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A Study on Repair Method using TRS for Fatigue Cracks in Orthotropic Steel Deck

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A Study on Repair Method using TRS for Fatigue Cracks in Orthotropic Steel Deck

Yoshiaki Mizokami [α], Masafumi Kamataa [σ], Yuki Kishia [ρ] & Masahiro Sakanob [ω]

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I. Introduction

The Honshu-Shikoku Bridges *(Fig.1)* that connect Honshu and Shikoku by three routes consist of 10 suspension bridges including the Akashi Kaikyo Bridge, the longest suspension bridge in the world, 5 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 the dead load, they use light-weight orthotropic steel decks (OSD). OSD consisting of deck plates, trough ribs, and cross ribs are supported by main girders in which the deck plates act as upper flange.

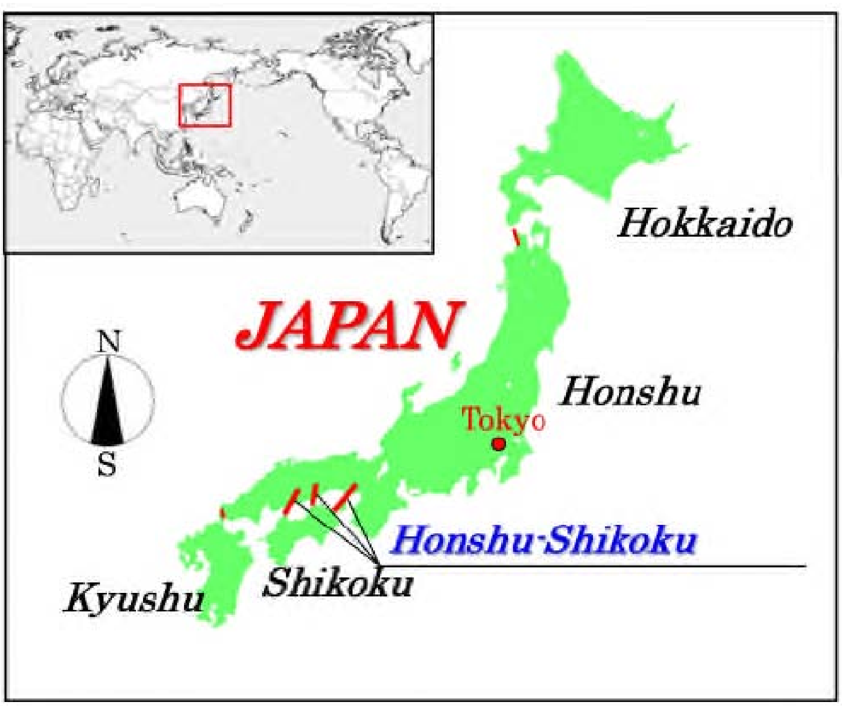

Fig. 1: Location of Honshu-Shikoku Bridges.

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II. Current Situation of Fatigue Cracks and Repair Methods

Several types of fatigue cracks are reported [1, 2]. For the OSD with closed-section trough ribs, many cases of cracks initiating from trough-deck welds toward the surface of the weld bead (hereinafter, "bead-penetrating crack") as shown in Fig. 2 are reported [1-4].

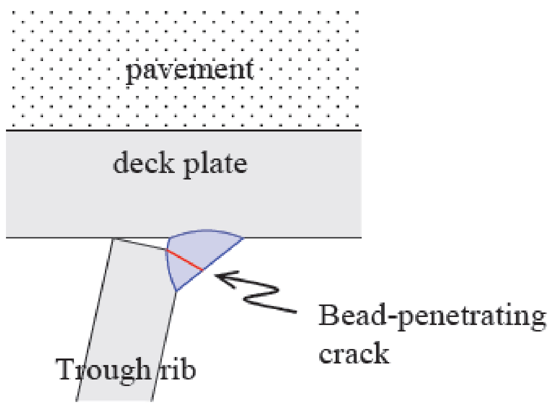


Fig. 2: Bead-penetrating crack.

The following existing repair methods have advantages and disadvantages. Replacement of trough ribs or plate-splicing require installation of high-tension bolts from the topside of the deck. Re-welding or plate-splicing with stud bolts are applicable from the underside.

Replacement of trough ribs or plate-splicing require traffic restriction for the removal of the pavement. Therefore, social impact is large for the heavy traffic highways or strait-crossing long span 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 repair methods for bead-penetrating crack were proposed, there is no effective method that is applicable from the underside of the deck currently.

III. Developped Repair Method and Outline of Fatigue Test

The repair method proposed here is a plate splicing method that requires no traffic control and applicable from the underside of the deck. In this method, 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 for all type.

In order to confirm performance of the method, fatigue tests with actual size test model (Fig. 3) are conducted. As bearing joint, a method using tap bolt (TB) in that steel plate is perforated and tapped, and the bolt is screwed, and a method using Thread Rolling Screw (TRS) in that after perforated steel plate, the bolt is screwed forming female threads are selected [5-7]. Also, as a bench mark to evaluate these methods, friction joint with torque shear bolt (HTB) is tested as well. Fig. 4 shows details of each repair method.

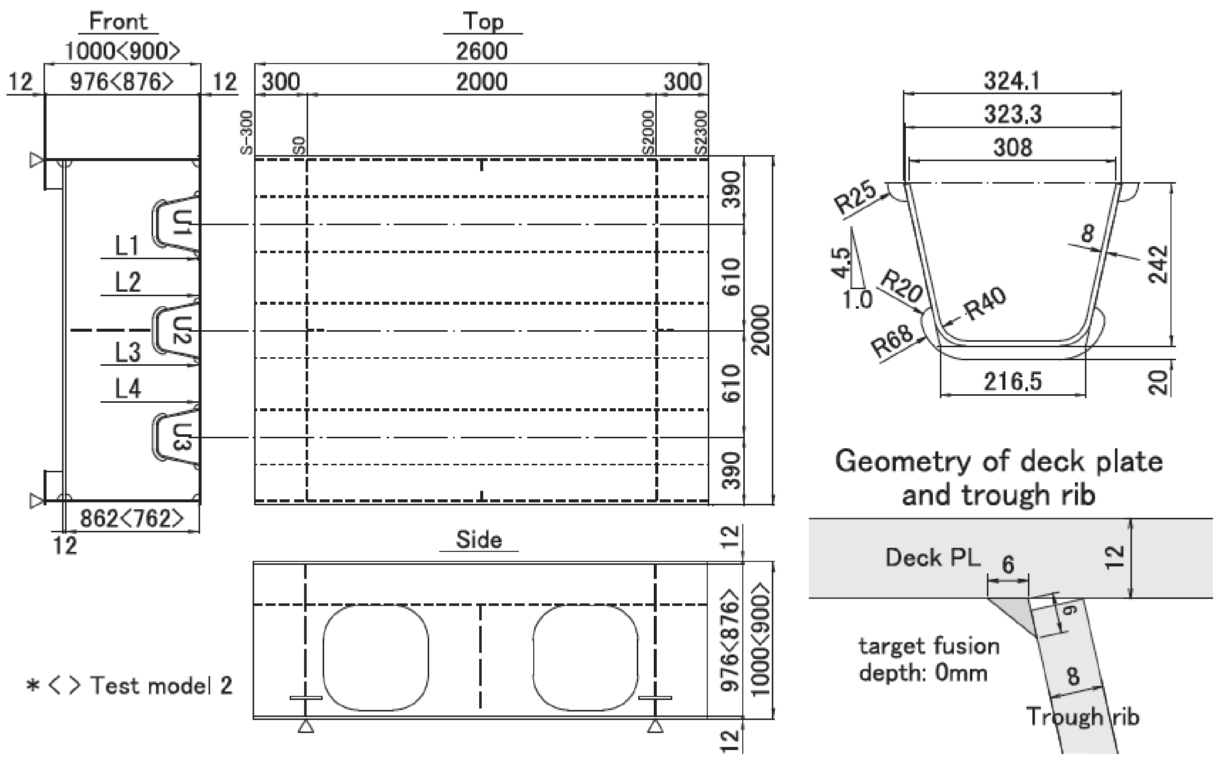


Fig. 3: Test model.

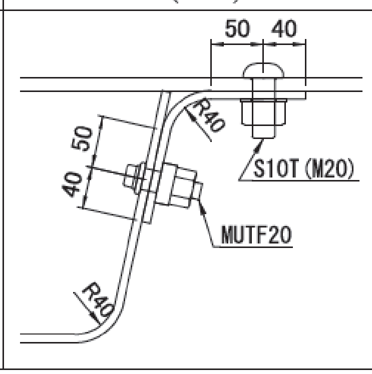
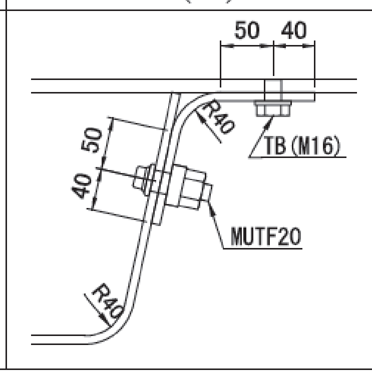
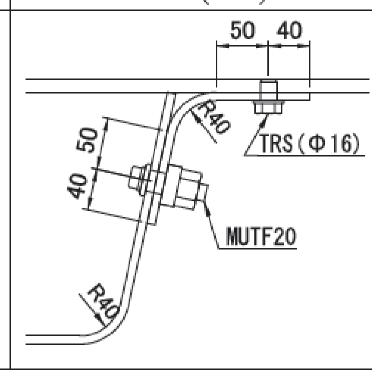
	L1(HTB)	L2(TB)	L3･L4(TRS)
Detail			

Fig. 4: Detail of plate splicing.

IV. Fatigue Test

a) Test model and applied load

The size of the test model is 2,000mm wide and 2,600mm long. Heights of the No.1 and No.2 are 1,000mm and 900mm, respectively. They have two cross ribs and three trough ribs (nominal dimension: 320x260x8-40) between two main girders. Spacing of trough ribs and cross ribs are 610mm and 2,000mm, respectively.

Thickness and materials of deck plate, trough rib and web of cross rib are 12mm (SM490Y), 8mm (SM490Y) and 9mm (SM400), respectively. Thickness and material of splicing plate are same as those of trough rib. The splicing plates are applied from L1 to L4 in Fig. 3. Longitudinally, they are applied between S-300 and S2000 and divided at 600mm and 1,400mm from cross rib.

Deck plate and trough rib are welded with target leg length of 6mm and fusion depth of 0mm.

Three types of connections of splicing plate and deck plate are shown in Fig. 4. L1 is a friction joint with HTB (M20), L2 is a bearing joint with TB (M16) and L3 and L4 are bearing joint with TRS (ϕ16). Connection of splicing plate and trough rib is one side bolt (MUTF20) for all types.

Applied load is 260kN/axle referring to [3]. With using loading beam, the load is distributed by 4 rubber seats (200x200mm, t=40mm) per axle mimicking double tires. The loading machine has three jacks and they are set at S0, S600 and S1200 or S800, S1400 and S2000. The load is applied dynamically with frequency of 3Hz. Phase difference of each jack is 2/3 π (120 degrees).

Two loading patterns are shown in Fig. 5. In the first loading case, load is applied directly above bead line of deck plate and trough rib. In the second loading case, load is applied so that the bead line is in between two adjacent loads.

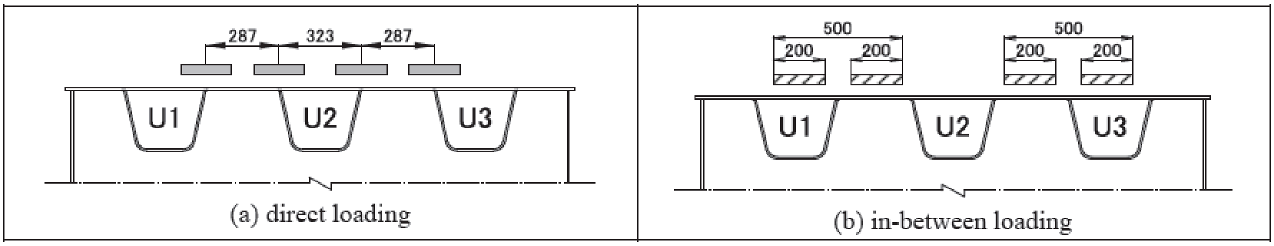


Fig. 5: Loading pattern.

b) *Test cases*

i. *Test model 1*

Corrective maintenance case and preventive maintenance case in which plate splicing is conducted after and before bead-penetrating crack is generated, respectively, are planned. For the preventive maintenance case, weld bead is left in one case (bead-left case). And in the other case, weld bead is cut in order to eliminate root where crack starts (bead-cut case).

Fusion depth of weld of deck plate and trough rib is confirmed to be 4mm instead of target value of 0mm. Since the generation of bead-penetrating crack is considered to be difficult with this fusion depth, this model is used for bead-cut case. And another model (test model 2) is made for bead-left case.

Range of the bead cut is the range of the loading rubber seat +10mm. Bead is cut carefully not to cut into deck plate with whetstone. Confirmation of fusion depth is shown in Photo. 1. Bead cut is shown in Fig. 6. Loading positions are directly above the bead lines of L1 - L4. Bead cut range and loading position is shown in Fig. 7.

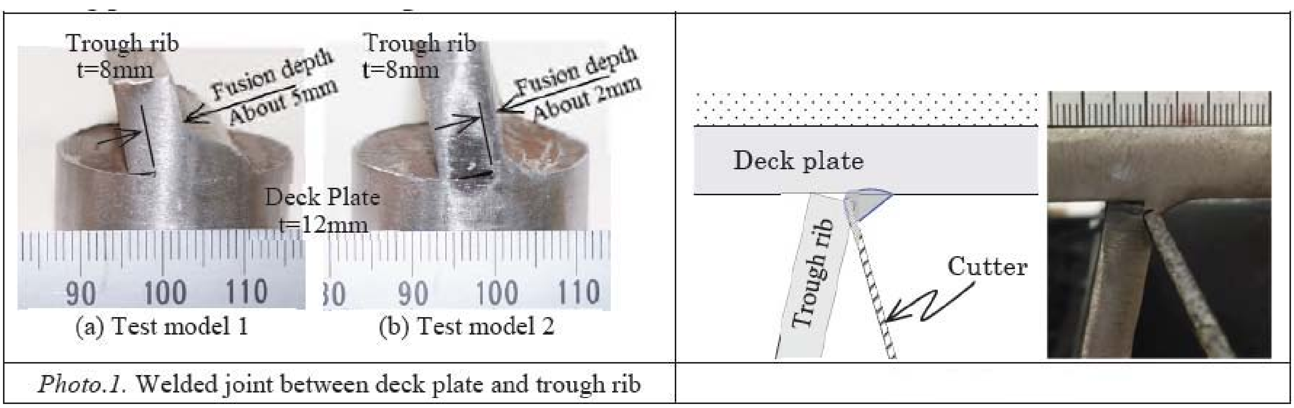


Fig. 6: Bead Cut.

Global Journal of Researches in Engineering (E) Volume XVII Issue IV Version I Year 2017

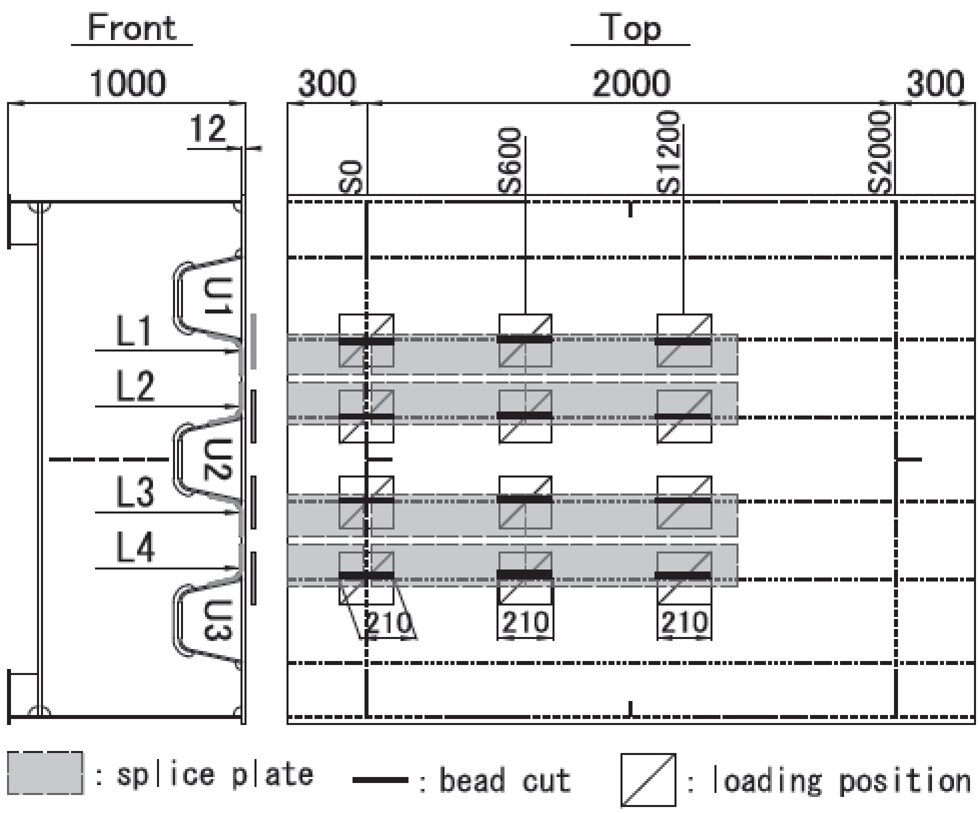


Fig. 7: Test model 1.

ii. *Test model 2*

Since the fusion depth of the test model 2 is less than 2mm (Photo 1(b)), corrective maintenance case and preventive maintenance case are tested. Flow of the test is shown in Fig. 8. Loading pattern and position is shown in Fig. 9.

In the corrective maintenance case, plate splicing is applied after bead-penetrating cracks are generated by the loading above cross rib (S0) and mid span (S600 and S1200). In the preventive maintenance case, load is applied above mid span (S800 and S1400) and cross rib (S2000) where plate splicing is applied without cracks. For L3, weld bead is cut before plate splicing.

In the corrective maintenance case, load is applied directly above weld lines of L1 - L4. In the preventive maintenance case, in-between loading above weld lines of L1 and L4 is conducted after direct loading.

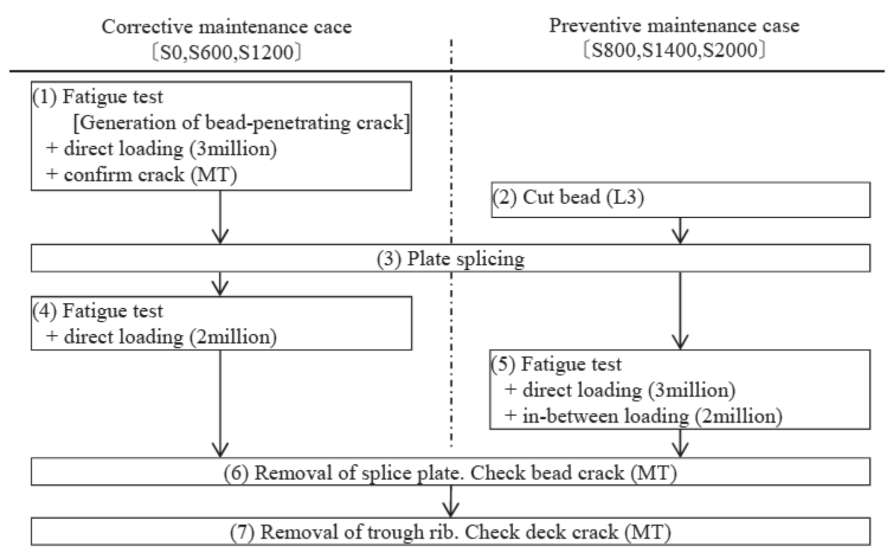


Fig. 8: Test flow of test model 2.

Global Journal of Researches in Engineering (E) Volume XVII Issue IV Version I Year 2017

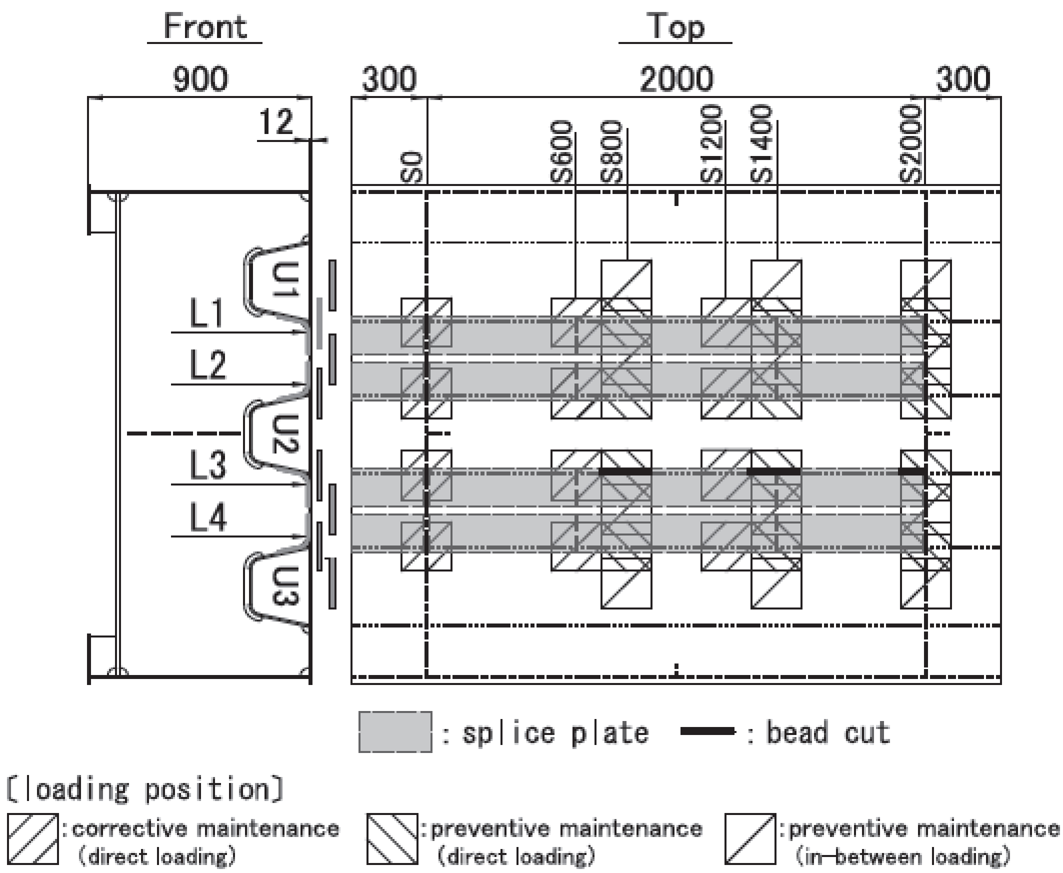


Fig. 9: Test model 2.

V. Test Result

a) Test model 1

After the direct loading of 3 million times, crack generation and loosening of the bolts are checked and adjacent area of bolt holes is surveyed.

No problems are found for HTB, TB and TRS. Splicing plates are removed and deck plate, trough ribs and bolt holes are surveyed by magnetic particle testing (MT) and no cracks are found. Further, deck plate and trough rib where load is applied is cut out by gas cutting and deck crack is surveyed by MT and no deck crack is found. It is confirmed that weld bead is completely cut by the progress of crack by the dynamic loading even if weld bead is partially uncut. No problems are found at the joint of splicing plates.

b) Test model 2 (Corrective maintenance case)

i. *Generation of bead-penetrating crack*

Distribution of cracks after direct loading of 3 million times (1 million times for S0 because crack is generated by 1 million times) is shown in Fig. 10. Bead cracks are checked by MT from the bead surface. Since deck cracks that do not appear on the surface cannot be surveyed without removal of trough ribs, they are surveyed by MT from the bottom side of the deck after all the loading cases and removal of trough ribs.

At S0 on L1, a bead-penetrating crack with surface crack length of 24mm is observed. At the other 11 loading locations, no bead-penetrating cracks are found and internal cracks with length of 1 to 6mm are found at the depth of 3 to 5mm by the removal of surface. At 7 locations out of 11, cracks with length of 6 to 60mm progressing toward deck are found. Progress of these cracks might suppress bead-penetrating cracks. At the other 4 locations, no deck cracks are found.

Global Journal of Researches in Engineering (E) Volume XVII Issue IV Version I Year 2017

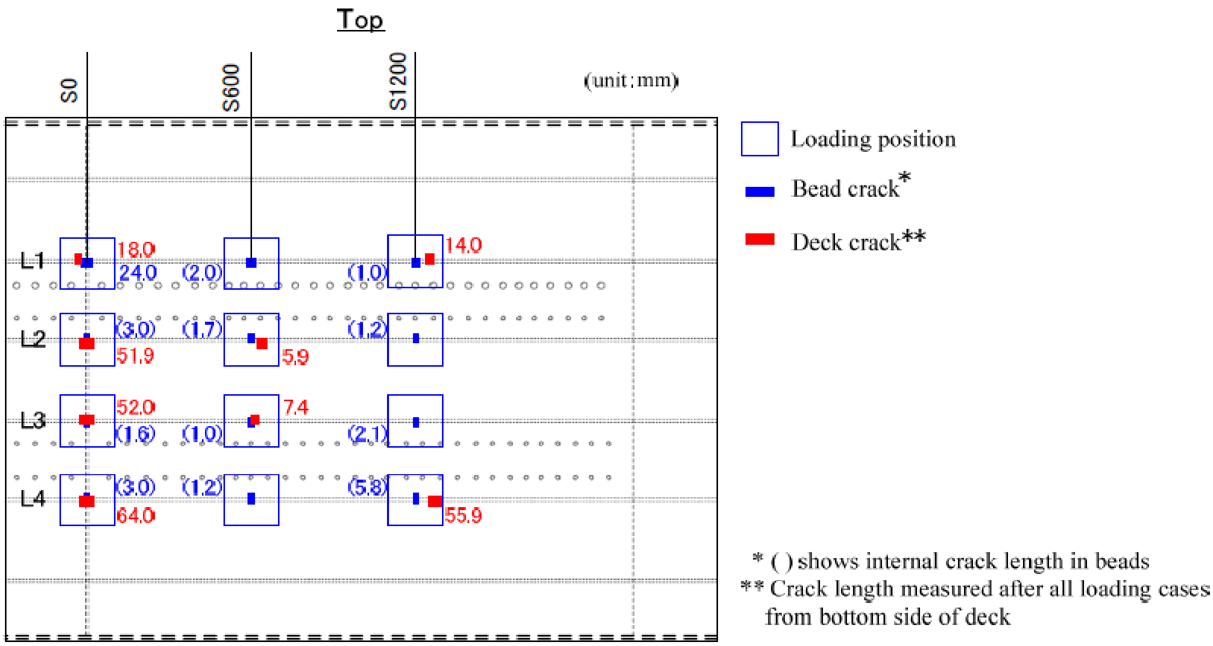


Fig. 10: Crack distribution (after generation of bead-penetrating crack).

ii. *Fatigue test*

After the generation of bead-penetrating and internal cracks, plate splicing is applied and direct loading of 2 million times is conducted. Distribution of cracks after loading is shown in Fig. 11. Bead cracks are checked by MT after loading. Deck cracks are checked after the removal of trough ribs by MT from the bottom side of deck plate.

Surface crack length at S0 on L1 grows from 24mm to 39mm. On L2 and L3, although bead cracks do not grow, deck cracks with length of over 50mm are observed.

At 4 locations out of 8 on S600 and S1200 where internal cracks are generated before plate splicing, bead-penetrating cracks with surface crack length of 120 -200mm are found. At one of them, deck crack initiates from the end of bead-penetrating crack. At the other 3 locations, although progress of internal cracks is not observed, deck cracks are found.

It is found that bead cracks or deck cracks may progress if plate splicing is applied without bead cut.

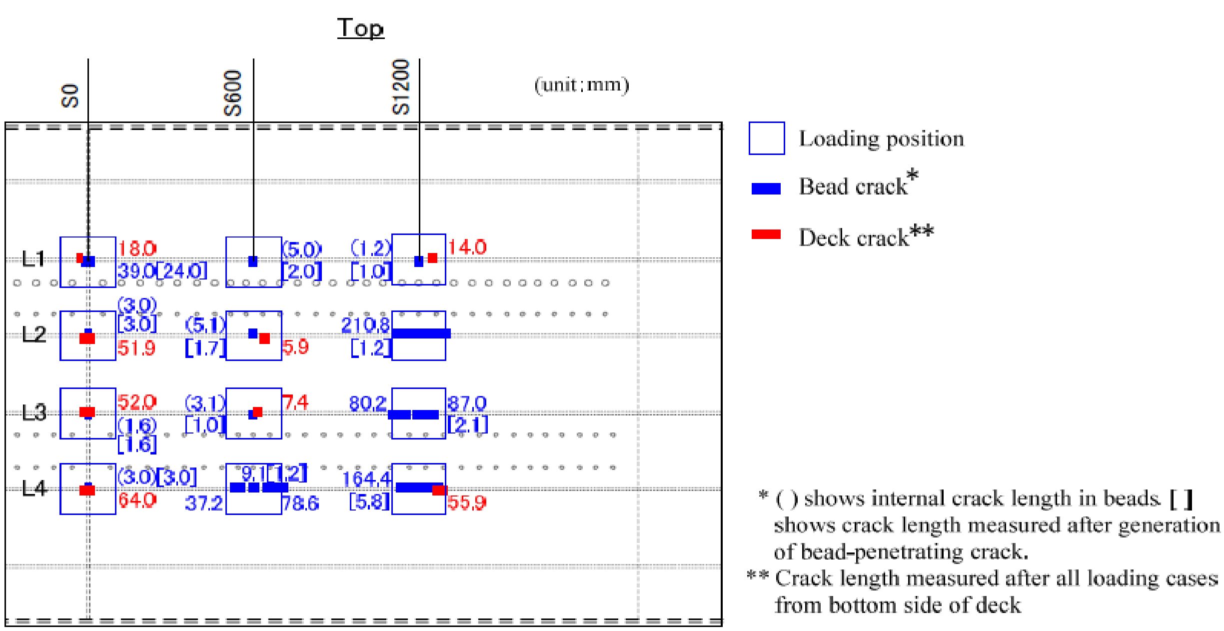


Fig. 11: Crack distribution (after fatigue test).

c) Test model 2 (Preventive maintenance case)

Distribution of cracks after direct loading of 3 million times with plate splicing before the loading is shown in Fig. 12. Bead cracks and deck cracks are observed by MT from bottom side of deck after all loading and removal of trough ribs.

On L3 where weld bead beneath loading positions are cut, no deck cracks are observed. On the other hand, bead crack and deck crack are found at the end of bead cut. From this, countermeasure is required at the end of splicing plate, like drilling holes [8] in order to suppress and monitor the reappearance of crack.

On L2 and L4, bead-penetrating cracks with surface crack length of 40 to 90mm are observed at all the locations. No deck cracks are found.

On L1, bead-penetrating cracks and deck cracks are observed at all the locations. Crack lengths of bead-penetrating cracks and deck cracks are 10 to 50mm and 30 to 70mm, respectively. Although the loading condition for L1 and L4 is the same, generation of cracks is different. Difference may be caused by difference of connection method (L1: HTB, L4: TRS) and fusion depth.

Plate splicing without bead cut causes bead cracks and deck cracks. On the other hand, no cracks are found where beads are cut although some are found at the end of bead cut. From these, bead is not required when plate splicing is applied and it is needed to be removed.

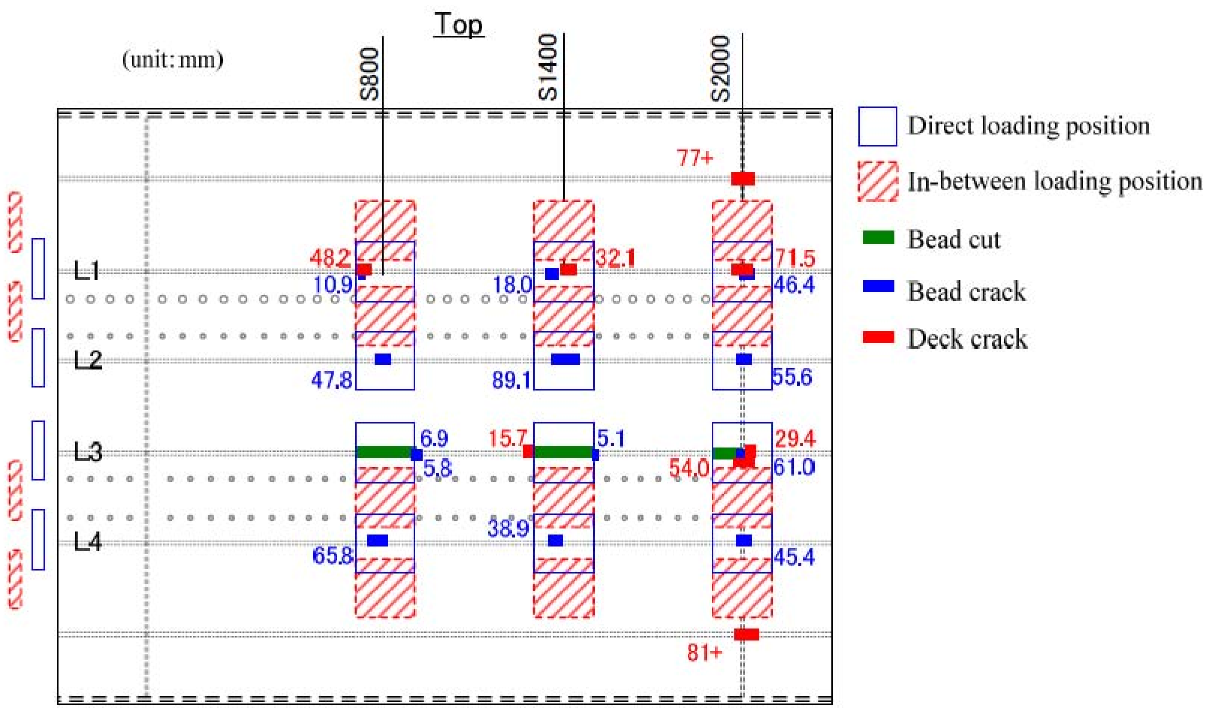


Fig. 12: Crack distribution (after all loading)

VI. Conclusion

a) Generation of bead cracks

A bead-penetration crack is generated at one of the intersections of cross rib (S0). Bead internal cracks are generated at the other 11 locations (three other locations on S0 and 8 on S600 and S1200). At 3 intersections and 4 mid-span locations out of the 11, deck cracks are generated. From these, both bead cracks and deck cracks tend to be generated at intersections.

b) Corrective maintenance case

From 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.

c) Preventive Maintenance

It is found that deck cracks can be suppressed if plate splicing is applied with bead cut as preventive maintenance. 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. No deck cracks are found 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.

d) 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 between the methods both in corrective maintenance case and preventive maintenance case, they can be evaluated as equivalent within the range of the repetitive load and number of loading of the test.

From 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. In addition, good workability with TRS is confirmed at the execution tests at factory and actual bridge [9]. The soundness of TRS connection applied at the execution test in actual bridge will be confirmed by periodical investigation.

Acknowledgement

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