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RESEARCH ON THE KEY TECHNOLOGY OF TIED-ARCH BRIDGE INCREMENTAL LAUNCHING METHOD CONSTRUCTION

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ABSTRACT

Steel tied arch bridge has been widely used in modern bridge construction due to its beautiful shape, high material utilization rate and overall structural stiffness. However, there are few cases in which the tied-arch bridge is constructed by incremental launching. Based on the steel tied arch bridge project, this paper uses finite element software to establish the finite element simulation analysis of the construction process and monitors the construction process of the bridge. The test results show that it is in the most unfavourable state when the cantilever at the end of the bridge reaches the maximum. At this time, the stress at the 117 m position of the beam reaches the maximum, the stress at the top edge is 33.7 MPa, and the stress at the bottom edge is -58.2 MPa. The stress in other sections did not exceed 30 MPa, and the beam was under uniform stress. When the foot of the internal arch passes through the temporary pier, the supporting force of the pier is maximum, which is about 6000 kN. The reasonable range of α is between 0.55 and 0.65, which is the ratio between the length Ln of launching nose and the maximum span L of incremental launching. The research results can provide reference for the construction of similar bridges.

KEYWORDS

Tied-arch bridge, Incremental launching method, Construction monitoring, Temporary pier, Launching nose

INTRODUCTION

Tied arch bridge has a beautiful shape, the curve is round, its construction history is relatively long. The cost of arch bridge is economical and has a good crossing ability. Meanwhile, the maintenance and repair are convenient and the cost is less. However, the arch bridge has some disadvantages. The main arch ring is mainly pressured during the use of the arch bridge, and its mechanical characteristics determine that there will be relatively large horizontal thrust at the foot of the arch. Therefore, the construction of the arch bridge has strict requirements on the foundation. Different from the arch bridge, the beam bridge is mainly subjected to the action of bending moment and there is no horizontal thrust. By combining the arch and beam in a reasonable design, their respective advantages can be fully exerted and the influence of force defects can be reduced. The mechanical performance of the bridge structure is optimized, so that the span capability of the bridge is increased and the use effect is better. The superstructure of girder and arch composite bridge usually includes arch rib, longitudinal beam, tie rod and vertical column, etc. The tie bar is mainly used to balance most or all of the horizontal thrust at the arch foot of the completed bridge. Therefore, the horizontal thrust at the arch foot of the girder arch composite structure bridge does not exist or is much smaller than the thrust at the arch foot under the same conditions, which can greatly reduce the requirements of foundation bearing capacity. In addition, in some special site environments, such as the bridge across the river navigation requirements are high, the bridge under the bridge navigation height is high, the combined system bridge will reflect a greater advantage. Due to the good application value of such bridges, a lot of such bridges have been built in recent years, which also promotes the faster development of bridge structures. With the emergence of various bridges with novel structures and unique shapes, the construction methods of bridges are also constantly innovating and developing. In the actual bridge construction, the choice of construction method is targeted. According to the structural characteristics of the bridge, construction technology and equipment, site environment and economic, to determine the most suitable construction method. There are many bridge construction methods, and each method has different applicable conditions. Due to the difference of site environment and construction conditions, the construction method selected will also be very different. When the bridge construction site environment is relatively complex and has a great impact on the bridge construction, the bridge structure can be prefabricated and assembled in sections, and then the assembled well-formed bridge structure can be jacked forward gradually along the direction of the bridge, making the bridge slowly pass through each temporary pier to complete the bridge construction. This construction method is called push - up construction.

The incremental launching method is used more in the construction of prestressed concrete bridges and less in the construction of steel bridges. With its unique and novel shape, beam and arch composite structure can be well integrated with the surrounding environment and has good crossing ability, which is increasingly widely applied in practical engineering, especially in the design and application of urban and landscape bridges. As a new bridge construction technology, the incremental launching method has few practical applications, and there are still some problems to be solved. Therefore, it is very necessary to analyze the force of the whole incremental launching construction process of the bridge by combining with the engineering practice.

PROJECT PROFILE

Fig.1 - Elevation drawing of push process

The bridge is 191.339 m in length and 38 m in width. The main bridge structure adopts steel truss arch beam structure with main span of 106 m to cross the river. The lower arch rib is 19.27 m high, the span ratio is 1/5.5, and the height of vault truss is 3.5m. Fixed support is set at one end of the bridge towards the arch foot, and sliding support is set at the other end. The overall structure is non-thrust system. The arch ribs are box girder structure and the material is Q345QC. A structure in which the main beam is the main longitudinal beam, steel beam and secondary longitudinal beam are under joint stress. The bridge deck is orthogonal special-shaped plate, and the beam height at

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the center line of the bridge is 2.57 m. The steel type is Q345Qc. The middle pier adopts the form of pile foundation extended by pile caps. The pile foundation is a bored pile with a diameter of 1.8 m.

The main girder adopts the structure form of all welded steel box girder. The box girder adopts a single box with a three-compartment section, with a height of 3.5 m and a cantilever length of 4.0 m outside the box girder. The beam is 39.0 m wide at the top and 18.5 m wide at the bottom. The steel box girder roof thickness is 16 mm, the bottom plate thickness is 14 mm. U - shaped longitudinal stiffeners are used for the top and bottom plates, and plate stiffeners are used for the rest. The longitudinal spacing of the cable anchor points is 9 m, and a beam is set at the corresponding lifting point. The arch ribs of the main bridge are in the form of steel truss. The upper and lower arch ribs are connected as a whole by vertical and oblique ventral rods, and two truss frames are arranged laterally. The trusses are connected by transverse braces to enhance lateral stability. The upper arch rib span is about 142 m, and the sagittal height is 23.5 m. The rib span of the lower arch is about 103 m and the vector height is 20 m. The net sagittal height of the truss arch is 19.288 m, the sagittal span ratio is 1:5.5, and the height difference between the upper and lower arch ribs is 3.5 m. The steel arch rib section adopts a closed box section with a section height of 1.2 m and a width of 1.2 m. The thickness of steel plates in the standard section of arch rib is 30 mm, the thickness of steel plates in the reinforced section of arch foot is 40 mm, and a diaphragm is set every 1m in the arch rib. The arch truss girders are the I-shaped sections, the section height is 1.2 m, the flange width is 0.4 m, and the plate thickness is 16 mm. The sling of this bridge adopts parallel steel wire sling, and the whole bridge is arranged with 30 slings. The sling is made of 85 parallel steel wires with a diameter of 7 mm, with a standard strength of 1670 MPa. The elevation of the bridge is shown in Figure 2, the span arrangement is 22 m+106 m+22 m.

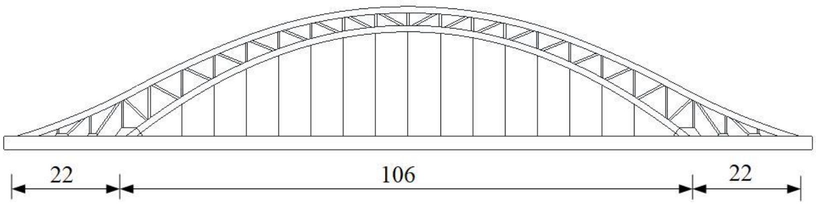

Fig.2 - Vertical view

CONSTRUCTION SEQUENCE

As the river has navigation requirements, supports cannot be set up in the river, so the steel truss arch bridge is recommended to use the push method for construction. The main construction steps are as follows:

Step 1: Two temporary piers shall be built between the 2 # and 3 # main piers, the slide beam shall be installed, and the vertical and horizontal jack adjustment devices and the incremental launching equipment shall be installed for debugging.
Step 2: In the assembly site, the steel box girder structure of arch bridge is assembled, and the arch rib steel tube, derrick and launching nose are installed. After installing the boom, preapply a certain tension of the sling. At the same time, the pier incremental launching traction system and deviation correction system are installed, and the debugging incremental launching system is ready.
Step 3: Start the incremental launching system and push forward. After pulling the anchor near the pier, pause the incremental launching and drag the strand to the next pier to be installed, and continue pushing forward. Remove the steel strand when the next anchor is close to the pier, then pull the anchor backward and change it. The changed steel strand shall be pre-tightened again and continue to push.
Step 4: When the launching nose is pushed to pier 1, remove the launching nose. Carry out system conversion, drop the whole bridge on permanent support, and complete incremental launching method construction.

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Step 5: Demolish the temporary piers and incremental launching equipment, drop the beam to the design elevation, and complete the incremental launching method construction.

The push process is shown in Figure 2. During the welding process of the arch ribs, support piers should be installed. Five support piers should be installed on each side of the arch ribs, and the support piers should be removed after the top of the bridge is pushed into place.

A finite element model of the construction process was established, as shown in Figure 3. The bridge has a total of 1680 units and 1371 nodes. The arch and beam are simulated by beam element, the sling is simulated by tension element only, and the temporary pier is simulated by supporting boundary condition. The incremental launching method process is divided into 30 working conditions, as shown in Table 1. The incremental launching distance of each working condition is 5m, and the total incremental launching is 150 m. The support piers in the incremental launching process are shown in Figure 4. L1~L6 are temporary support piers and the remaining four are permanent bridge piers. The determination of temporary pier distance is mainly based on the stress of the jacking structure in the maximum cantilever state. When the structure reaches the maximum cantilever state, the stress cannot exceed the allowable stress value in the construction process. The length of the slideway in the support position is 5 m, and a push cycle is 2.5m .

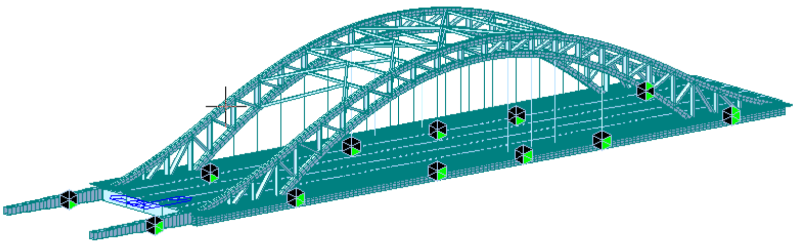

Fig.3 - Finite element model of bridge

Tab. 1 - Working condition of pusher

Construction Stage	Pushing Distance (m)	Construction Stage	Pushing Distance (m)	Construction Stage	Pushing Distance (m)
CS0	0	CS12	60	CS24	120
CS1	5	CS13	65	CS25	125
CS2	10	CS14	70	CS26	130
CS3	15	CS15	75	CS27	135
CS4	20	CS16	80	CS28	140
CS5	25	CS17	85	CS29	145
CS6	30	CS18	90	CS30	150
CS7	35	CS19	95	CS31	Demolition of nose
CS8	40	CS20	100	CS32	bridge deck pavement
CS9	45	CS21	105		
CS10	50	CS22	110	CS33	Demolition of temporary pier
CS11	55	CS23	115		

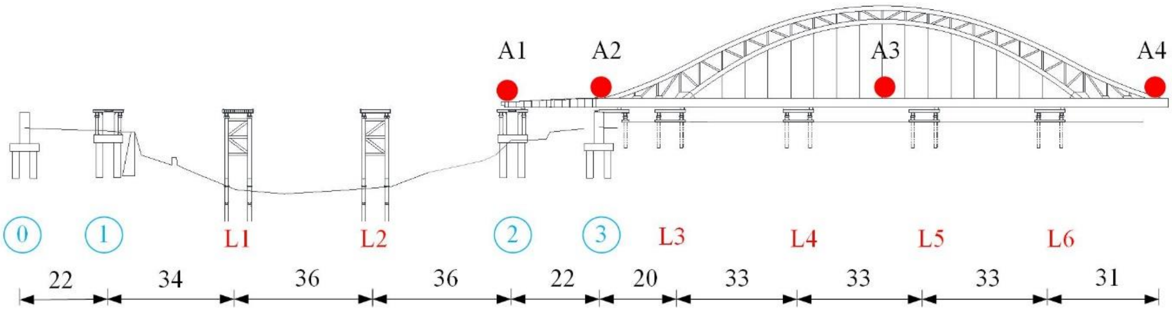

Fig.4 - Supporting pier diagram

MONITORING POINTS DURING CONSTRUCTION

The construction process control system mainly includes construction process simulation, construction process monitoring and construction process correction and adjustment. Among them, construction process monitoring is the core of the whole control system. By monitoring the important structural design parameters and state parameters, the data and technical information reflecting the actual construction state can be obtained, and then the construction path can be modified and adjusted reasonably according to the monitoring data results, so as to achieve the purpose of safe and smooth control in the construction process.

The key parameters of construction process monitoring can reflect the mechanical behaviour of the structure and its construction support system in any construction stage. Generally, monitoring key parameters can be divided into two categories: load parameters (such as temperature, thrust, etc.) and response parameters (such as stress, deformation, etc.). In the construction process, through the real-time monitoring of these key parameters, the results can be obtained together with the construction support system's stress behaviour and shape characteristics, so as to achieve the purpose of safety control in the construction process. The response parameters in this project include stress and deformation. The stress measurement points of beam and arch are shown in Figure 5, and the deflection measurement points of main beam and launching nose are shown in Figure 4. The stress measuring points of the beam and arch are arranged at the two ends, the middle point and the quarter point.

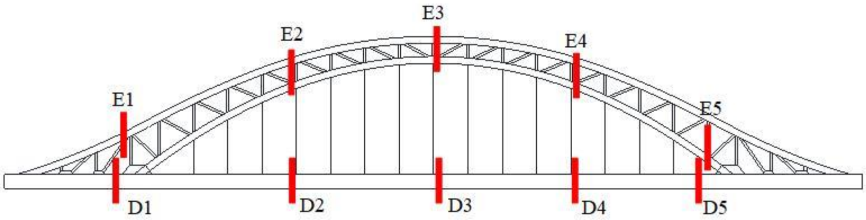

Fig. 5 - Arrangement of stress measuring points of beams and arches

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(a) Arch rib measuring point *(b) Main girder measuring point*

(c) Temporary pier measuring point *(d) Stress data acquisition*

Fig. 6 - Stress measuring

PUSH PROCESS ANALYSIS

Stress of main beam during incremental launching

In the whole process of incremental launching method, the measured and theoretical stress values of beam at different incremental launching method conditions are shown in Figure 7. Under the condition of CS11, the theoretical stress at the bottom edge of measuring point D1 is at most 21.3 MPa, and the measured stress is at 11.0 MPa. When it is pushed to CS22 working condition, the theoretical maximum stress at the bottom edge of the beam is -19.5 MPa, and then the measured stress is -13.7 MPa. When the working condition of CS22 is jacked, the maximum theoretical stress of the top edge is 18.2 MPa, and the measured value is 15.1 MPa at this time. The measured stress at the top edge and bottom edge during the whole process of incremental launching method is less than the theoretical stress. When pushed to CS22, the maximum theoretical stress of the top edge of D2 measuring point is 22.5 MPa, and the corresponding measured value is 18.3 MPa; the maximum theoretical stress of the bottom edge is -30.5 MPa, and the corresponding measured value is -18.9 MPa. The D2 measured stress at the top edge and bottom edge of beam in the whole process of incremental launching method is less than the theoretical stress.

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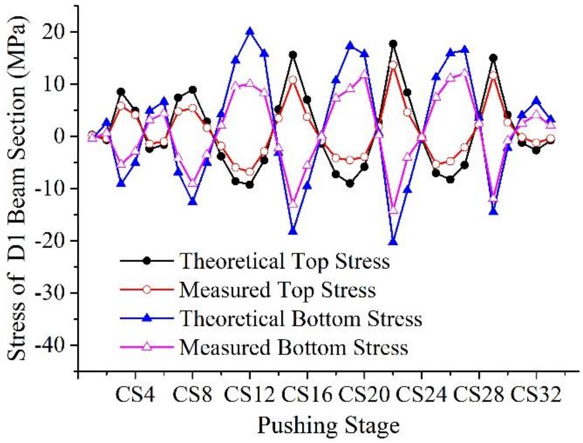
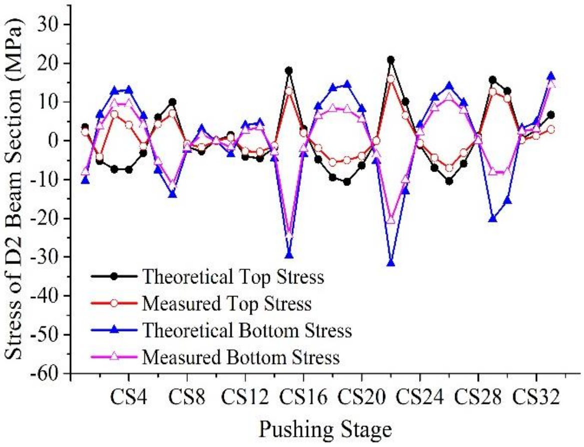
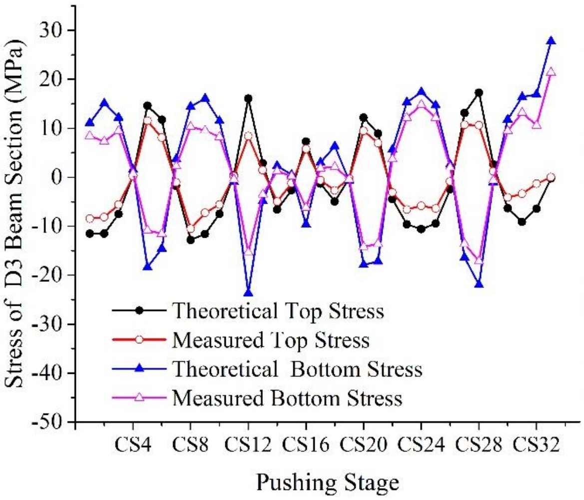


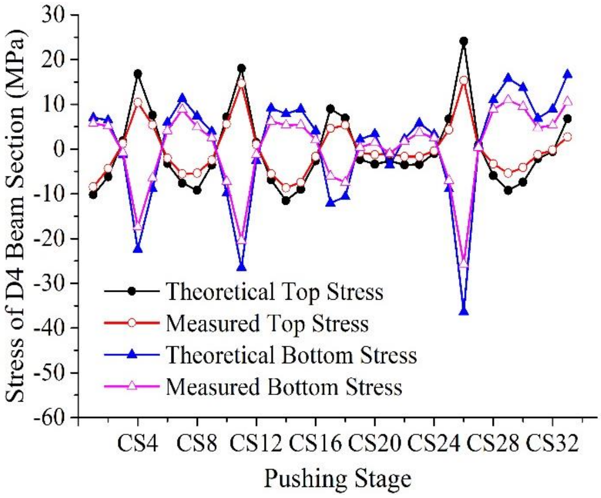
(a) D1 stress variation



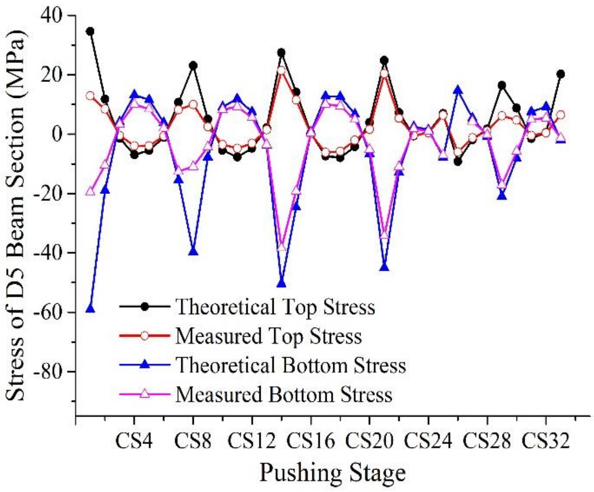
(b) D2 stress variation



(c) D3 stress variation



(d) D4 stress variation



(e) D5 stress variation

Fig. 7 - Measured value and theoretical value of beam stress measuring point

Under the working condition of CS12, the maximum theoretical stress at the bottom edge of the measuring point D3 is 23.4 MPa, and the measured stress is 14.2 MPa. When it is pushed to CS32 working condition, the theoretical maximum stress of bottom edge is 32.3 MPa, and the

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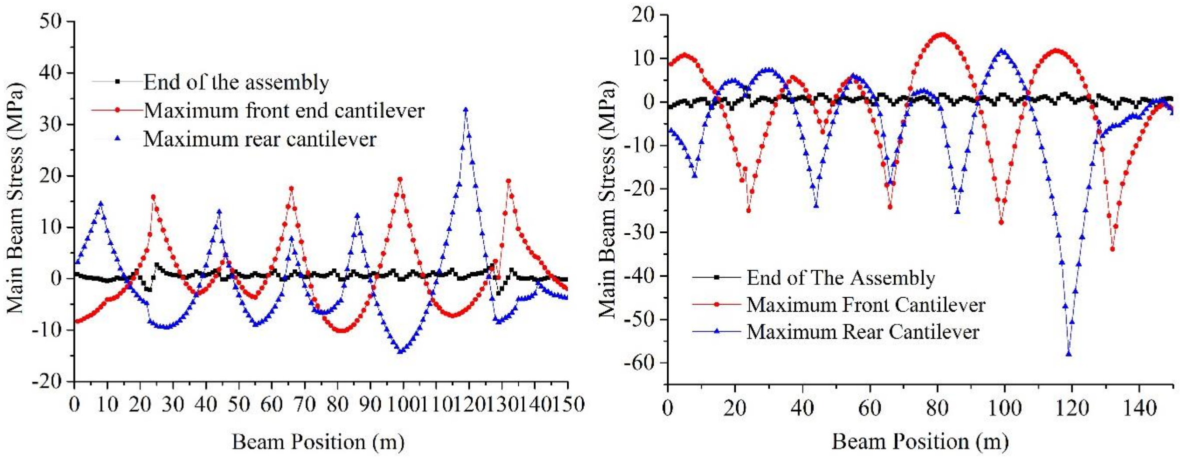
measured stress is 24.0 MPa. The measured stress at the top edge and bottom edge during the whole process of incremental launching method is less than the theoretical stress. When pushed to CS26, the maximum theoretical stress value of the top edge at the measuring point D4 was 25.2 MPa, and the corresponding measured value was 17.2 MPa; the maximum theoretical stress value of the bottom edge was -33.8 MPa, and the corresponding measured value was -23.5 MPa. The measured stress at the top edge and bottom edge of D4 measuring point in the whole process of incremental launching method is less than the theoretical stress. When pushed to CS1, the maximum theoretical stress of the top edge at the measuring point D5 was 35.6 MPa, and the corresponding measured value was 13.4 MPa; the maximum theoretical stress of the bottom edge was -58.6 MPa, and the corresponding measured value was -19.6 MPa. The measured stress at the top edge and bottom edge of measuring point D4 in the whole process of incremental launching method is less than the theoretical stress.



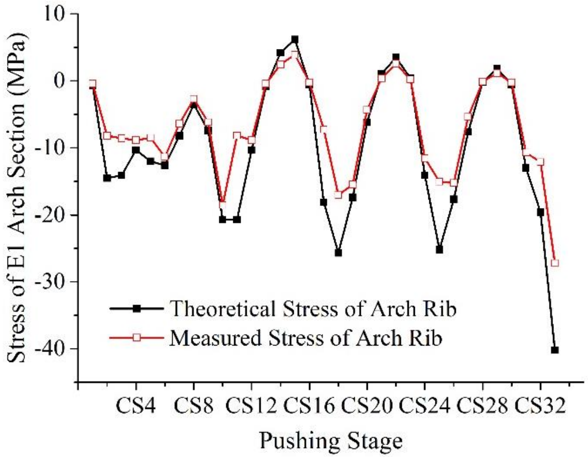
(a)Top Edge Stress *(b) Bottom Edge Stress*

Fig. 8 - Stress at top edge and bottom edge of beam at worst

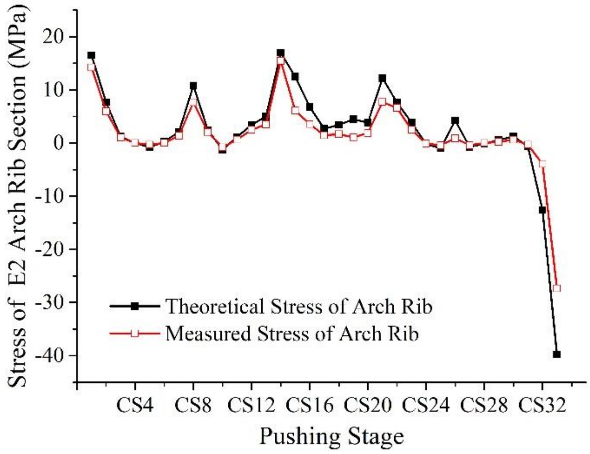
In the process of incremental launching method, the most unfavourable condition of structural force will occur. The maximum state of the cantilever at the front end of the bridge and the maximum state of the cantilever at the rear end of the bridge in this project are the most unfavourable conditions. The stress of the top edge and bottom edge of the beam under the most unfavourable conditions is shown in Figure 8. When the cantilever at the end of the bridge is the largest, the stress at 117 m of the beam is the largest, the stress at the top edge is 33.7 MPa, and the stress at the bottom edge is -58.2 MPa. The stress in other sections did not exceed 30 MPa, and the beam was under uniform stress.

Stress of arch rib for incremental launching method

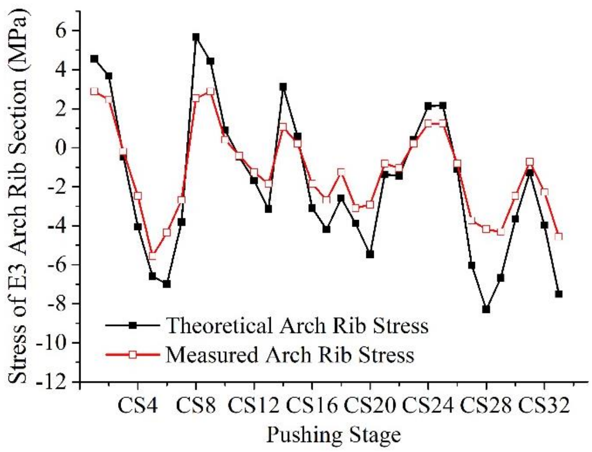
In the whole process of incremental launching method, the measured and theoretical stress values at the five measuring points of E1~E5 under different incremental launching method conditions are shown in Figure 9. Under the condition of CS33, the maximum theoretical stress of arch rib at the measuring point E1 was -41.3 MPa, and the measured stress was 28.0 MPa. The measured stress of arch rib was slightly less than the theoretical value, and the variation trend was consistent. Under the condition of CS33, the maximum theoretical stress of arch rib at measuring point E2 was -40.8 MPa, and the measured stress was 25.6 MPa. The measured stress of the arch rib was slightly less than the theoretical one, and the variation trend was consistent. When pushed up to the CS6 working condition, the arch rib stress at the measuring point E2 was -7.2 MPa at most, and the measured stress was 4.3 MPa at this time. Compared with the other four measuring points, the stress change at the measuring point E2 was uniform and did not exceed 10 MPa. The maximum stress at the measuring points E4 and E5 occurred under the working condition of CS33. Due to the removal of the temporary pier beam in the water, the cable force of the sling increased, which increased the axial force of the arch rib.



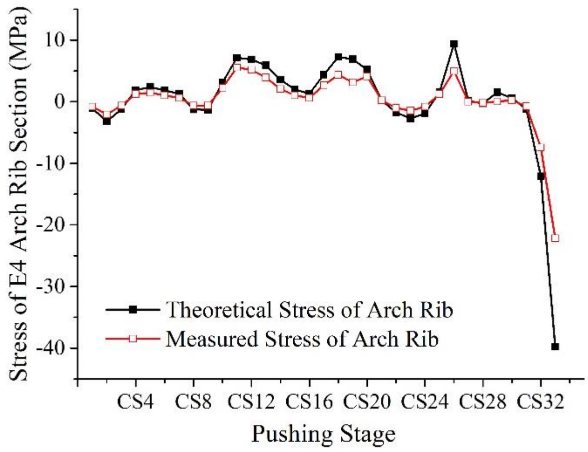
(a) E1 Stress variation



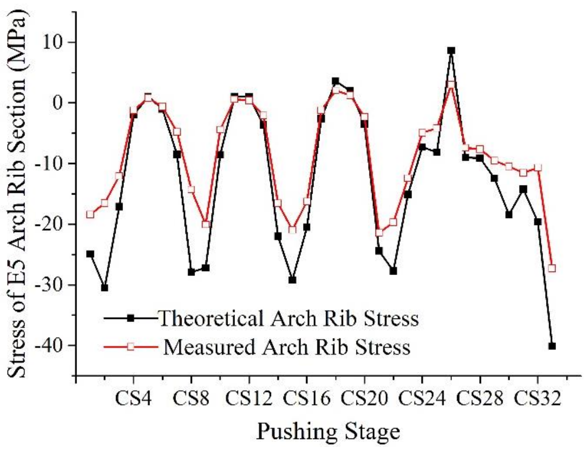
(b) E2 Stress variation



(c) E3 Stress variation



(d) E4 Stress variation



(e) E5 Stress variation

Fig. 9 - Measured value and theoretical value of beam stress measuringpPoint

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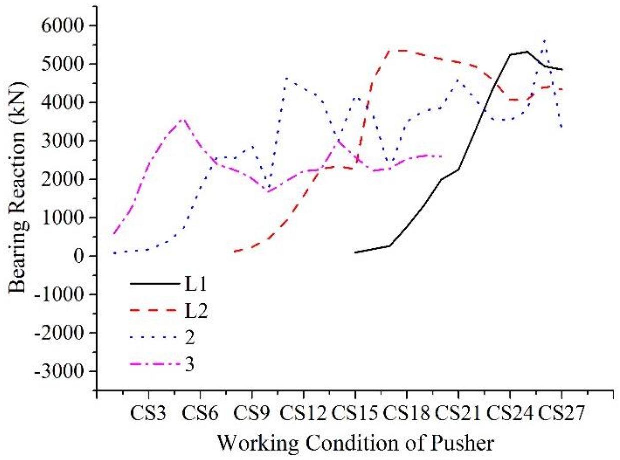
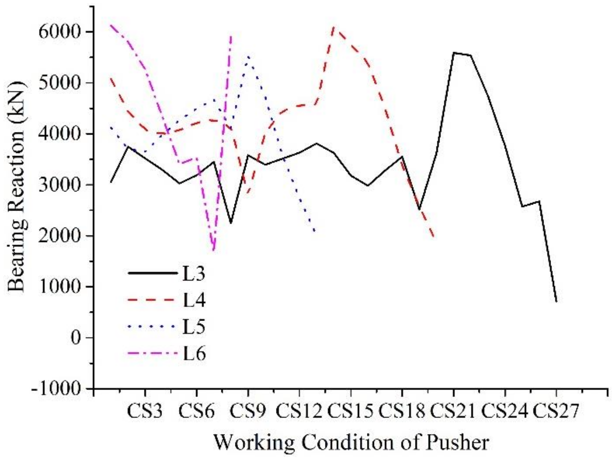
Temporary pier counterforce

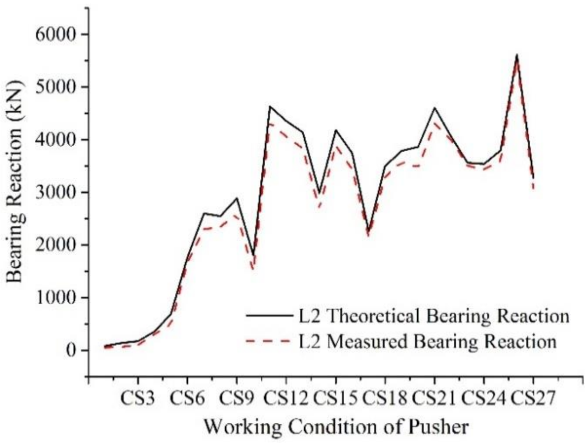
The temporary pier is supported by steel tube lattice column and the stress of steel tube is measured by vibrating string strain gauge affixed to the surface of the steel tube. L1 and L2 are temporary support piers in water, L3~L6 are temporary support piers on shore, and 1~4 are permanent support piers. The temporary pier buttress reaction varies with the change of the incremental launching position, and the maximum of the buttress reaction is about 6000 kN. The maximum bracing reaction of L1, L2, 2 and 3 temporary piers occurs at the arch foot position inside the head, while the maximum bracing reaction of L3-L6 temporary piers occurs at the arch foot position inside the tail. The test value of L2 and L3 temporary pier support reaction force is basically consistent with the theoretical value, and the test value is slightly less than the theoretical value.



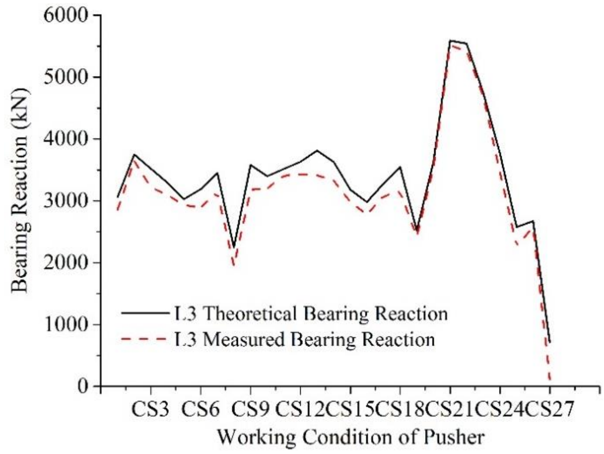
(a) Reaction values of piers L1、L2、2 and 3



(b) Reaction values of piers L3、L4、L5 and L6



(c) Theoretical and measured values of L2 pier



(d) Theoretical and measured values of L2 pier

Fig.10 - Temporary pier support reaction

Deflection of incremental launching process

During the whole incremental launching process, the deflection measurement points of the main beam and launching nose are shown in Figure 4. The deflection measurement point of the launching nose end is A1, the deflection measurement point of the beam mid-span is A3, and the deflection measurement points of the beam end are A2 and A4. The deflection range of the launching nose during the top pushing is -30mm~10mm, the deflection of the measuring point at the beam end is -35mm~0mm, and the deflection of the beam mid-span is -47.6 mm~0 mm. The deflection of the mid-span of the beam is almost unchanged before the temporary pier is removed.

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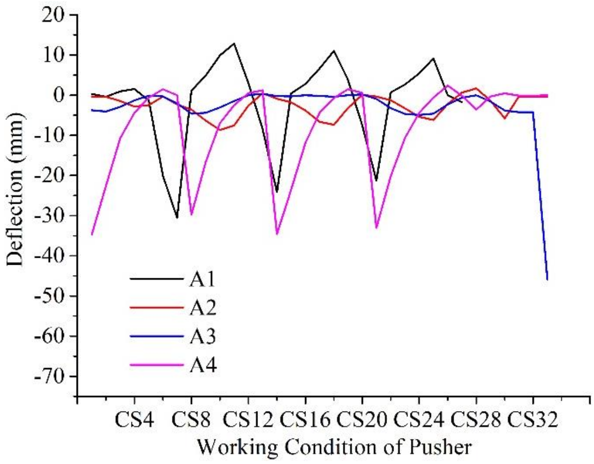

Fig.11 - Deflection value of main beam

Sling force

In the incremental launching process, the cable force value is about the mid-span symmetry of the bridge. The measured value is basically consistent with the theoretical value, and the error between the theoretical value and the measured value is within 5%.

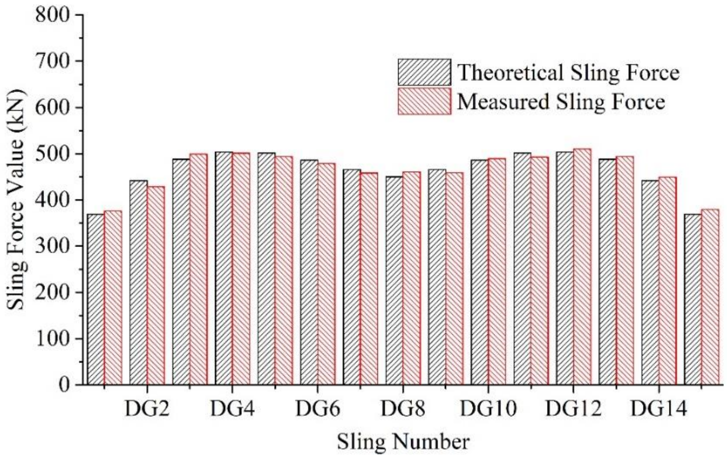

Fig.12 - Cable force of the sling

Launching nose parameter analysis

In the process of incremental launching construction, the structural system of the bridge is constantly changing, and each section should bear the action of positive and negative bending moments alternately. The application of launching nose effectively reduces the cantilever length of the main beam, improves the stress condition of the main beam, and also plays a role in increasing the structural stability and preventing overturning and instability. In the analysis of launching nose, the parameters such as the length, stiffness and the mass of the length of the launching nose have great influence on the stress of the main beam.

Although the structural form of girder and arch composite bridge is complex, its stiffness and dead weight are not uniformly distributed along the longitudinal direction, which is very different from the continuous beam with equal section, so it is difficult to configure launching nose according to the method of equal section beam. The model under different construction conditions was established by finite element software, and the influence of the variation of launching nose parameters on the bridge stress was studied from two aspects: the ratio of the length of launching nose to the maximum span of thrust (α), the ratio of the dead weight load per unit length of launching nose and the dead

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weight load per unit length of main beam (β). It provides a reference for the selection of design parameters for the overall incremental launching construction launching nose. In addition, the design of the launching nose can only be studied if the temporary support is set up first.

During the incremental launching process, if the length of the launching nose is too short, the structure may be damaged due to excessive stress under the maximum cantilever condition. If the length is too long, the launching nose will not play its role and the economy is poor. Therefore, an appropriate launching nose length should be selected. The length of the launching nose in this project is 23 m, and the ratio of the length of the launching nose L_n to the maximum span L of the thrust is α =0.7. Assuming that the cross-section and structural form of the launching nose remain unchanged and the length of the launching nose is changed, the value of is taken to be 0.45, 0.55, 0.65, 0.75 and 0.85, respectively. Bending moments of the upstream main beam and arch rib are listed, as shown in Figure 13 and Figure 14. When is 0.45~0.75, the bending moment of the main beam has little change, while when is 0.55~0.85, the negative bending moment of the main arch has little change. The maximum stress of the upstream main beam and arch rib is shown in Figure 15 and Figure 16. As the length of launching nose increases, the variation trend of stress is consistent. When is 0.75 and 0.85, the compressive stress of main beam is larger, with a maximum of -50 MPa; when is 0.75 and 0.85, the stress of arch rib is larger, with a maximum of 50 MPa. The appropriate range for α is 0.55~0.65 and the deflection of the launching nose is 21.1mm~22.8mm.

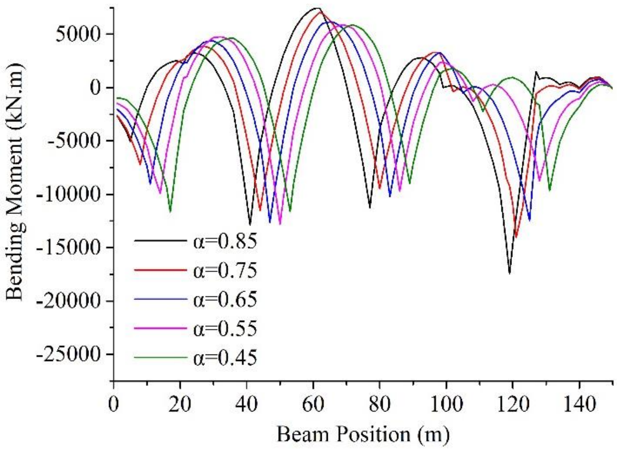

Fig. 13 - Beam bending moment of different guide beam length

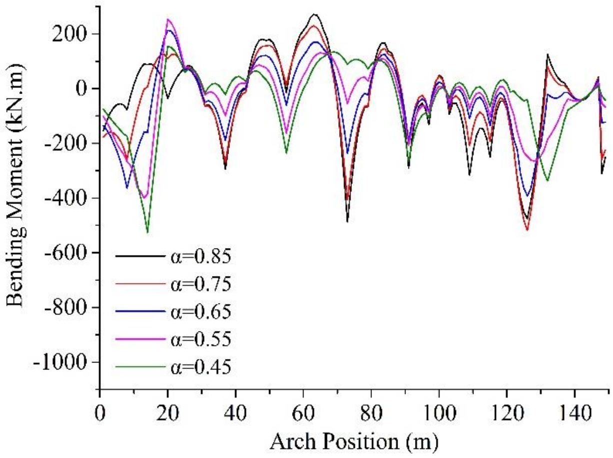

Fig.14 - Arch bending moments of different guide beam lengths

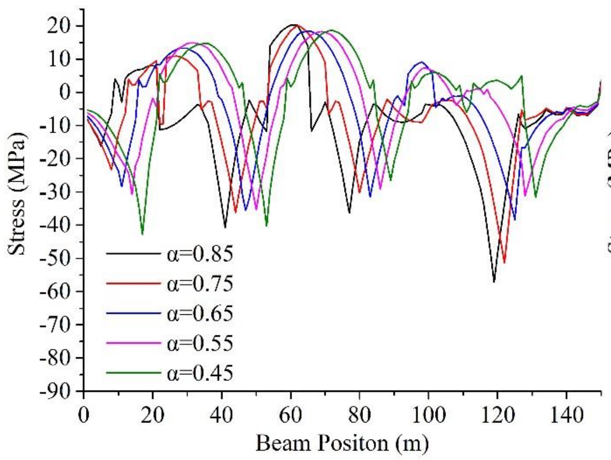

Fig.15 - Beam bending moment of different guide beam length

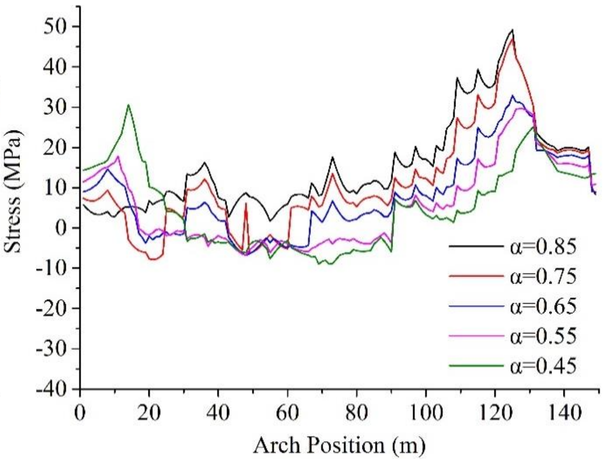

Fig.16 - Arch stress of different lengths of launching nose

Tab.2- Deflection of launching nose at different lengths

α	0.85	0.75	0.65	0.55	0.45
Deflection (mm)	22.7	25.8	22.8	21.1	20.6

It is assumed that the stiffness and length of the launching nose remain unchanged. The values of β were 0.2, 0.4, 0.6, 0.8 and 1. In view of these conditions, the influence of the dead weight per unit length of the launching nose on the structure is studied under the maximum cantilever condition. In finite element software, the change of value is achieved by changing the bulk density of the launching nose material. As shown in Figure 17 and Figure 18, when the launching nose weight per unit length is taken as different values, the stress variation trend of main beam and arch rib is the same and almost unchanged. As shown in Table 2, the deflection of the launching nose increases with the increase of density, and the maximum value is 25.8mm.

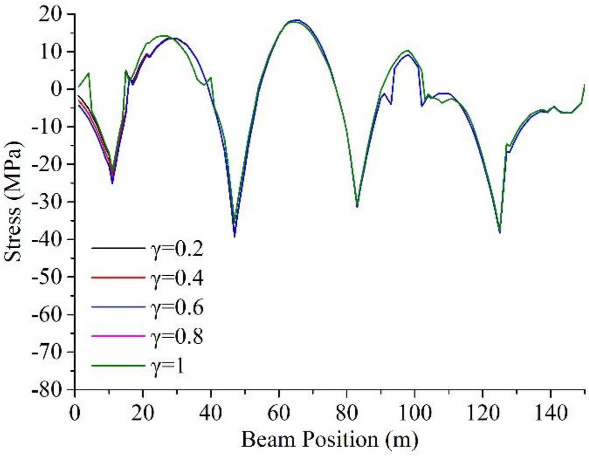

Fig.17 - Beam stress under different density Beam

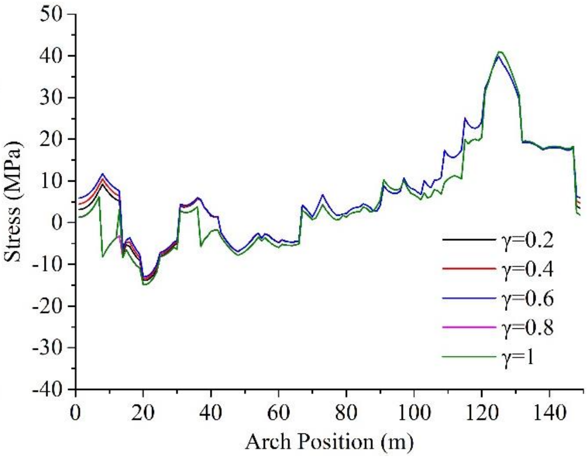

Fig.18- Arch stress under different density of guide of launching nose

Fig. 3 - Deflection of launching nose under different launching nose density

β	0.2	0.4	0.6	0.8	1
Deflection (mm)	5.9	10.1	14.3	19.4	25.8

CONCLUSION

At present, there are few researches on the overall incremental launching construction of the beam arch composite bridge, and the stress form of its temporary members in the incremental launching construction is not fully understood. Based on the research background of the whole incremental launching construction of the supported tie bar arch combination structure, this paper studies the temporary members in the incremental launching construction by establishing the finite element model, which provides reference experience for the temporary design of the same type of beam arch combination structure. The research results of this paper can provide reference for the construction of similar bridges. The conclusions of this paper are as follows:

In the process of incremental launching construction, the measured and theoretical stress values of the beam and arch have a high degree of coincidence, the stress is between -30.4 MPa and 16.5 MPa, all within the safe range. The field monitoring results show that the stress changes slowly in the measuring points of the bridge, which indicates that the external force is applied slowly and evenly in the construction process.

When the cantilever at the end of the bridge reaches the maximum, it is in the most unfavourable state. At this time, the stress at the 117 m position of the beam reaches the maximum, the stress at the top edge is 33.7 MPa, and the stress at the bottom edge is -58.2 MPa. The stress in other sections did not exceed 30 MPa, and the beam was under uniform stress.

The temporary pier buttress reaction varies with the change of the incremental launching position, and the maximum of the buttress reaction is about 6000 kN. When the front foot of the internal arch passes by, the maximum supporting reaction of each temporary pier at the beginning of the incremental launching appears at the rear foot of the internal arch. The maximum supporting reaction of each temporary pier at the beginning of the incremental launching occurs when the arch foot in the front of the internal arch passes, while the maximum supporting reaction of each temporary pier at the beginning of the incremental launching occurs when the arch foot in the rear of the internal arch passes.

During the incremental launching process, if the length of the launching nose is too short, the structure may be damaged due to excessive stress under the maximum cantilever condition. If the length is too long, the launching nose will not play its role and the economy is poor. Therefore, an appropriate launching nose length should be selected. The reasonable range of α is 0.55~0.65, which is the ratio between the length Ln of launching nose and the maximum span L of incremental launching.

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