Development of retrofitting method against fatigue cracks in orthotropic steel deck stiffened by trough ribs

Takahiro Shinno, Yoshiaki Mizokami, Akira Moriyama, Yuki Kishi
Honshu-shikoku bridge Expressway Co.,Ltd, Hyogo, JP

Masahiro Sakano
Kansai University, Osaka, JP

Contact: takahiro-shinno@jb-honshi.co.jp

Abstract

Orthotropic steel deck is suitable for a long span bridge because of its light weight. And closed section ribs, we call "trough ribs", are used for orthotropic steel deck in Honshu-Shikoku Bridges because of excellent bending capacity with less number of weld lines and less areas of anti-corrosion.

In orthotropic steel decks stiffened by trough ribs, fatigue cracks resulting from large vehicles have been observed with the increase of the service years. The cracks found in trough-deck welds are bead-penetrating type. Several retrofitting methods have been studied for these bead-penetrating cracks so far. However, effective method that is applicable from the underside of the deck is still under development.

In this paper, development of a retrofitting method using Thread Rolling Screw from the underside of the deck, fatigue test results and application test in an in-service bridge are described.

Keywords: orthotropic steel deck; bead-penetrating crack; thread Rolling Screw; retrofitting method from the underside of the deck

1 Introduction

The Honshu-Shikoku Bridges (Figure 1) that connect Honshu and Shikoku by three routes consist of ten suspension bridges including the Akashi Kaikyo Bridge, the longest suspension bridge in the world, five cable-stayed bridges, one truss bridge and one arch bridge.

For these long-span bridges, dead load occupies large part of the cross-sectional force of the major members. In order to reduce dead load, they use light-weight orthotropic steel decks (OSD).

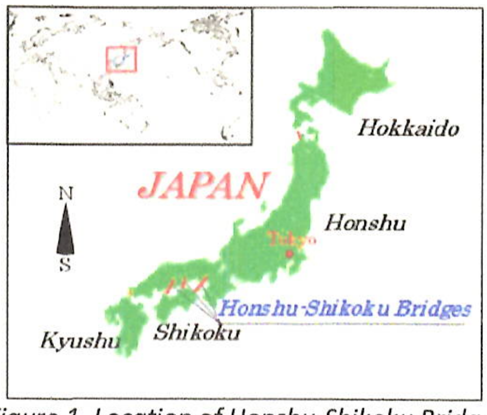

Figure 1. Location of Honshu-Shikoku Bridges

OSD consisting of deck plates, trough ribs, and cross ribs are supported by main girders in which deck plates act as upper flange.

2 Conventional retrofitting methods of fatigue cracks

OSD is frequently adopted to long-span bridges in strait and urban expressway because of its light weight and short building time. In recent years, many cases of cracks initiating from trough-deck weld root toward the surface of the weld bead (hereinafter, " bead-penetrating crack ") as shown in Figure 2 are reported mainly in heavy traffic route[1]~[4].

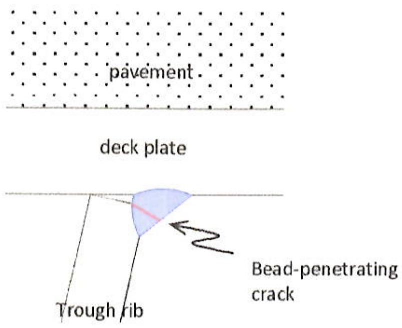

Figure 2. Bead-penetrating crack

The following existing retrofitting methods have advantages and disadvantages. Replacement of trough ribs or plate-splicing require installation of high-tension bolts from the topside of the deck. Rewelding[5] or plate-splicing with stud bolts are applicable from the underside[6]~[9].

Replacement of trough ribs or plate-splicing require traffic restriction for the removal of the pavement. Therefore, social impact is large for heavy traffic highways or strait-crossing longspan bridges that have no alternative routes. Also, pavement joint created by the partial pavement removal and repaving may degrade waterproofing performance.

For the re-welding from the underside, quality control is difficult because the method forces welders to weld in an upward direction. Also, if the traffic cannot be closed, traffic vibration is not avoidable during welding work and it may degrade welding quality. Because welding inside the trough rib is difficult and it is welded from the outside in general, full penetration welding cannot be done and unwelded parts tend to remain at root. That is, for the re-welding, quality may not be assured and anxiety for the reappearance of cracks from root remains.

For the plate splicing with stud bolts, quality control may be difficult because of upward welding. Also, because the studs are welded to the deck plate in which stress amplitude by the live load is large, fatigue cracks from weld toe toward the deck may be a concern. Although several retrofitting methods for bead-penetrating crack were proposed, there is no effective method that is applicable from the underside of the deck currently.

3 Developed retrofitting method and outline of fatigue test

The retrofitting method proposed here is a plate splicing method that requires no traffic regulation and applicable from the underside of the deck. In this method, the deck is drilled from the underside with caution not to damage the pavement, and connection of the splicing plate and deck plate is bearing joint with bolts or screws instead of conventional friction joint with torque shear bolts. Bolt holes are perforated from the underside of the deck. Connection of splicing plate and trough rib is one side bolt.

In order to confirm performance of the method, fatigue tests with actual size test model (Figure 3) are conducted[10],[11]. The load is 260kN/axle, and 2-3 million times of direct loading is applied.

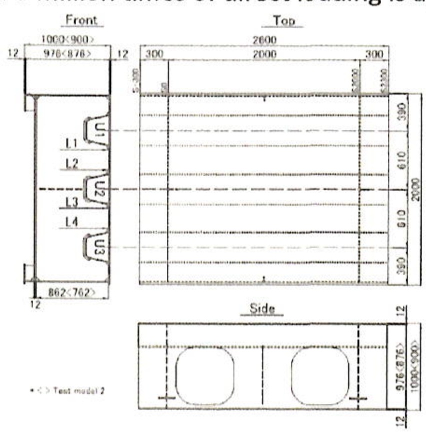

Figure 3. Actual size test model

As bearing joint, tap bolt (TB) and Thread Rolling Screw (TRS) are selected. In a method using TB, the bolt is screwed after steel plate is perforated and tapped. On the other hand, in a method using Thread Rolling Screw (TRS), the bolt is screwed forming female threads on perforated steel plate [12]～[14]. Also, as a bench mark to evaluate these methods, friction joint with torque shear bolt (HTB) is tested as well. Connection of splicing plate and trough rib is one side bolt (MUTF20) for all types. Figure 4 shows details of each retrofitting method, and Figure 5 shows TRS.

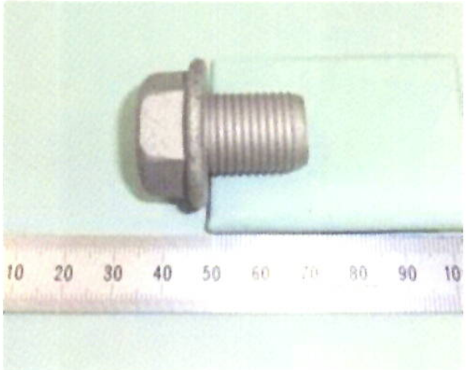

Figure 5. TRS

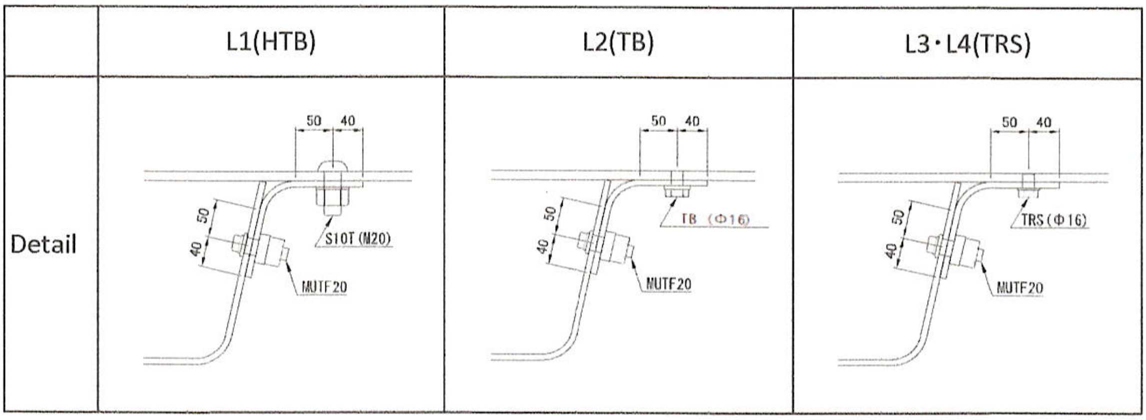

Figure 4. Details of plate splicing

4 Results of fatigue test

In fatigue test, the following results were confirmed.

①It is found that deck cracks can be suppressed if plate splicing is applied with bead cut. Even if bead is not fully cut before plate splicing, remaining bead will be cut by repetitive loading and no deck cracks will be generated.

②No deck cracks are found in the area where bead is cut. However, bead cracks or deck cracks may occur at the end of bead cut. From this, countermeasure is required at the end of bead cut in order to suppress and monitor the reappearance or progress of crack[15].

③From the fact that bead cracks and deck cracks appear and grow if plate splicing is applied without bead cut, it is confirmed to be necessary to cut bead.

④For three connection methods (HTB, TB, and TRS), neither bolt loosening nor cracks from bolt holes are observed. They can be evaluated as equivalent within the range of the load and number of repetitive loading of the test.

⑤From the view point of workability, TB and TRS can be applied from the underside. Especially for TRS, shaving process can be omitted compared with TB. TRS has higher workability and therefore has advantage over TB.

5 Test application

5.1 Retrofit procedure

A retrofit procedure manual for plate splicing method from the underside of the deck using TRS based on results of fatigue test was made before application in actual bridge. The procedure is as follows.

(1) Drill monitoring holes at both ends of cracks (Figure 6)

(2) Cut bead in trough-deck weld (Figure 7)

(3) Attach splicing plate temporarily using magnet tool (Figure 8)

(4) Drill hole for TRSϕ12 bolt in deck (drilling diameter is ϕ11.5, Figure 8)

(5) Attach splicing plate temporarily using TRS ϕ 12

(6) Drill bolt hole in trough rib for MUTF20

(7) Tighten temporarily two MUTF20 bolts near the center in trough rib side

(8) Drill bolt hole in deck for TRSϕ16 (drilling diameter is ϕ15.5)

(9) Tighten TRSϕ16 in deck (Figure 9)

(10) Tighten temporarily all MUTF20 bolts in trough rib side

(11) Tighten fully all MUTF20 bolts in trough rib

(12) Rustproof with sealing and painting

(8)-(9) is executed for each bolt from the end of splicing plate toward center. After all TRSϕ16 have been tightened, (10)-(12) are executed. Figure 10 shows splicing plate after installation, and Figure 11 shows details of each retrofitting method.

Also, some special tools were developed for the retrofit. The followings are examples.

・Drilling blade with drill stopper: control drilling depth not to damage pavement when drilling in deck side(Figure 12).

・Center pin with magnet : prevent drilled core from falling inside of trough rib(Figure 13).

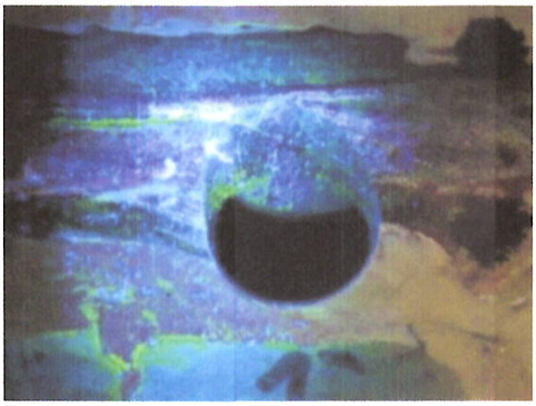

Figure 6. Monitoring hole

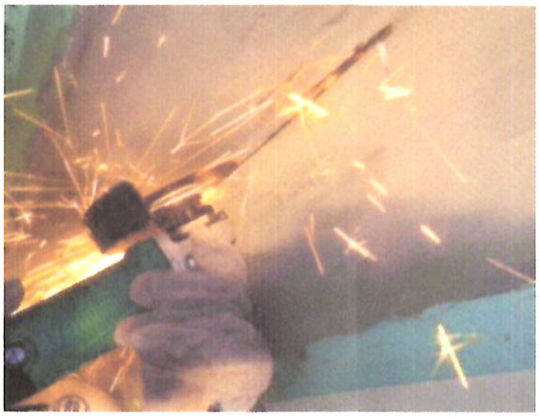

Figure 7. Cutting bead

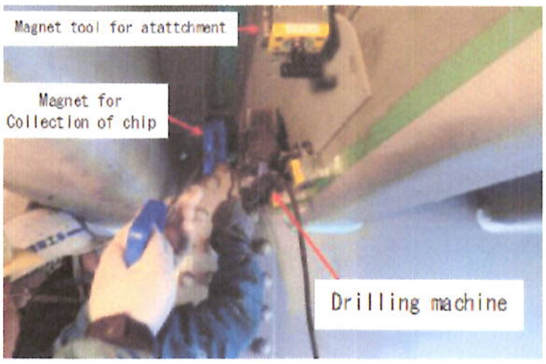

Figure 8. Drilling hole for TRSφ12

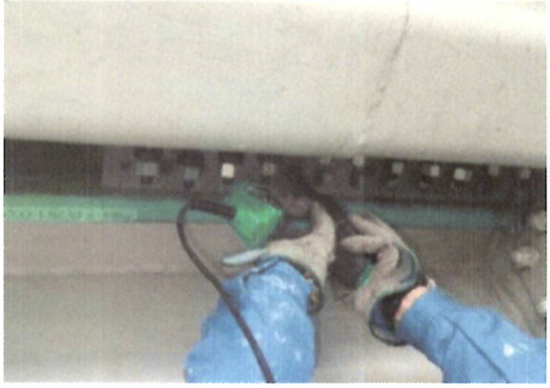

Figure 9. Tightening TRSφ16

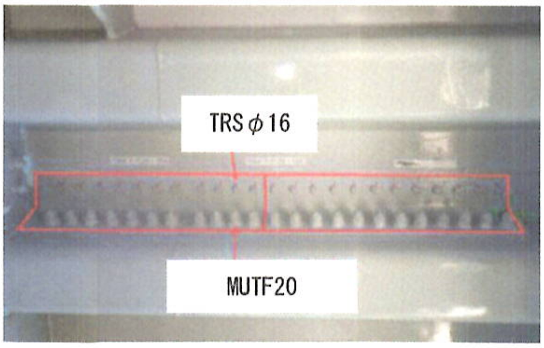

Figure 10. Installed splicing plate

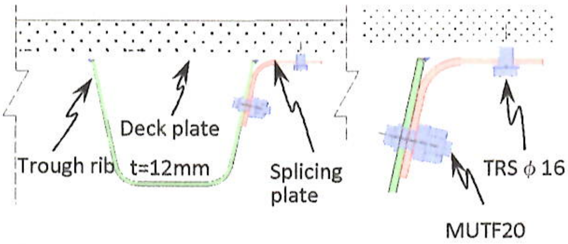

Figure 11. Details of retrofit

Figure 12. Drilling blade for deck side

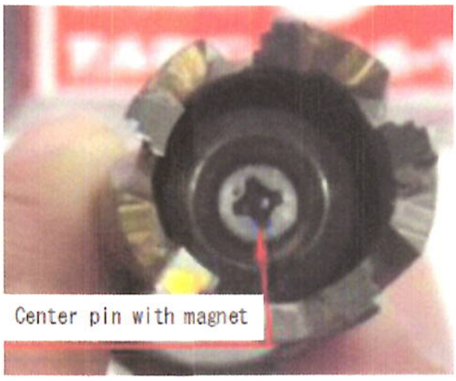

Figure 13. Drilling blade for trough rib

5.2 Factory test

In advance of actual retrofit in the bridge, test with actual size model is conducted in a factory for training of workers and confirmation of efficacy of developed tools. Some of checked items are as follows.

- Efficient application angle of cutting machine for bead cut, and how to recognize appropriate cut depth.
- Selection of proper cutting tools for general weld line and one close to cross rib for bead cut.
- Confirm that the protrusion of cutter above deck surface is less than 1mm by developed drill stopper.
- Confirm that splicing plate does not move by the temporally fixation by magnet when drilling.
- Confirm that TRS can be tightened vertically upward by the developed jig.

6 On-site test

On-site test was conducted in the bridge shown in Figure 14 using inspection vehicle installed on the bridge. Tests were conducted two times so far. Although the first test was conducted with traffic restriction above the test point as a precaution, second test was conducted without. It was confirmed that no problems were found in each case. Since installation of splicing plate is conducted upward direction by human power, splicing plate is divided into three parts to make the weight of one part is less than 10kg.

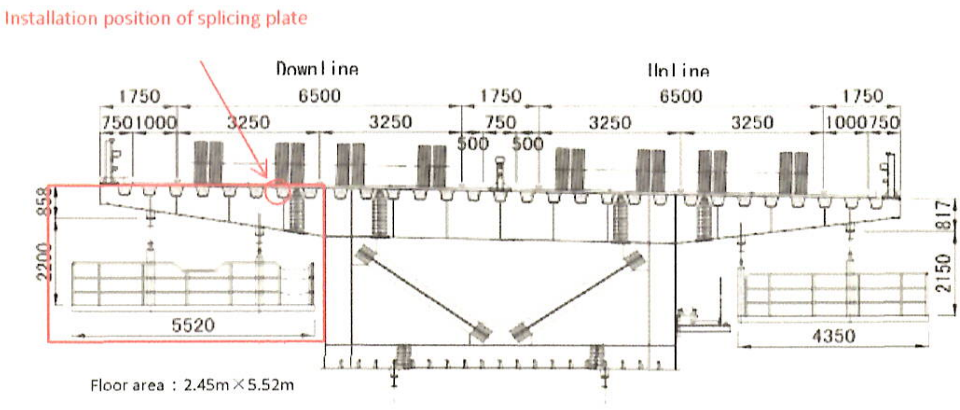

Figure 14. Section of the bridge

Table 1. Timetable of on-site test

	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9
Surface preparation	■								
Surface treatment/Protect paint (One layer of organic zinc)	■								
Installation of splicing plate (Cut bead~Tighten fully all bolts)		■	■	■					
Painting				■	■	■	■	■	
Sealing of monitoring hole									■

Table 1 shows the number of days for actual retrofit. It takes a total of 9 days, while installation of splicing plate takes 3 days, preparation and paint work take remaining days. Currently, two years have passed since the first installation of splicing plate, but no loosening of bolts, water leakage, or recurrence of cracks have been found.

7 Conclusion

7.1 Results of fatigue test

It is found that deck-penetration cracks can be suppressed by fixing plate after bead cut. Even if bead partially remains before plate splicing, remaining bead can be cut by repetitive loading and no deck penetration cracks will be generated. However, countermeasure are required at the end of cut bead in order to suppress and monitor the reappearance or progress of crack because bead cracks or deck cracks may occur at the end of bead cut.

7.2 Evaluation of connection methods

For three connection methods (HTB, TB, and TRS), neither bolt loosening nor cracks from bolt holes are observed. Since there is no distinct difference in fatigue behaviour among three methods, they have even fatigue performance with each other.

From the view point of workability, TB and TRS have advantage because they can be applied from the underside. Since shaving process can be omitted compared with TB, TRS has higher workability than TB.

7.3 Factory test and on-site test

It is confirmed that the proposed retrofitting method is applicable from the underside of the deck with no damage to the pavement. In addition, traffic restriction during retrofit is not required. Currently, two years have passed since the first on-site test of retrofit, but no loosening of bolts, water leakage, recurrence of cracks have been found. Monitoring through holes at the end of cut bead will be continued to confirm durability of the retrofitting method. With improving tools and efficiency, we will continue retrofits for bead penetrating cracks.

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