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Fatigue of Cross Beam Connections in Steel Bridges

Fatigue des liaisons traverses-poutres principales des ponts en acier

Ermüdung der Querträger-Anschlüsse bei Stahlbrücken

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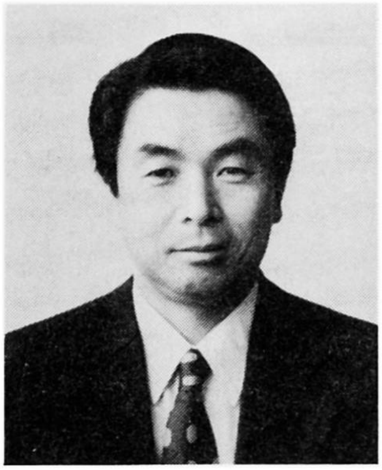

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SUMMARY
Fatigue cracks are often initiated at the connections of cross beams to main girders in plate girder bridges. The stress states at the cross beam connections are revealed by the static loading test of an actual plate girder bridge. The local stresses which induce fatigue cracks are related quantitatively to the three-dimensional behavior of the bridge.

RÉSUMÉ
Les fissures de fatigue apparaissent souvent dans les liaisons entre les traverses et les poutres principales de ponts à poutres métalliques. L'état des contraintes dans la liaison est donné par un essai de charge statique d'un pont en service. Les contraintes locales qui provoquent les fissures de fatigue dépendent du comportement tridimensionnel du pont.

ZUSAMMENFASSUNG
Bei Vollwandbalkenbrücken sind zwischen den Quer- und den Haupttträgern oft Ermüdungsrisse vorhanden. Die Spannungszustände wurden im statischen Belastungsversuch an einer Vollwandbalkenbrücke im Gebrauchszustand untersucht. Die lokalen Spannungen, die die Ermüdungsrisse hervorrufen, hängen qualitativ mit dem dreidimensionalen Verhalten der Brücke zusammen.

1. INTRODUCTION

In many steel bridges, fatigue cracks are observed at the connections of main members with secondary members such as cross beams, sway bracings and lateral bracings [1]. Such fatigue cracks are caused by locally induced stresses not generally considered in the bridge design practice. Usually it is very difficult to predict the local stresses, because they are produced by the three-dimensional behavior of the bridge.

This paper deals with the relation between the local stresses and the three-dimensional behavior of plate girder bridges. In plate girder bridges, as shown in Fig.1, the following four types of fatigue cracks are detected at the connections of cross beams to main girders [2]:

Type 1: This is initiated either on the bead or at the toe of the end return of the fillet weld between the connection plate and the top flange of the main girder.
Type 2: This is initiated at the upper scallop of the connection plate, and grows diagonally through the connection plate itself.
Type 3: This is initiated at the toe of the end return of the fillet weld connecting the connection plate to the main girder web, and grows downward along the toe on the connection plate side.
Type 4: This is initiated and grows along the toe on the web side of the fillet weld between the top flange and the web of the main girder.

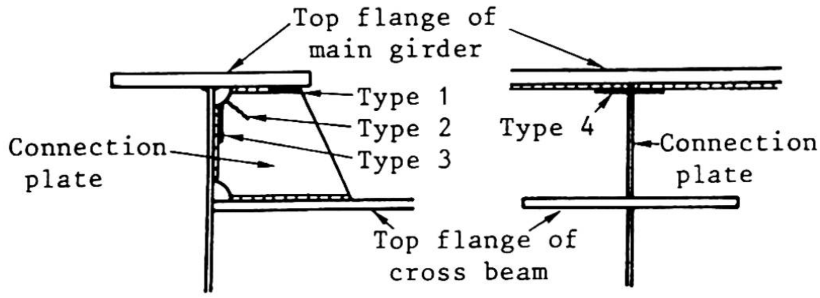

Fig.1 Fatigue cracks at cross beam connection

The difference in vertical displacement between main girders and the deformation of a concrete slab are pointed out as the main cause of the fatigue cracks [3,4]. However, until now it is not clear how these factors are related to the local stresses which induce the fatigue cracks.

2. STRESS MEASUREMENT OF PLATE GIRDER BRIDGE

2.1 General View of Plate Girder Bridge

In order to know the stress states at cross beam connections in plate girder bridges, stress measurement of an actual plate girder bridge shown in Fig.2 has been carried out [5]. It is a simply-supported composite plate girder bridge with a span length of 28.4 m and total width of 17.6 m, which was designed by the Japanese Specification for Highway Bridges. The bridge has five main girders, a cross beam in the middle of the span and six sway bracings. The concrete slab is 180 mm thick. The bridge was opened to traffic in 1970. Repair and reinforcement works for the slab were done in 1979. A steel plate 4.5 mm thick was attached to the bottom surface of the slab, and some stringers were installed, as shown by dotted lines in Fig.2.

The loading truck and its loading positions are shown in Figs.3 and 4, respectively. Four cases of A, B, C and D were considered according to the intervals

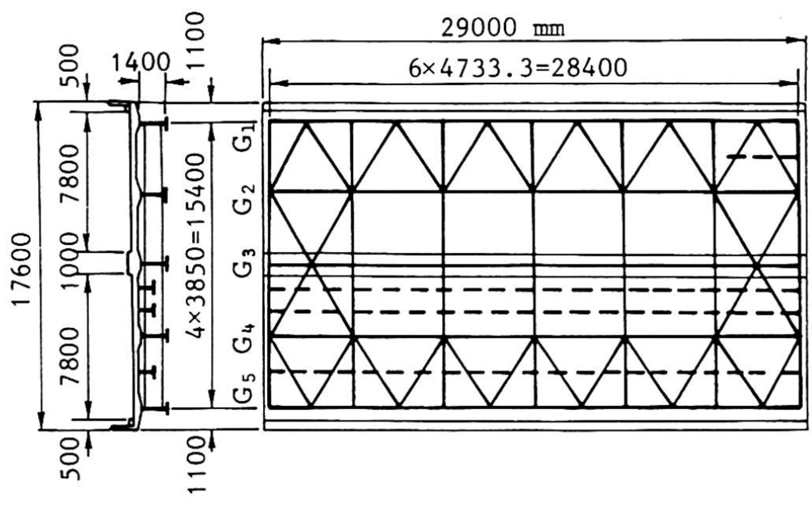

Fig.2 General view of plate girder bridge

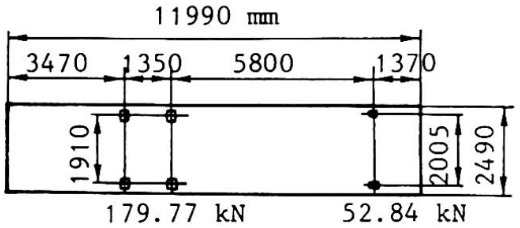

Fig.3 Loading truck

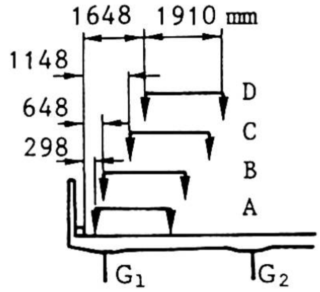

Fig.4 Loading positions of truck

between the coping and the center of the rear double-tires on the left side. The static stress measurement was done at 11 locations in the longitudinal bridge-axis direction for each loading case. 24 one-directional, 214 two-directional and 126 three-directional strain gauges were attached on the cross beam connections at G_1 and G_2 girders.

2.2 Stress States at Connection Plates

The stress measurement results show that the plate-bending strains are much smaller than the membrane ones at the connection plates. Accordingly, the membrane stress is considered to be influential for the initiation of Types 1, 2 and 3 fatigue cracks. Figure 5 shows the principal membrane stresses when the center of the rear two wheel axles exists just above the cross beam in the loading case D. A relatively large compressive principal stress occurs around the

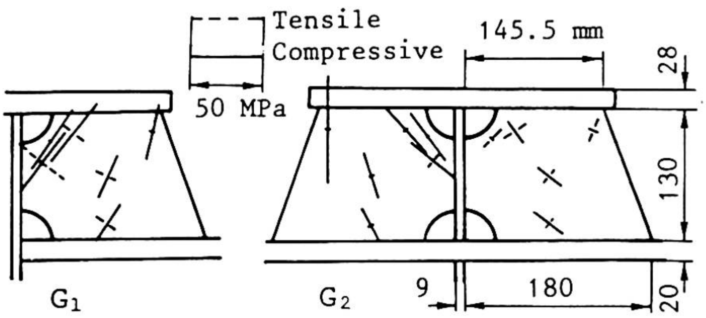

Fig.5 Principal membrane stresses of connection plates

scallop of the connection plate of G_1 girder and also at the left edge of the left connection plate of G_2 girder. The direction of the principal stress at the connection plate edge is almost vertical, and it is perpendicular to the direction of the propagation of Type 1 fatigue crack.

2.3 Stress States at Main Girder Webs

Referring to Fig.6, the components of plate-bending stress σ_{by} and membrane stress σ_{my} are significant for Type 4 fatigue crack, because they act perpendicularly to the direction of the propagation of the crack. Figure 7 shows the distributions of σ_{by} and σ_{my} along the x-axis at y=16 mm from the bottom surface of the flange plate. The plate-bending stress σ_{by} takes the large values between the connection plate at x=0 and the tip of the top flange of the cross beam at the section I-I (x=225 mm), and increases gradually toward the connection plate. The membrane stress σ_{my} changes sharply from compressive to tensile stress in the very vicinity of the connection plate. The ratios of σ_{my} to σ_{by} at the point of x=24.5 mm and y=16 mm where the strain gauges were glued nearest to the connection plate, vary from 20 % to 26 % depending on the loading cases.

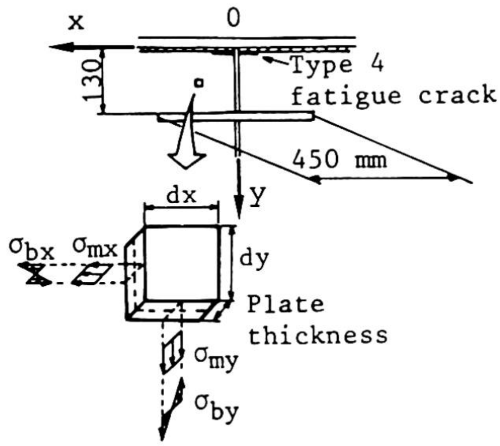

Fig.6 Stress components near Type 4 fatigue crack

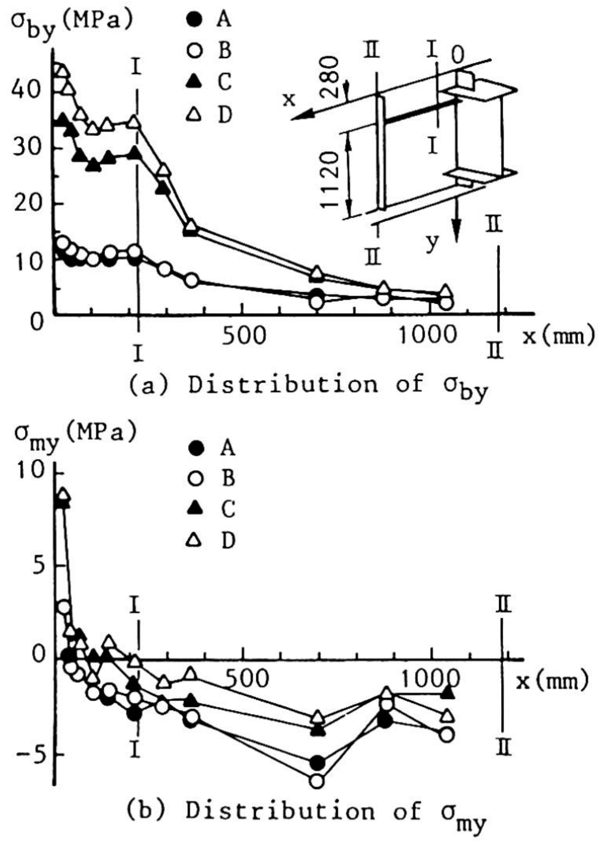

Fig.7 Distributions of σ_{by} and σ_{my} along the x-axis at y=16 mm of G_1 girder web

3. ESTIMATION OF LOCAL STRESSES

From the stress measurement of a plate girder bridge, the membrane stress σ_{my} and the plate-bending stress σ_{by} illustrated in Fig.8 are the governing stresses for the initiation of Types 1 and 4 fatigue cracks, respectively. Referring to Fig.9, they are caused by the respective rotations θ_s and θ_g of the concrete slab and cross beam and by their respective horizontal displacements u_s and u_g. Through the plate-bending analysis of the slab and the three-dimensional F.E.M. analysis of the whole bridge, the equation to estimate the local stresses of

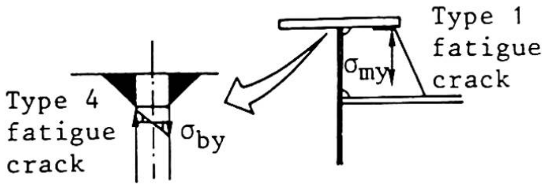

Fig.8 Fatigue crack types and local stresses

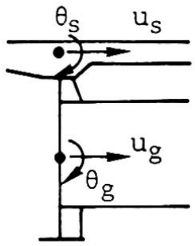

Fig.9 Notation

σ_{my} and σ_{by} has been obtained as follows:

$$\begin{bmatrix} \sigma_{my} \\ \sigma_{by} \end{bmatrix} = \begin{bmatrix} k_{m1} & k_{m3}(\gamma - k_{m123}) \\ k_{b1} & k_{b3}(\gamma - k_{b123}) \end{bmatrix} \begin{bmatrix} \theta_{s0} \\ \theta_g \end{bmatrix} \tag{1}$$

where θ_{s0} is the rotation of a slab due to its plate-bending deformation excluding the deformation of the slab produced by the different vertical deflections of main girders, θ_g is the rotation of a cross beam caused by the different vertical deflections of main girders, γ is a coefficient defined by $(u_s - u_g)/\theta_g$ and it takes different values depending on the positions of the truck loading along the width of the roadway, and k_{m1}, k_{m3}, k_{m123}, k_{b1}, k_{b3} and k_{b123} are coefficients which relate the local stresses σ_{my} and σ_{by} to the corresponding rotations θ_{s0} and θ_g [6].

Figure 10 shows a comparison of the values estimated by Eq.(1) with the measured ones when the loading truck moves along the longitudinal bridge-axis in the loading case D. It can be seen that Eq.(1) is very close to the measured values.

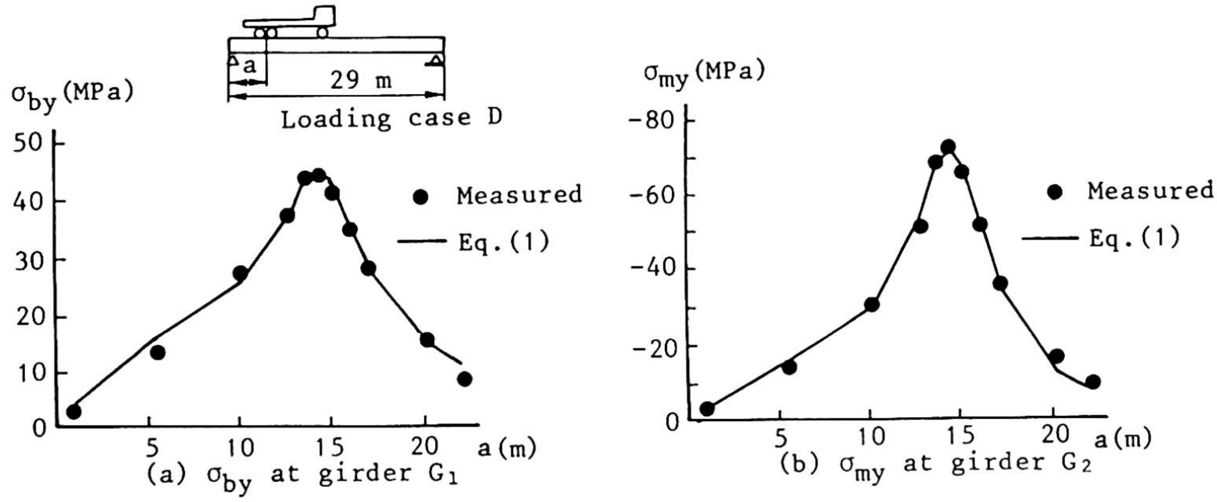

Fig.10 Comparisons between the values by Eq.(1) and the measured ones

Figure 11, which has been theoretically obtained by Eq.(1), shows the effects of the rotations θ_{s0} and θ_g on the local stresses σ_{by} and σ_{my} when a concentrated load P=9.81 kN moves on the slab along the cross beam between G1 and G2 girders. When the load is in the middle part between G1 and G2 girders, σ_{by} can be mainly induced by the term θ_{s0}, and on the contrary, when it moves near G1 or G2 girder, σ_{by} mainly induced by the term θ_g. The membrane stress σ_{my} is mainly induced by the term θ_{s0}. That is, the rotations of a slab due to its plate-bending deformation and of a cross beam caused by the different vertical deflections of main girders are equally influential for Type 4 fatigue crack, while only the former has a great influence on Type 1 fatigue crack.

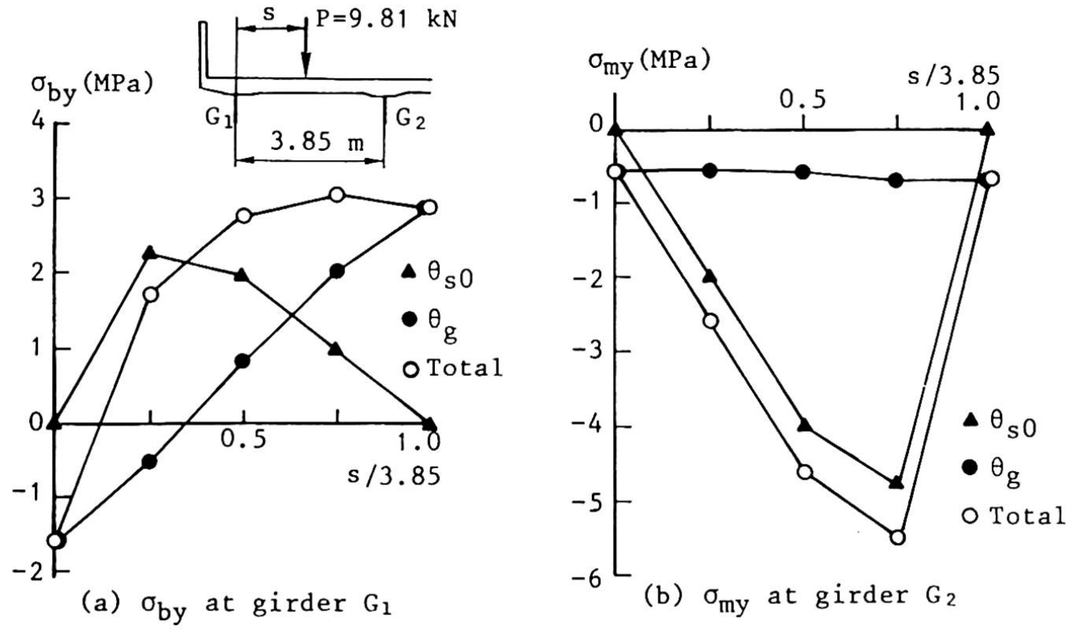

Fig.11 Effects of θ_{s0} and θ_g on σ_{by} and σ_{my}

4. CONCLUSIONS

In this paper, the stress states at the connections of cross beams to main girders in plate girder bridges were revealed by the static loading test of an actual plate girder bridge. The local stresses which induce fatigue cracks were related quantitatively to the three-dimensional behavior of the bridge.

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