DEVELOPMENT OF EDDY CURRENT TEST TO DETECT FATIGUE DAMAGES ON ORTHOTROPIC STEEL DECK

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Abstract

In recent years, a number of fatigue damages in steel orthotropic deck bridges have been reported. Among them, those occurring in the welded connections between orthotropic deck and U-shaped ribs, in which cracks starting at the weld roots develop in the direction of the deck thickness, penetrating into the deck plate, raise a serious problem. In case these cracks develop along a long extension, they may cause the road to sink and harm to third parties, requiring early detection and measures from the road administrators. As these cracks cannot be seen without the removal of the asphalt, various types of non-destructive testing methods, including ultra-sonic inspection methods, were carried out, without effective results. Thus, the Hanshin Expressway group has developed a sophisticated method to detect these cracks, by integrating infrared, eddy current and phased array ultrasonic inspections. Among these methods, efforts were made in the development of the eddy current method as an effective inspection method.

Introduction

Steel road bridges having orthotropic decks, due to its lightness and short construction time, have been widely applied in the costal area of urban highways. In recent years, with the increase in the traffic amount and the constant occurrence of overloaded vehicles, fatigue damages on orthotropic decks have been reported.

As it is shown in Figure 1, fatigue damages on orthotropic decks can be classified into 4 groups.

① Cracks occurring in along the weld between the deck and U-shaped rib
② Cracks occurring in the weld between the U-shaped rib and transverse beams.
③ Cracks occurring in the butt weld between U-shaped rib and transverse beams
④ Cracks occurring in the weld between the deck plate and the vertical stiffeners

In particular, type① cracks originated in the root of the weld between the U-shaped rib and the deck can be classified into 3 types.

①-1 Weld bead crack
①-2 Cracks originated in the weld bead and developing into the U-shaped rib base material
①-3 Cracks developed into the deck surface.

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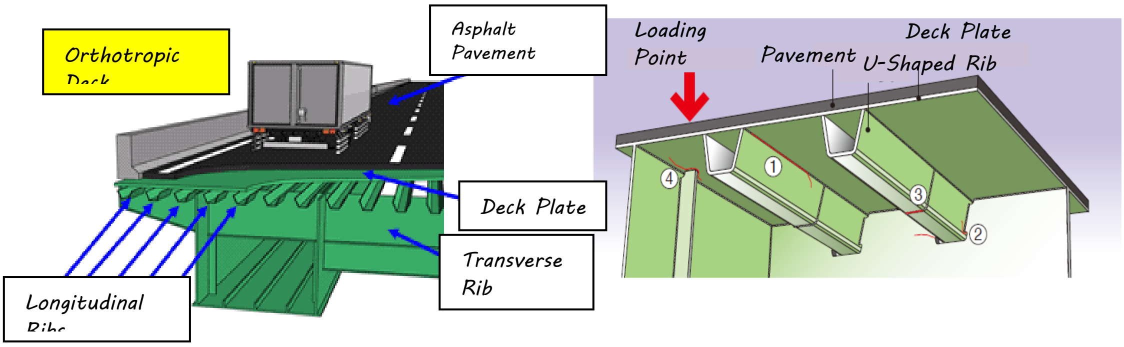

Figure 1. Types of fatigue damages

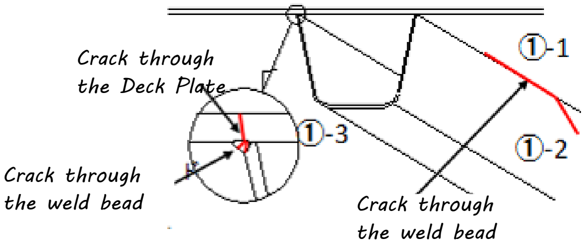

Figure 2. Fatigue cracks between deck plate and U-shaped ribs

In type①-3 in case the crack penetrates through the deck plate into the surface of the deck and extends along a long length, not only it affects the asphalt but also, causes the local reduction of the deck strength, what may cause local collapse of the road and consequent risk of harm to third parties.

Therefore, early detection and reinforcement of fatigue cracks in orthotropic decks, specially of type①-3, are required from the road administrators.

Thus, the Hanshin Expressway is performing inspections focusing in fatigue cracks in orthotropic decks. These inspections are carried out mainly by experienced inspectors and are based on visual inspection of the orthotropic deck from its lower surface. In case abnormality is found in the visual inspection, detailed inspections are carried out through non-destructive testing such as, eddy current test, penetrant test and ultrasonic test.

However, among crack types ① to ④, cracks of type①-3 develop from the weld root in the direction of the deck upper surface. These cracks not only cannot be visually detected from the lower surface of the deck, as it shown in Figure 3, but they cannot also be found by visual inspection of the upper surface of the deck without removing the pavement, as it is shown in Figure 4.

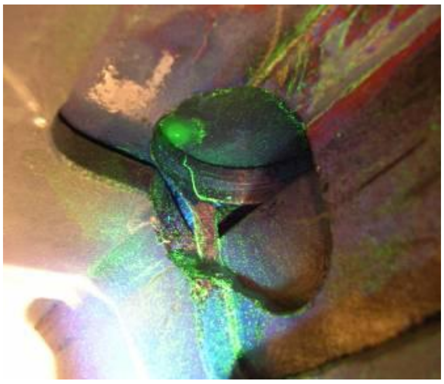

Figure3. Lower surface of the deck plate

Figure 4. Upper surface of the deck plate (without pavement)

Therefore the only inspection method available was the ultrasonic inspection carried out from the bottom surface of the deck plate.
However, ultrasonic inspections have the following disadvantages.

- ・Because they require contact with the steel orthotropic deck, proper equipment and scaffolding works are necessary.
- ・In high viaducts or water crossing, they require large-scale overall scaffolding works.
- ・Because of the above mentioned requirements, the efficiency or the whole inspection is not good.
- ・Comparing the inspection costs, the costs of the facilities are high, having budget restraints.
- ・Although the cycle of the inspections are not yet defined, periodic inspections are necessary.

Thus, a rational and economic inspection method with high performance to detect cracks penetrating the deck plate is required.

As rational and economic methods, ①infrared inspection, ②eddy-current inspection and ③phased array ultrasonic inspection can be mentioned. Among these methods focus was made on the eddy-current method as an effective method and an inspection of orthotropic decks was developed.

<u>Eddy current inspection</u>

When detecting cracks that perforate the deck plate and cannot be visualized through non-destructive tests, inspections can be carried out either from the upper, or from the bottom surface of the steel orthotropic deck.

As it was mentioned in the above lines, inspections from the bottom surface of the orthotropic deck are not effective due to the necessary scaffolding works. Thus,an inspection method that can be carried out from the pavement surface, without any physical contact with the deck surface, would provide a better performance.

The characteristics of the non-destructive methods considered in the present study are presented in Figure 5.

[Non-destructive test equipment]				
Type		upper surface crack	lower surface crack	perforating crack
Eddy Current	non-contact max. lift-off	OK	NG	OK
Phased Array	contact image processing	OK	OK	OK
Continuous Magnetic Saturation	non-contact min lift-off	OK	OK	OK

Figure 5. Testing methods

Considering that inspection through the pavement will have to be carried out without physical contact with the deck surface, the present investigation focused on the eddy current method, which can be carried out even with relatively high lift-offs. The eddy current test, being a test witch can be carried out without contacting the surface of the members, has been applied to slender pipes in thermal transformers of electrical plants. As shown in Figure 6, inspections were carried out inside slender pipes in a speed of over 2 m/s to detect cracks and corrosion without touching the pipes surface.

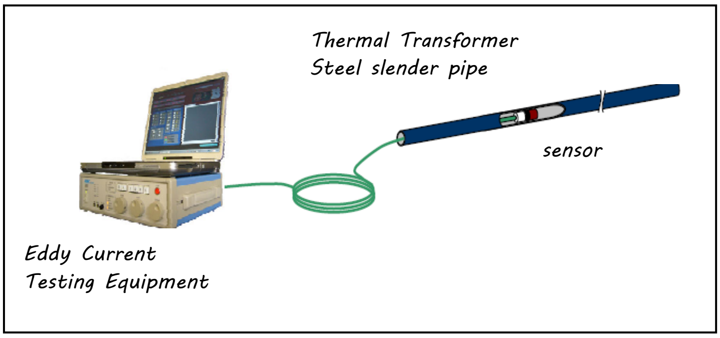

Figure 6. Eddy current test for slender pipes of thermal transformers

The development was carried out on a method applying the techniques of the eddy current inspection. The following problems were found in developing the present method.

① The traditional eddy current method is one-dimensional, whereas the steel deck is a two-dimensional structure

② The maximum pavement thickness being about 80 mm, is extremely big compared to the ordinary lift-offs found in eddy current tests.

③ The effects of the pavement on the magnetic field generated in the eddy current test are still not clear.

To solve these problems, the following steps were carried out in the development of a new method

① Laboratory Tests (vacant lift-off tests)
② Laboratory Tests (pavement lift-off tests)
③ Test in situ (vacant lift-off tests)
④ Test in situ (actual pavement tests)

Laboratory tests (vacant lift-off test)

Crack detection tests were carried out in specimens having the same thickness of that of the actual orthotropic deck plate, t=12 mm. The specimens also contained artificial cracks having a width of 0.5 mm and a length of 10 cm. As shown in Figure 7, eddy current detectors having horizontally distributed coils (DIF type) and vertically distributed coils (ABS type) were fabricated and comparisons were made.

Crack detection tests were carried out with lift-offs of 5 mm to 70 mm. To avoid the effects of surface roughness, an acrylic plate of 5mm was placed on the contact surface. (Figure 8)

The signal of the detection test is shown in Figure 9. With the increase in the lift-off, the ABS type was able to detect the crack through a lift-off of 70mm. However, for the DIF type, there was an inclination to decrease the detection rate and cracks could not be detected for a 70 mm lift-off. Therefore, the ABS type was selected for the sensor.

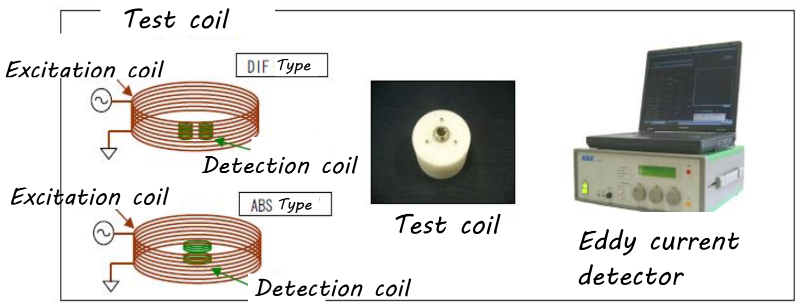

Figure 7. Eddy current test equipment

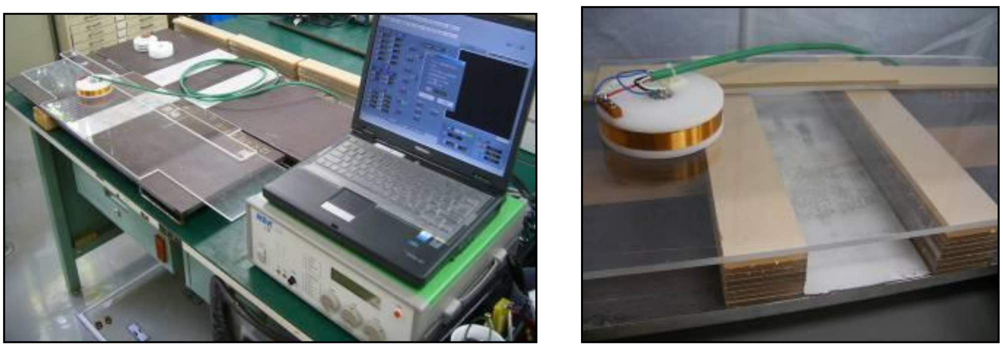

Figure 8. Laboratory tests

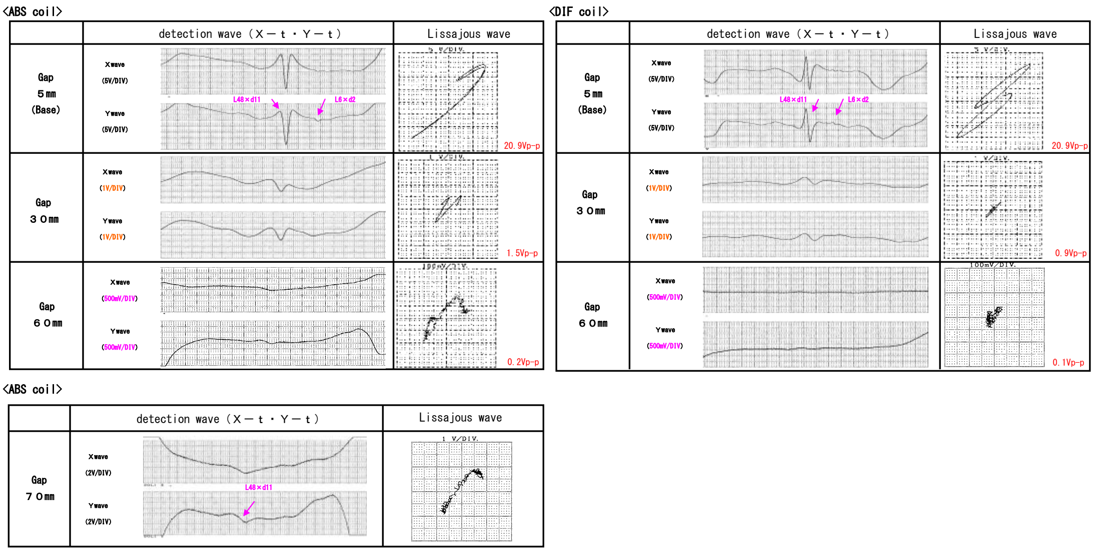

Figure 9. Laboratory tests (comparison of coils)

Laboratory tests (pavement lift-off test)

To investigate on the effects of the pavement during detection inspections performed in actual bridges, pavement blocks having thicknesses of 20 mm and 40 mm were placed on the specimens mentioned in the former section. Detection tests for lift-off of 25 mm and 45 mm were carried out, and the results were compared.

Detection signal data are shown in Figure 10. Comparison between the specimens with and without pavement, it was concluded that there is no influence of pavement on the detection test results.

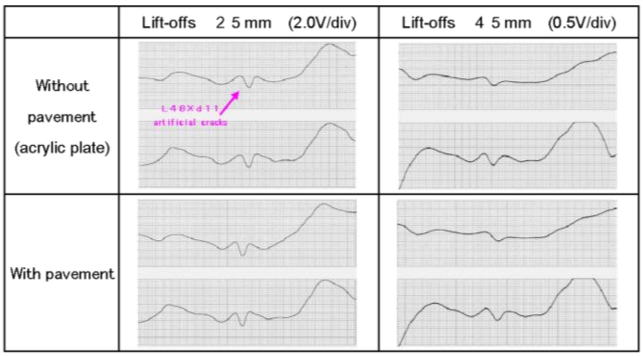

Figure 10. Laboratory tests for pavement lift-offs

Tests in situ (vacant lift-off test)

As shown in Figure 11, detection tests were carried out on cracks perforating the deck, found during pavement replacement works in the Hanshin Expressway. The detected crack was 245mm long.

Figure 11. Eddy current test (without pavement)

Detection tests were carried out for lift-offs of 5 mm, 30 mm, 55 mm and 85 mm. The results are shown in Figure 12.

It was confirmed that the cracks can be detected even for a lift-off equivalent to the pavement thickness.

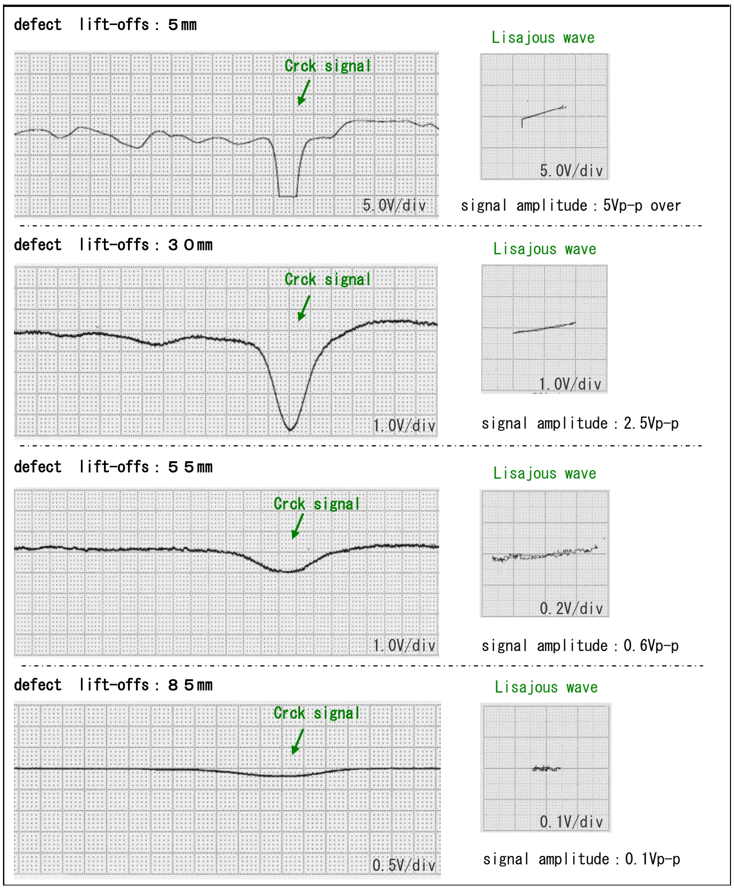

Figure 12. Detection tests in situ

Tests in situ (actual pavement test)

(1) Test 1

On the day after the executing pavement works after the completion of the detection tests, the sensor was improved and detection tests on the actual pavement surface were carried out (Figure 13). Because the pavement of this bridge has a thickness of 65 mm, detection tests for a lift-off of 70 mm, including the acrylic plate, were carried out. As shown in Figure 14, it was possible to obtain the crack signal.

Figure 13. Eddy current test (with pavement)

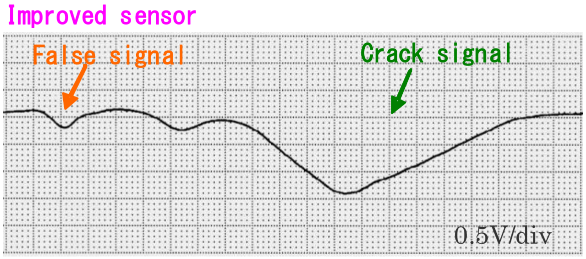

Figure 14. Improved sensor wave （85 mm lift-offs)

(2) Test2

Verification tests were carried out at locations where damages in the pavement had been repaired. Eddy current inspections were carried out over the pavement layer to verify whether the crack perforating the deck plate can be detected. Precision of the eddy current method was also verified by calibrating the results obtained by the eddy current test and the crack perforating the deck, after the removal of the asphalt layer.

As a result, the signal due to crack perforating the deck was detected. Comparing the results with the crack perforating the deck after the removal of the asphalt, it was confirmed that the results obtained by the eddy current test executed over the asphalt detected with good precision the crack perforating the deck along a length of about 500mm.

Figure 15. Field inspection on actual pavement

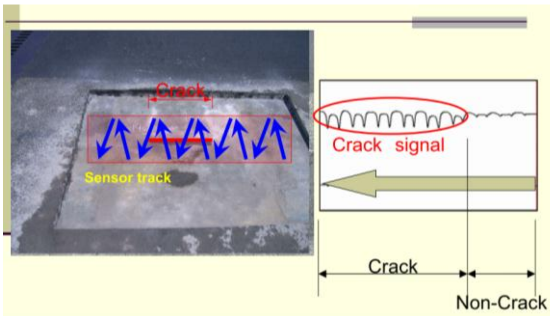

Figure 16. Output of eddy current test

Development of an automotive eddy current inspection device

Under the present conditions, the eddy current test method has to be executed manually, what is a limitation for the improvement of the test efficiency. Thus, to rationalize the inspections and tests works, with the objective of detecting early cracks in orthotropic decks, an automated eddy current device that can replace the manual works was developed.

The testing device system is composed by a multi-channel eddy current testing system, a detector with a scanning system, a power generator and a tractor to tow the whole system.

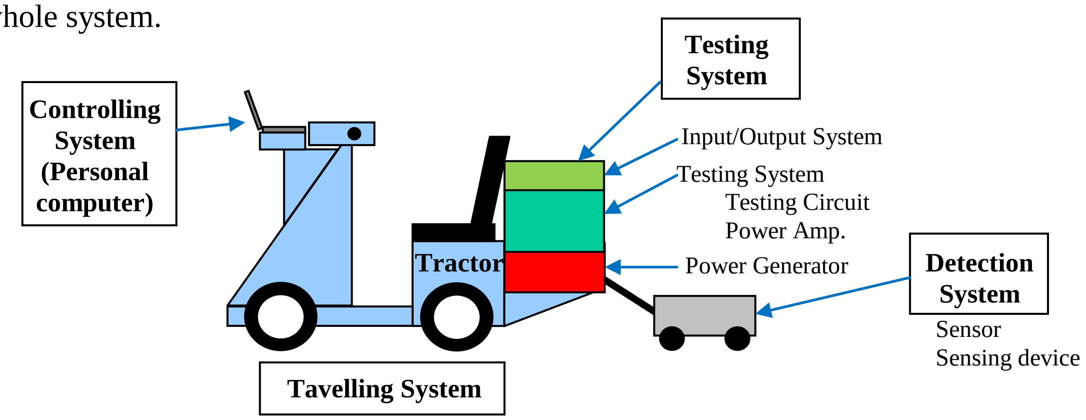

Figure 17. Scheme of the automated detection system

The detection device is pulled by the driving vehicle, and 4 coils mounted on it as sensors, with 1 coil measuring 1 U-rib weld line. The sensor is capable of moving in zigzag over the movement direction (transverse to the weld line) in a determined speed.

Required specifications

- One round trip per traffic control period (about 4 working hours), 1 span (about 80m), 1 lane (about 3.5m, 8 weld lines)
- Able to detect 100mm cracks perforating decks over an asphalt thickness of 100mm,
- Running speed: during measurement 1-10 cm/sec; while moving, 50 cm/sec.
- Load: 80kg (1 person riding)

  Measurement device: about 140kg

  Driving device: about 130kg (including detection device and control PC)

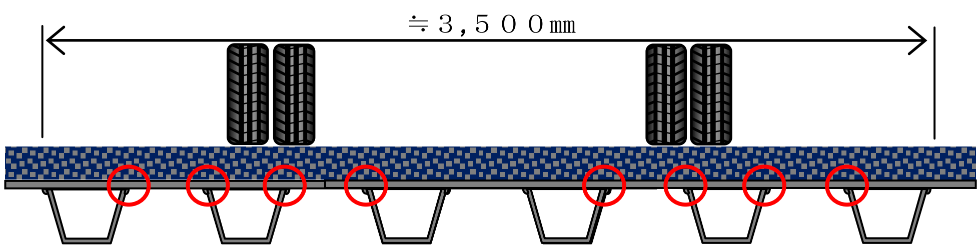

Figure 18. Sweep per lane (3.5m, 8 welding lines)

Figure 19. Automated detection system

Conclusions

It was confirmed that cracks perforating the deck can be detected through eddy current test carried out on the pavement surface, with good efficiency.
The detection limit for the improved sensor is 100 mm for length and a maximum of 85 mm for lift-offs.

The eddy current inspection can be applied as a simplified method of health diagnostic in the areas where cracks perforating the decks were found by screening through the infrared inspection mentioned in article 1.

With the increase in the heavy traffic volume and the consequent increase of the accumulated traffic volume, the number of occurrence of fatigue cracks is expected to increase. The authors shall continue to collect inspection data and make efforts to improve the detection limits and precision.

References

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