proceedings

Abstract

Applicability of fatigue crack detection with infrared thermography camera to bridges in Denmark †

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Abstract: This paper reports that applicability of fatigue crack detection with infrared thermography camera, T-gap method, to the steel bridge in Denmark. T-gap method is a non-destructive test developed in Japan and does not need to approach closely to the bridge members rather than visual inspections. The principle of T-gap method is to measure the thermal profile of welding point. One of the crucial factors generating temperature gap is the solar altitude, so that there is less solar altitude in high latitude area and it is unclear that whether T-gap method is applicable in higher latitude area than Japan. Then, trial of T-gap method in Denmark, which is located at higher latitude than Japan, was planned to grasp its applicability. As the results of trials, T-gap method successfully detected both locations and length of cracks even in Denmark.

Keywords: infrared thermography; bead penetrating crack; orthotropic deck; temperature gap method

Introduction

U-rib steel deck plates are widely adopted in structures such as long-span bridges in straits and urban expressways with stringent construction constraints due to their lightweight and short construction period. In recent years, several types of fatigue cracks caused by increased traffic of heavy vehicles have been reported in U-rib steel deck plates. Among these, cracks that propagate and penetrate from the root of the U-rib welded joint to the bead surface under wheel loads (hereinafter referred to as "bead penetration cracks") have been frequently observed [1].

Furthermore, fatigue cracks can be mitigated by early detection, but early detection at stages where no paint film cracking or rust formation occurs is difficult with visual inspections, which are generally performed. Non-destructive testing methods such as ultrasonic testing and eddy current testing can be used to detect cracks before coating cracking occurs. However, these methods often require the installation and removal of scaffolding for close inspection, and considering the vast number of weld lines to be inspected, they are not efficient for inspecting the entire weld line [2].

Honshu-Shikoku Bridge Expressway Company (hereinafter referred to as "HSBE") has researched and developed a method for detecting bead penetration cracks using infrared thermography-based temperature distribution measurements (hereinafter referred to as "T-gap method"), see Figure 1. The key feature of this method is that it can detect cracks at stages where no coating cracking has occurred, non-destructively and from a distance. This method enables measurement of the entire weld line by moving the camera while taking measurements [3, 4].

T-gap method is adopted practically by Honshu-Shikoku Bridges and other Japanese bridges, however, the method has never been applied to bridges outside Japan. Previous

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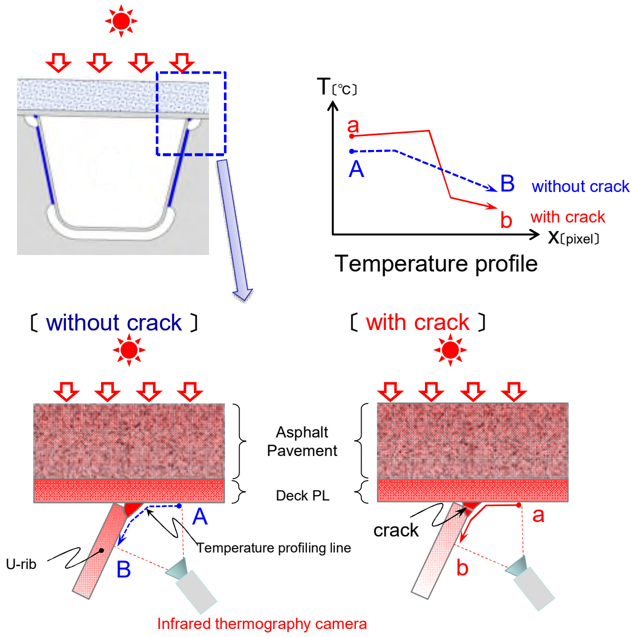

Figure 1. Schematic drawing of principle of T-gap method

study showed that the detectable period is from March to November in Japan, with the period from March to September being preferable when the temperature difference between the deck plate and the U-rib is 0.7°C or higher. However, the measurement period is based on results from bridge locations, Seto Inland Sea region, Japan [5]. When applying this to regions with different climates, the measurement period must be set based on data such as solar altitude. Then, test of T-gap method in Denmark, which is located at higher latitude than Japan, was planned to grasp its applicability.

Test object

Test of the T-gap method was carried out on New Little Belt Bridge which is a suspension bridge located in Denmark. Since 2017, cracks have been observed on orthotropic deck by visual inspection. The bridge owner is the Danish Road Directorate.

The Little Belt Suspension Bridge carries the E20 motorway over the crossing between the island of Funen and the mainland of Jutland, connecting east and west Denmark. The bridge was opened in 1970 and it carries three of traffic in each direction. The average daily traffic numbers is around 100,000 vehicles which is close to maximum capacity. The suspension bridge has a main span of 600m and two side spans of 240m for a total length of 1,080m. The approach spans have a total length of 620m, giving a total length of 1,700m for the entire connection.

The orthotropic steel deck structure with closed troughs that act as the upper flange in the closed steel box girder. The troughs have a height of 250mm, thickness of 6mm, width at the deck of 300mm and spacing of 600mm (Figure 2). Troughs are welded with a partial penetration butt weld with up to 2mm root gap. The plated bulkheads have a spacing of typically 3.0m, but the spacing can vary down to 1.0m at site connections. There are R=35mm cope holes at the trough to deck weld.

During a general visual routine inspection in the summer of 2017, indications of fatigue cracks in the orthotropic steel deck were first observed. And non-destructive testing (hereinafter referred to as "NDT") inspections were carried out later in2017. All crack indications were in the through to deck plate welds in through No.14 and 17 which correspond to the typical wheel positions of heavy vehicles in the slow lane (Figure 3). A total of 10 cracks were found. The cracks initiates at the weld root near the bulkhead cope hole and propagate through the weld bead to the face. Since 2017 a number of fatigue cracks, at approximately 160 locations, have been observed in orthotropic steel deck [6].

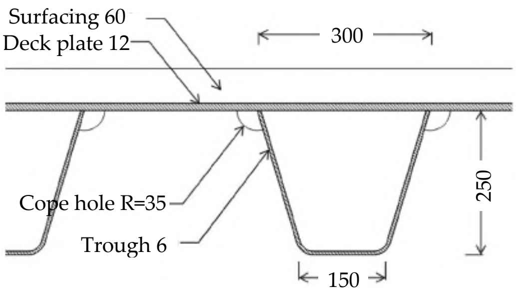

Figure 2. Trough lauout (unit: mm) [6]

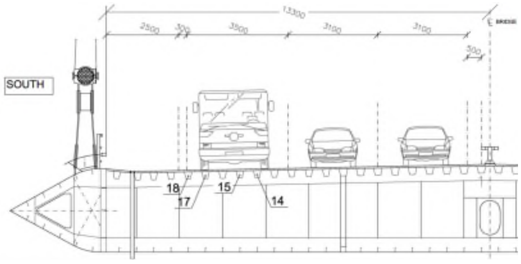

Figure 3. Cross section of box girder

Method and conditions

Considering the locations of detected cracks in 2017, No.14 and 17 of bead lines were tested by the T-gap method in this test. The test is to use the infrared thermography camera, tripod and PC which has the measuring system. The tripod is moved at intervals of 500mm in longitudinal direction while taking still images by the thermography camera. Specifications of the employed infrared camera are shown in Table 1. The test was carried out in July, 2024. After the test, detected cracks were confirmed and compared by magnetic particle testing (MT).

In order to detect cracks of approximately 40mm, temperature gap of more than 0.5℃ between deck plate and U-rib, and 1mm/Pixel shooting resolution are necessary [5]. Furthermore, temperature gap of more than 0.7℃ is desirable. This means that March to September is desirable in Japan to obtain the temperature gap of 0.7℃.

One of the crucial factors generating temperature gap is the solar altitude. Among the road temperature, air temperature and solar altitude, the solar altitude showed a high correlation with temperature gap of R2=0.983, see Figure 4. Figure 5 shows the comparison of solar altitude with Japan and Denmark. Denmark has a lower solar altitude because Denmark is located in higher latitude area. Then, based on the desirable duration March to September in Japan, May to August is desirable in Denmark.

Table 1. Specifications of infrared thermography

Manufacturer's name Product name	Type of detector	Pixels	Spatial resolution	Temperature resolution
Teledyne FLIR Boson	Microbolometer	640 x 512px	0.9mrad	0.050℃

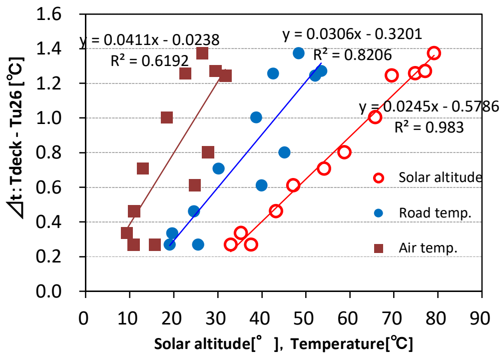

Figure 4. Correlation of temperature gap

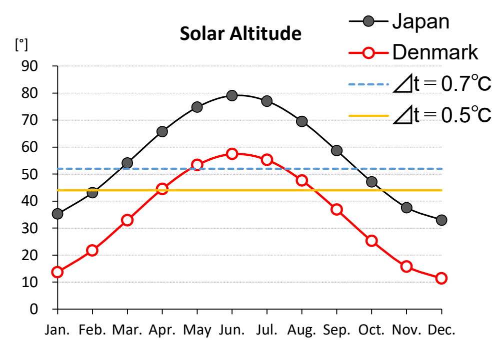

Figure 5. Comparison of solar altitude

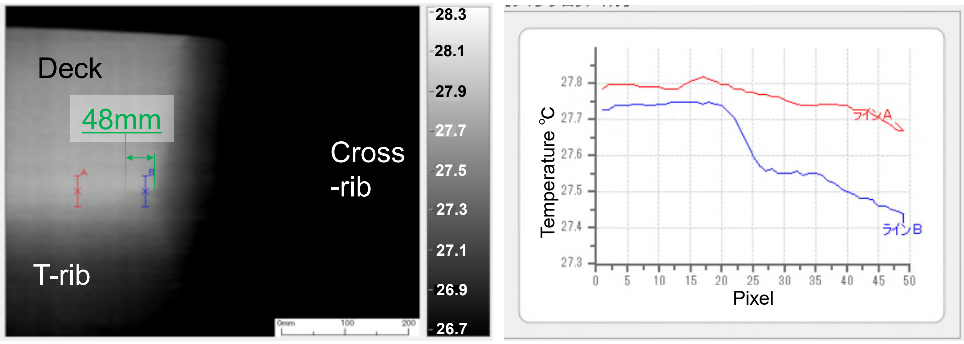

Figure 6. Results of T-gap method. Left-side image shows the temperature image taken by infrared thermography. Right-side graph shows the temperature profile along line A and B of temperature image.

Results

In the test, 3 cracks were detected by T-gap method. Results are shown in Figure 6. All detected cracks are located at the weld root near the bulkhead cope hole.

More than 0.5℃ temperature gap are necessary for T-gap method, but temperature gap were from about 0.20 to 0.33℃ in the test. Nevertheless, T-gap method can accurately detect cracks, as confirmed by comparison with MT results. This implies the possibility of changing the recommended value of temperature gap. But, further test and research are necessary.

Table 2. Result comparison with T-gap method and MT

Method	T-gap method	MT
Case 1	48mm	50mm
Case 2	121mm	120mm
Case 3	73mm	80mm

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