

Integrated Cable Force Release and Replacement Construction Technology for Group Anchor Steel Strand Cables of Long-Span Cable-Stayed Bridges

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Abstract: To address the technical difficulties associated with the replacement process of group-anchored steel strand cables for long-span cable-stayed bridges, such as the lack of force-release structures in the anchorages, large elongation, and difficulty in single-strand unloading, this paper takes the cable replacement project of the Yiling Yangtze River Bridge as the background and proposes an integrated cable force release device and construction technology suitable for long-cable replacement. The device connects the replacement anchorages with the exposed steel strands of the old cables and combines reaction support frame, tensioning rod, and jacking system to achieve graded and synchronous unloading of cable force, effectively addressing the limitations of the original anchorages, which cannot directly release cable force and have insufficient adjustment capacity. Engineering practices shown that this method ensures safe and controllable construction, smooth cable force unloading, and minimal structural disturbance, successfully achieving the replacement of all 236 stay cables on the bridge. Post-construction inspection confirms that the cable forces and deck alignment meet the design requirements, verifying the reliability of this technology. The technical system described in this paper can provide references for the design and construction of cable replacement in similar bridges.

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1 Introduction

As key load-bearing components of cable-stayed bridges, the performance of stay cables directly affects the safety and service life of the bridge. During bridge service period, stay cables are subjected to long-term high-stress states and complex environmental conditions such as wind, rain, and ultraviolet radiation, making them prone to issues such as steel wire corrosion, anchorage head corrosion, cracking of the PE sheath, and abnormal cable forces [1-6]. Many scholars have proposed various suggestions for improving the durability and maintenance of stay cables. For example, Xu et al. [7] proposed recommendations for monitoring the corrosive environment and protecting the anchorage zones of cables. However, such suggestions are applicable only to newly built or recently replaced bridge cables. For cables that have already sustained damage, replacement measures must be taken.

Wedge-type group-anchored steel strand cables are widely used in long-span cable-stayed bridges both domestically and internationally because of their excellent load-bearing capacity and corrosion resistance. As the service life of bridges increases, issues such as fatigue and corrosion of stay cables become increasingly prominent, making cable replacement a key focus of maintenance and rehabilitation. Currently, there are two main methods of cable replacement: single strand replacement and whole strand replacement. Single strand replacement is suitable for structures where anchorages can be released strand by strand; however, it becomes difficult to implement when mortar is grouted inside the anchorage or when the reserved length

of steel strands is insufficient. Whole strand replacement requires addressing the challenge of releasing cable forces under large tonnage and significant displacement, which poses considerable technical difficulty. Particularly for long-span cable-stayed bridges with a main span exceeding 300 m, the elongation of cables during tensioning can exceed 1,000 mm, whereas the adjustment capacity of conventional anchorages is typically less than 200 mm, making conventional methods insufficient for achieving safe and controlled integrated force release [8]. To address such technical challenges, Dou et al. [9] developed a specialized tooling system that enables the rapid replacement of such stay cables.

The Yiling Yangtze River Bridge, a three-tower prestressed concrete cable-stayed bridge, features long-stay cables of widely varying specifications. The original anchorages were not designed with provisions for cable replacement, and the presence of grout inside the anchorages further increases the difficulty of the replacement process. To address this, in this paper, an integrated detensioning device for group-anchored steel strand cables is developed, and, combined with structural simulation and construction monitoring, a systematic cable replacement technique is established. This approach successfully addresses technical challenges, such as long-span cable unloading and synchronized construction across multiple towers, providing a referenceable technical pathway for similar engineering projects.

2 Integrated Detensioning Device for Existing Group-Anchored Steel Strand Stay Cables

The device consists of a reaction support frame, cable-replacement anchorage, tensioning rod, connecting cylinder, through-bore jack, ring-type brace, and tensioning nut, among other components (Figure 1). Its core innovation lies in the following:

- (1) The cable-replacement anchorage adopts the same structure and material as the original anchorage, clamping the old cable through exposed steel strands and providing an external threaded interface to achieve connection with the tensioning system.
- (2) The tensioning rod is made of 40Cr material with a full-thread design and is forged and qualified by ultrasonic flaw detection to ensure reliability under high-stress cycles.
- (3) The reaction support frame is precompressed and verified in the factory to ensure that its stiffness and stability meet the requirements of large-tonnage tensioning.
- (4) The device enables "non-destructive detachment" of the existing cable from the original structure, resolving the defect where the original cable could not be released.

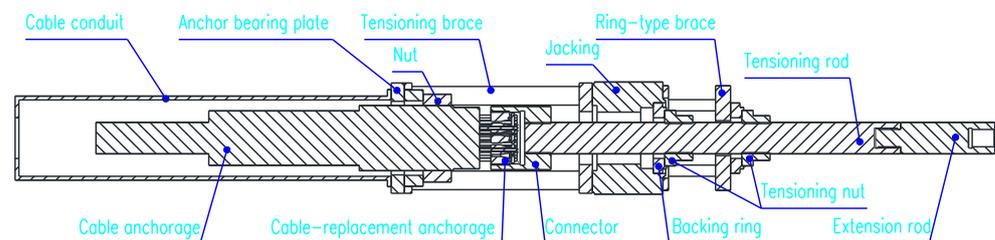


Figure 1 Integrated detensioning device for existing group-anchored steel strand stay cable

3 Engineering Case

The main bridge of the Yiling Yangtze River Bridge is a three-tower cable-stayed bridge with a total length of 936 m, which is equipped with 236 stay cables of six specifications: PES 15–27, PES 15–31, PES 15–34, PES 15–37, PES 15–41, and PES 15–47 (Figure 2). The bridge was opened to traffic in 2001 and has been in operation for

more than 20 years. After evaluation, the stay cables were found to have exceeded their design service life and, therefore, a full-bridge replacement was required.



Figure 2 Yiling Yangtze River Bridge

4 Key Points of Integral Cable Force Release and Cable Replacement Construction

4.1 Main Bridge Cable Replacement Sequence

The main bridge of the Yiling Yangtze River Bridge is a three-tower cable-stayed bridge, that requires the replacement of a total of 236 stay cables (Figure 3). The determination of the stay cable replacement plan is crucial and must consider factors such as structural stress, alignment, temperature, and construction schedule to ensure structural safety, mature techniques, and a reasonable timeline. By using finite element analysis to compare structural stresses under different cable replacement sequences, the following optimal stay cable replacement sequence was derived: for the side towers, replace cables symmetrically, from long to short; for the central tower, replace cables symmetrically, from short to long. The specific sequence is as follows: replace central tower cables #1–#4 and #23 → replace central tower cable #5 and side tower cable #18 → replace central tower cable #6 and side tower cable #17 → replace central tower cable #7 and side tower cable #16 → replace central tower cable #8 and side tower cable #15 → replace central tower cable #9 and side tower cable #14 → replace central tower cable #10 and side tower cable #13 → replace central tower cable #11 and side tower cable #12 → replace central tower cable #13 and side tower cable #10 → replace central tower cable #14 and side tower cable #9 → replace central tower cable #15 and side tower cable #8 → replace central tower cable #16 and side tower cable #7 → replace central tower cable #17 and side tower cable #6 → replace central tower cable #18 and side tower cable #5 → replace central tower cable #19 and side tower cable #4 → replace central tower cable #20 and side tower cable #3 → replace central tower cable #21 and side tower cable #2 → replace central tower cable #22 and side tower cable #1 → full-bridge stay cable force adjustment.

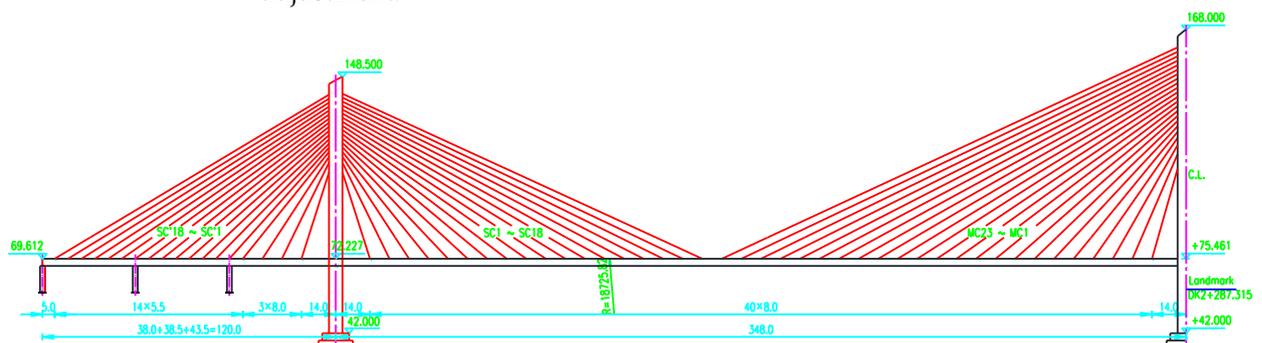


Figure 3 Elevation layout diagram of the Yiling Yangtze River Bridge (half bridge) (unit: m)

4.2 Construction Process for the Removal of Existing Cables

4.2.1 Anchorage Head Cleaning

- (1) The protective cup of the anchorage head is removed, and the grease on the exposed steel strands is removed. The anti-corrosion grease on the anchor cup is wiped clean with cotton yarn, and a file is used to treat any rusted areas;
- (2) The upper and lower end vibration dampers are removed.

4.2.2 HDPE Sleeve Removing

Workers outside the tower secure the Half-type clamp (split clamp) onto the HDPE sleeve, with the split clamp connected to the winch wire rope. As the winch lowers the HDPE sleeve, operators on the bridge deck cut it until the lowering is complete. Meanwhile, a dedicated vehicle is arranged to transport the old HDPE sleeve to the designated location.

4.2.3 Integrated Release of Stay Cables

- (1) Before the tensioning rod is installed, the oil, dirt, and rust are removed from the threads of the tensioning rod and tensioning nut to ensure smooth rotation of all the components.
- (2) The reaction support frame, cable-replacement anchor, tensioning rod, connecting cylinder, jack, ring-type brace, tensioning nut, etc., are installed in sequence (Figure 4). After the equipment is installed, the reliability of all the connections is checked. The following points should be noted after installation
 - The reaction support frame is placed on a stable surface, and the contact areas between the reaction support frame, tensioning nut, anchor plate, etc., must provide surface-to-surface contact.
 - During tensioning work, the reaction support frame is placed with one end flat against the anchor plate and the other end supporting the jack, with the entire assembly under compression.
 - The flatness of the plate should be verified through inspection. When the reaction support frame is being assembled, ensure that the upper and lower plates of the reaction support frame remain parallel.
 - The height of the reaction support frame should meet the spatial requirements for removing existing cables and tensioning new cables.
 - During the release of existing cable, sufficient space is required below the jack to tighten or loosen the anchor nut, and the reaction support frame should have an adequate height to allow a sufficient margin for tensioning the new cable.
 - When the old cables are removed, the exposed steel strands at the tensioning end are used to install the cable-replacement anchorage and complete the whole release for removal. Based on the internal thread dimensions of the cable-replacement anchorage, matching tensioning rod and extension rods are fabricated.
 - During the tension release and cable removal process for long cables, the large elongation may prevent the cable force from being fully unloaded in a single operation. To accommodate the cable removal requirements for long cables, several extension rods of the same outer diameter are prepared at the tensioning end. The tensioning rod is 2.0 m long, and the extension rods are 0.5 m long. The rear end of the tensioning rod and both ends of the extension rods feature female and male connections, allowing them to be joined together.
- (3) Based on the measured cable forces, four cables of the same number are replaced simultaneously and independently.
- (4) The four symmetrical cables are tensioned in five stages, with the tension force at each stage being 20%, 40%, 60%, 80%, and 100% of the measured cable force. When the tensioning equipment reaches the specified force at each stage, the load is paused and held for 5 minutes, and the next tensioning instructions from technical personnel are awaited. After tensioning to 80% of the measured cable

force, the operation should be performed cautiously to allow the pressure gauge reading to rise slowly until the initiation cable force is reached.

- (5) When the measured cable force is approached during the final tensioning stage, the looseness of the anchor nut relative to the anchor plate must be observed (monitored using a dial indicator). If the dial indicator shows that the anchor nut has loosened from the anchor plate, the corresponding cable force at that moment is the initiation cable force for that stay cable. The initiation cable force value is recorded and compared with the measured cable force value. If a significant discrepancy is found between the tensioning force and the cable force measured by the frequency spectrum method, tensioning shall be stopped and the design and monitoring parties shall be notified.
- (6) After tensioning to the initial cable force and loosening the anchor nut, unscrew the anchor nut until it is flush with the anchor cup.
- (7) The jack oil is slowly retracted to release the cable force. During operation, two indicators—the tension force and the anchor head retraction amount—are used, with synchronous unloading performed in increments of 1 to 5 cm each time (the specific value is determined based on the retraction amount corresponding to the graded cable force reduction for cables of different lengths and specifications). During release, close attention must be paid to the cable forces on both sides to ensure synchronized deformation, preventing unbalanced loading on both sides of the pylon and maintaining force balance. For long cables, due to their large elongation, a single jack stroke (200 mm) is insufficient for complete unloading. In such cases, the two tensioning nuts behind the jack are alternately swapped until the stay cable force is fully unloaded.



Figure 4 Schematic of the installation of the integrated detensioning device

4.2.4 Cable Lowering

- (1) At the position above the cable guide pipe on the bridge deck, fit the split anchor block of the open-type clamping device over the steel strand to be removed along the slot. Install the tapered wedge to tighten it. Connect the circular through-holes on the ear plates on both sides to the winch wire rope using connection devices such as shackles. Start the winch and pre-tension the wire rope.

- (2) At the position above the cable guide pipe on the bridge deck, cut the steel strand (Figure 5), then start the winch until the steel strand is relaxed to a stress-free state. Maintain clear communication via two-way radios with unified and explicit instructions, and designate a dedicated person for command.

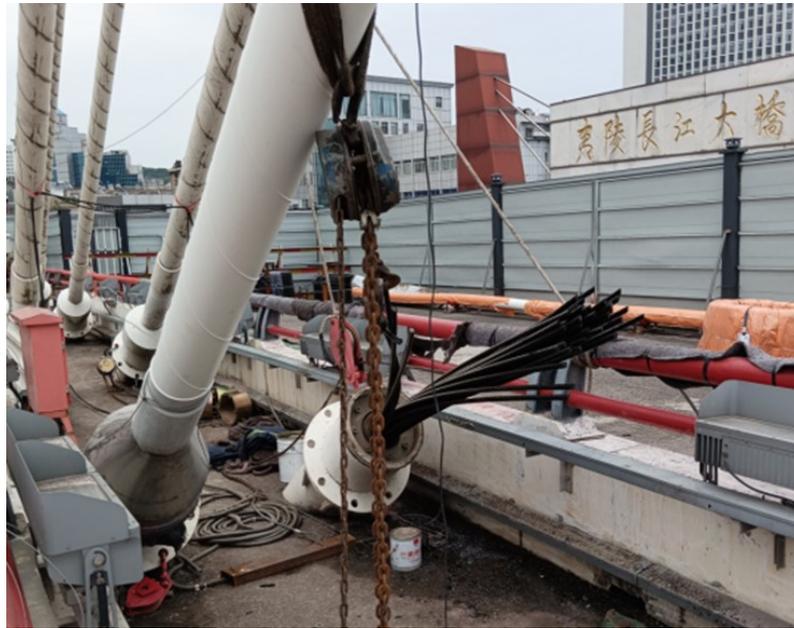


Figure 5 Schematic diagram of steel strand removal at the beam end

- (3) At the position below the cable guide pipe outside the tower, fit the split anchor block of the open-type clamping device over the steel strand to be removed along the slot (Figure 6). Install the tapered wedge to tighten it, then start the winch until the steel strand is lowered to the bridge deck.
- (4) During the lowering process of the old cable, use the winch pulling system on the bridge deck to straighten the old steel strands on the deck, then cut the old steel strands and load them onto a vehicle for transport away from the construction site.
- (5) Repeat this cycle until all steel strands of this cable are completely removed.

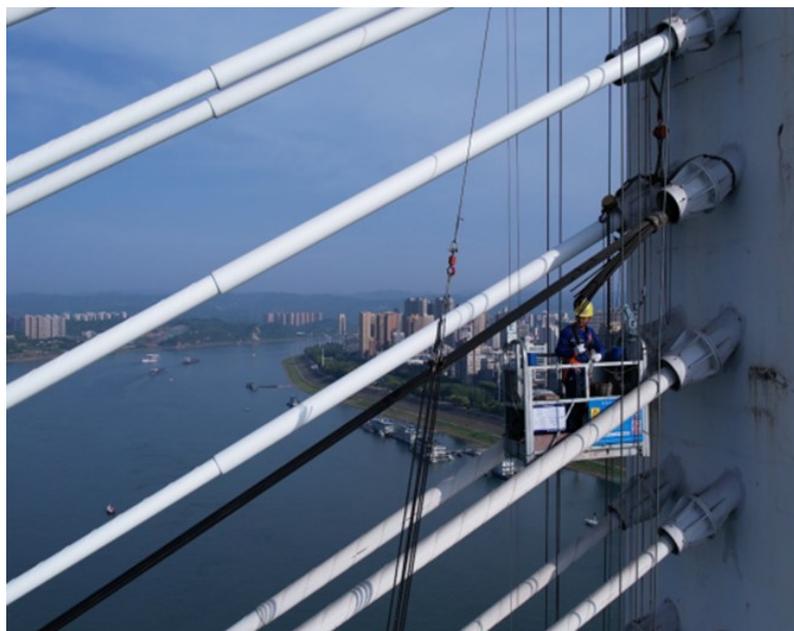


Figure 6 Schematic diagram of steel strand removal outside the tower

4.2.5 Dismantling of Upper and Lower Anchor Heads

- (1) After all steel strands have been removed, connect the pylon-end anchorage to the winch wire rope at the top of the pylon. Use chain hoists to assist in extracting the anchor head together with the steel strands as an assembly, then lift it down to the bridge deck for dismantling.
- (2) For the anchor head inside the box girder, use chain hoists to lower it to the bottom surface of the box girder, then remove the remaining steel strands and wedges one by one, and transfer them together with the anchorage to the bridge deck.
- (3) Clean any foreign matter from inside the cable guide pipe, apply anti-corrosion treatment, and make preparations for installing the new anchorage.

5 Construction Process for the Installation of New Stay Cables

5.1 HDPE Pipe Welding

- (1) The HDPE pipe storage area shall be kept away from fire sources and the ground shall be leveled. HDPE pipes shall be stacked by specification, with a stacking height not exceeding 6 layers. Select HDPE pipes using a tape measure and mark alignment indicators. HDPE pipes with severe deformation shall not be used.
- (2) Place the HDPE pipe on the support stand and perform butt welding at the HDPE welding machine. Adjust the position of the HDPE pipe and the clamps to keep the pipe basically straight.
- (3) Shape and plane the ends of the HDPE pipe.
- (4) After shaping and planing, adjust the clamps to align the pipe ends, ensuring the outer circumference height difference is less than 1 mm.
- (5) Perform trial welding for each specification of HDPE pipe before formal welding to determine the welding parameters.
- (6) Perform formal welding (Figure 7).



Figure 7 HDPE pipe welding

5.2 HDPE Pipe Hoisting

- (1) Select a suitable construction site and use supports or sleepers to erect the HDPE pipe to prevent damage. Weld the HDPE pipes according to design requirements in preparation for hoisting.
- (2) Thread an extended-length steel strand (i.e., an "extension cable") of length L_{plus} through the pipe, and install hold hoops at both ends of the HDPE pipe.
- (3) Use a tower crane or other lifting equipment to lift the extension cable (with a certain length reserved before the lifting point of the extension cable for

threading into the pylon-end anchorage) together with the HDPE pipe. After reaching the predetermined height, thread one end of the extension cable into the pylon-end anchorage and fix it. Use wire ropes and chain hoists to suspend the HDPE pipe at the corresponding position of the pipe opening of the outside the pylon (Figure 8).

- (4) Guide the lower end of the HDPE pipe to the lower embedded pipe opening, and thread one end of the extension cable into the lower anchorage and fix it.
- (5) Use the extension cable to straighten and raise the HDPE pipe to the designed angle, facilitating the subsequent cable installation work.



Figure 8 HDPE Pipe Hoisting

5.3 Single-Cable Tensioning Construction

- (1) Cut the steel strands of the new cable to length on-site according to the original cable length. Thread them into the anchorage as required by construction specifications, temporarily fix them with wedges, and install the construction equipment.
- (2) Install a CYL200A load sensor as a reference sensor through the tensioning bracket at the tensioning end, along with a set of single-hole tool anchorage as a temporary anchorage.;
- (3) Tension the first steel strand to the set value (tensioning control force), anchor it securely with the temporary anchorage, and unload the jack (Figure 9).



Figure 9 Schematic diagram of single-strand tensioning for stay steel strands

- (4) Insert the second steel strand. The tensioning system will display the force value from the reference sensor. Input this force value in the tensioning setting interface as the tensioning control force value. Tension the second steel strand, install wedges in the cable anchorage head to anchor it securely, and unload the jack (Figure 10).
- (5) Use the same method to install and tension the remaining steel strands of the stay cable.
- (6) Install the jack onto the first steel strand of the cable, read the force value from the reference sensor as the tensioning control force value, tension to the required position, maintain pressure, remove the temporary single-hole anchorage, install the working anchorage wedges in the anchor plate holes, anchor securely, and unload the jack.
- (7) After the cable installation and tensioning is complete, proceed to install and tension the second cable.

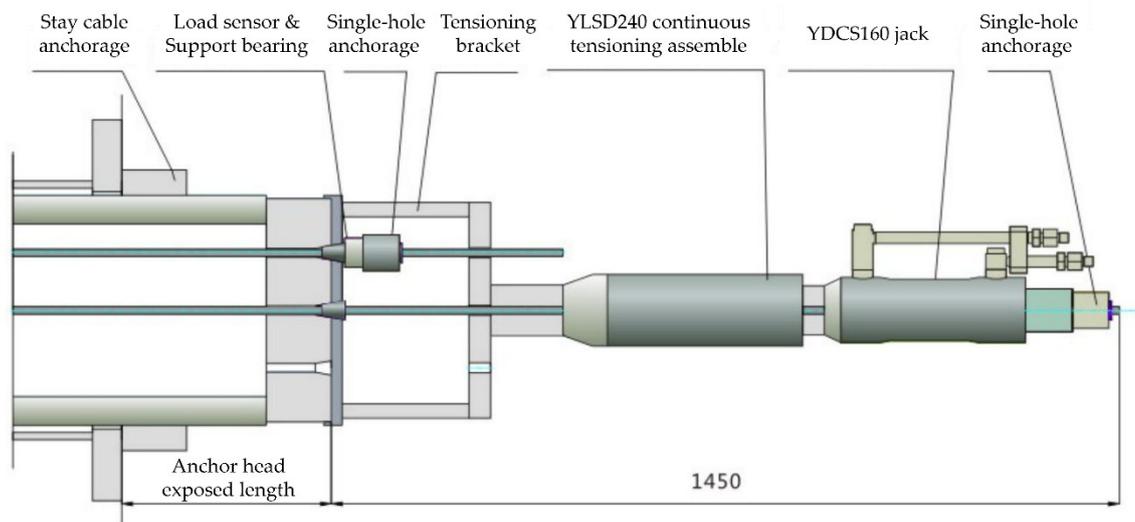


Figure 10 Tensioning system diagram

5.4 Cyclic Tensioning of Single Steel Strands for Cable Force Adjustment

- (1) During the initial tensioning of steel strands, calculate the tensioning control force for the first steel strand F_1 , for the second steel strand F_2 , ..., and for the n -th steel strand F_n based on the equal tension method.
- (2) The steel strands are anchored to the tensioning-end anchorage and the fixed-end anchorage using working anchorage assembly (i.e., anchorage and wedges). A load sensor is installed on the first steel strand. The single-strand tensioning support assembly (single-strand tensioning bracket + honeycomb plate) and the tensioning and jacking equipment (jack + stroke conversion support cylinder + hydraulic jacking device + stroke limiter combined as an integrated unit) are installed. The steel strand must pass through all the above equipment, with the stroke limiter simultaneously passing through the honeycomb plate to reach the front end of the working wedge.
- (3) During tensioning, the steel strand and wedge are pulled out synchronously. After being pulled out, the wedge is restrained by the stroke limiter, keeping it positioned within the anchorage hole. Continuous tensioning is achieved by alternately anchoring with the working anchorage assembly and the temporary anchorage assembly. During the continuous tensioning process, the working wedge remains in a suspended state.
- (4) During tensioning, collect the actual tensioning data fed back by the sensor and compare it with the theoretical tensioning data. After obtaining the adjustment

parameters, adjust the oil pressure of the pump, and finally push the working wedge into the anchor hole to complete one cycle of tensioning and jacking.

- (5) After completing tensioning and jacking, remove the single-strand tensioning equipment, move it to the next steel strand, and repeat the above construction steps until the entire cable tensioning is completed.

5.5 Stay Cable Force Adjustment

5.5.1 Principles of Adjustment

The principles to be followed for cable force adjustment are to ensure that the new cable force matches the original cable force before the cable replacement construction.

After completing the cable replacement tensioning, the cable forces of all the stay cables on the entire bridge are measured, and those cables where the deviation from the original target cable force exceeds $\pm 2\%$ are adjusted. During cable adjustment, consider the cable forces of the three adjacent cables and the corresponding bridge geometric alignment.

5.5.2 Cable Adjustment Method

Before adjusting the cables, the cables must be prepared for cable force measuring and other related observations. During adjustment (Figure 11), based on predetermined tension levels, the corresponding elongation of the stay cables is calculated. The cable force is adjusted by advancing (or retracting) the electric oil pump and tightening (or loosening) the anchor nuts.



Figure 11 Schematic diagram of stay cable force adjustment

6 Key Technical Control Points

- (1) Before cable replacement, measure and verify the actual length of the existing stay cables on site, and record the actual construction details of the original stay cables to confirm whether the fabricated dimensions are consistent with the design. The measured length of the original stay cable shall serve as the basis for cutting the new stay cable to length. The cutting length of the new stay cable shall also be temperature-corrected based on the on-site temperature.
- (2) When replacing stay cables, the cable force is obtained under the condition that the structure is subjected only to dead loads. Therefore, before cable

replacement, remove all unnecessary items from the bridge deck. During cable replacement, it is strictly prohibited to concentrate construction equipment, tools, materials, etc., on the bridge deck. In particular, it is not allowed to stack excess tools, equipment, materials, debris, etc., near the stay cable being replaced.

- (3) The jacks and oil pressure gauges used for tensioning stay cables shall be calibrated, and oil pressure gauges with finer scale divisions shall be used.
- (4) Individual steel strand wedge seating in the new stay cable anchorage: Use the jack tensioning bracket as a reaction frame, and employ a dedicated wedge seating device to seat the wedges for each steel strand individually. The total stress shall be controlled not to exceed 0.45 times the breaking stress of the steel strand, with the aim of ensuring the gripping performance of the wedges under low stress conditions.
- (5) After the stay cable replacement is completed, measure the cable forces of all stay cables on the entire bridge and the bridge deck elevation, and perform cyclic adjustments until the cable forces and deck alignment are substantially consistent with the design adjustment requirements.
- (6) The sequence of cable replacement for the entire bridge shall be determined through calculation, as detailed in Section 4.1.
- (7) Main monitoring items during the cable replacement process: Structural stress and deformation verification during the cable replacement process of the cable-stayed bridge to ensure structural safety and feasibility of the construction procedure; simulation calculation analysis of the cable replacement construction process (simulation calculations of various working conditions and load effects during the construction process based on the construction procedure); measurement of control parameters during installation (including monitoring of pylon and girder deformation, stay cable forces, etc.); error analysis and feedback control calculation analysis (analyze various errors occurring during construction, make corrections, provide feedback to construction based on calculation results, and issue instructions for the next construction step).

7 Conclusion

The practice of the main bridge cable replacement project at Yiling Yangtze River Bridge demonstrates that the integrated cable force release device and associated construction techniques proposed in this paper effectively solve the problems of difficult unloading and insufficient adjustment capacity for long cables in long-span cable-stayed bridges, enabling the completion of full-bridge cable replacement without compromising the safety of the original structure. During construction, the structural response remained stable, and both the final cable forces and bridge alignment met the design requirements. This technology offers significant reference value for cable replacement projects on similar bridges.

Conflict of interest: The author disclosed no relevant relationships.

Data availability statement: Data supporting the findings of this study are available from the corresponding author Gan upon reasonable request.

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