Monitoring of Fatigue Failure in Steel Plate Deck by FSM†

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Abstract

For investigating the applicability of FSM (Field Signature Method) on fatigue failure monitoring, a series of fatigue tests on steel plate decks (4,625×2,200(mm)) was carried out by using a wheel load traveling test machine. From the results of the experiments, the position where the fatigue cracks initiated could be accurately specified. The initiation of minuscule cracks, which could not be confirmed by visual inspection, was specified. The direction of propagation and the length of fatigue cracks could also be specified. The results have shown that the fatigue failure could be detected adequately and with high accuracy in a real-sized steel plate deck.

KEY WORDS: (Fatigue), (Steel plate deck), (Non-destructive inspection), (Monitoring), (FSM)

1. Introduction

A lot of damage, such as fatigue cracks, in existing steel structural members have been reported and it is important how the damaged members are managed.

For detecting initiation of fatigue cracks and monitoring their propagation, the applicability of FSM (Field Signature Method)[1], which is one of the non-destructive inspections based on the electric potential difference method, has been investigated[2), 3)].

In FSM, electrodes and many sensing pins are attached to an inspection object. The sensing pins are arranged in a lattice formation which is a characteristic of FSM and pairs are made by selecting any two sensing pins. A direct pulse current is applied and potential differences between the pairs are measured at any interval. If a fatigue crack occurs between a pair, the potential difference is changed. Based on the potential difference change, the crack initiation and propagation are specified.

In FSM, if the sensing pins are attached at once, a remote monitoring is possible. Therefore, in the case of bridges, there are benefits such that access to the bridges is not required and the shut off of the road from traffic is not needed. Furthermore, extensive monitoring is possible in the area in which the current can be applied.

In this paper, being conscious of application of FSM on real structures like bridges, a series of fatigue tests on steel plate decks were carried out by using a wheel load traveling test machine. It is examined whether the fatigue failure of a large steel structure can be monitored with high accuracy.

2. Test Specimen and Procedure of Experiment

2.1 Test specimen

Figure 1 shows the shape and dimensions of the test specimen.

The test specimen is a real-sized steel plate deck stiffened with longitudinal and lateral ribs. The size of the steel plate deck is 4,625×2,200(mm). The distance between each longitudinal rib is 320mm and between each lateral rib is 1,208mm.

The material is SS400 and the thickness is 12mm. Two specimens are prepared.

2.2 Procedure of experiment

A fatigue test for the steel plate deck is carried out by using the wheel load traveling test machine.

Figure 2 shows the appearance of the experiment.

It is assumed that the double tires of a vehicle travel in the axial direction, bestriding a longitudinal rib (Fig.1). The magnitude of the wheel load is 150kN.

Firstly, a number of sensing pins are attached in the monitoring area and electrodes are set up outside the monitoring area on the reverse side of the deck plate by stud welding for detecting crack initiation and then monitoring for crack propagation by FSM. The diameters of the stud bolts are 3 and 6 (mm) respectively. The lengths of the bolts are 8 and 15 (mm) respectively.

Selecting any two pins (known as a pair) from the attached sensing pins, a potential difference generated between the pairs is measured at any interval by applying around 100A direct pulse current.

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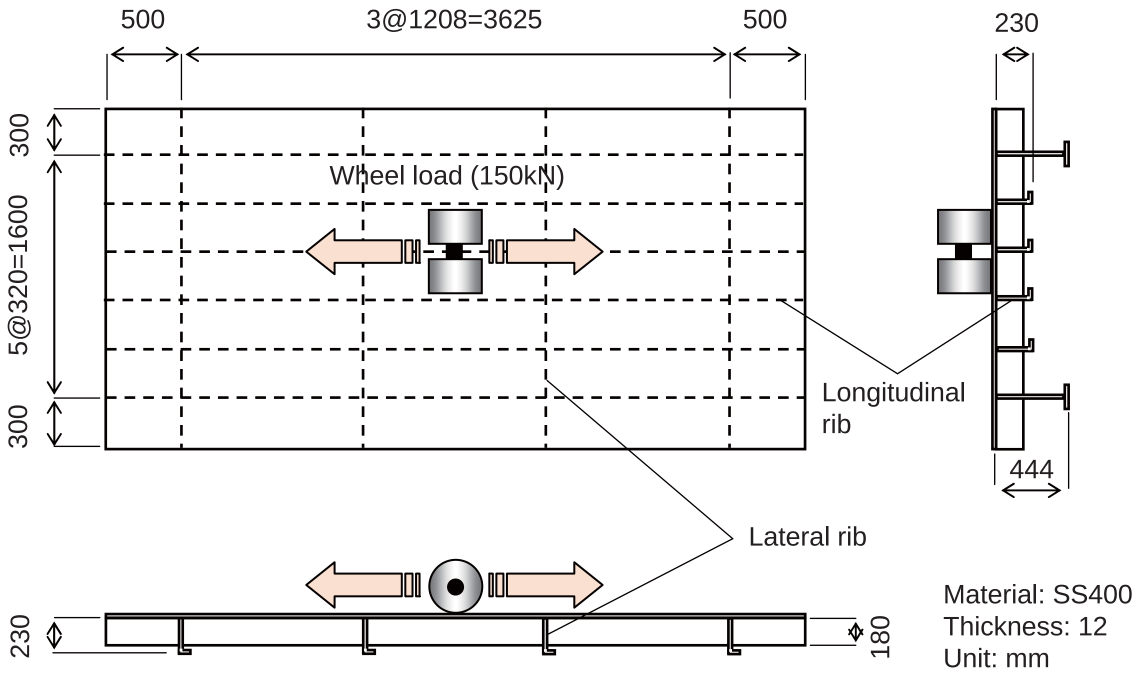


Fig. 1 Test specimen.

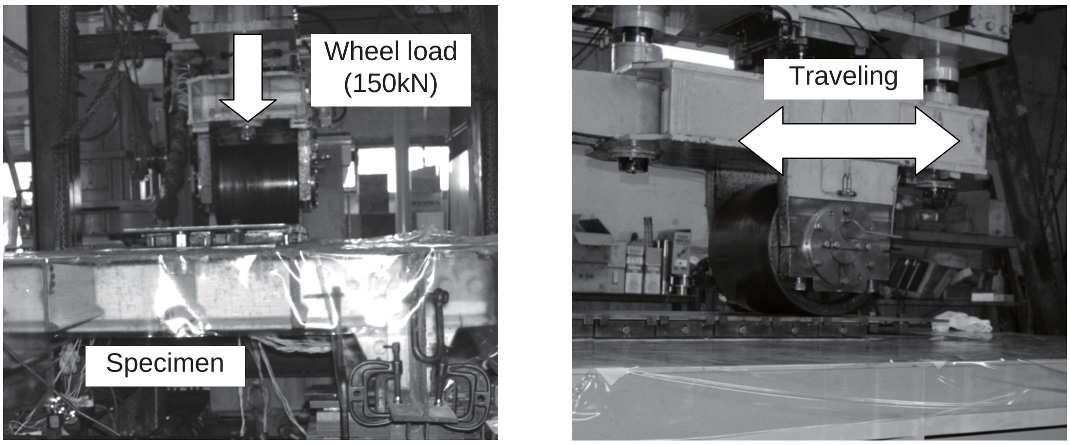


Fig. 2 Appearance of experiment.

During the experiment, the potential difference is measured at any interval.

Alternatively, initiation and propagation of fatigue cracks by visual inspection is also monitored. The measured results of the electric potential difference with passage of the time are compared with the visual results. In the first experiment, the basic applicability of FSM on detection of crack initiation and monitoring of crack propagation is investigated. In the second experiment, the distances between sensing pins are investigated which is necessary for extensive monitoring with high efficiency.

3. Detection of Crack Initiation and Monitoring of Crack Propagation by FSM

3.1 Arrangement of sensing pins and pairs

In order to investigate the basic applicability of FSM on detection of crack initiation and monitoring of crack propagation, the first experiment is carried out.

Figure 3 illustrates the set up positions of the electrodes and the arrangement of the attached sensing pins within the monitoring area where fatigue cracks are expected to be initiated.

The region of the monitoring area is around 1,208 × 640 mm^2.

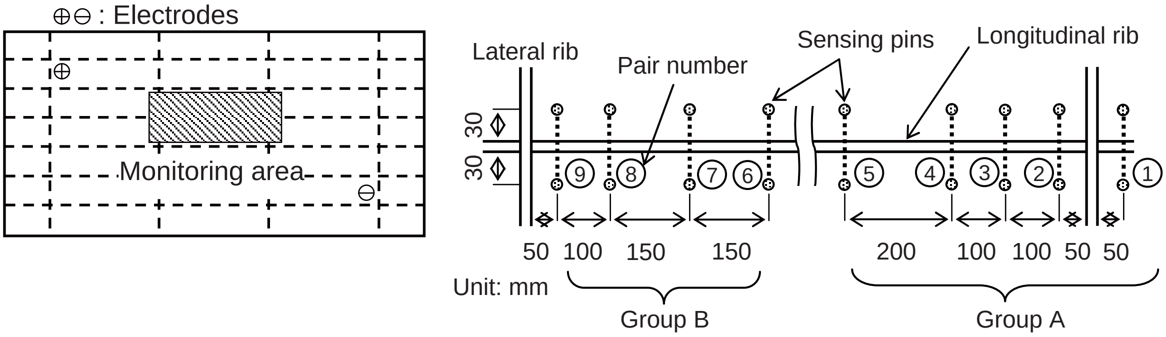


Fig. 3 Monitoring area and arrangement.

The electrodes are diagonally attached to both edges of the deck plate.

The sensing pins are attached sandwiching the longitudinal ribs and welds of the deck plate. The pairs are then divided into two groups, Group A (Pair 1 to Pair 5) and Group B (Pair 6 to Pair 9).

3.2 Results of experiment

Figure 4 shows the monitoring results by FSM in the experiment.

The vertical axis represents the FC value which is one-thousandth of an electric potential difference between the pairs[2]. The FC value is calculated by Eq. (1). The horizontal axis represents the number of repetition of the wheel loads.

$$FC_i=(R_0/V_{0i}\times V_i/R_i-1)\times 1000 \quad (‰) \qquad (1)$$

Where,

V_{0i}: Initial potential difference of Pair-*i*.

R_0 : Initial potential difference of reference pair.

V_i : Potential difference of Pair-*i* at the measured time.

R_i: Potential difference of reference pair at the measured time.

The reference pair means the pair attached on an other steel plate than the specimen for revising the effect of temperature change or humidity change on the potential differences of the pairs.

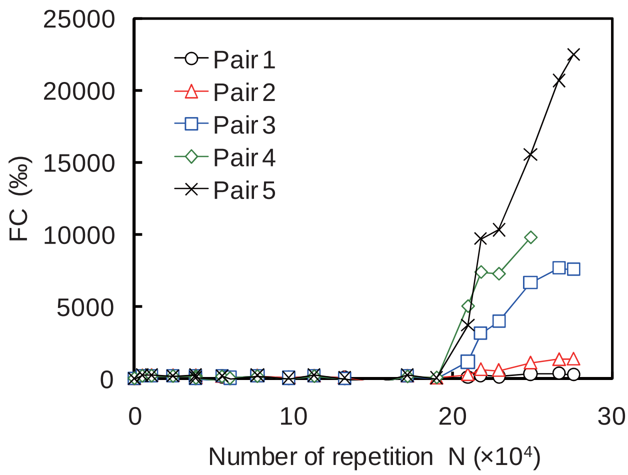
The monitoring results of the group A is noted (Fig.4 (a)).

Both the FC values of Pair 4 and Pair 5 increase. That of Pair 5 increases significantly more. Accordingly it can be predicted that a crack is initiated near Pair 4 and Pair 5. By delaying it, the FC values of Pair 3 increases. The crack is probably propagated near Pair 3.

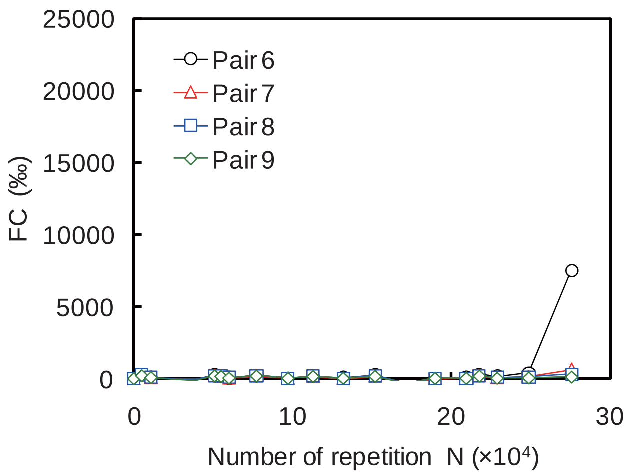
The FC value of Pair 4 rapidly increases when the number of repetition is from 170,000 to 190,000. It can be considered that the crack is initiated at this time.

The monitoring results of the group B is noted (Fig.4 (b)).

The FC value of Pair 6 increases when the number of repetition exceeds around 240,000. It is considered that the crack initiated near Pair 4 is propagated near Pair 6 or the other crack is initiated near Pair 6.



(a) Group A.



(b) Group B.

Fig. 4 Monitoring results by FSM.

Figure 5 shows the propagation of the crack by visual inspection and the number of repetition.

When the number of repetition is around 210,000, a fatigue crack is observed at the toe of the welds of the deck plate and the longitudinal rib between Pair 4 and Pair 5. The length is around 180mm. After that, the

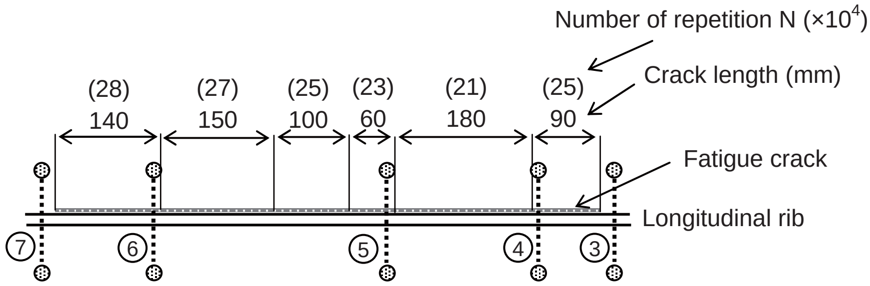


Fig. 5 Crack propagation observed by visual inspection.

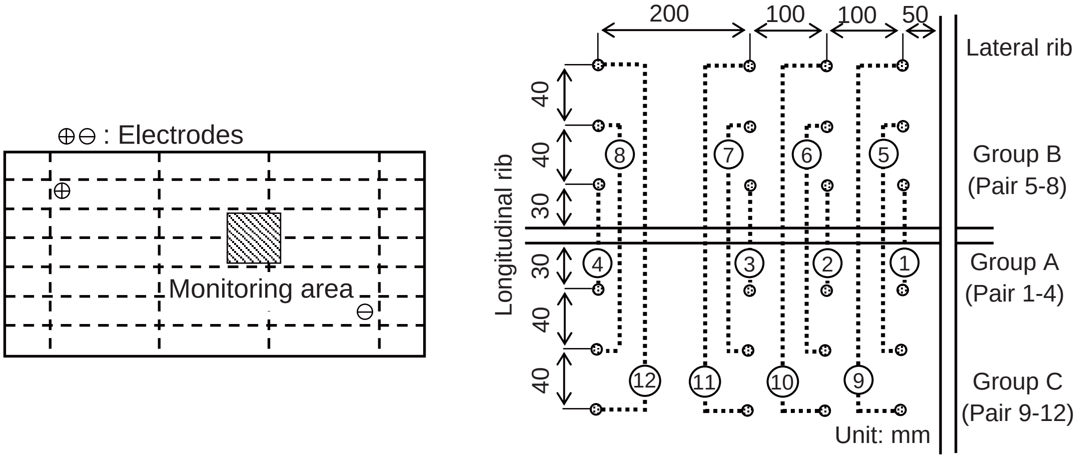


Fig. 6 Monitoring area and arrangement of pairs.

crack is largely propagated to the left of Pair 5 and near Pair 3 when the number of repetition is around 250,000. Finally, it is propagated to Pair 6 and Pair 7 when the number of repetition exceeds 270,000.

The change of the FC values agrees with the behavior of the crack propagation observed by visual inspection.

From these results, it is confirmed that the initiation of the fatigue crack can be detected by FSM considerably earlier (the number of repetition is from 20,000 to 40,000) than by visual inspection. The minuscule crack which cannot be observed by visual inspection is able to be detected by FSM. The behavior of crack propagation can be monitored by FSM with high accuracy.

4. Extensive Monitoring by FSM

4.1 Arrangement of sensing pins and pairs

For investigating the distance between the sensing pins of FSM, which is indispensable in the extensive monitoring with high efficiency, the second experiment is carried out.

Figure 6 shows the set up positions of the electrodes and the arrangement of the attached sensing pins.

The sensing pins are attached at three positions sandwiching the longitudinal ribs. The pairs are divided into three groups, Group A (Pair 1, Pair 2, Pair 3 and Pair 4, in which the distances between the sensing pins are the narrowest.), Group B (Pair 5, Pair 6, Pair 7 and Pair 8, in which the distances between the sensing pins are median.) and Group C (Pair 9, Pair 10, Pair 11 and Pair 12, in which the distances between the sensing pins are the widest.) The distances of the sensing pins are around 70, 150 and 230mm including the longitudinal ribs and welds.

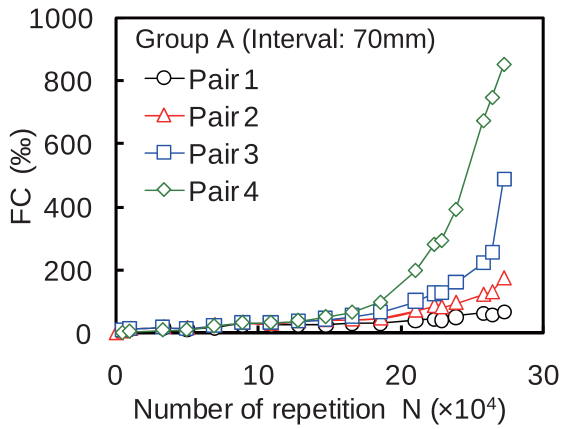
4.2 Results of experiment

Figure 7 shows the results of the monitoring. The scales in each of the vertical axis in Fig.7 (a), (b) and (c) are different from each other.

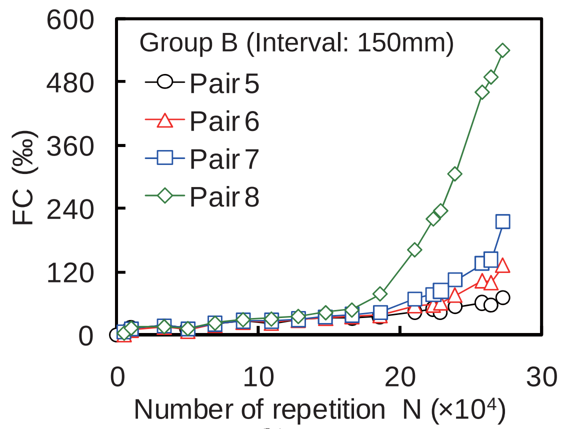
The FC values of Group A, of which the distances between the pairs are the narrowest, are the largest compared to the FC values of the other groups. The wider the distances become, the smaller the FC values are. Naturally this is due to the fact that the narrower the distances between the pairs are, the more accurate the change of the potential difference can be detected.

The FC values of Pair 4, Pair 8 and Pair 12 tend to increase when the number of repetition exceeds around 140,000. After that, the FC values of Pair 3, Pair 7 and Pair 11 increase.

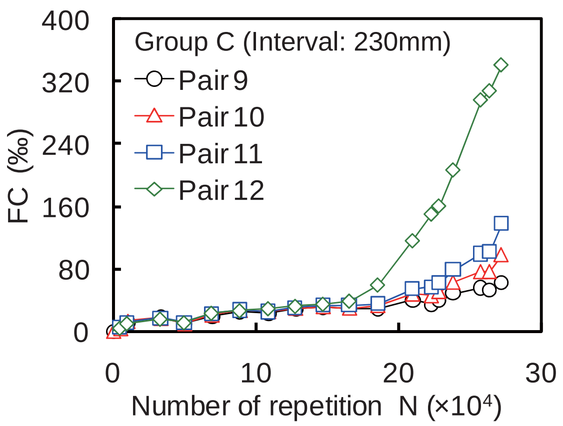
From these results, it can be anticipated that the crack initiated from the position sandwiched by Pair 4 (Pair 8 and Pair 12) is propagated to the direction of Pair 3 (Pair 7 and Pair 11).



(a) Group A.



(b) Group B.



(c) Group C.

Fig. 7 Monitoring results by FSM.

Although the magnitudes of the FC values in each group are different, the tendencies are the same. It can be said that the positions of the crack initiation and the direction of crack propagation can be accurately detected and monitored even if the distances between the pairs is extended up to 230mm under the condition of this experiment.

It is clear that when the distance between the sensing pins becomes wider, the accuracy of detecting the crack initiation and monitoring the crack propagation is reduced. However, if some responses can be detected, by attaching new sensing pins between the original sensing pins detecting the responses, the distances between the sensing pins can be straitened. Therefore there is no difficulty in monitoring by FSM on site.

5. Conclusions

In order to elucidate applicability of FSM on detection of fatigue failure monitoring, a series of fatigue tests on steel plate decks (4,625×2,200 (mm)) was carried out by using a wheel load traveling test machine.

The obtained main results are as follows:

(1) The initiation of the fatigue crack in a steel plate deck could be detected by FSM considerably earlier than by visual inspection.

(2) The propagation of fatigue cracks, such as their direction, could be monitored with high accuracy by FSM.

(3) The wider the distances between the sensing pins became, the smaller the FC values (the measure evaluating the crack initiation and propagation in FSM) were. However, the tendencies of FC values were not changed. It was confirmed that the crack initiation could be detected and the crack propagation could be monitored adequately even if the distances between the pairs was extended up to 230mm.

(4) It was clear that when the distance between the sensing pins became wider, the accuracy of detection of the propagation of cracks was reduced. Nonetheless even though a few responses could be detected between a pair, attaching new sensing pins between the original sensing pins, the distances between them could be straitened. Therefore there was no difficulty in monitoring by FSM on site.

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