Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 57/1/57/2 (1989)

Artikel: Method of repair for fatigue damage in steel bridges
Autor: Natori, Tohru / Fukazawa, Makoto / Terada, Hiromasa
DOI: https://doi.org/10.5169/seals-44320

Method of Repair for Fatigue Damage in Steel Bridges

Méthode de réparation de fissures par fatigue des ponts métalliques

Verfahren zur Reparatur von Ermüdungsschäden an Stahlbrücken

Tohru NATORI
Research Engineer
Yokogawa Bridge Works, Ltd
Chiba, Japan

Makoto FUKAZAWA
Senior Res. Eng.
Yokogawa Bridge Works, Ltd
Chiba, Japan

Hiromasa TERADA
Mgr, Res. Lab.
Yokogawa Bridge Works, Ltd
Chiba, Japan

SUMMARY

Recently, steel highway bridges in Japan have suffered fatigue cracks. This paper deals with some cases of fatigue damage occurring in steel roadway bridges and the tungsten inert gas (TIG) arc remelting process being effective as a method of repairing such fatigue damage. It also includes discussions on detailed re-welding procedure, optimum condition and effects of retrofitting on the fatigue strength.

RÉSUMÉ

Récemment, les ponts routiers métalliques au Japon subissent des fissurations par fatigue. Cette communication présente certains exemples de dommages par fatigue survenus dans les ponts routiers métalliques, ainsi que le procédé de refusion à l'arc avec électrode de tungstène sous gaz inerte (TIG), procédé effectif pour la réparation de tels dommages par fatigue. Elle traite également la procédure détaillée de resoudage, la condition optimale du rétro-ajustement et ses effets sur la résistance à la fatigue.

ZUSAMMENFASSUNG

In letzter Zeit hat man in Japan Rissschäden an Strassenbrücken aus Stahl festgestell. Die vorliegende Abhandlung behandelt verschiedene Fälle von Ermüdungsschäden an Strassenbrücken aus Stahl sowie die wirksame Anwendung des Wolfram-Inertgas-Lichtbogenschweissverfahrens (WIG) zum Ausbessern solcher Ermüdungsschäden. Weiter werden das Nachschweissverfahren in seinen Einzelheiten und die optimalen Bedingungen sowie die Auswirkungen einer Nachrüstung auf die Dauerfestigkeit diskutiert.

1. INTRODUCTION

Recently, fatigue cracking has damaged steel highway bridges in Japan. It has resulted from higher volume of traffic and heavier truck weight than originally anticipated, lower rigidity of floor systems and a lack of attention to fatigue cracking on welded connections in the design stage.

Fatigue damage appears first in the reinforced concrete floor slab 5 to 10 years after the bridge commences service. Over a period of 15 years, fatigue crack begins to be detected mainly at the toe and/or bead surface of the boxing-welds on connection plates [1]. Investigations and analyses have revealed how cracking occurs. However, a question arises frequently as to what is a proper method of repairing or retrofitting the damaged structure because of the absence of past experience in this regard in Japan.

The strengthening of a cracking detail by welding a new member in the field appears to result in "defective repair," as reported in U.S.A. [2], and there is a possibility of new fatigue cracks being induced due to a change in the stress distribution by splicing plates. Therefore, repair using the tungsten inert gas (TIG) arc remelting process seems to be effective.

This paper deals with the status quo of the fatigue cracks in Japan, how to apply the TIG arc remelting process, a detailed method of re-welding, optimum condition, and effects of retrofitting on the fatigue strength.

2. CASES OF FATIGUE DAMAGE

The cases of fatigue damage reported to have developed in many of the steel highway bridges in Japan are shown in Fig. 1. Most fatigue cracking has concentrated at the secondary members such as the transverse stiffeners with sway bracing members, and gusset plates with lateral bracing members.

These members are not subject to a safety verification for fatigue resistance in ordinary

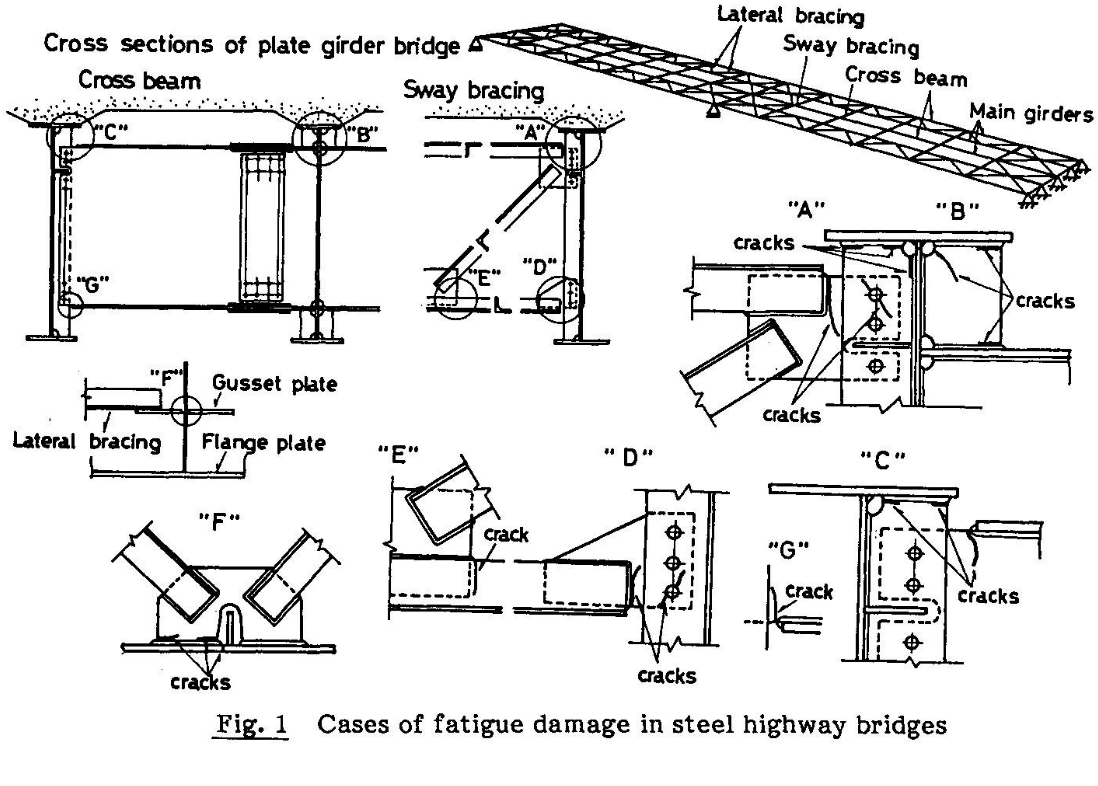
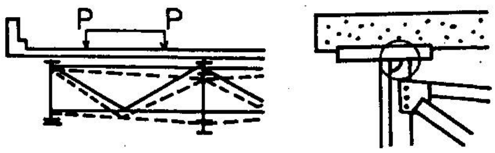


Fig. 1 Cases of fatigue damage in steel highway bridges

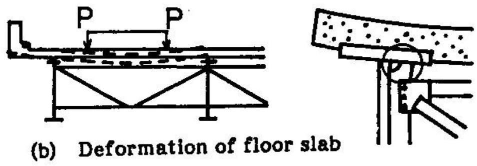
design practice, and these details were applied to the steel highway bridges as the standard details until the early 1970s.

Examining the locations of fatigue damage by the type of joint connection, the majority have developed in the welded joints, particularly in the fillet-welded joints.

Of the cracks, those that have developed at the toes of fillet-welded joints, which connect the transverse stiffeners to the upper flanges or the webs of girders with sway bracings, are numerous and the most typical in Japan's highway bridges. Such a crack is characteristic in that it occurs simultaneously in the bridges of same structural type with identical weight, traffic volume, and speeds of traveling vehicles. This situation urges the need for clarification of the cause of crack occurrence and the development of reliable methods of repairing and strengthening. The probable cause of crack occurrence that can be considered at present is that, as shown in Fig. 2, it is generated by the local stresses due to the differences in deflection of the main girders with sway bracing members and the deformation of reinforced concrete floor slabs [3]. The properties of these local stresses, however, would vary with such factors as the spacing between the main girders, the thickness of the deck, the construction of the transverse stiffeners or sway bracings, and the location of traffic lanes.



(a) Difference in deflection of main girders



(b) Deformation of floor slab

Fig. 2 Probable cause of local stress occurrence

3. RETROFITTING OF FATIGUE-DAMAGED DETAILS

3.1 Repair Methods

In retrofitting of fatigue-damaged bridge members, it is necessary to investigate the causes of crack occurrence and extent of damage to determine a repair method capable of eliminating the causes.

The idea of preventing the occurrence of fatigue damage, and also its repair, consists of two cases; one is to reduce the stresses that are generated in the damaged member under live load and the other is to enhance the fatigue strength of the damaged member. In the former case, it is necessary to change the type of structure or details. In the case of applying it to the existing structure, achieving a construction or joint, and considering on-site workability, is very often difficult.

Most fatigue damage occurs at welded joints, initiating often from the toes of fillet-welded joints where stresses are highly concentrated. As shown in Fig. 3, the crack develops from boxing-welded joints. In many cases, cracks that occur at such locations are relatively small in size, and the extent of damage is also minor. In such a case, an effective method would be to carry out the repair welding of only the damaged area, followed by smoothing the weld toe to increase the fatigue strength of the joint.

The tungsten inert gas (TIG) arc remelting process is shown in Fig. 4. TIG remelting process is usually used to finish the weld toe by smoothing its shape by melting the toe with a non-consumable tungsten electrode. This process surpasses grinding finish in work execution time and cost. Also, with cracks already developed, the use of the TIG process would be effective to remelt the fatigue crack into the base metal. Primarily this process was applied to

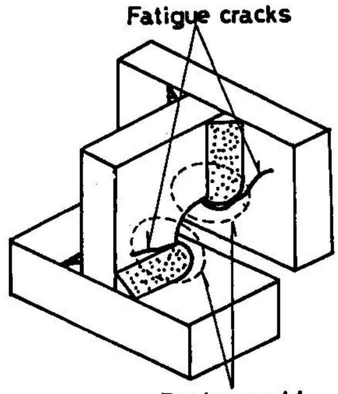


Fig. 3 Fatigue cracking initiated at boxing-welds

offshore structures, though it has been applied also to bridge fatigue damage recently [4][5].

The remelting equipment ordinarily used is driven by DC power with drooping V-I characteristics. A high frequency source is used to generate arc. The electrode is 3.2mm or 4.0mm in diameter and composed of 2 percent thoriated tungsten. The shielding gas is 100% argon. The welding unit is equipped with a water tank and a recirculating pump to cool the torch.

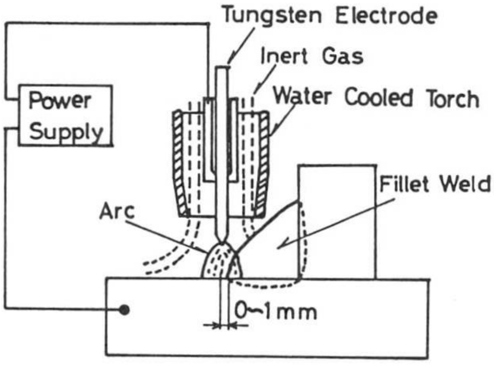


Fig. 4 TIG arc remelting process

Experience in laboratory and field has proved that few-hour training is all that required to achieve the desired retrofit condition. The results of in-situ retrofitting test revealed that a small change in the arc length due to the vibration of the bridge did not affect the TIG remelt, and under the normal service conditions, the flow of traffic was not disrupted.

3.2 Effects of the TIG Process

The possible mechanism of increasing the fatigue strength by means of the TIG process is to reshape the profile of the weld toe and to increase the tensile strength with an increased hardness of the TIG processed area. TIG process was applied to the boxing-toe of fillet weld as shown in Fig. 5, so as to examine the profile of weld toe and depth of penetration. The specimen was sectioned, polished and etched after the performance of TIG remelting. Fig. 6 (a) and (b) show the appearances and macroscopic photographs of boxing-toes. The remelting conditions are shown in Table 1. The remelting of all welds was performed at the flat position. Although there seems no difference in the appearances of bead surfaces shown in Fig. 6 (a), the weld toe was smoothed by the TIG process as shown in the macroscopic photographs. Thus, the application of the TIG process enables the profile

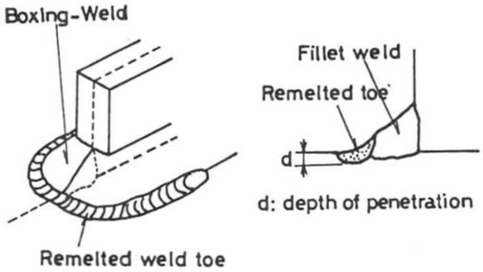
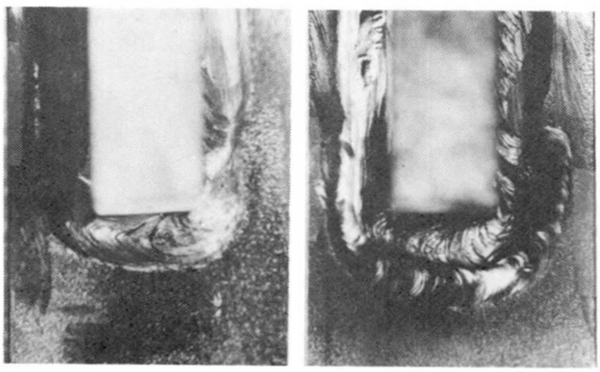


Fig. 5 TIG process at a boxing-weld

Table 1 TIG arc remelting condition

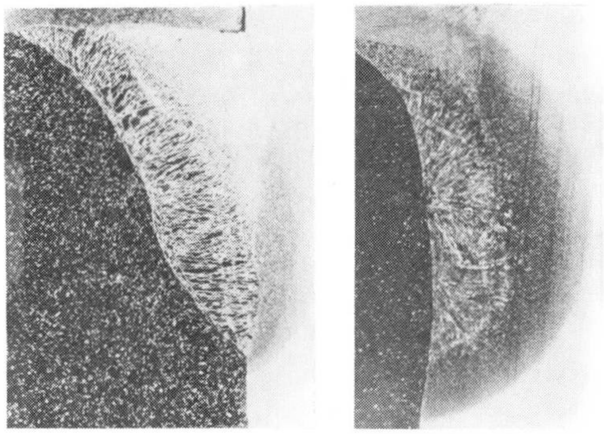
polarity	dirrect current electrode negative
electrode	2% thoriated tungsten (3.2mm ϕ)
welding position	flat position
current	240 A
speed	50s / 100mm
flow rate of gas	10l / mm (argon)



As-welded TIG-remelted

Fig. 6(a) Appearance of bead surface at a boxing-weld of the weld toe to reduce the magnitude of stress concentration, thereby preventing the occurrence of cracking at the weld toe. Fig. 7 shows the results of measuring the Vickers' hardness near the weld toe before and after the application of the TIG process. While the maximum hardness before the TIG process is H_∇ = 240, that after the process is H_∇ = 275, indicating an increase in the hardness. This could be another factor in improving the fatigue strength.

In the case of remelting to remove the fatigue crack by TIG process, the depth of remelt penetration is an important factor for the effectiveness of retrofitting. Being evident from Fig. 6(b), 2.5mm is the approximate remeltage by the TIG process, and cracks with a depth less than 2mm can be removed by the TIG process. On the other hand, the crack that occurs at the fillet-weld toe is semi-elliptic in the early stage of crack growth. As shown in Fig. 8, the ratio of its surface length ℓ to depth a is a/ℓ = 1/5. Thus, with cracks less than 10mm in length, it is possible to estimate that their depth is less than 2mm. By the current magnetic particle examination, it is fully possible to detect a crack with a surface length of about 10mm. Furthermore, the estimated crack length corresponds well to the actual crack length [6]. Therefore, with the crack length measured in advance by the magnetic particle examination, on finding that its length is less than 10mm, the crack can be removed by TIG process.



As-welded TIG-remelted

Fig. 6(b) Macroscopic photographs of boxing-weld

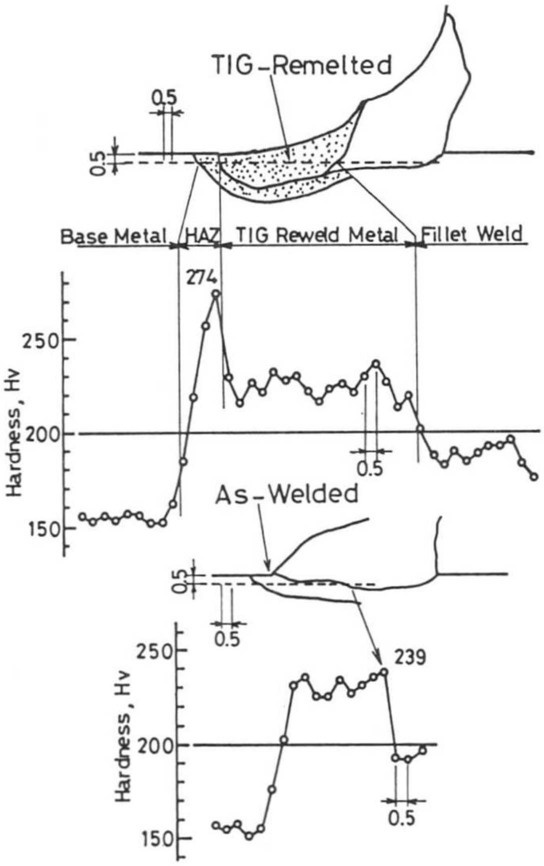


Fig. 7 Vickers' hardness near a boxing-weld toe

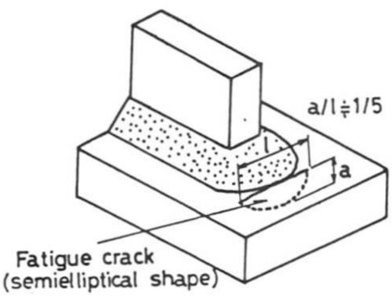


Fig. 8 The profile of the fatigue crack

In addition, the remelting position slightly affects the depth of reweld penetration. In the case of remelting at the overhead position, cracks smaller than approximately 2.0mm deep can be removed.

References

(1) MIKI, C., SAKANO, M., TATEISHI, K., FUKUOKA, Y., Data Base for Fatigue Cracking in Steel Bridges. Proc. of JSCE, No. 392, 1988.

(2) PENSE, A.W., DIAS R. and FISHER, J.W., Examination and Repair of Bridge Structure, Welding Journal, Vol. 63. No. 4, 1984.

(3) S. KATO, O. YOSHIKAWA, H. TERADA and Y. MATSUMOTO, Studies on Fatigue Damages Based on Strain Measurements of a Highway Bridge, Proc. of JSCE Struct. Eng. 1 Earthg. Eng., Vol. 2. 1985.

(4) M. HANZAWA, H. ISHIGURO, T., Improvement of Fatigue Strength in Welded High Tensile Strength Steels by Toe Treatment, IIW-Document XIII-829-77, 1977.

(5) FISHER, J.W., Fatigue and Fracture in Steel Bridges, JOH WILEY & SONS, 1984.

(6) C. MIKI, M. FUKAZAWA, M. KATOH, H. OHUNE, Feasibility Study on Non-destructive Methods for Fatigue Crack Detection in Steel Bridge Members, IIW V-874, 1988.