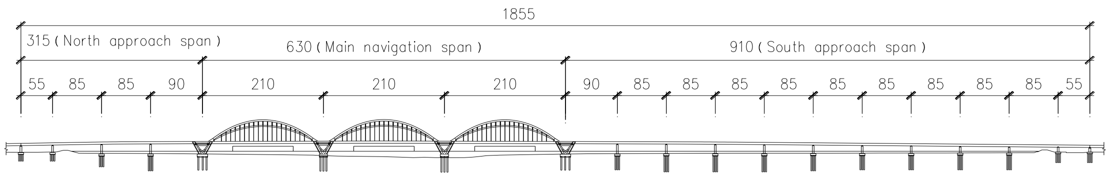

Fig. 1 Schematic layout of the Jiubao Bridge

II. SCHEMATIC DESIGN

With benefits from rapid technical development, innovative design and construction methods have been more and more commonly adopted for constrained bridge environment. Since first successful application on Ager Bridge, Austria in 1959, the incremental launching construction technology has more than half century application history in Europe and US with over 30 years in China [2]. Incremental launching construction has special advantages for bridge sites of deep valleys or non-interrupted transportations like railway and navigation channels, where traditional method is commonly restricted. Also for projects with large river or valley crossing, traditional construction method uses massive frame work construction with huge difficulty [3]. The site conditions like Jiubao Bridge which is within river tidal zone and the riverbed has severe scouring and sediments, the cost of the traditional method is extremely high and the site workload is huge, also with high risk of safety and quality management. Therefore, innovative design and construction scheme is highly expected for Jiubao Bridge for excellent technical and economic benefits.

Considering the unique characteristics of the Qiantang River site environment and bridge structure, continuous hybrid arch-girder structure design scheme is adopted for the main navigation span. The river navigation channel is designed to be covered by the three 210m-spans to satisfy the navigation needs and the deck is composed by steel-concrete composite girder. Tracked incremental launching method is accordingly adopted for construction. Compared with the wedge pushing launching construction method, which firstly realized self-balanced launching process and was applied in Millau Viaduct with great success [4], equipments for tracked incremental launching method are less expensive and more widely employed [5]. The design scheme for Jiubao Bridge, combination of composite girder design with tracked incremental launching, greatly transfers the offshore construction activities to land, avoids the usage of large number of temporary piers and frame work with reduced interruption of the construction work to the environment and navigation activities. Also, the high risk and difficulties of the arch assembly over water is avoided with improved quality control due to the steel structure offshore assembly.

III. STRUCTURAL DESIGN OF THE MAIN NAVIGATIONAL CHANNEL BRIDGE

The main navigational channel bridge is a three-span structure, with span length of 210 m each. The superstructure is continuous with span arrangement of 188 m + 22 m + 188 m + 22 m + 188 m. Four V-shape piers are used for the main bridge, and the pier contour profile is designed to have smooth transition with the superstructure arch curve for better aesthetic effect. Pier is designed to separate from the superstructure with bearing connection in between. Sixteen 2m-diameter bored piles are used for the main pier foundation.

The layout of the arch structure is shown in Fig. 2 [6], which is composed by major arch and subarch connected by connecting ties. The major arch is the main load bearing structure, the central axis of which is a quadratic parabola, located in the same plane but 12 °externally inclined, the arch rise of which is 43.8 m high. Rectangular steel box of 3.2 m high and 2.2 m wide is used for the major arch, and the plate thickness is about 16~22 mm. The central axis of subarch is a spatial curve with rise of 33 m; the cross section of the subarch is 1.5 m×1.5 m square, and the steel plate thickness is around 12~16 mm with some local part to be 18 mm. Transverse connection ties of 600 mm~1000 mm diameter pipe at 8.5 m interval are used between the major arch and subarch. Three transverse ties at the top of the arch are specially strengthened to satisfy the stability requirement.

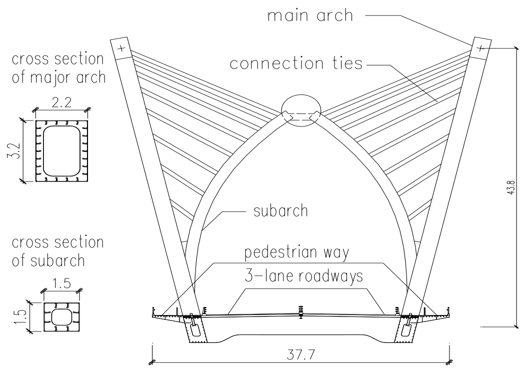

Fig. 2 Elevation of the hybrid arch-girder structure in main navigation span

The typical cross section of the bridge deck system is shown in Fig. 3, which is composed by open steel box and concrete slab, of 37.7 m full width and 4.5 m height at the middle of cross section.

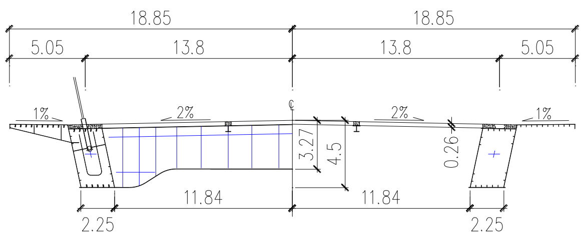

Fig. 3 Girder cross section of the hybrid arch-girder bridge

The steel part of the bridge deck system is composed by two main longitudinal beams, I-shape transverse beam and external cantilever beam. The main longitudinal beam is steel box with cross section size of 2.25 m×3.96 m. The I-shape transverse beam is longitudinally arranged at 4.25 interval. The external cantilever is for the pedestrian lane, in which the transverse stiffener is arranged in line with the I-shape transverse beam at 4.25 m interval. For ease of concrete slab fabrication, two smaller longitudinal beams are designed within those two main longitudinal beams. Q345qD steel is used for the arch structure.

C50 concrete is used for deck slab and the thickness is 26 cm without prestressing tendon arrangement. Longitudinally the slab is designed to allow crack with crack width controlled within tolerance. The precast concrete slab is transversally divided into three pieces with cast-in-place concrete strips arranged at the main and small longitudinal beams, and longitudinally divided according to the location of steel transverse beams to have cast-in-place concrete strips.

Hangers at 8.5 m interval are used for arch-girder connection. The bottom and top of the hanger is anchored in the main longitudinal beam and hanger connector at the major arch, respectively. 121-string 7mm-diameter parallel wire cable system is used for the hanger.

Looking from the load bearing mechanism of the structure, for this hybrid arch-girder structure design, as long as the steel structure is in good condition and even if the concrete slab losses its longitudinal load bearing capacity, the entire bridge is also structurally safe, which makes the concrete slab repair and replacement simple and practical.

IV. INCREMENTAL LAUNCHING EQUIPMENTS AND SYSTEM CONTROL

A. Working Principles of the Launching Equipment

The launching process of the long-span arch bridge is very complicated with sensitive and frequent changing structure loading performance. Therefore, a set of tracked incremental launching system is specially developed with highly modularized equipments and automatic control. The set of incremental launching system has adjusting capacity in vertical, longitudinal and transverse direction, powered by hydraulic jack and automatically controlled by monitoring computer. The basic working principle is to use the vertical jack to lift the structure simultaneously in multiple points, and the horizontal jack to push the structure forward to achieve the launching purpose, then vertical jack is released and entire structure laid down on temporary pad beam to complete a launching process. The procedures of lifting, launching, descending and withdrawing are then repeated to complete the entire bridge launching process [7].

Step 1 *lifting*: the lifting oil cylinder is activated to uplift the entire steel arch-girder structure from the pad beam.

Step 2 *launching*: the launching oil cylinder is activated to move the steel arch-girder structure and the upper part of the launching system forward.

Step 3 *descending*: the lifting oil cylinder is released and descended, the steel arch-girder structure is laid down on temporary pad beam.

Step 4 *withdrawing*: the launching oil cylinder is released and the whole launching system back to initial state, a launching cycle completed and prepare for next repetition.

B. Structure of the Launching Equipment

This set of tracked incremental launching system is composed by upper sliding part, lower supporting part and hydraulic equipment.

The core structure upper sliding part of the launching system is the support steel base box, the bottom of which is fixed with a 3mm-thick stainless steel plate, together with the tetrafluoro slide plate in the lower support part to form the friction pair, and the friction coefficient is effectively reduced. The support steel base box is stiff enough to prevent excessive deformation and excessive stress in the main girder bottom plate during the launching process. Two sets of transverse adjust oil cylinders with guiding wheel are designed at the two sides of the sliding structure. These four oil cylinders can achieve excellent guiding performance for superstructure longitudinal launching, also to solve the transverse discrepancy adjusting problems during the arch-beam launching.

The core structure of the lower support part is the vertical lifting and incremental launching oil cylinders. Four lifting oil cylinders are designed at the four sides of the support structure to form the supporting system of the entire equipment. In order to reduce the equipment height, the lifting oil cylinder is installed inversely inside the support structure with spherical hinge bearing installed for slope self-adjustment. The ascending and descending of the arch-girder structure during the launching process can be achieved by controlling the support lifting oil cylinder, or separately adjusting the height of four lifting oil cylinders, to suit for different longitudinal and transverse bridge slopes, with deformation requirements of the arch-girder structure automatically satisfied. Four dual-head hydraulic oil cylinders, two at both front and back sides, are internally installed inside the lower support part of the launching equipment. Longitudinal incremental movement of the upper sliding part and lower support part can be achieved by the left and right movement control of the oil cylinders. The structural layout of the launching equipment is shown in Fig. 4.

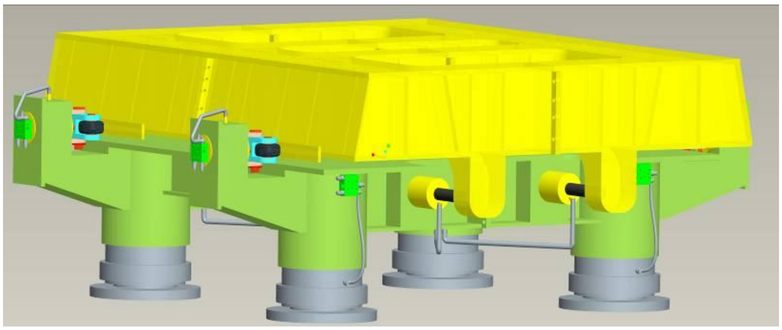

Fig. 4 Structural layout of the launching equipment

C. Equipment Control of the Launching Process

Centralized computer control is used to ensure the simultaneous operation of the entire launching system, with control strategy of synchronized position and tracked loading adopted.

With help from different sets of sensors, including mainly pressure sensors to measure working pressure of lifting oil cylinder, displacement sensors for launching oil cylinder travel distance measurement, and angle sensors to record the hybrid girder longitudinal slope with accuracy up to ±0.05°, the synchronized state of the lifting oil cylinder, launching oil cylinder and transverse adjusting oil cylinder can be simultaneously recorded and monitored to limit the horizontal force of the support pier within the allowable limit and ensure a steady launching process. The load reaction of the lifting oil cylinder at pier position is used as basic reference, and the launching force and displacement of the launching oil cylinder as control parameter, to achieve a both load and displacement (speed) comprehensive control.

Accurate site measurement is also simultaneously carried out to control the launching process. After the first sector of the hybrid arch-girder assembly, three measuring stations are arranged at the back and rear ends and also middle of the longitudinal girder. Measurements are taken down and recorded for each complete launching cycle, and simultaneous discrepancy analysis of the hybrid arch-girder structure is carried out to avoid excessive deformation. After first arch successful launching, measurement stations for the first arch launching process are used as reference control points, with extra three more measuring stations set at the back and rear and also middle of the second sector of arch-girder structure. The same arrangement is done for the third arch sector launching process. Besides, during the launching process, settlement measurements of the launching platform and all piers including temporary piers are closely monitored to ensure steady launching and accurate positioning of the arch-girder structure.

All signals from sensors and measuring equipments are then transmitted to the main control computer to go on data analysis and processing, and the driving signals sent out to adjust the movement and speed of the oil cylinders, therefore the simultaneous ascending and descending of the launching equipments at the top of all piers can be achieved. Any transverse discrepancy can be instantly monitored with automatic transverse adjustment.

V. CONSTRUCTION METHOD OF THE HYBRID ARCH-GIRDER STRUCTURE

The steel structure of the main bridge, which includes the steel girder and steel arch, is firstly assembled on land and then launched to the design position by multi-point simultaneous launching method. After that, the precast concrete deck slab is consequently assembled. Construction of the three-span main bridge is divided into three steps. Upon one span assembly completion, it is launched by a span distance towards the river direction. Then the second span is assembled at the assembly yard, this two-span structure is accordingly launched forward. Upon the completion of third span assembly, the entire three-span structure is then continuously launched crossing pier of the approach span towards the designed position in center of the river. Guiding girder of length of 45 m is designed at the front and back of the launched steel structure during the launching process. The back guiding girder is assembled after the completion of last span assembly.

After incremental launching completion, according to the designed sequence, hanger was stretched and the temporary support between arch and composite girder was removed. The precast concrete deck slab was then assembled with in-situ concrete casted.

It is no doubt a new and creative attempt to have this hybrid arch-girder bridge to be constructed by incremental launching method and even more, only one temporary pier is used for this 210 m long span. The concrete deck slab is not casted until the steel hybrid arch-girder structure is finally launched, therefore, the steel structure of the hybrid arch-girder bridge has profound load bearing capacity compared. Also, temporary connectors are used to connect the steel arch and longitudinal steel beam of the composite girder, which integrate the steel arch and steel longitudinal beam for joint load bearing and reduce the free length of this steel beam, and also help to effectively strengthen the overall load bearing capacity of the entire structure. Therefore, the benefits and competitiveness of this construction method are very obvious both technically and economically. The incremental launching construction process of the arch-girder structure is presented as Fig. 5.

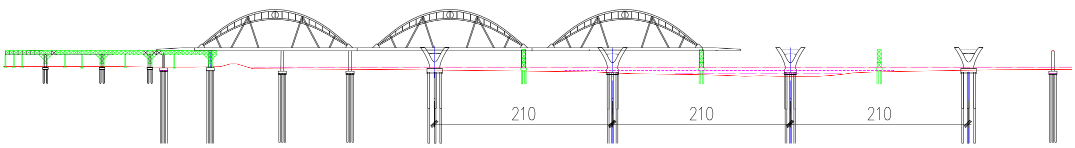

Fig. 5 Incremental launching construction process

Tracked incremental launching system has been successfully applied in the Jiubao Bridge three-span hybrid arch-girder structure construction. The launching process is under entire computer automatic control, with launching efficiency of 2.5 m/h and up to maximum twenty launching equipments are working simultaneously. The total launching weight is as high as 14,500 t and maximum launching distance up to 970 m [8]. The launching system is proved to have excellent synchronization performance with discrepancy of less than 1 mm between piers, and the lifting and launching reaction forces are all within control limits. The frictional sliding during the launching construction all occurs within the launching equipment, and the pier takes no horizontal force. The lifting oil cylinder can be flexibly controlled both individually and simultaneously, to suit for different longitudinal bridge slopes.

VI. CONCLUSION

Jiubao Bridge is the first great river crossing completely using composite structure, in which the hybrid arch-girder structure design and corresponding incremental launching construction method is used for the main navigation span with excellent integration of the site conditions and structural characteristics achieved. This method greatly transfers the offshore construction activity to land and avoids the risk and difficulty of assembling the arch over water in high position, with increased project construction quality and reduced cost. The launching construction of the Jiubao Bridge started from March, 2010 and finished in October, 2010. The launching process is stable and safe, with highly accurate simultaneous control and flexible discrepancy adjustment, therefore, perfect incremental launching construction is achieved. The picture of Jiubao Bridge after construction completion is shown in Fig. 6.

Fig. 6 The Jiubao Bridge, Hangzhou, China

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