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Fatigue of Nodal Joints and Box-Section Members in a Bridge Truss

Fatigue des joints soudés, des membrures en caisson dans un pont à poutres en treillis

Ermüdungsfestigkeit von Schweissverbindungen in den Gurten eines Brücken-Fachwerkträgers

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SUMMARY
This paper describes tests to verify the fatigue strength of welded joints in quenched and tempered high strength steel. Typical welded joints from a bridge truss were tested in a 400 t maximum capacity fatigue testing machine.

RESUME
Cet article décrit des essais destinés à vérifier la résistance à la fatigue des joints soudés en acier à haute résistance trempé et revenu. Des assemblages soudés typiques d'un pont à poutres en treillis ont été essayés au moyen d'une presse pour essais de fatigue dont la capacité maximale de charge dynamique est de 400 t.

ZUSAMMENFASSUNG
Der Beitrag behandelt die Ermüdungsfestigkeit geschweisster Verbindungen aus hochwertigem Stahl. Typische Schweissverbindungen von Fachwerkträgern wurden mit einer 400 t Presse für dynamische Lasten geprüft.

1. INTRODUCTION

The Kobe-Naruto and Kojima-Sakaide routes of the Honshu-Shikoku bridges in Japan are designed to be of the highway and railway combination type. Consequentry, fatigue due to live load will pose a problem of grave imfortanse. The fatigue design criteria had been set in 1974 [1][2] based on results of past fatigue tests on various joints. However, configurations and dimensions of test specimens in past tests were fairly restricted due to limitaions in the capacities of testing machines. Considering the scale of the actual structures which will use of maximum plate thickness of 75mm, it is necessary to verify the appropriateness of this fatigue design criteria using larger specimens and structural models. Accordingly, Honshu-Shikoku Bridge Authority has had a fatigue testing machine of capacity of 400 ton made and is now carrying out fatigue tests of joints and parts of structures. This paper describes the results of fatigue tests on partially penetrated longitudinal groove welded joint and non-loadcarring cruciform fillet welded joint which are typical weld joints of truss members, and box section members and truss panel point structures as their composite structures.

2. SPECIMENS

2.1 Joint Specimens

The mechanical properties of the steels used for joint specimens are shown in Table 1. Fig. 1 shows the configurations and dimensions of the specimens. The non-loadcarrying cruciform fillet welded joint (a) simulates the stress condition at the joint of a diaphragm attached to a chord member of a truss. Welding was done manually using an electrode exclusively for fillet welds

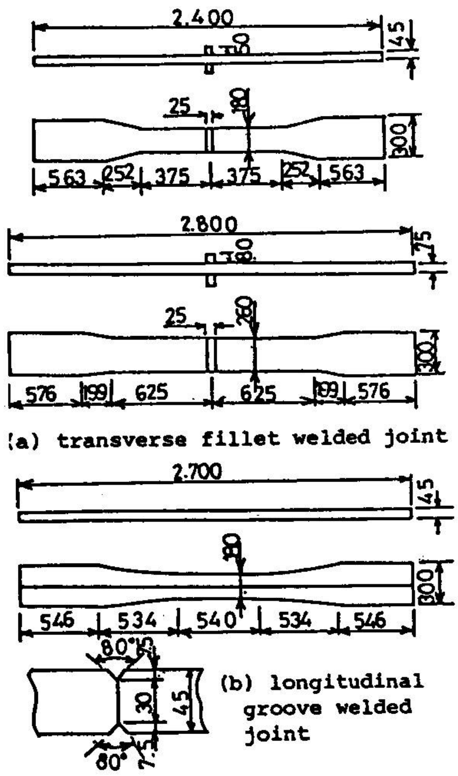


Fig. 1 Joint Specimen

Specimen	Steel	Thickness (mm)	Y.P (N/mm²)	T.S. (N/mm²)	El (%)
Joint Specimens	HT80	45	775	823	24
		75	813	862	24
Box Section BB, BA	HT80 (Flg.)	15	764	823	28
	(Web)		833	882	29
BD, BE, BF	HT80	15	794	843	26
Truss Panel Point A, B, C	HT80 (Flg.)	15	804	853	30
	HT80 (Web)	15	813	862	30
D, E, F	SM58	15	559	647	36
G	HT80	15	784	823	31
H	HT80	15	794	843	30

Table-1 Mechanical Properties of Steels

said to produce a regular bead shape as shown in Fig. 2. Leg length of fillet welds for 45mm thickness specimens and 75mm thickness specimens are 10mm (two paths) and 13mm (three paths) respectively. Partially penetrated longitudinal groove weld joint simulate for corner welds of truss members with box section. Welding was done using the submerged arc process.

2.2 Specimens of Box Section

The mechnical properties of the steels used for specimens of box section are shown in Table 1. Fig. 3 shows the configurations and dimensions of the specimens. Type BA has a diaphragm used SM41 steel at the center of the specimen, and other types have no diaphragm. Welding of the diaphragm was done manually using the same electrode used for joint specimens mentioned above. Corner Welding of these specimens were conducted with automatic welding. Kinds of welding are shown in Table 2. Three types, BB, BD, BF, were with partially penetrated groove welds and one type, BF, was with fillet welds.

2.3 Truss Panel Point Structures

The mechnical Properties of the steels used for truss panel point structures are shown in Table 1. Fatigue tests were performed using the loading apparatus shown in Fig. 4. The hatched portion in the figure represents a specimen. Fig. 5 gives details of the vicinities of panel points of eight varieties of test specimens. The major points of difference between the each types lie in the methods of connecting the diagonal members, the numbers of diaphragms and fillet radii of gusset plates. Corner welds of chord members were made by manual welding for the specimens A, B and C and by the submerged-arc welding for D, E, F, and G. Kinds of Corner welds are single bevel groove welds, and bevel angle is 45°, depth is 7.5mm for type A, B and C, 8mm for type D-G.

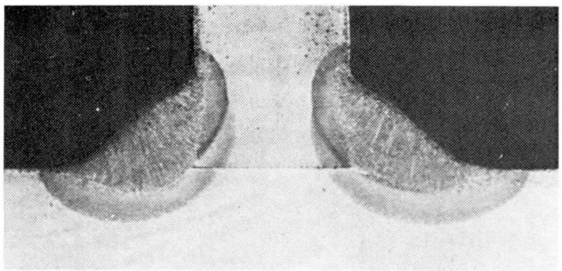


Fig. 2 Shapes of Fillet Welds

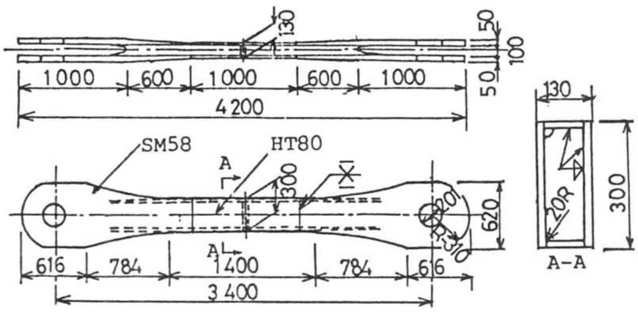


Fig. 3 Box Section Specimen

3. RESULTS OF TESTS AND DISCUSSIONS

3.1 Transverse Fillet Welds

Fig. 6 shows the results of fatigue tests on cruciform joint specimens, box-section specimens with diaphragm and panel point structures concerning about transverse fillet welds. Twelve cruciform joint specimens of t = 45mm and three cruciform joint specimens of t = 75mm

Type of T.P.	BA,BB	BD	BE	BF
Method of Weld	SAW (Single)	MIG	SAW (Double)	SAW (Single)
Kind of Joint	50°, 8, 15, 15	15, 95R, 8, 15, 15	50°, 8, 15, 15	15, 15, 8, 15
No. of Path	1	3	1	1

Table-2 Kinds of Corner Welding

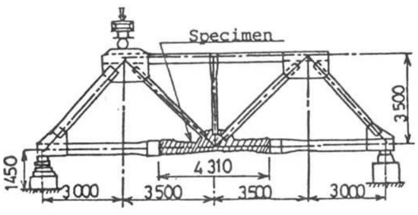


Fig. 4 Truss Type Loading Apparatus

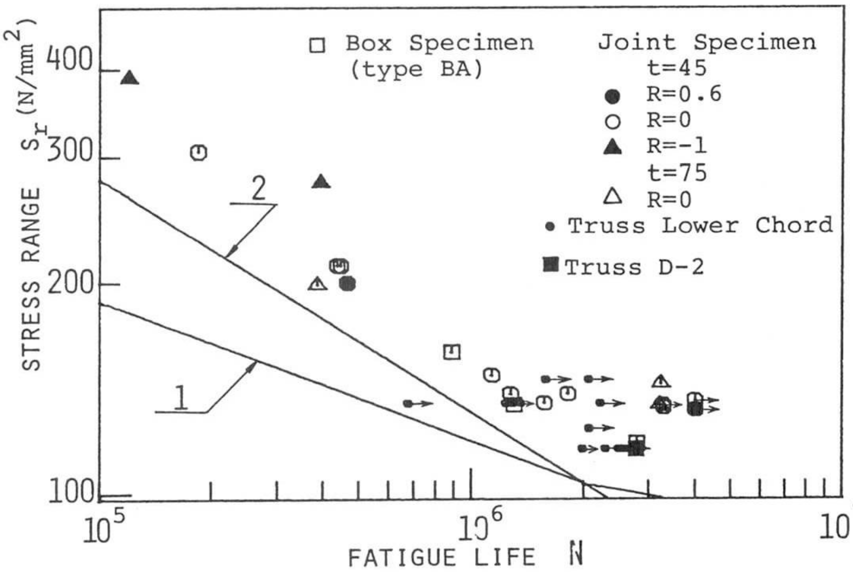
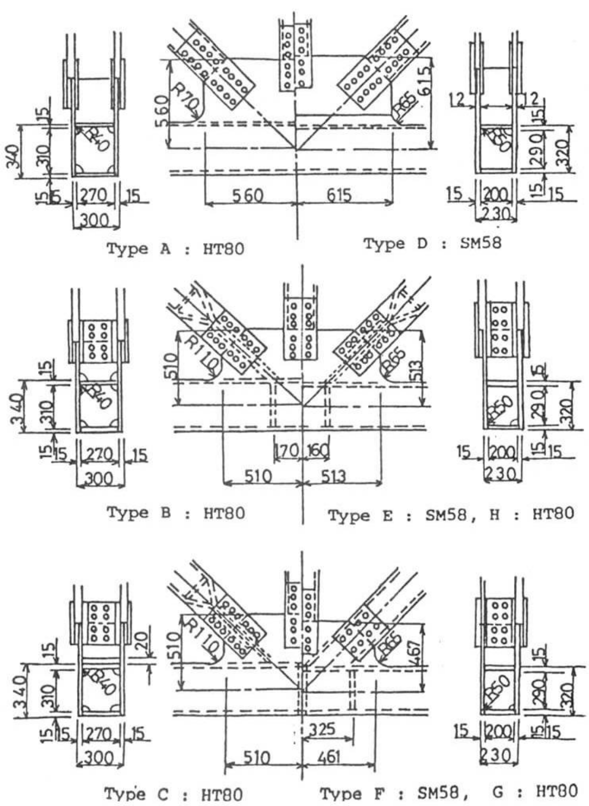


Fig. 6 Results of Fatigue Tests on Transverse Fillet Welds



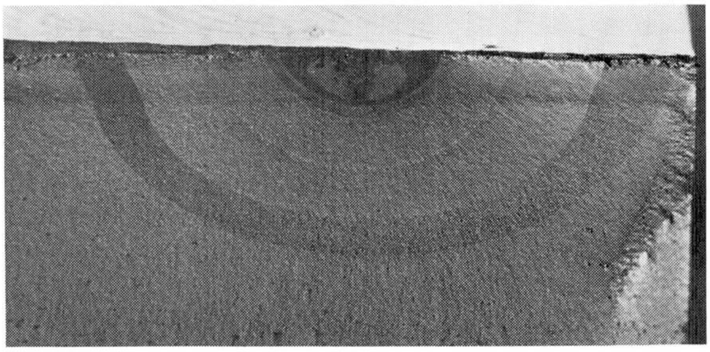


Fig. 7 Fracture Surface of Cruciform Joints

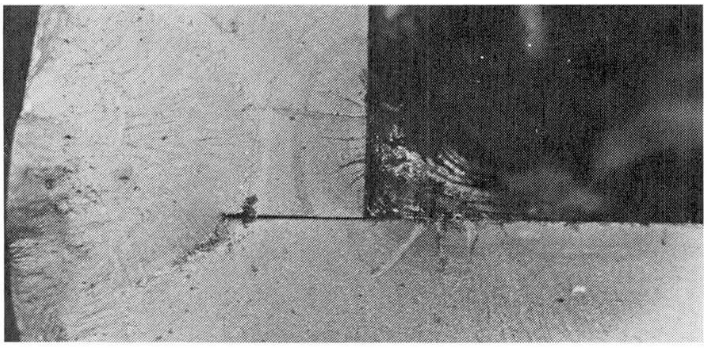


Fig. 5 Truss Panel Point Structures

Fig. 8 Fracture Surface of Box Section Specimen

were tested. With joint specimens of t = 45mm, fatigue tests were performed with stress ratios (R) at 0.6, 0 and -1. The influences of differences of mean stress on fatigue strength are not very prominent. Differences in fatigue strengths depending on differences in plate thickness of base metals were also small. Fatigue cracks were initiated at the toe of first path fillet welds in most specimens, but in some specimens cracks were initiated at the toe of second path welds.

With one joint specimen of t = 45mm, two stage multi-stress amplitude test was performed to form the beach marks on the fracture surface (Beach mark test). Fig. 7 shows the result of beach mark test. In this figure, five beach marks can be counted, and numbers of loading block for this specimen are also five. So it was found that the fatigue crack had initiated at the first stress block (prior to 0.18 N with N_f being failure life) from the concave part at the toe of fillet weld.

Three specimens of box-section with diaphragm (Type BA) were tested. In Fig. 6 the results of these tests are plotted. Fig. 8 shows fracture surface of BA-1 specimen. With these three specimens, beach mark tests were performed. Fatigue cracks initiated at the corner of fillet welds of diaphragms at the early period in the life.

In Fig. 6, results of tests on panel point structures are also plotted. In these tests only one fatigue crack was occurred at the toe of fillet welds of diaphragms arranged in the chord members of D type specimen. Line 1 in Fig. 6 shows the former design allowable stress [3] for this type of joint under pulsating stress for the Honshu-Shikoku bridges. All of the test results satisfy the requirement of this criterion. However, the slope of line 1 is too gentle in comparison with the test results. Line 2 in Fig. 6 shows the current design allowable stress for this type of joint. This curve is revised based on the fatigue test results and the analysis of fatigue life by fracture mechanics concept.

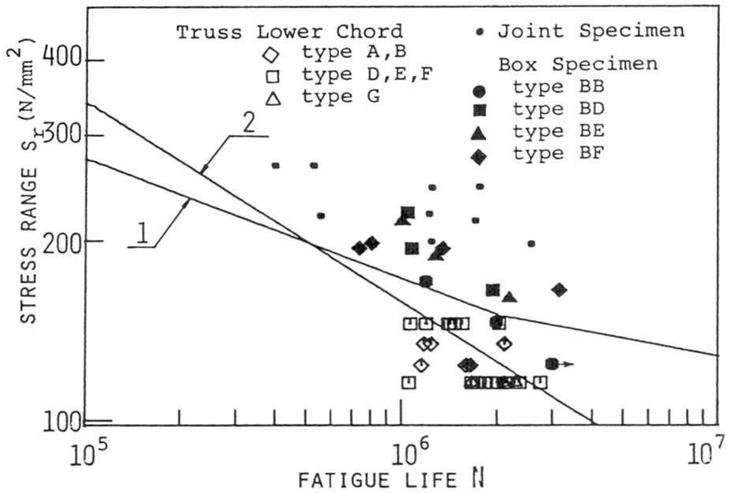


Fig. 9 Results of Fatigue Tests on Longitudinal Welds

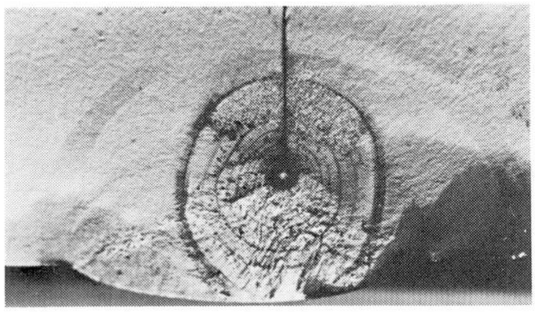
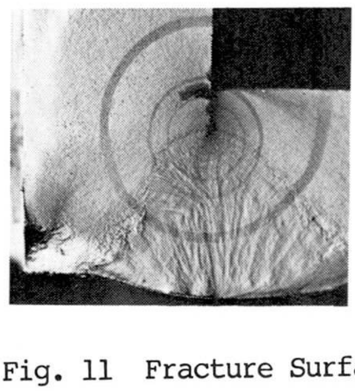
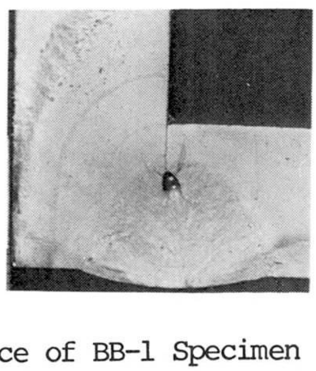


Fig. 10 Fracture Surface of Longitudinal Weld Joint





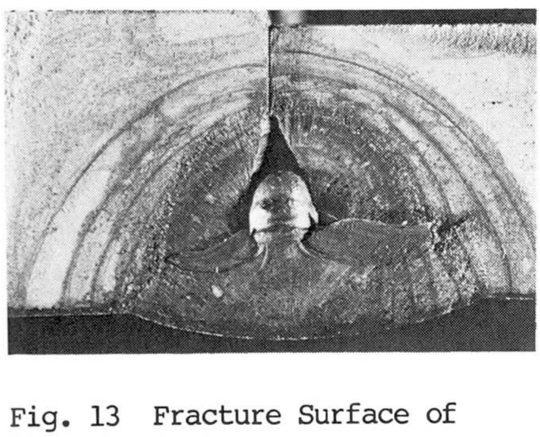


Fig. 11 Fracture Surface of BB-1 Specimen

Fig. 12 Fracture Surface of BE-2 Specimens

Fig. 13 Fracture Surface of Truss Lower Chord

3.2 Longitudinal Welds

Fig. 9 indicates the results of fatigue tests on longitudinal weld joints, box section specimens and panel point structures concerning about longitudinal welds. With longitudinal weld joints, initiation points of fatigue cracks in six out of the entire nine test specimens were blowholes or pores existing at roots of welds, the size being 0.6 to 1.2mm in diameter. Other initiation points were a small pit at bead surface, grinder scratch at surface of base metal and defect at part of base metal reparied by welding. Residual tensile stresses of approximately 340 N/mm^2 and 250 N/mm^2 were measured at joints of an unloaded specimen and an after fatigue test specimen, respectively.

Beach mark tests were performed with three joints specimens. Fig. 10 shows the fracture surface with beach marks. Fatigue crack had been initiated from the wall of a blowhole at the root of weld. In this fracture surface, thirty beach marks can be counted and numbers of loading block are thirty four so the fatigue crack of this specimen had started growing before 0.12 N_f cycles of loading.

With box section specimens, each three test specimens of type BB, BD and BE, and four of type BF were tested. Results of fatigue tests on these specimens are shown in Fig. 9. The locations of fatigue crack initiation in each type of specimens are as follows.

- BB type : blowhole (2.5 x 1.8, 4.1 x 3.4mm) at the root of welds.
- BD type : bead surface, blowhole (3.9 x 3.6mm) at the root of welds and imperfection of weld metal.
- BE type : weld root (no blowhole) and blowhole (1.1 x 0.5, 1.4 x 0.7mm) at the root of welds.
- BF type : slag inclusions at the end of butt joint (2 specimens) and slag inclusions at the toe of fillet weld and root.

Fig. 11 and 12 shows the fracture surface of BB-1 and BE-2 specimens.

Test specimens type BB were fabricated as the first series of test. Type BD, BE and BF were second test series, and much attention were paid in corner welding to avoid the occurance of imperfection or defect in the root of welds. In the results of fatigue tests fatigue strength of second series can be seen about 20 N/mm^2 higher than those of first series. These results are due to size of blow holes at the root of welds, and when the size of blowhole is 2mm or so, the influence of blowhole on the fatigue strength seems to be comparable to other imperfection, such as irregularily of bead surface and root line and small blowhole of butt joints near the surface of plate.

Fatigue tests on truss panel point structures were performed on two specimens each of type A - G.

All specimens except C-1 and C-2, fatigue tests were terminated by growth of fatigue cracks initiated at corner welds of bottom chord members. The relation between nominal stress range and number of cycles of stressing the fatigue crack was discovered at a bottom chord is shown in Fig. 9. In the type A and B specimens fatigue cracks at corner welds were initiated from irregularities at the roots of welds due to nonfusion or lack of penetration. The number of fatigue cracks initiated in the four specimens of type A and B was 13, with surface length from 9mm to 310mm. In the type D, E, F, and G specimens most of fatigue cracks were initiated from blowholes existing at the roots of welds. Fig. 13 shows one example of fracture surface of corner welds. In E-2 and G-1 each one crack occurred at the corner of butt joint of lower chord member, where some small pits existed near the surfaces of plates. The number of fatigue cracks initiated in the eight specimens of type D, E, F and G was 30, with surface length 4 to 87mm.

In Fig. 9, line 1 shows the former design allowable stress and line 2 shows the current design allowable stress for this type of joints under pulsating stress. Most of experimental values of panel point structure specimens are below the former design allowable stress. Furthermore, about half of experimental values of panel point structure specimens are below the current design allowable stress. The current design allowable stress is established based on the fatigue test results of box section specimens and the analysis using fracture mechanics concept. From that analysis, weld defects as blowholes exceeding 1.5mm in diameter of inscribed circle must be avoided to remain therein.

3.3 Gusset plate

With truss panel point structure specimens, fatigue cracks were initiated in gusset plates of three specimens B-1, C-1 and C-2 in the fatigue tests. Fig. 14 shows the position of these fatigue crack occurrences at gusset plates. These fatigue cracks were all initiated from the end of fillet welds close to bottom chord member flanges of plates inserted diagonally between the gusset plates at both sides. Repeated stresses measured at outer surfaces of gusset plates of these position and number of loading cycles are shown in Table 3. Stresses at fatigue crack initiation point are expected to be higher than these values in Table 3, because at that point, there are stress concentration due to the stop of weld bead and out-plane bending. In the Table 3, N_c is loading cycles when cracks were observed at the first time, and crack length are 25mm in B-1 and 10mm in C-2. In the specimen C-1, cracks occurred at both sides of gusset plates and propagated to free edge of plates.

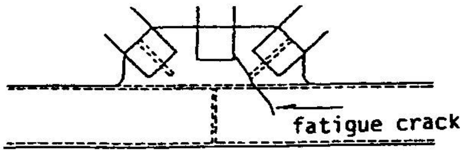


Fig. 14 Fatigue Crack in Gusset Plate

Type of T.P.	Stress Range (N/mm^2)	Nc ($\times 10^5$)	N_f ($\times 10^5$)
B-1	94	4.14	12.38
C-1	83	—	6.77
C-2	64	3.07	13.59

Table-3 Results of Fatigue Tests on Truss Panel Point Structures, type B-1, C-1 and C-2

4. CONCLUSIONS

The design allowable fatigue stress for the Honshu-Shikoku Bridge were revised based on the fatigue test results mentioned here and the analysis of fatigue life by fracture mechanics concept. All of the fatigue results of non-loadcarrying transverse fillet weld satisfied the requirement of this revised criteria. However, with the corner welds of truss chords, when weld defects of large size are contained at the root of welds, fatigue failures occurred under fairly low stresses which are below the allowable stress. Therefore, it is necessary to fabricated the members carefully to avoid the defects at the root of corner welds.

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