Intelligent and controllable synchronous lifting slipforming technology for super-high bridge piers

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Abstract. There are still many problems to be solved in the rapid construction of unequal-span continuous rigid bridge, and it is urgent to study the key technology of high pier construction. During the impoundment period for the non-navigable, high water level floating bridge project in the reservoir area, water construction has great difficulties. Based on the Heishui River Bridge project, this study proposes the intelligent and controllable synchronous lifting slide mould platform technology and the high-efficiency measurement and control technology of the slide mould of the super-high pier, which improves the construction efficiency and intelligent level of the super-high pier. The safety of the technology is verified through finite element analysis. Provide reference for similar projects.

Keywords: super-high bridge piers, construction technology, slipform platforms, finite elements

1 Introduction

With the rapid development of China's infrastructure construction, many high-pier and large-span bridges have been built to meet the needs of mountain and valley areas with steep terrain and large height differences[1]. High pier construction is the key to the overall construction of the bridge, high pier bridge construction requirements, construction difficulty[2]. It is of great importance to study the construction technology to improve the construction efficiency and ensure the safety[3].

The project is affected by the proposed reservoir water storage, the pressure of the construction period; at the same time, the water storage period bridge construction is usually used pontoon, floating cranes and other methods of water construction, but for the non-navigable, high water level floating bridge project in the reservoir area, there are great difficulties in the construction of water; In addition to the conventional continuous rigid are designed for symmetrical and other spans of cantilever construction[4],

Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_14

and for the unequal spans of continuous rigid bridges, how to achieve the rapid construction, there are still many problems to be solved[5]. At present, for the above special conditions, to achieve the rapid construction of high pier construction can draw on the construction experience is more, there is an urgent need for high pier construction of the key technology research[6]. Because of the construction speed of sliding mould construction, low project cost and other significant advantages, and is widely used in the construction of high piers of mountain bridges[7]. This study proposes intelligent and controllable synchronous lifting slipform platform technology and efficient measurement and control technology of slipform on high piers, which improves the construction efficiency and intelligence level of high piers.

Through this study, intelligent and controllable synchronous lifting slipforming technology is applied to solve the key technical problems in the construction of large-span continuous rigid bridge girders with ultra-high piers in steep mountainous areas, to provide technical support for the supporting relocation and reconstruction of the Baihetan Hydropower Station Reservoir Area Road Project, and to provide technical reserves for the construction of similar projects.

2 Project overview

This project is located in Ningnan County, Sichuan Province, belongs to Baihetan Hydropower Station Reservoir area to support the relocation and reconstruction of road projects, the project includes G353 line (the former S310 provincial highway), Yanghulu Road, Ning will be transferred to the Club Road and other three roads. The total length of the line is 30.5km, of which G353 line is 6.716km, Yanghulu Road is 18.755km, Ninghui Road and Turn Club Road is 5.122km. 13 bridges, including continuous rigid structure, prestressed concrete beam, reinforced concrete beam and 40m prefabricated T-beam, and the road surface is asphalt concrete road surface. The project area is located in the northwestern part of Yunnan-Guizhou Plateau, the basic geomorphological type is erosion folded high mountains and mountains, crustal rise and Jinsha River deep cuts the formation of high mountain canyon geomorphology, the summit elevation of 2000~3000m, the river deep cuts the "V" type. Ninghui Turn Club Road, Yanghulu Road, G353 line along the left and right bank of the Heishui River, the overall flow direction of the Heishui River in the project area is nearly southeast, and the terrain along the route is mostly sloping, with a small number of gently sloping platforms or terraces.

The main bridge of Heishui River Bridge is the controlling work point of the whole line, which is a 60m+150m+110m unequal span continuous rigid bridge located in the reservoir area of Jinshajiang River Baihetan Hydropower Station. In order to meet the water storage requirement, the superstructure of the bridge will be constructed after the water storage, and the disposal of the hazardous rock body, the pile foundation and the construction of the lower structure must be completed before the water storage, and the number of piles is many and the diameter of the piles is large, and the main pier is as high as 156m, which puts pressure on the construction time.

3 Intelligent control synchronous lifting slide mould system structure composition

3.1 Slide and crawl system structure

Multi-functional self-control synchronous lifting mould system adopts hydraulic overall sliding lift to ensure the overall stability, the mould adopts the overall steel structure design, including mould jack, integrated pumping station, oil circuit, lifting frame and support rod composition. Including formwork system, lifting system, construction platform, auxiliary platform, support rods, temporary support and electro-hydraulic control, laser target measurement and control device system. The working condition of the closed mould system is shown in Figure 1.

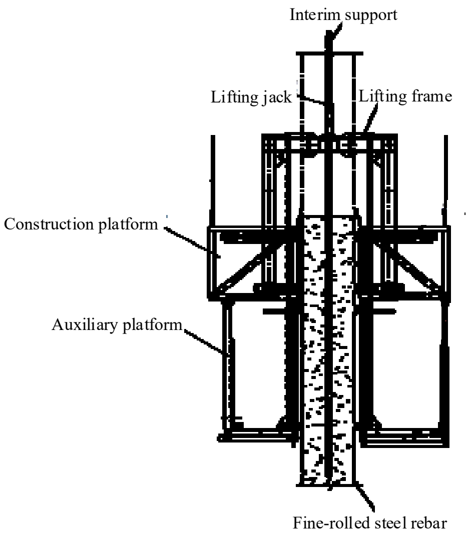


Fig. 1. Schematic diagram of the working condition of the slipform system for mould closing.

The formwork system is mainly made of 5mm thick stainless steel plate to ensure the surface finish to reduce the friction between the concrete. With 5mm thick steel plate and groove 6.3 for reinforcement ribs, with the construction platform skeleton fixed by welding, formwork height of 1200mm, formwork taper in accordance with the 6mm control, ie, The lifting frame is mainly used to support the mould body, and through the installation of jacks at the top of the support in the climbing pole, the entire sliding load is transferred to the climbing pole, lifting frame and formwork using a sleeve connection, formwork and lifting frame relative position of the climbing pole. The lifting frame is connected to the formwork by a sleeve, and the relative positions of the formwork and lifting frame can be moved back and forth by a screw to enter and exit the formwork. The supporting column is made of $\Phi48\times5$ steel tube, and the lifting frame is made of "door-type" frame body welded with groove 18a and 12mm steel plate as reinforcing ribs and 14mm steel plate as platform plate. The construction platform bears the loads of work and materials, and at the same time is the supporting member of the mould body, which is the main structure of the sliding mould body, and adopts the whole frame steel structure. Due to the process of concrete construction, the vertical load and lateral force are large, so to ensure the strength and rigidity of the construction platform, <100×100×10 and < 75×75×7 angles are selected to be processed into the composite truss beams, which have a width of 1,200mm and a height of 1,000mm. A 3mm thick patterned steel plate is laid on the truss to form the working platform. The temporary support system of the frame is used as a sliding formwork in/out device to avoid long interruptions of the construction due to accidental factors, so that the formwork cannot slide up. The mould in/out device is arranged according to the horizontal vertical height, using double groove 14a as the supporting legs and beams, and Φ32 fine-rolled rebar as the adjusting screw. Electro-hydraulic control system The electro-hydraulic control system consists of pump station and control cabinet, solenoid valve, signal feedback cable, control cable, power cable, tilt switch, etc. It sends a warning signal when the platform tilt angle exceeds the set value and can automatically adjust the formwork position.

3.2 Hydraulic System Composition and Arrangement

Multi-point synchronous lifting system is the key equipment in the construction of slipforming process, which mainly consists of slipform jacks, integrated pumping station, oil circuit, lifting frame and support bar.

The system consists of a main oil circuit to supply oil to 4 groups of cylinders (8 in total) using high flow electro-hydraulic directional valves to control the action of the oil circuit, and each group of cylinders is equipped with electromagnetic shut-off valves to control opening and closing. Driven by the motor high-pressure oil pump, the oil through the electromagnetic directional valve, oil separator, electromagnetic shut-off valve and pipeline delivery to a jack, in the process of continuous oil supply and return to make the jack piston constantly retracted, with the help of jack internal wedge-shaped block of special structure, so that the template device along the support rod upward sliding.

In the process of sliding up the jack, the individual stroke is levelled by limit cards. In the process of sliding up, the tilt switch real-time monitoring platform tilt angle data, when the platform tilt operation above the warning value, real-time transmission to the integrated pumping station in the control core PLC controller, through the control of pumping station outside the electromagnetic shut-off valve, from the high through the low, the platform for automatic adjustment.

4 Sliding mould platform workflow

4.1 Slide crawl all-in-one formwork system installation process

The first step is to install the first section of reinforcement. The height of the first section of the main reinforcement is 4.5 m and the height of the first section of the tied hoop reinforcement is 2.1 m. The second step is to install the outer mould and outer mould platform. The outer mould and outer mould platform are bolted together. The third step is to install the vertical bar of the lifting frame. Lift the vertical bar of the lifting frame and install it to the sleeve position on the formwork. Step 4: Install the screw and screw holder. Install the screw and screw holder on the formwork sleeve, adjust the screw so that the vertical bar of the lifting frame can reach the specified position of the formwork. The fifth step, lifting frame beams, hydraulic jacks, installation of support rods. Sixth step, pour the concrete in the range of 1.2m at the bottom. 0-6h every 1.5 hours or so, pour the qualified concrete 300mm, vibrate the concrete. Step 7, push the outer mould up to the variable section. Pour the concrete at the rate of 300mm every 1.5 hours to the bottom of the variable section. Step 8, the outer form is removed and pushed up and the reinforcement is tied. When the concrete strength of the top layer has reached the demoulding strength, the temporary support is installed, the outer mould is retracted 300mm and slid up 900mm and the steel reinforcement of the variable section is tied. Step 9, close the outer mould and install the inner cavity support and formwork. Remove the temporary support and install the inner cavity support and formwork after the outer mould has been closed. Step 10: Pour the variable section concrete. Pour the variable section concrete in layers of 300mm. Stage 11, Extend the stringer, tie the reinforcement, lift the outer mould, install the auxiliary platform, remove the inner cavity formwork adjustment bracket. Stage 12, install the chamfered inner formwork. Install the chamfered inner formwork on the inner cavity support platform. Step 13: Install the chamfered inner mould screw, screw holder, vertical beam and horizontal beam of the lifting frame. Install the lifting frame vertical beam to the inner mould sleeve on the chamfered inner mould, install the inner mould sleeve screw holder and screw, install the lifting frame vertical beam and cross beam bolts and remove the inner cavity support platform. Step 14: Install the inner auxiliary platform after the concrete has been poured to a certain height. The concrete is poured in 300mm layers, and the inner auxiliary platform of the hollow pier is installed after the concrete is poured to a certain height. The installation diagram is shown in Figure 2.

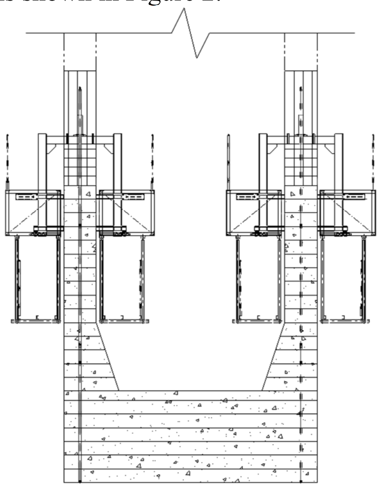


Fig. 2. Formwork system installation schematic.

4.2 Slide crawl one template system operation process

The operation of the slip mould system to enter and exit the mould is as follows. The first step is to remove the connecting angles of the inner mould platform and the connecting bolts of the outer mould trusses after the sliding mould system has been positioned, and to remove the locking fine-rolled rebars. In the second step, the inner formwork first adjusts the 4 adjustment screws on the flat formwork to allow the flat formwork to retract 300mm, the inner platform is closed and fixed with bolts, the locking fine-rolled rebar is installed and the jacking mechanism at the bottom edge of the formwork is tightened to the surface of the poured concrete. For the outer formwork, the first step is to adjust the 2 adjustment screws on the wrap-around side formwork to allow the formwork to recede 300mm, install the locking fine-rolled rebar and tighten the jacking mechanism along the bottom edge of the formwork against the poured concrete. The third step is to adjust the 4 adjustment screws on the chamfering formwork for the second time so that the chamfering formwork can be set back by 300mm, adjust the 2 adjustment screws on the wrapped side formwork for the second time so that the formwork can be set back by 300mm, install the locking fine-rolled rebar and tighten the upper jacking mechanism along the bottom edge of the formwork to clamp the poured concrete. Install the outside platform connecting bracket and bolt it in place.

5 Measurement and control technology for ultra-high strut moulds

High pier slipform construction in the normal stage of sliding, each slide 0.03m, every 0.3m pouring a concrete, each slide must be calibrated once the template (calibration interval of 6 hours), 24 hours of construction, the measurement personnel must be divided into three shifts, uninterrupted observation, personnel workload is very large. In the mountainous area of high pier pier body construction measurement process, often encountered in the measurement of directional time is long, and high pier body template positioning process of blocking, blind zone and other problems lead to measurement of repeated station change, not only low efficiency and the existence of repeated station error, so in the mountainous area of high pier pier body construction of the conventional measurement method shortcomings are significant.

Fig. 3. Fast monitoring device of laser plumb bob.

By installing the monitoring device in the place of pier axis(Figure 3), it can always show the deviation of the template in the process of mould sliding up. It solves the personnel's long-term observation and realises the real-time measurement and positioning of the template and real-time adjustment. Combined with the actual situation of the site sliding mould platform, calculate the pier axis outside the deviation of 0.15m, through precision processing and installation, in the size of the kilometre / left and right amplitude symmetrical arrangement of the laser plumbing instrument and the target to determine the direction of template deviation. Make the laser plumbing instrument strictly centred and levelled, the target is placed below the platform and placed horizontally, in the process of sliding up at night, if the laser deviates from the centre of the target, the technician should notify the construction team in time to carry out the calibration to ensure that the laser and the centre of the target are reunited.

6 Structural safety calculations

To verify the safety of the slipform platform, Beam188 and Shell63 unit modelling were used to perform simulation calculations and analysis(Figure 4). The lifting working condition, the pouring working condition and the non-operating working condition are checked respectively.

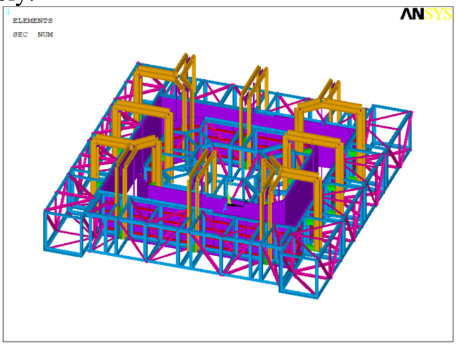


Fig. 4. Finite element model of the slipform.

The loads borne by the slipform system mainly include gantry structure, walkway structure, vibration load and wind load. According to the relevant specification, the loads are taken as follows: portal frame structure, catwalk structure and formwork structure are given by the model. The weight of stacked steel is 871.2kg, which is provided by the project department. The operation platform load is taken as 2.5kN/m^2 according to GB/T50113-2019[8]; the hanger platform load is taken as 2.0kN/m^2 according to GB/T50113-2019[8]; the lateral pressure of freshly poured concrete on the formwork is taken as 16.0kN/m^2. The vibration The load is taken as 4kN/m$_2$, and the vibration area is 0.5mx0.5m. The wind load, the standard value of the wind load in the working condition of the working surface is 0.879kN/m^2, and the standard value of the wind load in the non-working condition is 1.19kN/m^2. The combination of the working condition load is shown in the following Table 1. The calculation working condition is shown in the following Table 2.

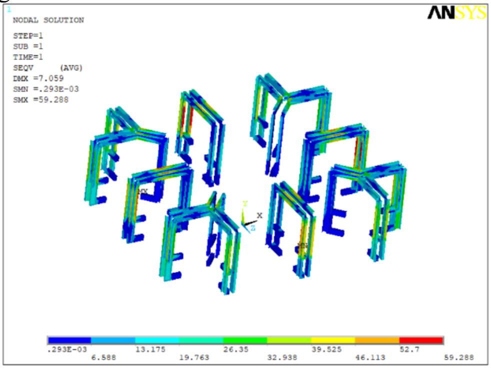
Table 1. Working condition load combinations.

No.	Working condition	Safety Technical Specification for Fastened Steel Pipe Scaffolding in Building Construction, Safety Technical Specification for Formwork in Building Construction.	
		Strength and stability calculations	Stiffness calculation
1	Lifting conditions	1.05×（1.2SG+0.9×（1.4SQ+1.4Sw））	SG+SQ+Sw
2	Pouring conditions	1.05×（1.2SG+0.9×（1.4SQ+1.4Sw））	SG+SQ+Sw
3	Non-operational	1.05×（1.2SG+1.4Sw）	SG+SQ+Sw
Remarks: The construction limit condition is the partial load case. Wind speed is considered in transverse and longitudinal directions. The lifting condition considers the dynamic load factor.			

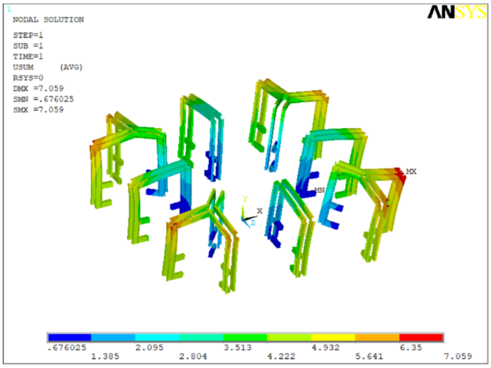
Table 2. Calculated working conditions.

Working condition	Optimization
1	Working surface wind speed 28.4m/s (class 10), demoulding lift, wind blowing along the large surface of the formwork, loads on site personnel and equipment, force and deformation calculations.
2	The wind speed at the working surface is 28.4 m/s (class 10), without stripping and lifting, the wind blows along the large surface of the formwork, the load of construction personnel and equipment, and the calculation of forces and deformations.
3	Wind speed of 28.4m/s (class 10) at the working surface, pouring concrete, wind blowing along the large face of the formwork, loads on workers and equipment, lateral pressure on the concrete, vibration loads, calculation of forces and deformations of the structure.
4	The wind speed at the working surface is 28.4m/s (class 10), only the outer mould is lifted from the mould, the wind blows along the large surface of the formwork, the load of the construction personnel and equipment, calculate the force and deformation.
5	The wind speed of the working surface is 28.4m/s (class 10), only the outer formwork is not stripped and lifted, the wind blows along the large surface of the formwork, construction personnel and equipment load, calculation of force and deformation.
6	Wind speed of 28.4m/s (class 10) at the working surface, concrete poured in the outer formwork only, wind blowing along the large face of the formwork, loads on construction personnel and equipment, lateral pressure on concrete, vibration loads, calculation of forces and deformations of the structure.
7	Wind speed of 33m/s at the working face, non-working condition, calculate the force and deformation of the structure.

After finite element calculation, the stress and displacement of the portal frame structure are shown in Figure 5.



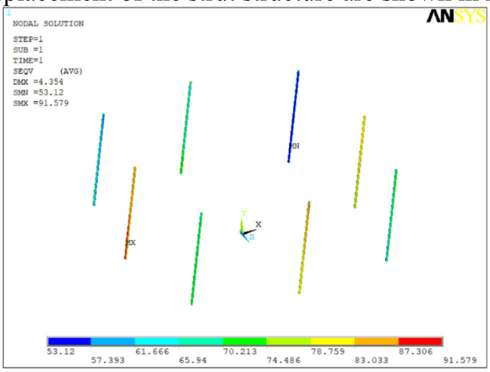
(a) Stress cloud diagram.



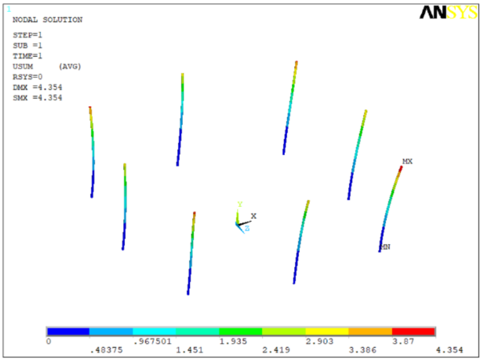
(b) Displacement cloud diagram.

Fig. 5. Calculation results of portal frame structure.

The stress and displacement of the strut structure are shown in Figure 6.



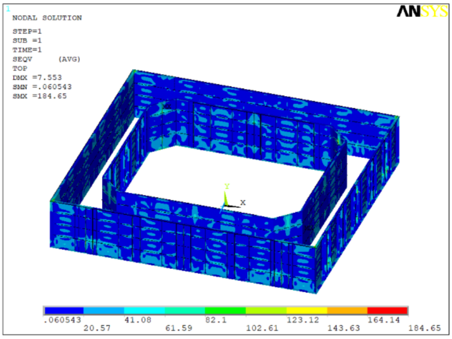
(a) Stress cloud diagram.



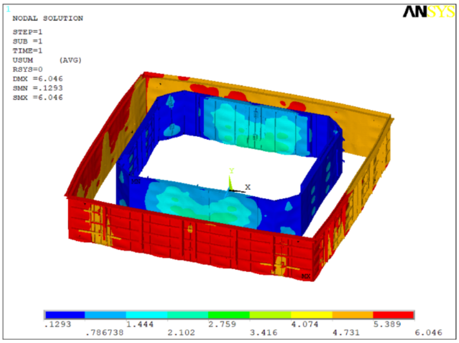
(b) Displacement cloud diagram.

Fig. 6. Calculation results of brace structure.

The stress and displacement of the shell structure are shown in Figure 7.



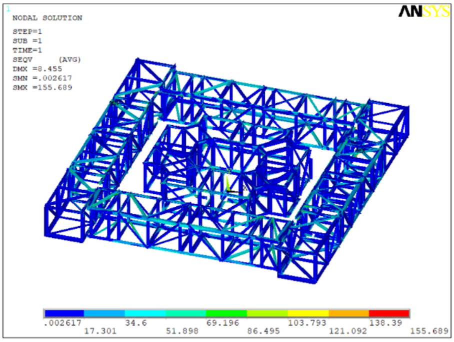
(a) Stress cloud diagram.



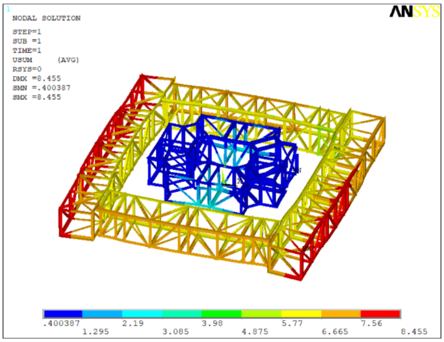
(b) Displacement cloud diagram.

Fig. 7. Calculation result of formwork.

The stress and displacement of the truss structure are shown in Figure 8.



(a) Stress cloud diagram.



(b) Displacement cloud diagram.

Fig. 8. Calculation results of truss.

The results of finite element analysis show that the stress and deformation of the portal structure, brace, formwork and truss meet the requirements of structural stress. The maximum combined stress and maximum deformation of the steel truss appear in the middle diagonal bar of the bridge, the welding of angle steel should be strengthened or higher grade steel should be used in the construction, meanwhile the gathering of personnel and centralised stacking of materials and equipment should be reduced to avoid larger deformation of the steel truss. The maximum combined stress and the maximum deformation of the steel beam appear in the centre diagonal bar of the bridge, the welding of angle steel should be strengthened or higher grade steel should be selected during construction, meanwhile the gathering of people and centralised stacking of materials and equipment should be reduced to avoid the large deformation of the steel beam.

7 Conclusion

Aiming at the rapid construction of super-high piers of bridges in the non-navigable water storage area, this study proposes an intelligent and controllable synchronous lifting slipform platform. This study first describes the structural composition and operation of the intelligent controllable synchronous lifting slipform system. Then, it proposes the efficient measurement and control technology of ultra-high pier slipform, and the accuracy meets the requirements of high pier design and specification. Finally, the structural safety of the proposed slipform platform is verified by finite element analysis and calculation. In conclusion, the intelligent and controllable synchronous lifting slipform platform proposed in this paper has good practicability and adaptability, and can be used as an effective reference for the rapid construction of ultra-high pier.

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