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Monitoring of Accumulative Traffic Loads on Bridge Members by Sacrificial Test Pieces †

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KEY WORDS: (Fatigue)(Accumulative Load)(Crack Growth)(The Sacrificial Test Piece)

1. Purpose of this study

The purpose of this study is to show the practical applicability of "the Sacrificial Test Piece" for monitoring of the accumulative traffic loads on the bridge members.

2. Sacrificial Test Piece

The Sacrificial Test Piece is used in the specimen attached to the member of a main structure in order to evaluate the damage before appearance of a crack in the member of main structure. The Sacrificial Test Piece is designed so that it is damaged earlier than the main members under the same loading because of its crack and stress magnification. The damage to the bridge members can be estimated by the observation of the Sacrificial Test Piece.

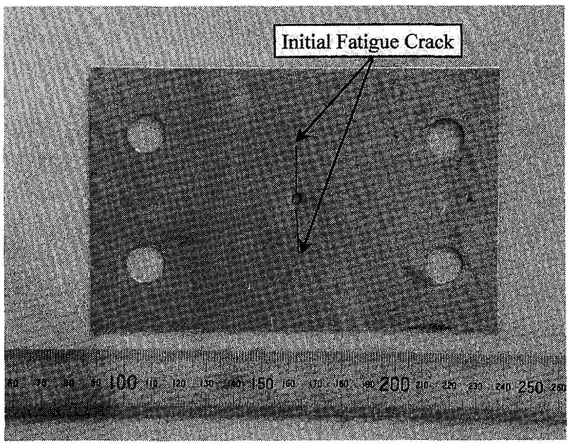

Fig.1 Sacrificial Test Piece.

If the accumulative fatigue load can be made clear by the behavior of the Sacrificial Test Piece, overall the maintenance management of the structure can be determined.

As shown in **Fig.1**, thin steel plates, which have an initial crack at the center, are used as Sacrificial Test Pieces in this study. When strains are applied to the main member carrying the Sacrificial Test Piece, these are transmitted from the main member to the Sacrificial Test Piece and the crack in the Sacrificial Test Piece will grow as a result. Therefore, the monitoring of accumulative traffic loads on the structure, for example the bridge, can be carried out by the observation of the crack growth in the Sacrificial Test Piece.

3. Accumulative traffic loads

The bridge members are forced to carry various loads irregularly. Then, it is assumed that "the load history" due to stress on the member can be written as;

$$\sum(\sigma_i^m n_i) \qquad (1)$$

where σ is stress amplitude, n is number of cycles and lower suffix i is operation number. Formula (1) is termed "the accumulative traffic load" in this paper.

If the load history on the members can be measured, "the fatigue damage" ratio can be determined as following equation;

$$D = \frac{1}{C_0}\sum(\sigma_i^m n_i) \qquad (2)$$

where D is the fatigue damage ratio, C_0 is a constant which is determined by the fatigue strength at each member.

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If D is cleared in a certain period, the residual life can be estimated under this assumption, as the traffic will not be changed until it fractures.

4. Crack growth on the Sacrificial Test Piece

We propose a method for measuring the accumulative traffic loads by the crack growth of the Sacrificial Test Piece. The basic theory and assumptions are shown as follows;

1) The crack at the center of the Sacrificial Test Piece grows by the strain that is transmitted from the member to the Sacrificial Test Piece.
2) The relationship between a stress component of the live load and the crack growth generated by the stress component is expressed by Paris's law as follows;

$$\frac{da}{dn} = AK^m \qquad (3)$$

where a is the crack growth, A is a constant , and K is the stress intensity factor.

3) The stress intensity factor coefficient under constant displacement amplitude can be expressed as follows;

$$K_i = B\sigma_i \qquad (4)$$

where B is a constant. Eq.(4) shows that the stress intensity factor for the constant displacement amplitude testing can be expressed only as the function of stress amplitude " σ ", and can be expressed without considering the effect of crack length "a".

4) Substituting eq.(4) in Paris's law, produces eq.(5);

$$\frac{da_i}{dn_i} = A\left(B\sigma_i\right)^m \qquad (5)$$

It is assumed that m is approximately 3 for steel.
It follows from equation from eq.(5), that;

$$a_i = AB^m(\sigma_i^m n_i) \qquad (6)$$

5) The crack growths due to each stress component of live load does not affect each other and can be summed simply. Thus the total crack growth can be written as follows;

$$a^* = AB^m \sum(\sigma_i^m n_i) \qquad (7)$$

where a^* is the total crack growth. By these assumption, if a^* is measured, the accumulative traffic load (eq.(1)) can be obtained via eq.(7).

5. Outline of experiment

Two Sacrificial Test Pieces were attached at lower flanges of a highway bridge under open traffic, and the crack growth on each test piece was measured for six months. At the same time, the actual accumulative traffic load was measured by conventional methods with a digital measurement device. Values obtained by proposal method and the conventional one were compared.

This experiment was carried out on the highway bridge of Route 3 of Hanshin express highway, which is located between Maya and Ikutagawa in Kobe city. The Sacrificial Test Pieces were attached from April 23, 1998 to December 6, 1998.

The specimens, which have been attached consist of four steel jig-plates, some bolts and the Sacrificial Test Piece. The shape and the dimension of the specimen are shown in **Fig.2**. Thickness of the Sacrificial Test Piece is 0.5 mm, and thickness of one side edge of the jig-plate is 12mm and other part of the jig-plate is 10mm. Bolts at both edges tightened up the Sacrificial Test Piece, and the specimen has been attached on the lower flange of a main girder by high strength vices at the edge of the jig-plate parts, as shown in **Fig.3**.

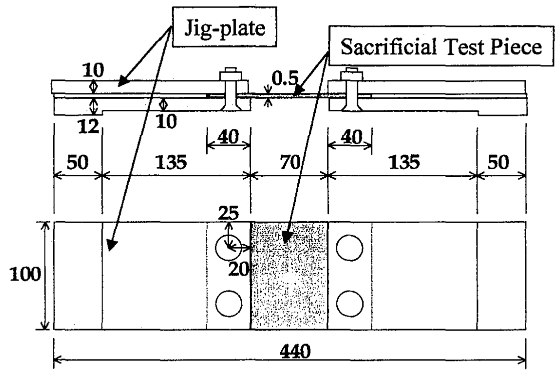

Fig.2 Specimen.

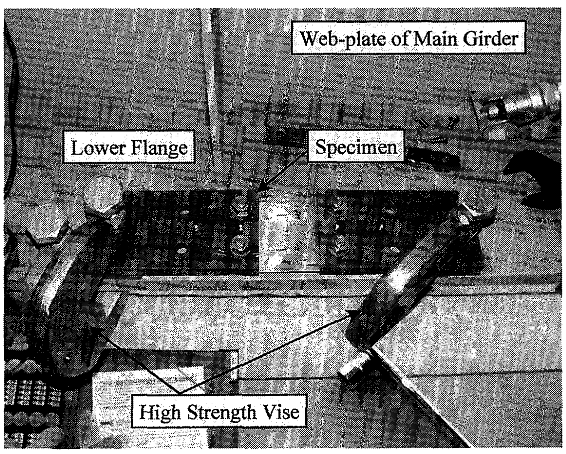

Fig.3 Site Experiment.

The high strength vice is often used on site for rigid fixing and the vice is tightened up using a torque wrench.

The specimen can be attached to, and removed from, the steel flange of the highway bridge by this means, without damage to the member. Using this method, a strain between the connected points is concentrated at the Sacrificial Test Piece by the difference in stiffness between thin plate and jig-plate. Strain in the Sacrificial Test Piece is concentrated more than 4 times that of the flange by theoretical calculation. This strain concentration makes the crack growth faster, and the measurement can be carried out in short period.

To avoid compression loads on the Sacrificial Test piece, pre-tensile strain is applied to the Sacrificial Test Piece by heating the specimen before attached to the member.

After the specimen is attached, the temperature of the specimen falls to room temperature and pre-tensile strains will be forced into the Sacrificial Test Piece because of thermal deformation.

6. Results and Consideration

Comparison between crack growth obtained by actual measurement and the proposed method is shown in **Fig.4**.

From this result, the crack growth by the proposed method accorded with that of actual measurement within 5% until May 19. However, as more time has passed since the specimen was attached, the estimated value with the proposed method becomes lower than the measured one and error tends to increase.

It is considered that the error is caused by a decrease of axial force in the bolt, that may be caused by the passage of time. This problem must be studied much more.

7. Closing Remarks

This paper proposes a method to monitor the accumulative traffic loads and the accumulative fatigue damage on bridge members. In the proposed method, a Sacrificial Test Piece is used. The accumulative traffic loads are calculated by Paris's law and measured crack growth on the Sacrificial Test Piece.

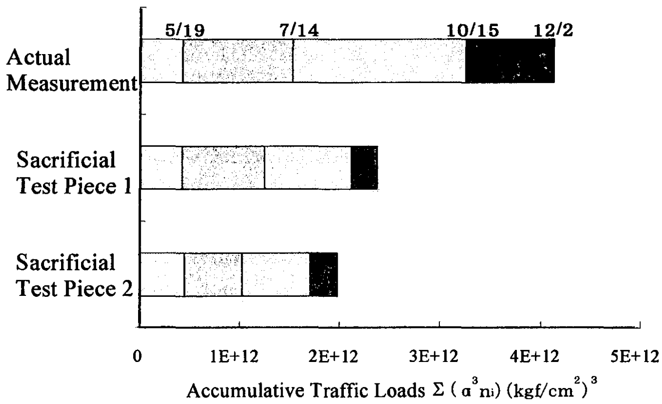

Fig.4 Comparison of Accumulative traffic Loads

By using this method, the accumulative traffic loads can be estimated with lower cost than by conventional methods, and the estimated values show good agreement with conventional one. One month after attachment of the specimen, the error between the values obtained by the proposed and by conventional methods is within 5 %.

For practical use, some problems remain before this method can be fully implemented, but it is considered that the possibility for practical use of the proposed method is good.

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