The Key Technology of Multi-span Steel Plate Bridge Incremental Launching Construction

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Abstract. Incremental launching erection is a widely construction technology, which has the advantages of low cost, low environmental requirements, simple equipment. In this project, the multi-point support rolling device is used instead of the linear or planar slide support system, and the short nose bridge-fishing method is further used to realize the smooth pier of the beam body. According to the site, a simple and easy deviation correction device is designed. According to the simulation results of deflection calculation and field deflection measurement data, the construction monitoring of the process of incremental launching was carried out, and the incremental launching construction was successfully completed.

Keywords: Multi-span steel plate bridge, rolling device, incremental launching construction technology, simulation analysis

1. Introduction
Incremental launching construction technology has proved to be an economical and convenient method for the erection of long-span bridges. It is of particular advantage for bridge sites with deep valleys, long rivers, or near by transportations systems that cannot be interrupted (such as railway and navigation channels), where conventional construction technologies are commonly restricted [1,2]. The incremental launching method has become particularly useful in recent years for the construction of bridges including the Millau Viaduct in France [2], the Ilsun Bridge in South Korea [3], the Vaux Viaduct in Switzerland [4], and the Yandangshan Bridge in China [5].

On the basis of a large number of concerned information of incremental Launching construction of bridge to be collected, a special study on Incremental Launching Method (ILM), Construction Control Technology and the Development Trend of bridge are reviewed in this thesis. As the collected literature, in the engineering background of Kilombero Bridge from Tanzania, the key technology of incremental launching construction has been studied and implemented.
Longitudinal slope of the Kilombero Bridge deck (fig.1) is 0.25%. The beam body is disconnected from the steel beam on top of P4 pier (expansion joint). Main bridge consists of H-type four-steel structure steel-plate girder (fig.2); girder height is 2.40 m (standard section, not including up and down thickness of batten plate); center distance of every two steel structures is 2.85 m, and distance at both sides is 2.8 m. The section of the H-type single-steel structure steel-plate girder consists of two parts: 1) standard sections; 2) variable sections. The difference between the two parts is that the width and thickness of the top plate is increased from 600 mm to 700 mm, and from 50 mm to 65 mm, respectively; that is, the top plate of the variable section is 700 mm * 65 mm in size, and top plate of the standard section is 600 mm * 50 mm. The variable sections locate on the beam section in which 12 m are left respectively at both sides (24 m in total) of the middle pier P1 ~ P7, and the rest of beam section adopts standard sections. Bottom plates are all 600 mm * 55 mm in size, and the thickness of the web is 20 mm. The stiffened ribbed plates is 15 mm thick, and are welded every 3 meters. A 400 mm channel is used as lateral connection on middle-down section of the stiffened ribbed plates every 9 meters between the steel structures. The two-steel structures on both sides are individual for each other. The center distance of the steel beams is 2.8 m, and the center distance between the 2nd and the 3rd steel beam is 2.85 m. Their sections and lateral connections are different depending on the positions of the beams.

2. Key technology of incremental launching construction
Kilombero Bridge is multi-span, which has a large span and mainly crosses water areas. It is the typical long and light bridge structure with a large-span. The foundation of the bridge head is straight and level, the length and bearing capacity of the roadbed are qualified for pre-assembly of the long-combined beam body. This project adopts the scheme of perforated long steel plate beam incremental launching construction. Bridge span can be simulated on the roadbed behind the abutment as per the features of the small-section steel plate girder so that the support rolling device with intervals is
independently set and is reusable for the pier. Steel beams can be pre-assembled on the support rolling device with intervals, and positioned in place by means of the incremental launching equipment. Temporary buttress, long nose girder, or non-assistance by launching nose pier can be used for bridge span depending on concrete situations. The advantages include: expenditures of support rolling device is small, self-propelled equipment can be used for the incremental launching device with fast advance and simple construction.

2.1. Design of the support rolling device
In consideration of the small section of the beam body and the large span, stress conditions of the bridge for permanent support is simulated, and the multi-point support rolling device is used instead of the linear or planar slide support system; that is 4 (V1~V4) support rolling devices are set on the roadbed behind the A1 abutment, with 48-meter span as an interval (seen in Fig 3).

![Figure 3. Diagram of the support rolling device](image1)

2.2. Key technology of girder pass over pier
For no-nose girder pier, a short distance between the bottom of the beam body (top of the slide-way) and the top of the permanent bridge support shall be kept small as far as possible in order to control the height of dropped beams. Due to the large front deflection of some beam bodies (particularly the steel beam) during incremental launching, the beam bottom is usually lower than the pier bottom. To eliminate this phenomenon, nose bridge is introduced to assist the spanning (fig. 5); that is, a short nose bridge is installed at the specified position of the front of the primary beam, making the bottom elevation of the short nose bridge higher than the top elevation of the support device on the pier top (or the top of the slide-way). When for spanning the pier, a jack can be used to jack the nose on the pier so as to cooperate with incremental launching of the primary beam. In this way, pier spanning and girder erection are realized.

![Figure 4. Detail drawing of the rolling device](image2)
2.3. Design of deviation correction device
Lateral deviation of the center line of the steel beam during incremental launching is usually slight; in case of large deviation, a lateral-correction jack can freely adjust the lateral displacement of the steel beam in corresponding sections for the overall semi-steel beam. By means of the abovementioned rolling device, a trench is set for orientation correction at the side board between rollers of the rolling device (Fig 6). Small screw jack of deviation-correction can be installed within the trench in which the top of the push rod of the jack is equipped with rubber slider, contacting with the edge of the bottom plate of the steel beam. Lateral position deviation of the center line of the steel beam can be corrected in time.

3. Analysis of construction process
3.1. Deflection calculation of primary beam
Internal force of the beam body varies during construction process, and sections of the beam shall bear hogging moment when crossing the supporting points and sagging moment when crossing the middle sections. To guarantee the beam body from stress damage during the construction, analysis of a mechanical model for the deflection changes of the beam body (vertical displacement), counter-force of the support, overall stability and changes of stress of the beam body shall be analyzed:
Figure 7. General construction procedures

LC14 (advancing distance I = 42 m)

LC15 (advancing distance I = 45 m)

LC16-1 (advancing distance I = 48 m, maximum cantilever)

LC16-2 (advancing distance I = 48 m, through P1 pier)

Figure 8. Working conditions of restrain

Design of the working conditions is made without consideration of temporary pier, launching nose, and multi-point support rolling device, as per steps ①～④ in Figure 7, in which the construction steps from A1 abutment to P1 pier are shown as a complete spanning of 48 m. The span of the subsequent cross-holes is 48 m with a straight-line distribution and repeated working conditions, and individual calculation is not given.

Table 1. Support of A bridge from A1 to P1 varies with working conditions during incremental launching

| Condition | Distance | V₄ | V₃ | V₂ | V₁ |
|-----------|----------|----|----|----|----|
| LC00      | d=0m     | DyDz| DyDz| DyDz| DyDz|
| LC01      | d=3m     | DyDz| DyDz| DyDz| DyDz|
| LC02      | d=6m     | DyDz| DyDz| DyDz| DyDz|
| LC03      | d=9m     | DyDz| DyDz| DyDz| DyDz|
| ......     | ......    | ......| ......| ......| ......|
| LC14      | d=42m    | DyDz| DyDz| DyDz| DyDz|
| LC15      | d=45m    | DyDz| DyDz| DyDz| DyDz|
| LC16-1    | d=48m    | —   | DyDz| DyDz| DyDz|
| LC16-2    | d=48m    | —   | DyDz| DyDz| DyDz|
In which: (1) $D_x$, $D_y$ and $D_z$ represents restraints in the longitudinal direction, cross-section direction and gravity direction, respectively;
(2) “-” represents there is no support;
(3) $d = 3$ m refers to the distance from the center line of V1 to the end face of the primary beam; the same applies hereinafter.

![Figure 9. Deflection calculation of the girder](image)

As the calculation, the maximum deflection of the beam end is -420 (fig.9) mm in the status of the maximum cantilever. It can be realized by the fishing method when for beam pier.

3.2. Stability calculation of the pier

Counter-force of the supporting points is calculated as per the above working conditions with results seen in Figure 10:

![Figure 10. Calculation of Counter-force of the support](image)

Based on the calculation, counter-force of the support reaches maximum of 1067.4 kN at the maximum length of the cantilever(fig.10); the maximum height of the pier is 10.165 m, and the concrete grade is C40. Given the longitudinal static friction coefficient as 0.1 by experience, longitudinal friction is applied to the top of the pier, and vertical counter-force is applied to the support. Given the partial factor of dead load as 1.2 and construction load as 1.4, build-in P-Δ is used to calculate the stability of the pier (Fig. 11~13).
As per calculation, when $P$-$\Delta$ effect is taken into account, the critical loading coefficient is 293.6 and is qualified; the longitudinal maximum displacement of the pier top is 4 mm with deformation less than $L/400$, thus the stiffness is qualified; maximum pressure should be 1.7 MPa, and is less than the designed 19.5 MPa of the compressive strength of C40 concrete, which is qualified for construction and design.
4. Execution of incremental launching construction

4.1. Beam body assembly
Semi-steel beams are assembled before incremental launching construction as follows:

① Inspecting the elevations of the base, pier, and pinner on top of the bedstead, and the position and depth of the preformed hole. Cleaning the pinner and the reserved anchor bolt hole, and marking center line of the beam, center line of the support and line of the beam end on the pinner.

② Steel beams are aligned in parallel and assembled in sequence from A1 abutment backward.
Concentration sequence of longitudinal joint of single-steel structure: bottom slab →web →top slab. When for assembly, drift pins are inserted into the four corners first, then other pins are inserted in triangular distribution. The number of the pins are not less than 30% of the total number of high-strength bolts. After that, the rest of the cotter holes on the connecting plate are all fixed by high-strength bolts through initial twisting and final twisting. Last, withdrawing and replacing the drift pins with high-strength bolts, and then tightening up. Construction sequence of the lateral connection of two-steel structure steel beams: hoisting the deck beam and inserting it into the gusset plate at the inside of the two pieces of steel slab girder; putting it in place, and inserting four drift pins into the four corners, and then fixing the rest of the bolts through initial twisting and final twisting. After that, replacing the pins, and the first steel beam is assembled.

③ After the first steel beam is assembled, putting it in the support position as per the axis position; then assembling the latter beam body in sequence of longitudinal connection first and lateral connection second until the 192 m-long semi-beam body is assembled.

4.2. Incremental launching construction
The constitution of the whole bridge as per segments of the steel beams is 6 m + 15×12 m + 6 m = 192 m, so, there are 16 joints on the bottom slab of the whole beam body of single-steel structure, and the superposed height of the connecting plates and the bolts is higher than that of the bottom slab of the steel beam. When the connecting bottom plate moves across the rolling device, cyclical hoisting operation is realized through the front and back rollers of the device so as to guarantee the smooth transit of the beam body. Detailed procedures are seen as follows (Fig. 14):

![Figure 14. Incremental launching construction procedures](image)

Step 1: Commissioning the bulldozer and marking the 3-meter pace on the ground as required to ensure the thrust augmentation and unloading for the bulldozer.

Step 2: The front end of the beam body starts showing a state of cantilever with the process of incremental launching construction. When the beam body is suspended for 36 m (when the trailing end is 12 m away from the V4 temporary support), that is, the initial position in step ② in Figure 5-1, advancing is paused, and anti-slip measures should be taken for the beam body. The front end of the primary beam is assisted by the fishing method.
Step 3: The crane hoists the front end of the beam and restarts incremental launching for 9 meters, and then pauses again; workers taking in charge of the P1 pier top shall adjust the height of the rollers to ensure the smooth transit of the nose girder through the above of the rollers, and then place the jack. If the deflection is large to affect pier construction, the crawler crane will used to cooperate with the jack to assist pier construction through incremental launching the nose girder. Then disassembling the rolling device at V4 and installing it on the top of P2 pier. After that, advancing is continued until both ends of the primary beam reaches to the above of the support of P1 pier, as seen in Step ③ in Figure 5-1.

Step 4: After the steel beam reaches to the top of P1 pier, longitudinal displacement of the steel beam axis should be inspected and deviation correction will be made as required. After correction, repeating steps ①–③ until the primary beam reaches to and crosses the P2 pier, as seen in step ④ in Figure 5-1.

Step 5: Repeat steps ①–③ until the primary beam reaches to and crosses the P3 pier, as seen in step ⑤ in Figure 5-1.

Step 6: Repeat steps ①–③ until the primary beam reaches to and crosses the P4 pier, as seen in step ⑥ in Figure 5-1. After the whole steel beam is jacked in place, the nose girder will be disassembled in time, and the planimetric position of the steel beam shall be adjusted until it is qualified for the design.

4.3 Deviation correction
During the construction, the top face of the steel beam corresponding to the center line of the web is marked with a gauge point every 8 meter first; one connection through two centerlines of the steel beam is made and then another connection is made through the ideal common centerline (center point on top of the lateral beam). The total station is used monitor these three lines for comparison during incremental launching construction, and manual correction will be made through the deviation-correction jackscrew when there is significant deviation. The main approach: a lateral 20T jack is installed at the side of the support device, with rubber blanket on top of the push rod of the jack, incremental launching the bottom plate of the beam for deviation correction by gradual pressure pressurization. It is noted that deviation correction should be synergistically carried out from the longitudinal bases, during which the total station is used to monitor the restoration of each support point until the adjustment is finished.

4.4 Falling beams
After the whole 192-meter steel beam are in place, the steel beam is jacked by a vertical jack first, and then the planimetric position of the steel beam is corrected by a horizontal jack. Beams are dropped after the bridge support is corrected. A jack is used synergistically to drop the beams, and double control by oil-pressure gauge and travel value are adopted for the beam dropping, and the falling height is not more than 50 mm each time. After the temporary whole steel beam is in place, the steel beam is jacked and its position is corrected; the slide-way and orientation device are disassembled and replaced by the formal support. Shape steel or hard lumps of wood are used to set the insurance for safety.

5. Conclusion
With fast growth of the infrastructure construction in China, options for the perforated long steel plate beam incremental launching construction are limited. Incremental launching construction is usually the first choice for its high efficiency, good convenience and flexibility on condition that a well-equipped rolling device is provided. This study is carried out against the backdrop of Kilombero Bridge A in Africa with consideration of challenges by the construction and supervision from different nations, and solutions are put forward. The bridge construction method, design and scheme selection, and construction control etc. are analyzed with conclusions as follows:
(1) Intercontinental engineering projects should consider the transportation and loading-unloading, which are essential to control the design scheme.

(2) Single-point force application is adopted at the tail of the steel beam instead of multi-pint force application by the synchronized crawler device. This scheme is easy and simple, and widely used in construction.

(3) During the scheme selection and in practice, the scheme only with nose girder and no launching nose is feasible. But for the last 8 meters in consideration of the maximum cantilever of the bridge is 48 m, a truck crane is recommended for assistance.

(4) Deflection during the steel beam incremental launching is controllable, and strength of the parts is qualified for the design with good operation in practice and good stability. However, lateral deviation is inevitable for long incremental launching construction, therefore, a lateral guiding device can be used for correction.

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