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Rehabilitation of an old Concrete Lohse Arch Bridge: Replacement of all hanger

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ABSTRACT

The Kimitsu Shinbashi Bridge is a Lohse arch bridge with reinforced concrete arch ribs and prestressed concrete deck slab. On October 23, 2008, it was discovered that one of the 40 hanger connecting the arch ribs and deck slab had broken. The bridge was closed to traffic and breaking mechanism followed by a detailed investigation. Repairs were effected step by step, ensuring the safety of the bridge throughout the process. This report describes the circumstances and procedures leading up to the replacement of hanger, and reports on the hanger replacement work utilizing newly developed tension releasing equipment.

Keywords. Steel bar break, galvanic corrosion, tension releasing equipment, hanger replacement, Lohse arch bridge

1 INTRODUCTION

The Kimitsu Shinbashi Bridge is concrete Lohse arch bridge constructed in 1973. It has a length of 68.3 m, width of 18.2 m. The deck slab is supported by 40 hanger, arranged with pairs of steel bars (32 mm dia.) at 10 locations each on the upstream and downstream sides of the bridge. The original steel bars were coated with anti-corrosion paint, and then sheathed in stainless steel pipes. Photo 1 is an overall view of the retrofitted bridge.

Photo 1. Retrofitted Kimitsu Shinbashi Bridge

2 OUTLINE OF RENEWAL WORK

On October 23, 2008, it was discovered that one of the 40 hanger had broken. The bridge was closed to traffic and emergency repairs performed to prevent the bridge collapsing, followed by permanent repairs including hanger replacement and seismic reinforcement. The repairs were completed and the bridge reopened to traffic on September 11, 2009, after being out of service for 11 months. Table 1 shows the overall progress schedule.

Table 1. Overall Progress Schedule

Process	Year/Month	2008			2009												2010		
		10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Surveys/design	Emergency survey																		
	Detailed surveys																		
	Emergency repair planning																		
	Investigation of hanger																		
	Bridge seismic capacity evaluation/repair planning																		
Emergency repairs	Step 1																		
	Step 2																		
Permanent repairs	Hanger replacement work																		
	Arch ribs seismic reinforcement work																		
	Tests to confirm bridge soundness																		
	Deck slab reinforcement/repair work																		
Bridge closed to traffic			・Break occurred Oct. 23											・Bridge reopened to traffic Sep. 11					

3 INVESTIGATION CAUSE OF BREAK

3.1 Emergency Investigation

An emergency investigation performed immediately after break of the hanger consisted of recovering the broken steel bar and visually inspecting the extent of corrosion and the breaking section. The steel bar had broken close to a joint in the sheath pipe. As can be seen in Photo 2, the anti-corrosive paint applied at the time of construction was peeling, and substantial corrosion had occurred, reducing tendon diameter from 32 mm to only 19 mm. Investigating other hanger revealed additional cases where the steel bars had reduced thickness due to corrosion, so the bridge was closed to traffic.

3.2 Detailed Investigations

Detailed investigations were conducted to discover the cause of break of the steel bar. Table 2 shows the Items covered by the investigations, together with the results. Material tests on the steel bar did not find any abnormalities in terms of chemical constituents, metallographic structure, hardness, or tensile strength, so it was judged that there were no deficiencies in terms of materials. Furthermore, examination of the breaking surface suggests that rather than ductile fracture, this breaking was a brittle fracture starting at the section where the surface was corroded.

Next, because of conspicuous reduction in thickness of the broken steel bar due to corrosion, electrical continuity between the steel bar and stainless steel sheath pipe was tested in situ.

This test showed that although there was no continuity at points on the steel bar where the coating remained, there was electrical continuity when the coating was removed. To discover the cause of corrosion, the anti-corrosion paint was removed from a steel bar, and a dissimilar metals corrosion test (galvanic corrosion test) performed between the steel bar and the stainless steel sleeve. The test showed that galvanic current between the steel bars and stainless steel sleeve significantly promoted corrosion of the steel bars near a boundary. Figure 1 outlines the galvanic corrosion test and the results obtained. A current density of 20 μAcm^{-2} was produced at the boundary between the steel bar and sleeve.

From the results of these investigations, it is surmised that the joint between sheath pipes protecting the steel bar separated due to degradation and vibration, that, in addition, dissimilar metals corrosion occurred due to partial electrical contact between the stainless steel sheath pipe/sleeve and the steel bar, and that the steel bar subject to conspicuous reduction of cross-section lost resistance capacity and had broken. This corrosion mechanism is illustrated in Figure 2.

Table 2. Detailed Surveys of Steel Bars

	Tests	Results
Material tests	Appearance	Section reduced to 35% at point of breaking
	Chemical constituent analysis	JIS standards compliant
	Metal structure observation	OK
	Hardness measurement	OK
	Tensile test	JIS standards compliant
Dissimilar metals corrosion testing	Galvanic corrosion test	Corrosion likely (Corrosion current density: 20 $\mu A/cm^2$)

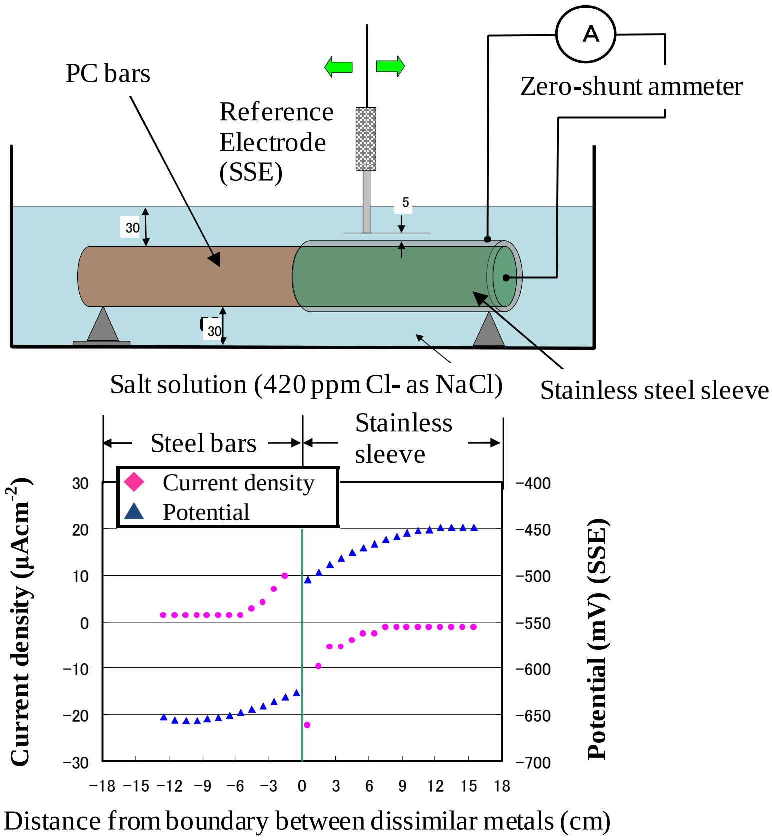


Figure 1. Steel corrosion test

Photo 2. Broken steel bar

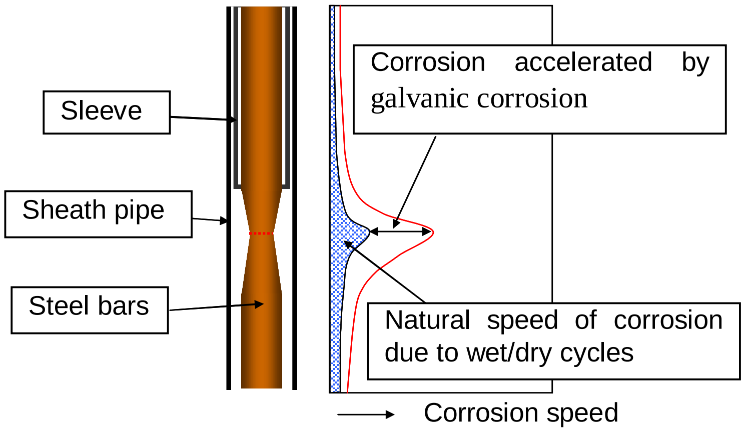


Figure 2. Corrosion mechanism

4 OUTLINE OF REPAIR WORK

4.1 Emergency Repairs

4.1.1 Outline of Emergency Repairs

The bridge has a structure with the deck slab supported by 40 steel bars from the arch ribs, so a breaking of a steel bar results in an excessive load on other steel bars and affects the structural integrity of the structure overall. Emergency repairs were performed in two steps to prevent bridge collapse or other serious situations in the event of breaking of other steel bars. The emergency repairs are illustrated in Figure 3.

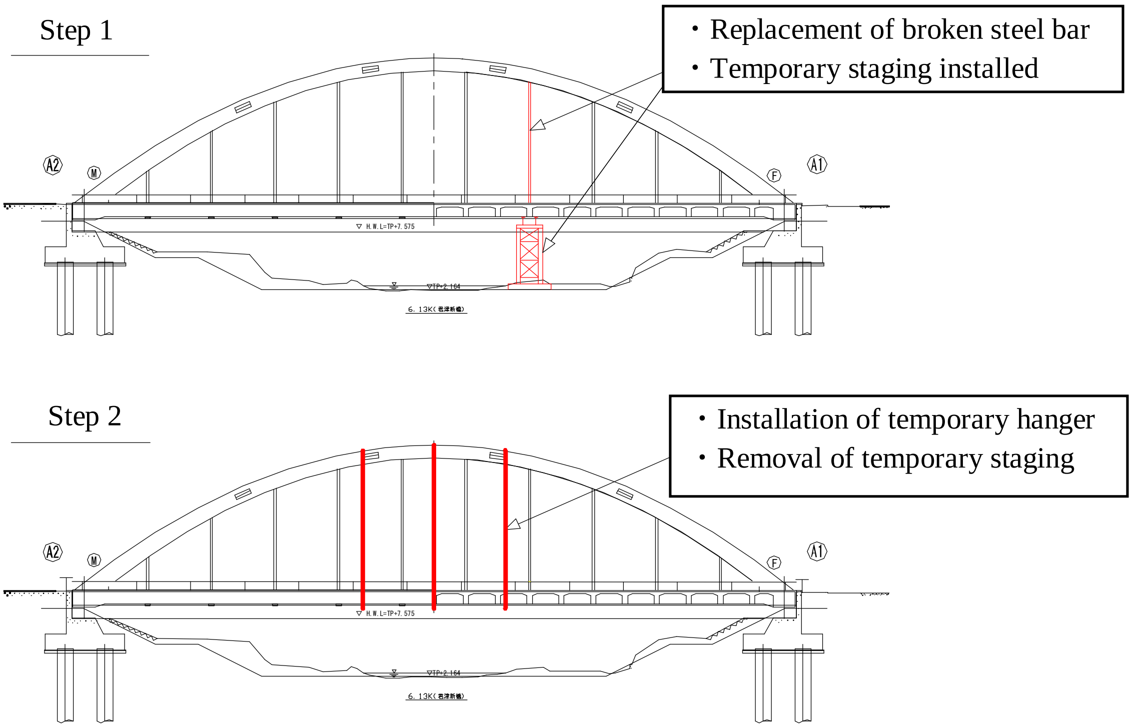


Figure 3. Outline of emergency repairs

4.1.2 Emergency Repairs: Step 1

Step 1 of the emergency repairs envisaged potential break of the steel bars adjacent to the broken steel bar. As a precautionary measure, a temporary staging was installed directly under the broken steel bar to support the deck slab of the bridge, and the broken steel bar was replaced. The existing coupler embedded in the deck slab was not corroded, so after testing its load capacity, it was reused when replacing the steel bar, connecting a new tendon to the coupler. The temporary staging was constructed by using large sandbags to make a coffer dam in the river, then assembling steel staging materials on a concrete foundation.

4.1.3 Emergency repairs: Step 2

Step 2 of the emergency repairs consisted of temporarily installing 12 additional hanger with the objective of ensuring structural integrity and preventing the bridge from collapsing in the event of break of up to 24 of the steel bars, equivalent to 60% of the hanger. The structure of the temporary hanger consisted of steel support beams secured to the top surface of the arch ribs and to the bottom surface of the deck slab, with these beams linked by new steel bars. Out of consideration for the overall balance of the structure and in order to facilitate the work of hanger replacement at the permanent repair stage, these temporary members were positioned midway between existing hanger. It was necessary to drill through the deck slab to accommodate the additional steel bars. As there was a risk that drilling might damage nearby longitudinal PC cables or steel reinforcements, X-ray inspection and ground-penetrating radar were used to locate steel elements before starting work, and the drilling was performed cautiously to prevent damage. Installation of the temporary members made it possible to remove the temporary staging from the river, ensuring that the bridge would remain safe during the flood season.

4.2 Permanent repairs

4.2.1 Outline of permanent repairs

The permanent repairs consisted of replacement of the hanger, using PC cables instead of the original steel bars because of the superior fatigue and corrosion performance provided by cables, and also of measures to enhance durability and meet the load performance and seismic performance criteria of the current Specifications for Highway Bridges. The permanent repairs are illustrated in Figure 4.

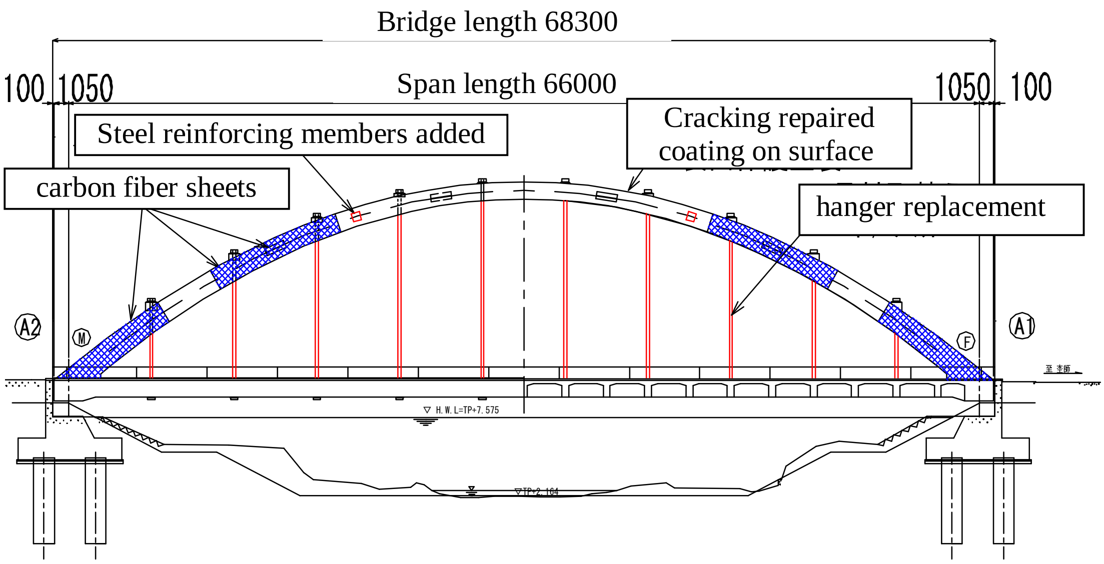


Figure 4. Outline of permanent repairs

4.2.2 Hanger replacement work

Since the cause of break of the hanger was corrosion, it was decided to replace the steel bars with PC cables. The cables have a dual protective coating, provide greater corrosion performance, and moreover meet current standards. To further enhance corrosion performance, anchorages were sprayed with zinc-aluminum pseudo alloy, and anchorage covers were filled with polyurethane resin to prevent infiltration of rainwater, etc.

Replacement of hanger began with the hanger in the center of the span where corrosion was most severe and bar thickness was most reduced, then moved towards the ends of the bridge, replacing the two members at each location together. The replacement process consisted of releasing the tension from the existing steel bars, and then after removing the old bars, core drilling the arch ribs and deck slab, installing the new cables and tensioning them to the design tension for the old hanger. Hanger replacement is illustrated in Figure 5.

Tension in existing steel bars is usually released by fitting jacks to the ends of the bars at the anchorages, but for this project, because the length at the ends was insufficient for the threading required, tension was released using specially developed tension releasing equipment attached partway up the member. The tension releasing equipment was performance tested to confirm its safety and efficiency before being used.

In order to ensure that replacement of the hanger proceed safely, tension of hanger and deflection of the deck slab were constantly monitored during the process. Cutting and removing the old hanger changes the bridge structurally so that the remaining hanger bear the load, changing the stresses on each of the members. Because of this, hanger tension, stresses for each member, and deck slab deflection were calculated for each execution step before commencing the hanger replacement work. To ensure structural integrity during execution, control limits were established so that the increase in load on each hanger and deflection of the lower could be checked as the work proceeded. Changes in tension of the old hanger were measured by fitting strain gauges to the surface of each of the hanger and calculating the tension from the changes in strain. Deflection was measured using laser displacement gauges fitted to both upstream and downstream handrails.

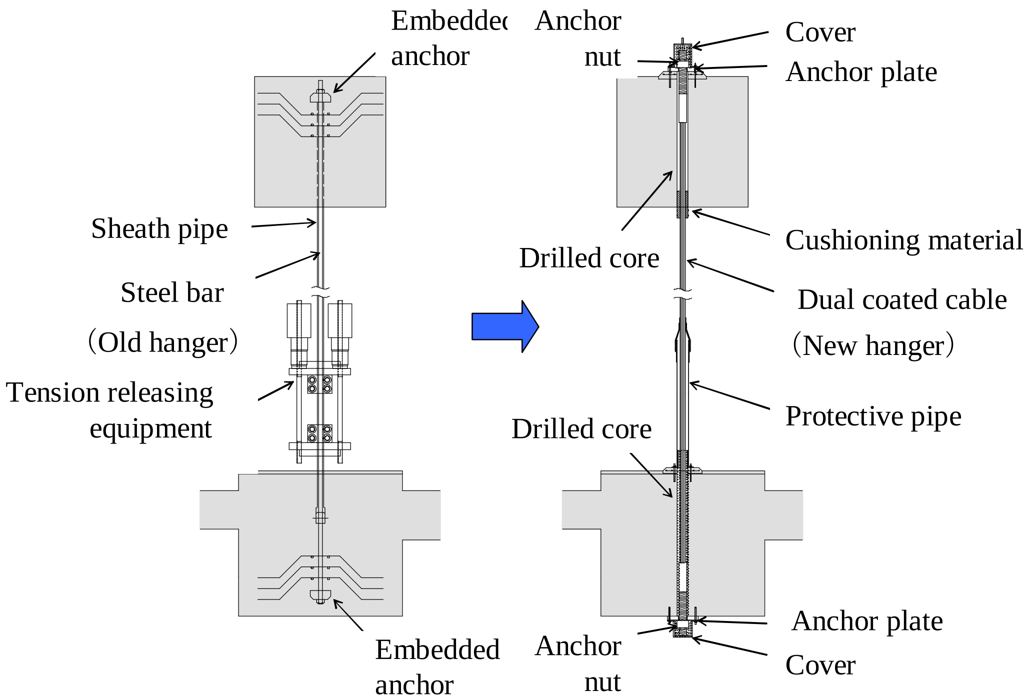


Figure 5. Replacement hangers

5 DEVELOPMENT OF TENSION RELEASING EQUIPMENT

5.1 Outline of Tension Releasing Equipment

The old hanger on this bridge did not have sufficient length at the anchorages for releasing tension. For this reason, there was a need for a system that could reliably attach to the steel bar under tension and release the tension safely. The following issues were considered with regard to releasing the tension.

a. Development of a reliable system for attaching the equipment and diverting the existing tension

b. Shock-free method for safely cutting steel bar

c. Method for releasing tension while minimizing increase in tension on old hanger

d. Method for minimizing increase in tension on other hanger

Tension releasing equipment using wedge anchorage devices was developed as a system to meet all these requirements. The equipment is illustrated in Figure 6. The anchorage wedges and anchorage cones both have a two-part structure so that they can be easily attached wherever required. The steel tension diversion bars are fitted with hydraulic jacks and load gauges. The procedure for releasing tension is as follows.

① Fit the wedge anchorage devices to the old steel bar, and put the tension releasing equipment in position.

② Use the two hydraulic jacks to tension the steel tension diversion bars. The tension is transferred to the old steel bar through the bearing plates and anchorage wedges, releasing the tension in the steel bar between the wedges.

③ Cut the old steel bar between the anchorage wedges with a gas cutter. The tension between the wedge anchorage devices is transferred to the tension diversion bars.

④ Slowly release the hydraulic jacks. The tension is released over the whole length of the steel bar.

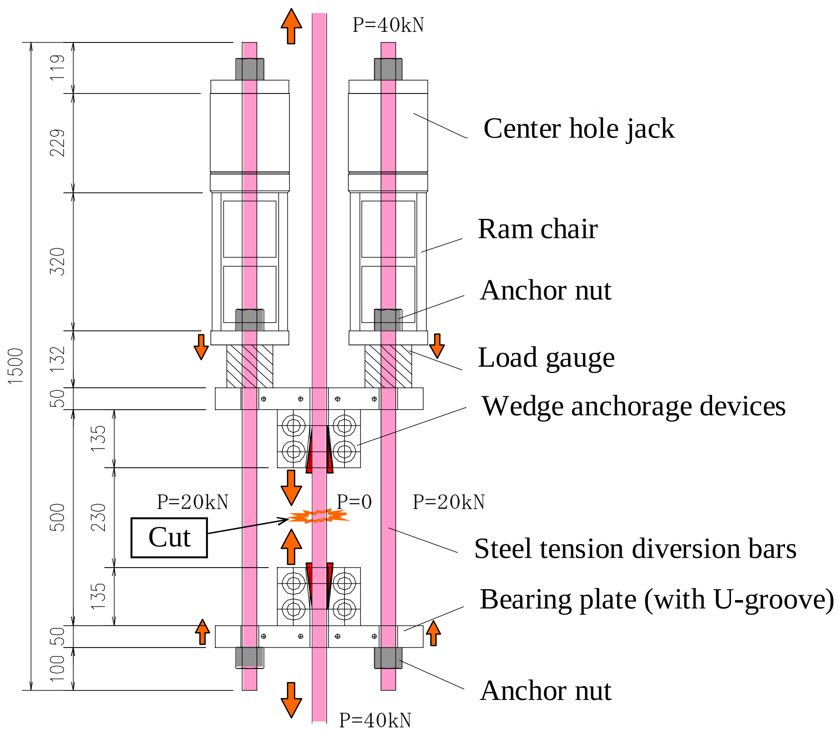


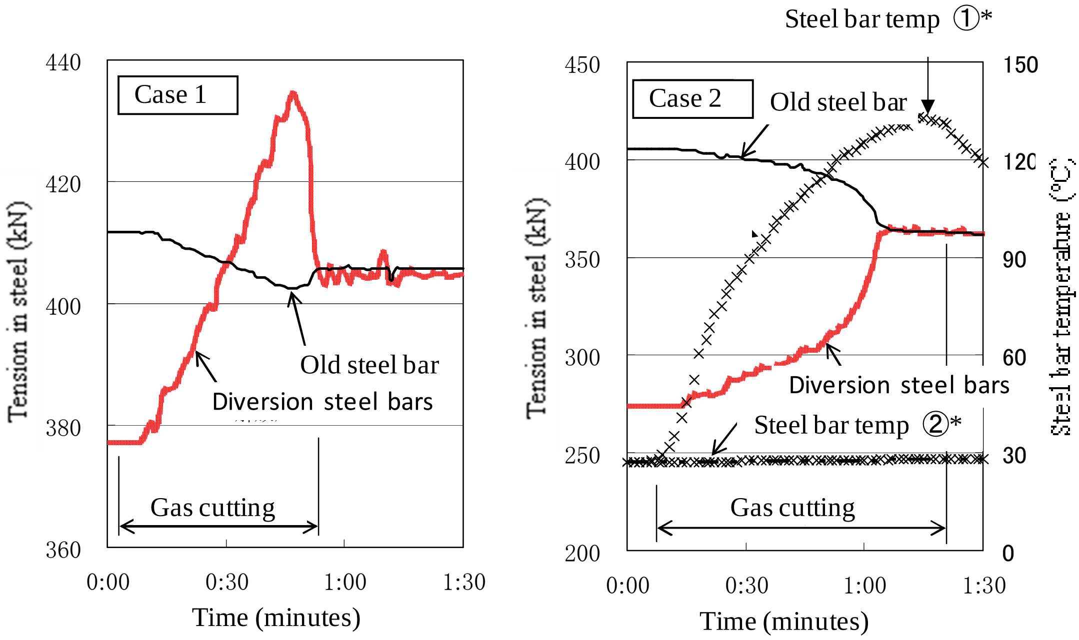
Figure 6. Tension releasing equipment

5.2 Performance testing

The system was tested before using the releasing equipment for replacement work on the actual bridge. Testing focused on the following points.

1. Confirming that the wedge anchorage devices function reliably
2. Confirming the effect of residual tension in the old steel bar
3. Confirming the effect of temperature when the old steel bar is cut with a gas cutter

The testing was performed for two different cases in order to take account of potential error on site. Assuming residual tension of 40 kN at the time of release for Case 1, and residual tension of 140 kN at the time of release for Case 2, the test involved producing a 1 mm offset in one of the sets of wedges. The resulting changes in tension at the time of cutting in the old steel bar and in the steel bars for taking over the tension are shown in Figure 7.



(*Steel bar temp ① : under wedge, Steel bar temp ② : over wedge)

Figure 7. Changes of tension in steel bars

In Case 1, the difference in tension was approximately 40 kN before cutting. When gas cutting started, the old steel bar underwent heat expansion, releasing the residual tension in the old bar and increasing the tension in the steel tension diversion bars. As cutting continued, the tension in the tension diversion bars exceeded the tension in the old steel bar, so that the old steel bar came under compression. After cutting, both the old steel bar and the tension diversion bars were at the same tension.

Case 2 is the case where there is residual tension in the old steel bar at the cutting position. When cutting begins, the tension increases in the tension diversion bars, confirming that the tension is being transferred from the old steel bar. This result demonstrates that even in cases where there is residual tension, the tension is steadily transferred to the tension releasing equipment, confirming that the anchorage can be released in safety. It also showed that the anchorage wedges were able to provide a reliable anchorage, even when the wedges had an offset of approximately 1 mm.

6 APPROACH TO MAINTENANCE

6.1 Measuring Tension of Hanger

As this bridge has a distinctive structure, with the deck slab supported by PC cable from the concrete arch, it was considered that variations in the state of the bridge could be reliably identified by identifying variations in the tension of the PC cable. Consequently, it was decided to measure tension in the hanger using a vibration technique.

The ratios between estimated and measured tension of hanger at completion of repairs are shown in Figure 8. The tension in the hanger is within a range of 0.91-1.03 relative to the design values, with the exception of hanger at the ends of the bridge, confirming that the tension is acting as designed. These measurements will be a very useful benchmark for detailed inspections in the future.

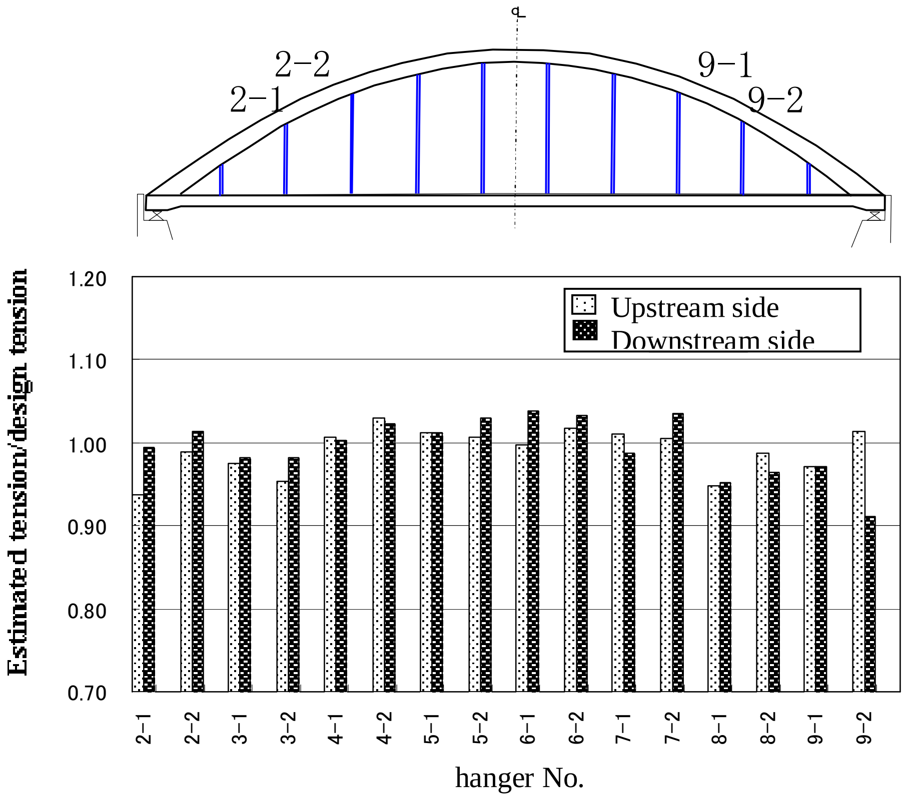


Figure 8. Comparison of tension in hanger with design values

6.2 Soundness Testing

Loading tests of the actual bridge were performed to confirm the effects of repairs and reinforcements, and to provide data for use as a benchmark in future detailed investigations. In the loading tests, loading vehicles were placed on the bridge deck, and measurements taken of strain in the arch ribs/deck slab, deck slab deflection, and tension of hanger. These measurements were compared with the calculated estimates to confirm the load capacity of the bridge after reinforcement. Three vehicles of 196 kN each were used as the loading vehicles, taking measurements for 6 different cases. The estimates were produced by 3D framework analysis.

The results of measurement for the case of loading at 1/4 span are shown in Figure 9. The graph on the left shows the deflection of the deck slab under load. The measurements of deck slab deflection and of strain in the arch ribs and deck slab match well with the calculated estimates, confirming that the required flexural stiffness and load carrying capacity have been achieved. The distribution of strain in the arch ribs and deck slab was consistent with Bernoulli-Euler model assumptions, confirming that each of the members was behaving as an elastic body.

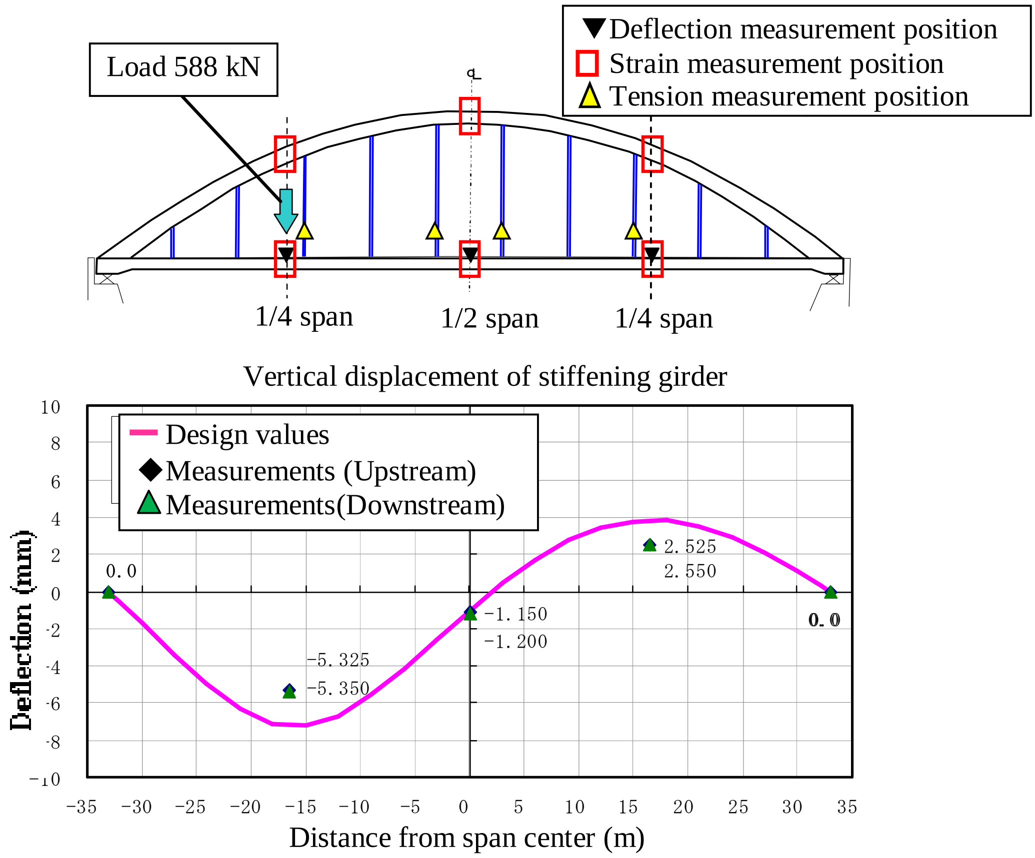


Figure 9. Results of loading test on bridge after repairs

7 CONCLUSIONS

This repair project has three major characteristics.
1. Tension releasing equipment was specially developed for the old steel bar, and subjected to performance testing before use on the bridge.
2. Variations in tension of the old hanger and displacement of the bridge were measured in real time, constantly confirming safety as the work progressed.
3. As a solution to maintenance, hanger tension was measured and loading tests performed, producing data that can be a benchmark for future detailed investigations.

This paper describes an example of maintenance procedures to extend the service life of a bridge, a requirement that is likely to become increasingly common in the future.

REFERENCES

Hayashi, Ishiyama, Watanabe, Fujiwara, Kumagai and Asai, H. (2010). "Renewal of concrete Lohse arch bridge." Bridge and Foundation Engineering, Vol. 44, No. 9, 49-55.