INSPECTION AND REINFORCEMENT FOR FATIGUE DAMAGES ON ORTHOTROPIC STEEL DECK BRIDGE

Akiko Tabata[1], Yoshihiko Takada[1],Yoshihei Horie[1]

Abstract

This paper describes overview of the fatigue cracks detected in orthotropic steel decks in Hanshin Expressway. From the latest inspection result of fatigue crack are detected by 142 spans among 1,347 spans of the orthotropic steel decks current as of March 2007. It is assumed that main factors of fatigue damages are attributed to the stress concentration caused local deformation of the thin deck plate and running of the wheel load larger than the design load. Especially a fatigue crack penetrated an orthotropic steel deck plate was found in 2005. The authors also studied on emergency repair in order to prevent possible subsequent crack growth and road caving. In case of penetrate crack, adding splice plates was carried out on both the deck plate top surface and undersurface.

Introduction

The Hanshin Expressway Company Limited was established in 1962 to construct and operate an urban expressway network in Kansai Metropolitan Area in Japan. These are linking the major cities of Osaka, Kobe and Kyoto is an important transportation network. The Hanshin expressway currently expands to 233.8 km in total length and is used averagely by about 900,000 vehicles. About 90% of Hanshin Expressway consists of viaduct structures. There are 1,347 spans of orthotropic steel deck bridges among 6,500 spans of steel girder bridges. From the latest periodic inspection result of fatigue crack are detected by 142 spans among 1,347 spans of the orthotropic steel decks current as of March 2007. It is assumed that the reason of such a fatigue cracks are considered to be remarkable increase of traffic volume and existence of overloaded vehicles. In addition, the factors of fatigue damages are contemplated the stress concentration attributed to the local deformation of the thin deck plate. Such fatigue cracks are classified according to the structure of the longitudinal rib of orthotropic steel decks and the type of a crack.

Firstly, the typical cracks generated in the trough are described briefly. These are crack penetrating the deck plate(1), cracks in the longitudinal weld between deck plate and trough web(2), cracks in the longitudinal stiffener splice joint(3), cracks in the weld between vertical stiffener and deck plate(4) and cracks in the connection between the trough profile and the crossbeam(5). Finally, it describes that the author also studied on emergency repair in order to prevent possible subsequent crack growth and road caving. In

[1] Hanshin Expressway Company Limited, Osaka, Japan

case of penetrate crack, adding splice plates was carried out on both the deck plate top surface and undersurface.

Outline Of Fatigue Cracks In Orthotropic Steel Decks In Hanshin Expressway

Hanshin Expressway of approximately 53% of length has passed away more than 20 years since open to traffic. The ratio of the large vehicles of Hanshin Expressway is approximately 20% on the average as a result of the origin-destination survey. The daily traffic volume is 50,000 vehicles per two lanes in the city routes and 40,000 vehicles per two lanes in Wangan Route in Osaka Bay. In those routes, large vehicles ratio is high with an average of 30%. Equivalent 98kN conversion cumulative axes numbers of the network in Hanshin Expressway are calculated based on the origin-destination survey, the traffic according to type of vehicles, the axle load data obtained in tollgates, the axle load frequency distribution model according to type of vehicles, and cumulative traffic in service. Those results provide annual equivalent 98kN conversion cumulative axes numbers to figure 1. Figure 2 shows equivalent 98kN conversion cumulative axes numbers in service by 2006. It is confirmed that equivalent 98kN conversion cumulative axes numbers of the network in Hanshin Expressway shows the accumulation speed of fatigue damege. As a results of the annual equivalent 98kN conversion cumulative axes number, It is assumed that Wangan and Kobe Route which have high mixture ratio of large vehicle are accumulated by fatigue damage quickly(over 2 million axes in it).

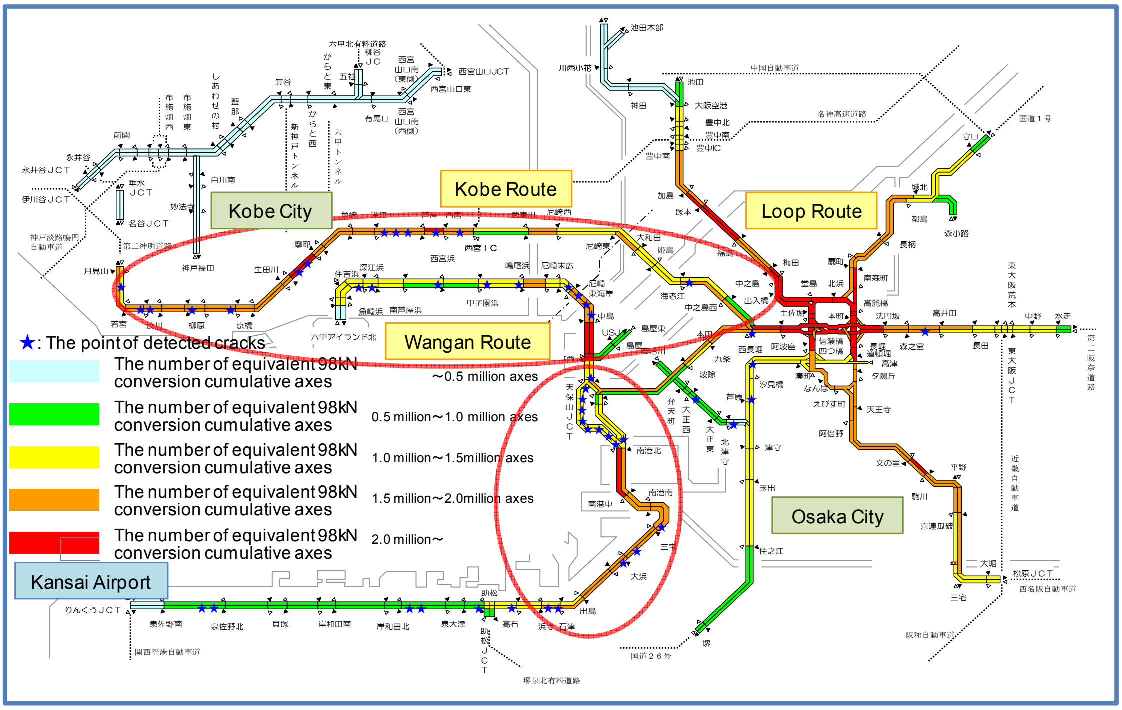


Figure 1 Annual equivalent 98kN conversion cumulative axes number

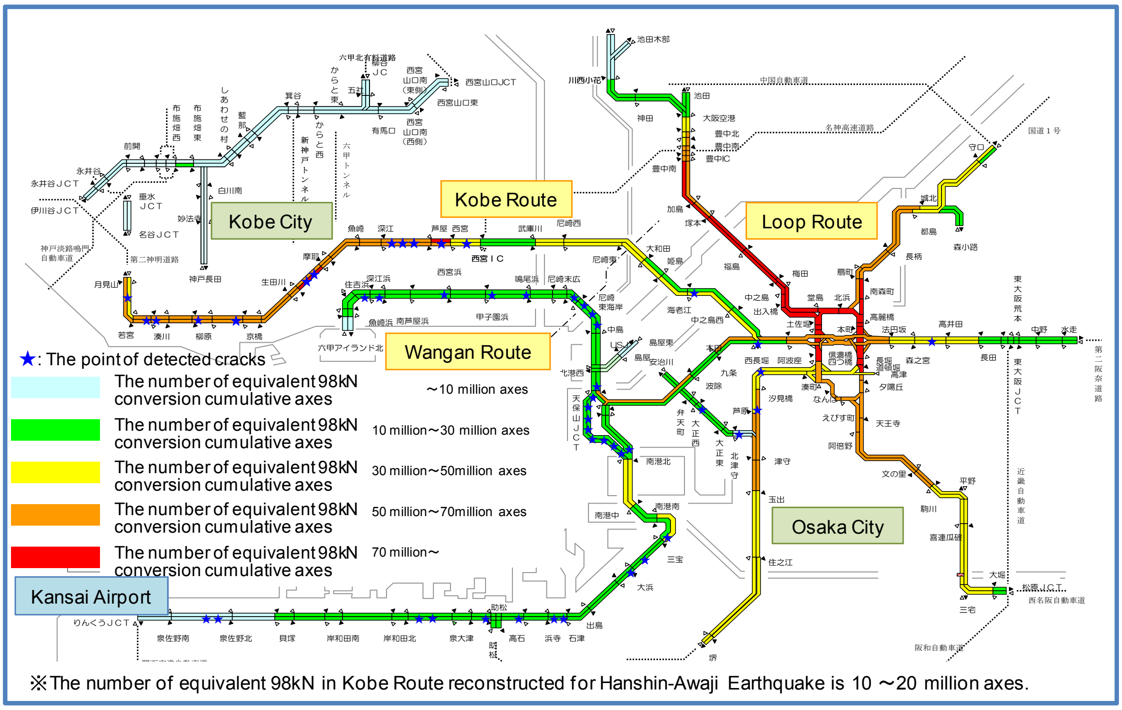


Figure 2 Equivalent 98kN conversion cumulative axes number by 2006

The overview of the inspection for orthotropic steel deck

There is facility equipment quantity of 1,347 orthotropic steel decks in Hanshin Expressway, as shown in table 1. It consists of 629 spans of trough rib and 718 spans of bulb rib. Bulb rib is the vertical rib form adopted by Hanshin Expressway among open section rib forms. Almost all the orthotropic steel decks constructed before 1980 were the structures which used the bulb rib. After 1980, the trough rib has adopted. Superstructures, such as the orthotropic steel decks, are performing the periodic inspection for all the routes by approach viewing with the cycle of 4 to 8 years. When the painting cracks are detected during inspection, we use Eddy Current Testing(ET) or remove coating in order to carry Magnetic Testing(MT). Now we have inspection plan which is scheduled to take a round of all the orthotropic steel decks of troughs for 5 years from 2004 to 2008 in order to increase inspection frequency for severe damages grasp as soon as possible. The typical fatigue cracks in troughs are shown in Figure 3. Such fatigue cracks are classified according to the structure of the longitudinal rib of orthotropic steel deck. Table 2 gives the number of the cracks classified into the crack type. The crack of the bulb rib is caused by 34 spans (1,170 cracks) in the the connection between bulb rib and crossbeam, and it has attained to 66% of the cracks total of the orthotropic steel decks. It is shown clearly that this crack type is generated in the different specified structure details from the structure detail recommended by the design criteria instituted by Hanshin Expressway Public Corporation. The overview of five types of cracks which exist in trough form are as follows. Penetrating cracks of the deck plate(1) was detected by Shinhamadera Bridge located in

Wangan Route in 2005. This crack type may a threat of traffic safety if the crack progresses considerably. Cracks in the longitudinal weld between deck plate and trough web(2) exist in 127 cracks on the bridges of 22 spans. We carry out to stop hole for the tip of the crack, rarely we exchange damage part of the throug rib for new pieses in the case of severe crack progresses. Cracks in the longitudinal stiffeners splice joint(3) exist in 43 cracks on the bridges of 14 spans. A part of the damages are progressed in crack type(1). Cracks in the weld between vertical stiffener and deck plate(4) exist in 157 cracks. This crack type have the examples penetrated to the deck plate, and may conduct damage to pavement. As for the connection between trough and crossbeam(5), 302 cracks are detected by the 35 spans.

Table 1 The number of the cracks classified into the crack type.

	The number of spans	Extension (Km)
Bulb rib	718	40.99
Trough rib	629	43.35
Total	1347	84.34

Table 2 The number of the cracks classified into the crack type.

	Crack types	Longitudinal stiffeners				Sum total	
		Bulb rib		Trough			
		The number of spans	The number of cracks	The number of spans	The number of cracks	The number of spans	The number of cracks
(1)	Penetrating cracks of the deck plate	0	0	1	1	1	1
(2)	Cracks in the longitudinal weld between deck plate and trough web	0	0	22	127	22	127
(3)	Cracks in the longitudinal stiffeners splice joint	0	0	14	43	14	43
(4)	Cracks in the weld between vertical stiffener and deck plate	0	0	30	157	30	157
(5)	Cracks in the connection between longitudinal stiffeners and crossbeam	34	1170	35	302	69	1472
(6)	Others	1	2	5	23	6	25
Sum total		35	1172	107	653	142	1825

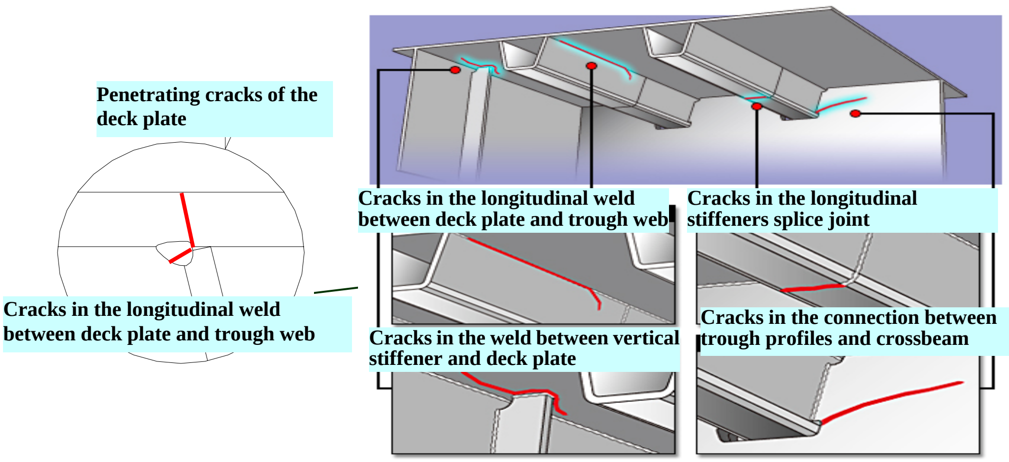


Figure 3 The typical types of crack in troughs

Figure 4 shows the number of damaged spans for every year in orthotropic steel decks based on the latest inspection results. The years are shown on a horizontal axis, and the number of spans is shown on an axis of ordinate. A bar graph shows the number of inspection spans and damaged spans, and a line graph shows the sum total number of damaged spans. The numbers of inspection spans for the past ten years are 80 to 360 span per year. The numbers of damaged spans have tended to increase since 2004. It is concidered that frequency of the inspection are increased caused by discovery severe crack on existing bridge but also improvement of consciousness. However, the number of the fatigue cracks will certainly increase according with the service life will increase in the future. Figure 5 shows the number of spans for every completion year of the orthotropic steel bridge deck. Most of the orthotropic steel decks of the completion years pre-1979 are the bulb ribs, also completion years post-1979 are the troughs. The damaged spans of completion years pre-1969 have cracks in the connection between longitudenal stiffeners and crossbeam in the bulb rib. Besides these have characteristic with many cracks per a span. The damaged spans of through rib after 1995 have reconstructed by the Great Hanshin-Awaji Earthquake. It is necessary to consider that there are no correlation between the number of cracks and increasing service time.

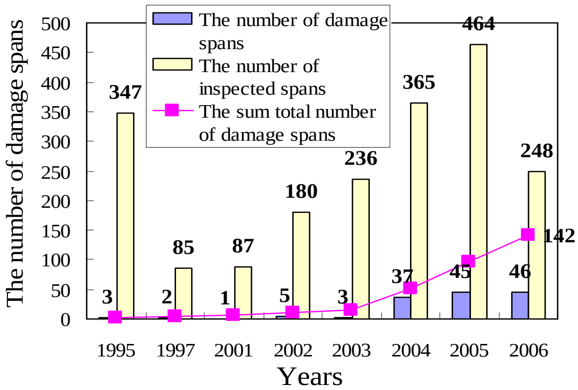


Figure 4 Correlation with the inspection and number of damaged spans

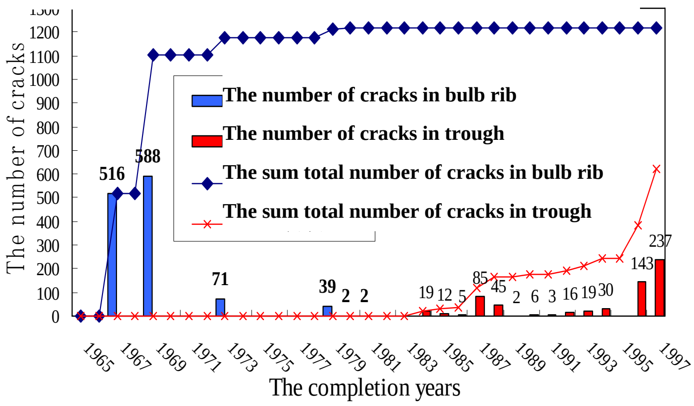


Figure 5 Correlation with the completion years of damaged spans and number of cracks

<u>Penetrating Cracks Phenomenon of the deck plate in Trough Rib</u>

Penetrating crack of the deck plate in Hanshin Expressway was detected by Shinhamadera Bridge located in Wangan Route during repair work of pavement, as shown in Figure 6,7,8. This is a Nielsen-Lolse bridge with Basket-Handle type, and has a 254m center span carrying four traffic lanes. The bridge was opened in 1993. The crack occured under the right axle location of truck wheels in the inner lane, 70m far from the pier. The total daily traffic in 2005 was 75,000, and 20 % were trucks. An estimated Figure 7 shows the crack on a orthotropic steel deck plate. This crack was detected by chance when asphalt paving was removed. The 6 mm thick trough were butt-welded to 12 mm thick orthotropic deck plates. The total thickness of a two-layer pavement is 65mm. Water spilled from trough rib below the fatigue crack during inspection.

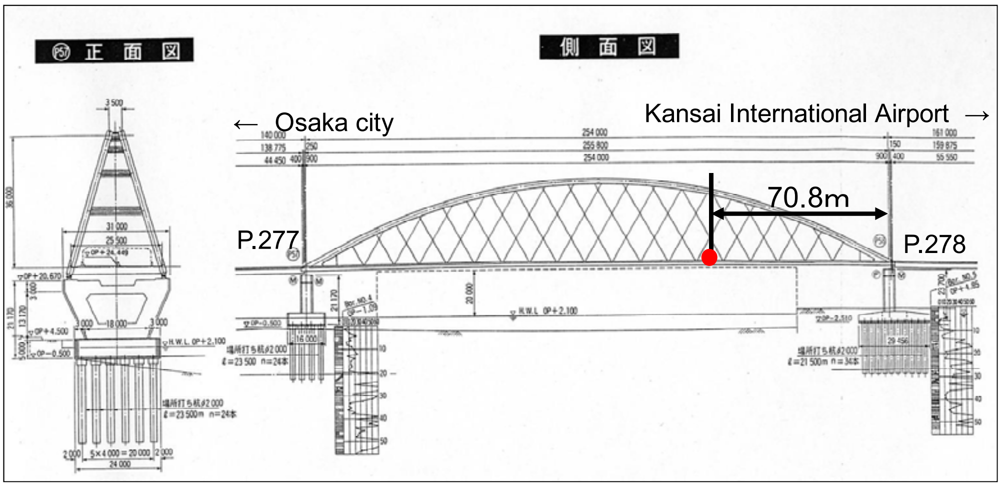


Figure 6 Elevation of Shinhamadera Bridge.

(a)After removing pavement (b)Closeup of the crack

Figure 7 Crack on an orthotropic steel deck.

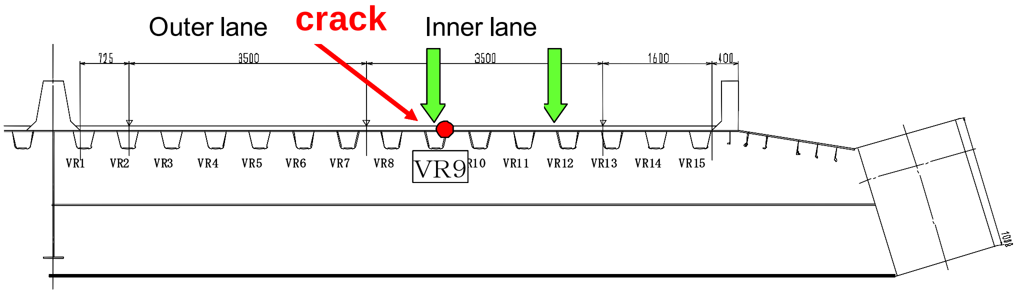
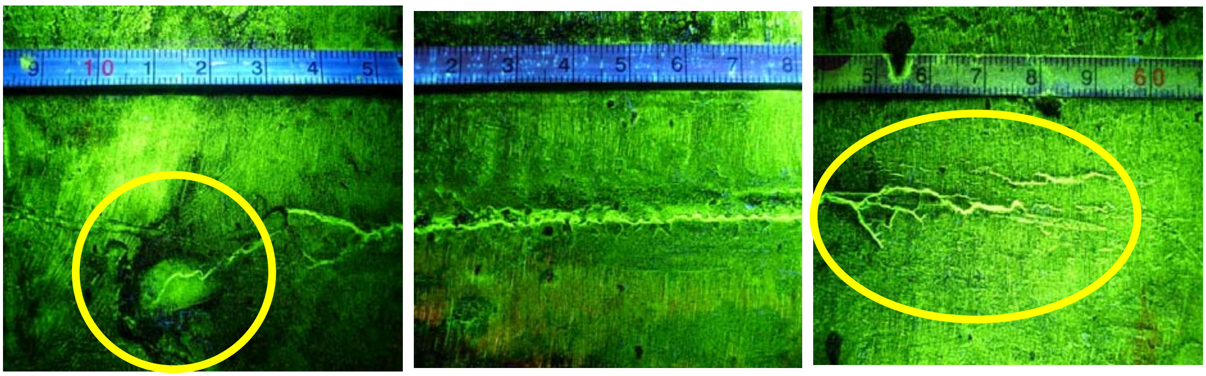


Figure 8 Crack under the right axle location in the inner lane

A detailed inspection was carried out from the deck top using MT. The length of the crack was 520 mm, which is longer than the 450 mm observed visually. The crack disappeared after grinding down 3mm in depth at a crack tip, as shown in Figure 9(a). The fracture surface showed evidence of friction of the surfaces either side of the crack in the intermediate part of the crack in Figure 9(b). Crack bifurcation (branching) was clearly observable at another crack tip in Figure 9(c). Ultrasonic Testing (UT) for inner crack detection was implemented using both angle beam and creeping wave techniques. A fatigue crack penetrating an orthotropic steel deck plate was detected as shown in Figure 10. The crack was 560mm long, 305 mm and 255 mm long on each side of the transverse beam. The undersurface crack was longer than the deck top crack. Two vertical holes were cut into the deck plate at both crack tips to restrict crack growth and to inspect. MT, applied for detection of inside defects at the drilled cores in the orthotropic deck, also indicated that the crack propagated from the interior rib-to-deck weld to the deck surface while changing direction, as shown in Figure 11. Macro-fractographic observations showed the 6mm longitudinal ribs had 2 mm penetration welds, which were about 30 percent penetration, as shown in figure 12. Investigation with an infrared camera from the ground revealed that the longitudinal rib had a lower temperature than other longitudinal ribs, as shown in Figure 13. It was also discriminated the difference of sound by hammering longitudinal ribs with and without water.



(a) Crack tip (b) intermediate part of the crack (c) Another crack tip

Figure 9 Magnetic Particle Testing

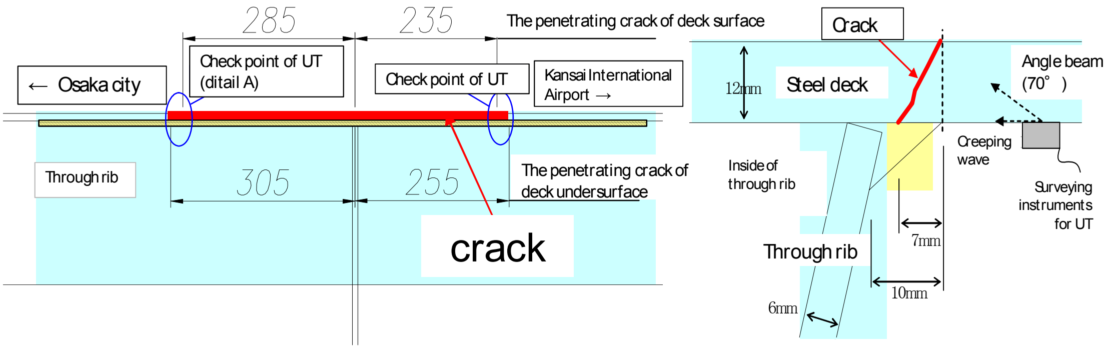
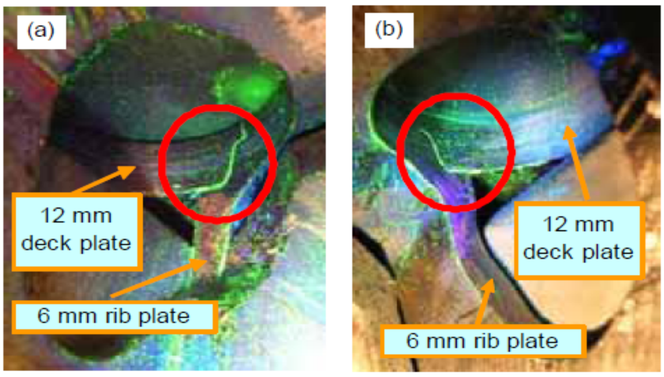
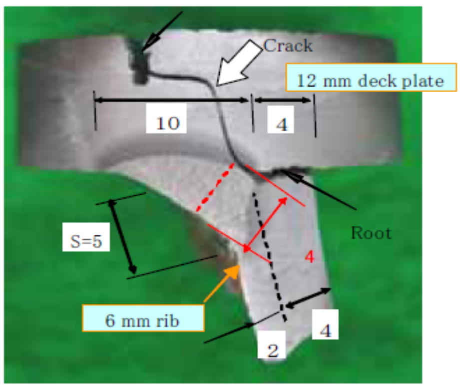


Figure 10 A fatigue crack penetrating an orthotropic steel deck plate.





(a) at crack tip (b) at another crack tip

Figure 11 MT in cores Figure 12. Macro-fractographic observation

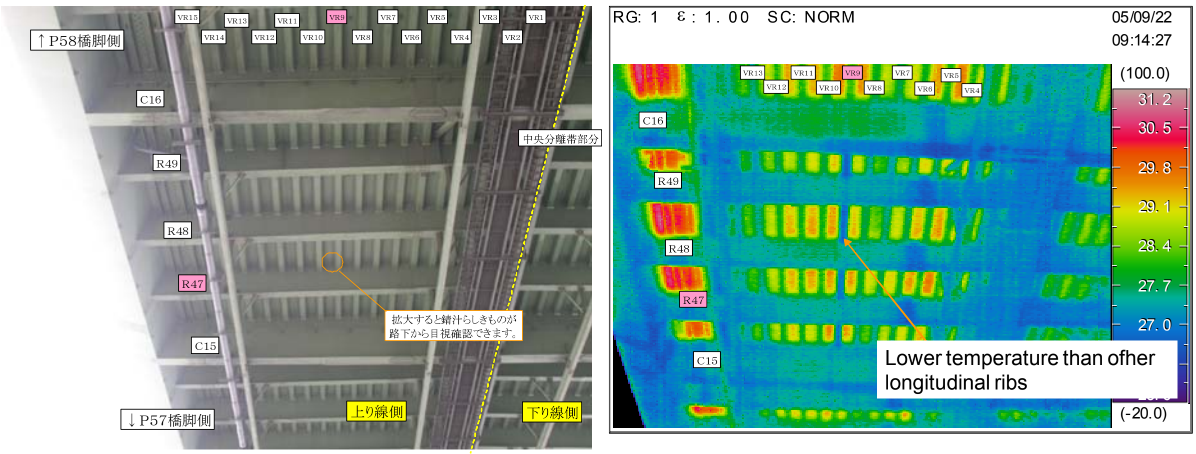


Figure 13 infrared Camera Investigation(a)Photo;(b)Infrared photo

In order to prevent possible subsequent crack growth and road caving, emergency repair with splice-plates and hole-drilling was carried out. The scheme used to repair the structure is shown in Figure 14, mainly considered stiffening for smooth transportation. Adding splice plates was carried out on both the deck plate top surface and undersurface to prevent deck caving caused by the discontinuous deck plate. Splice plates were the same materials and thicknesses as those of the existing bridge. A method of increasing the fatigue durability of a bolted joint was considered. The crack was spliced with bolted butt splices instead of welding.

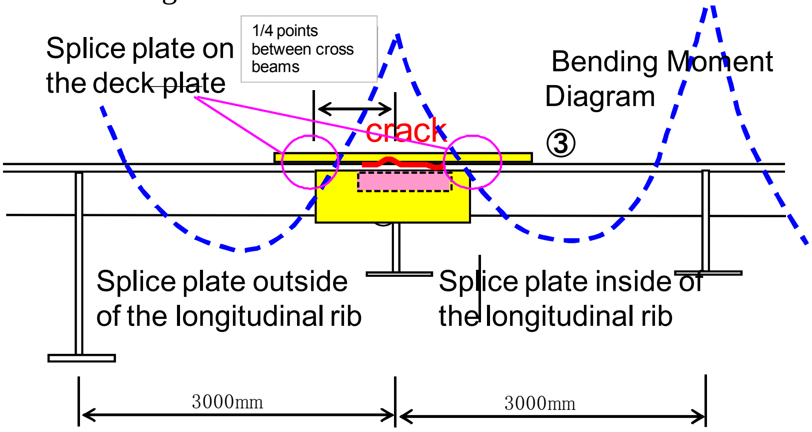


Figure 14 The length of splice plates

The longitudinal length of splice plates is designed with a method to mitigate the stress concentration, as shown in Figure 15. The length of splice plates outside of the longitudinal rib was decided to cover the full negative moment region. The splice plate on the deck was about 240mm (2 bolt-rows)longer than that of splice plates outside of the longitudinal rib to avoid a drastic steel-thickness change at the same point. The length of splice plates inside of the longitudinal rib was the same as that of the fatigue crack. The width of splice plate on the deck was based on the expected locations of 2 rear wheel tires. Retrofit splice plates on completed deck repair and on completed rib repair are shown in Figure 16.

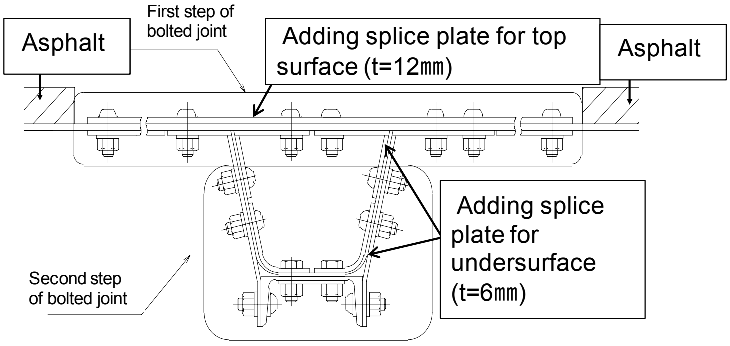


Figure 15 Structural retrofit

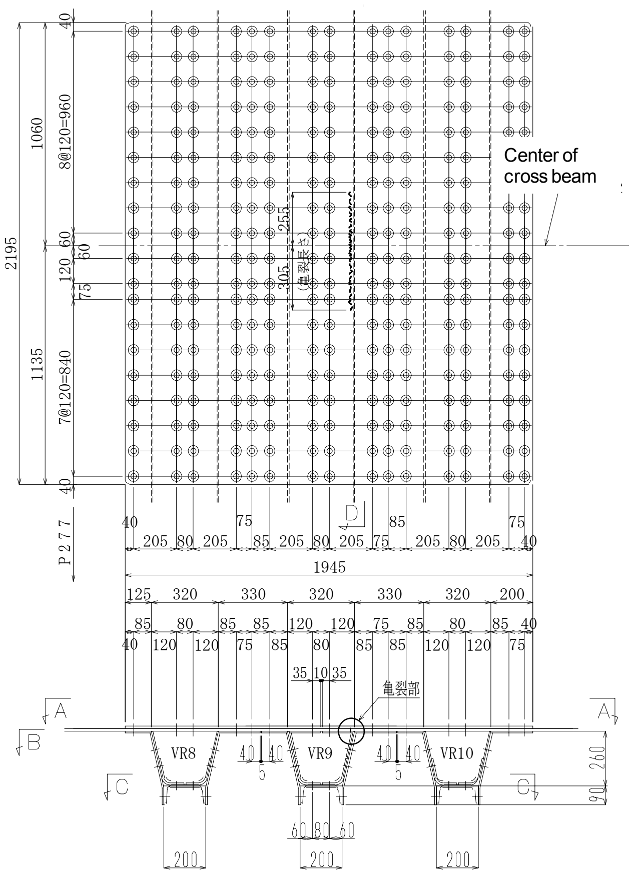


Figure 15-2 Structural retrofit


(a)Completed deck repair (b)Completed rib repair

Figure 16 retrofit splice plates

Triaxial strain gauges were placed on the longitudinal rib, at the cross beam, and at the midspan of the longitudinal rib, as shown in Figure 17.Stress measurement was carried out for 72 hours before and after the repair work. Table 3 shows the maximum stress ranges with the rainflow cycle counting. After the emergency repair, the maximum stress range was greatly reduced from 100 MPa to 40Mpa at point no.1 of the cross beam section, and from 200 MPa to 136 MPa at Point no.8 of center span of the longitudinal rib. Some amount of decrease was also observed at other points.

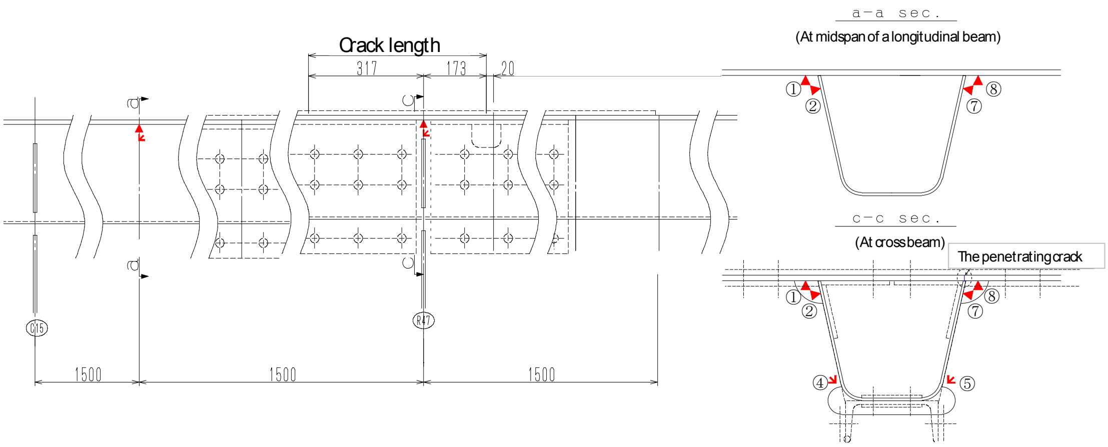


Figure 17 Resistance strain gauges placed on the longitudinal rib(VR9)

Table 1. Stress range alteration.

Measurement point		Maximum stress range(MPa)			
	No.	Before repair	After repair	Difference	After/Before
At cross beam	①	100	40	60	0.40
	⑧	Crack			
	②	64	48	16	0.75
	⑦	24	16	8	0.67
	④	44	40	4	0.91
	⑤	68	48	20	0.71
At midspan of longitudinal rib	①	184	156	28	0.85
	⑧	200	136	64	0.68
	②	184	156	28	0.85
	⑦	200	152	48	0.76

Conclusion

- Fatigue cracks are detected by the 142 spans of 1,347 spans (10 percent of the number of the orthotropic steel decks) from results of the periodic inspection as of March, 2007.
- It is confirmed that equivalent 98kN conversion cumulative axes numbers of the network in Hanshin Expressway shows the accumulation speed of fatigue damege.
- As a results of the annual equivalent 98kN conversion cumulative axes number, It is assumed that Wangan and Kobe Route which have high mixture ratio of large vehicle

are accumulated by fatigue damage quickly(over 2 million axes in it).

- A 520 mm long fatigue crack in a longitudinal direction was found on an orthotropic steel deck during repair work of pavement. This crack occurred at the rib-to-deck welds and penetrated the orthotropic steel deck plate.
- A fatigue crack penetrating an orthotropic steel deck plate was detected by UT for inner crack detection.
- MT at the drilled cores in the orthotropic deck indicated that the crack plopagated from the interior rib-to-deck weld to the deck surface while changing direction.
- Macro-fractographic observations showed the 6mm longitudinal ribs had 2 mm penetration welds (30 percent penetration), which were about 40 percent of JRA requirements (75 percent penetration).
- Stagnant water in longitudinal ribs was found by investigation with an infrared camera from an underpass.
- Emergency repair with splice-plates and drilling holes (40mm) was carried out in order to prevent possible subsequent crack growth. The crack was spliced with bolted butt splices, located at the deck plate top surface and inside and outside of the longitudinal rib.
- After the emergency repair, the maximum stress range was greatly reduced.

References

[1] Takada.Y,Aoki.Y,and Sakano.M “Examination and review of fatigue cracks in orthotropic steel decks in Hanshin Expressway”, Proceedings of 7th Japanese-German Joint Symposium on Steel and Composite Bridges, Osaka,Japan, 2007

[2] JRA(2002),Fatigue Design Specifications for Steel Bridges, Japan Road Association, Tokyo, Japan