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

SAKINO Yoshihiro*, KIM You-Chul** and HORIKAWA Kohsuke***

Abstract

The purpose of this study is to show the practical applicability of "the Sacrificial Test Piece" for monitoring the accumulative traffic loads on bridge members. In this Report, the applicable range of notch length and crack propagation properties of the Sacrificial Test Pieces are obtained from experiments. And we veriy that the accumulative traffic loads under constant amplitude loading can be carried out by the crack growth of the Sacrificial Test Piece.

KEY WORDS: (Fatigue) (Bridge Maintenance) (Fatigue Damage Parameter)(Crack Growth) (The Sacrificial Test Piece)

1. Introduction

"The Sacrificial Test Piece" is used as a specimen attached to the member of a main structure in order to evaluate the damage before the appearance of a crack in a member of main structure. The Sacrificial Test Piece is designed so that it is damaged earlier than the main members under the same loads because of its crack and stress magnification. The damage to the bridge members can be estimated by the observation of the Sacrificial Test Piece.[1)-4)]

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

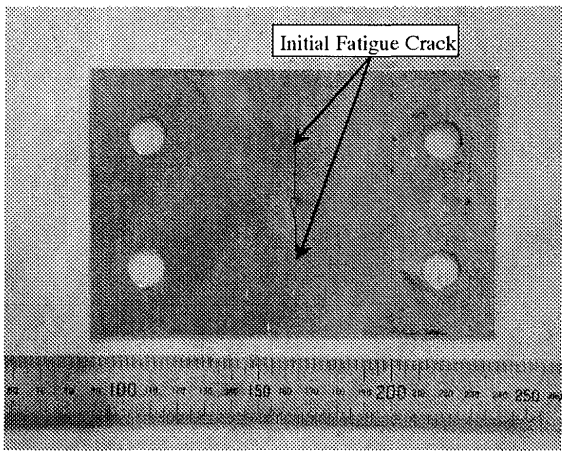

Fig.1 Sacrificial test pieces

As shown in **Fig.1**, thin steel plates, which have initial cracks at the center, are used as the Sacrificial Test Pieces in this study.[1)-4)] 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 bridge can be carried out by the observation of the crack growth in the Sacrificial Test Piece.

2. Monitoring of Accumulative Traffic Loads

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

$$\sum\left(\sigma_i{}^m n_i\right) \qquad (1)$$

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

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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, which is generated by the stress component, is expressed by Paris' law as follows;

$$\frac{da}{dn} = AK^m \qquad (2)$$

where a is the crack growth, A and m are constants, and K is the stress intensity factor.
3) The stress intensity factor coefficient under constant displacement amplitude can be expressed as follows;

$$K_i = B\sigma_i \qquad (3)$$

where B is a constant. Eq.(3) 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.(3) in eq.(2), produces eq.(4);

$$\frac{da_i}{dn_i} = A\left(B\sigma_i\right)^m \qquad (4)$$

It is assumed that m is approximately 3 for steel. It follows from eq.(4), that;

$$a_i = AB^m\left(\sigma_i{}^m n_i\right) \qquad (5)$$

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

$$\sum\left(\sigma_i{}^m n_i\right) = a/AB^m \qquad (6)$$

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.(6).

3. Application to Bridge Members

The Sacrificial Test Piece has been attached to four steel jig-plates by some bolts. The shape and the dimension of the jig-plates are shown in **Fig.2**. The thickness of the Sacrificial Test Piece is 0.5 mm, and the thickness of one side edge of the jig-plate is 12mm and other part of the jig-plate is 10mm. Using the jig-plates, a strain between the connected points is concentrated at

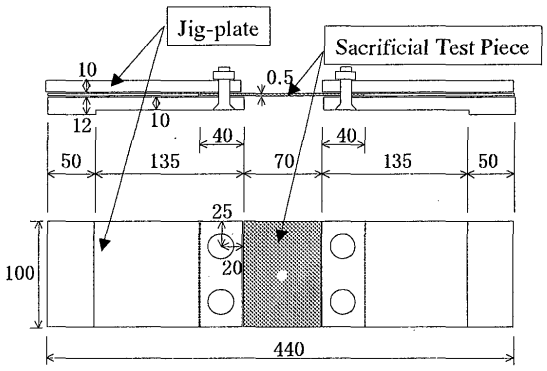

Fig.2 Sacrificial test pieces with jig-plate

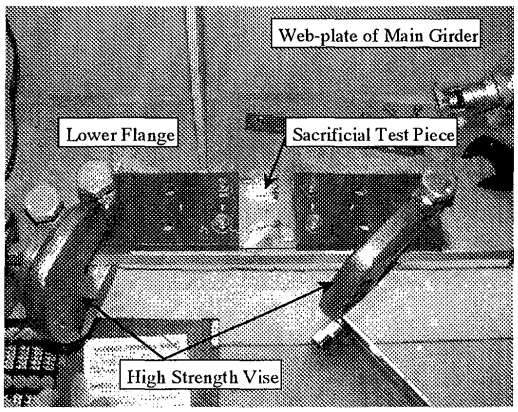

Fig.3 Example of attachment to lower flanges of a highway bridge

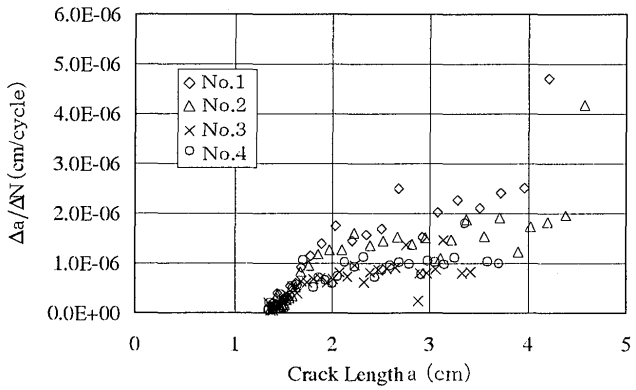

Fig.4 Δa/ΔN-a relationship (Δσ=60MPa)

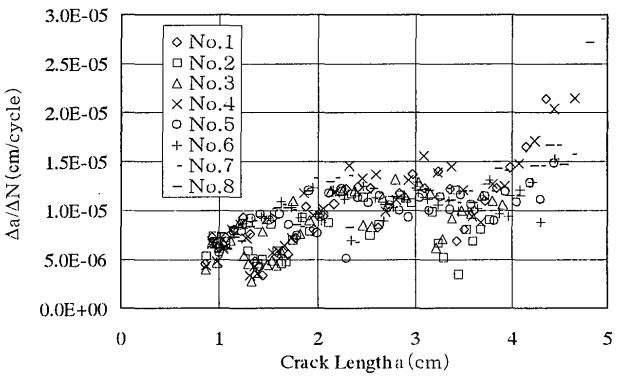

Fig.5 Δa/ΔN-a relationship (Δσ=120MPa)

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 about 3 times that of the flange by theoretical calculation. This strain concentration makes the crack growth faster, and the measurement in bridge members can be carried out in short period.

To avoid compression loading on the Sacrificial Test piece by uplift of the bridge member, pre-tensile stress 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 stress will be forced into the Sacrificial Test Piece because of thermal deformation.

The specimen is attached on the lower flange of bridge members by high strength vices at the edge of the jig-plates, as shown in **Fig.3**. The high strength vices are often used on site for rigid fixing, and the vice is tightened up using a torque wrench.

4. Applicable Range of Crack Length

As one can see from eq.(4), crack propagation velocity "da/dn" is not affected by crack length "a". So crack propagation velocity should remain stable under constant stress amplitude in all ranges. But eq.(3) is valid only in the case that both of the plate width and the crack length are infinity. The plate width and the crack length in the Sacrificial Test Piece are not infinity, so we should make clear the applicable range of crack length that eq.(3) and eq.(4) can be valid.

Figure 4 and **Fig. 5** show examples of relationship between the crack propagation velocity and the crack length under constant stress amplitude. The crack propagation velocity from 2cm to 4cm of the crack length remains approximately stable. It can be said that the applicable range of the crack length in the Sacrificial Test Piece is from 2cm to 4cm.

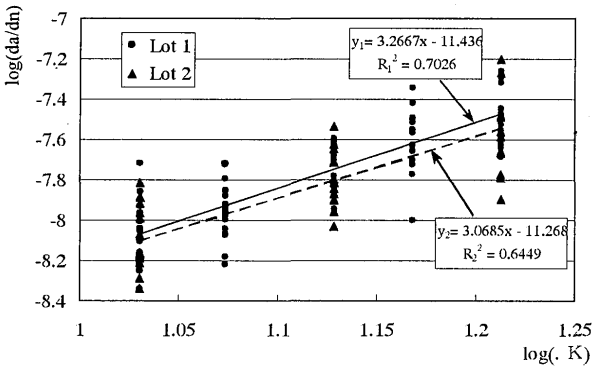

Fig.6 da/dn – ΔK relationship

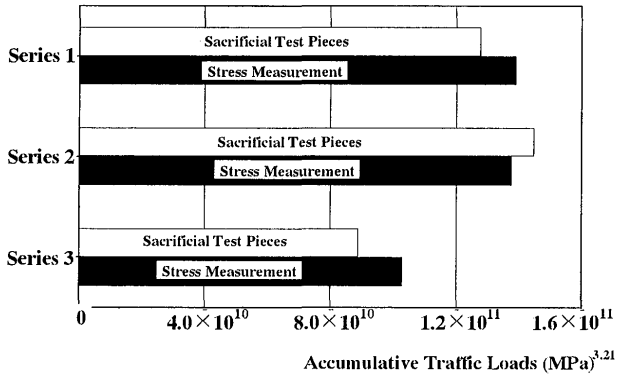

Fig.7 Comparisons of accumulative traffic loads measured by sacrificial test pieces and stress measurement under constant amplitude loads

5. Crack Propagation Properties under Constant Amplitude Loading

Figure 6 shows relationships between the crack propagation velocity and the stress intensity factor in the Sacrificial Test Piece. From these results, it can be said that the Paris' law, eq.(2), can also apply to the Sacrificial Test Piece. And we also obtain values of m and A used in eq.(6) from these experimental results.

In **Fig.7**, the accumulative traffic loads measured and calculated by the crack length of the Sacrificial Test Pieces under constant amplitude loading are compared with those calculated by the stress amplitude and loading times (Stress Measurement). They approximately agree, so it is demonstrated that the Sacrificial Test Piece can estimate the accumulative traffic loads accurately under constant amplitude loading.

6. Monitoring under Fluctuating Amplitude Loading

Figure 8 shows some experimental results under fluctuating amplitude loading. A gradual increase-decrease cycle, which has 170,000 times of frequency per a cycle, is used in this experiment. The stress frequencies, which are measured by the site experiment in the highway bridge, are used. Under this pattern of fluctuating amplitude loading, the accumulative traffic measured by the Sacrificial Test Pieces agrees well with those by stress measurement. But more experiments under other patterns of fluctuating amplitude loading and

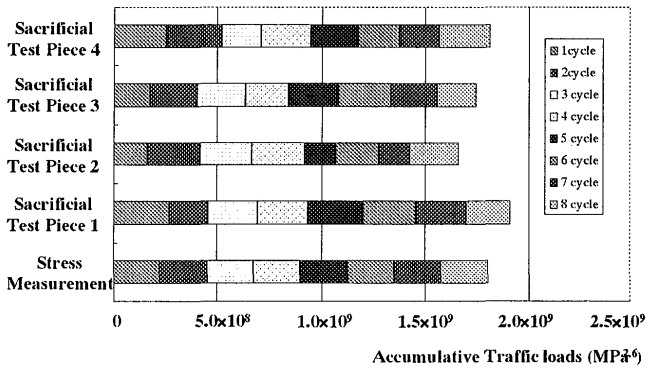

Fig.8 Comparisons of sacrificial test pieces and stress measurement under fluctuating amplitude loads

more considerations will be needed to verify that the Sacrificial Test Piece can estimate the evaluate accumulative traffic loads accurately under fluctuating stress amplitude loading.

7. Closing Remarks

We propose a method to monitor the accumulative traffic loads on bridge members by the Sacrificial Test Piece. By using this method, the accumulative traffic loads can be estimated with lower cost than by conventional methods. In this repot, the applicable range of notch length and crack propagation properties of the Sacrificial Test Pieces are obtained by experiment. And we have verified that the accumulative traffic loads under constant amplitude loading can be carried out by monitoring the crack growth of the Sacrificial Test Piece. A part of the experiments under fluctuating amplitude loading are shon, but more experiments under other patterns of fluctuating amplitude loading and more considerations will be needed.

Acknowledgments

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