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Fatigue Strength of Field-Welded Rib Joints of Orthotropic Steel Decks

Résistance à la fatigue des joints de raidisseurs soudés au montage des tabliers métalliques orthotropes

Ermüdungsfestigkeit von montagegeschweissten Versteifungsrippen orthotroper Fahrbahnplatten

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SUMMARY
The field-welded trough ribs of orthotropic steel decks may be susceptible to fatigue due to the unfavorable welding conditions. Fatigue tests are carried out on tensile and bending specimens of the decks with trough ribs. Both specimens contain joints butt-welded in overhead position with the backing strips at the center. The misalignment of the ribs and the lack-of-fitof the backing strips are also introduced to the specimens. Fatigue test results show the possible reduction of the fatigue strength.

RESUME
Les radisseurs en auge soudés au montage des tabliers métalliques orthotropes peuvent être sensibles à la fatigue due à des conditions de soudage défavorables. Des essais de fatigue ont été effectués sur des échantillons de tabliers raidis par des auges, sollicités à la traction et à la flexion. Les deux échantillons contiennent des joints soudés bout à bout en position renversée avec les couvre-joints au centre. Le mauvais alignement des raidisseurs et le manque de précision des couvre-joints ont aussi été introduits dans les échantillons. Les résultats des essais de fatigue montrent la réduction à apporter pour la résistance à la fatigue.

ZUSAMMENFASSUNG
Montagegeschweisste Hohlrippen orthotroper Fahrbahnplatten können infolge der ungünstigen Schweissbedingungen ermüdungsempfindlich sein. Es wurden Ermüdungsversuche an Fahrbahnplatten-Ausschnitten mit geschweissten Rippen unter Biege- und Zugbeanspruchung durchgeführt. Die Prüfkörper wurden über Kopf geschweisst und enthalten einen Längsstoss in der Mitte. Der Effekt des schlechten Ausrichtens der Rippen sowie die mangelhafte Ausführungsgenauigkeit beim Stoss mit Zusatzblech wurden bei den Prüfkörpern berücksichtigt. Ergebnisse aus diesen Ermüdungsversuchen zeigen eine mögliche Reduktion der Ermüdungsfestigkeit auf.

1. INTRODUCTION

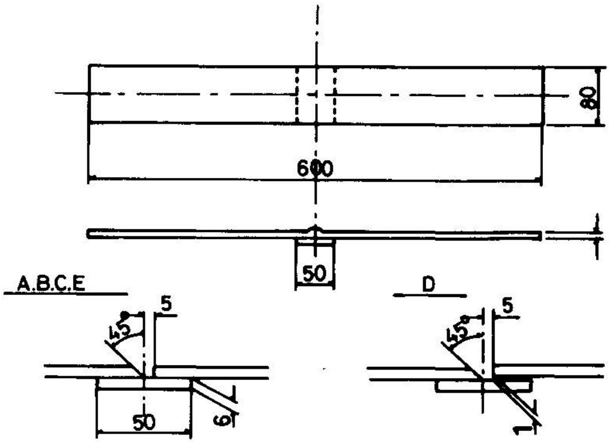
Trapezoidal trough closed ribs are increasingly used to stiffen the orthotropic steel decks of the medium to long span bridges in Japan. This system is economical due to the effective use of their bending stiffness and tortional rigidity. Moreover, amount of fillet welds and painting can be reduced compared with the open rib systems [1].

The orthotropic steel deck panels are often welded together on the erection sites. After connecting the steel deck plates, the trough ribs are normally butt-welded with backing strips. This system have advantage over the conventional bolted connections because it is simple in detail and can be air-proof. However, some engineers point out that the field-welded closed ribs may be susceptible to fatigue for the following reasons: 1) It is subjected to weld defects due to the unfavorable welding positions; 2) the misalignment of the closed rib cannot be corrected by itself, because the final profile is mainly determined by the profile of the deck; 3) out-of-fitness of the backing strip is often anticipated; and 4) tensile residual stresses are induced at the connection [3].

This report deals with the fatigue test results of tensile specimens and bending specimens of decks with trapezoidal trough ribs. Both specimens have the butt-welded joints with backing strips at the center. The welding is carried out in various positions to simulate the field welding of the trough rib joints. The misalignment of the ribs and the out-of-fitness of the backing strips are also introduced to the specimens.

2. TEST SPECIMENS AND FATIGUE TESTS

The dimensions and the type of the tensile fatigue test specimens with groove welds are shown in Figure 1. The welding is carried out in the same way as the field welding of the trough rib joints. A series of specimens A and B are cut-out from the side and the bottom of the trapezoidal trough ribs, respectively. The specimens D are welded with rusted backing strips. The backing strips are intentionally placed 1 mm apart in one side. The specimens E contain stop and restart welds at the middle. Both specimens D and E are welded in overhead position. The specimens C are control specimens welded in flat position. Low hydrogen type electrodes of 3.2 mm diameter are used for all manual groove welds. Root opening of 5 mm and 45 degrees of bevel angle are maintained for all specimens.



Series	Chracteristic
A	Specimens cut out from the side of full scale U-Section closed rib (Welded vertical)
B	Specimens cut out from the bottom of full scale U-Section closed rib (Welded in overhead position)
C	Control specimens welded in flat position
D	Specimens with out-of-straitness welded in overhead position. Rusted backing strip is used.
E	Specimens welded in overhead position with stop and re-start weld at the middle

Figure 1: Tensile fatigue test specimens

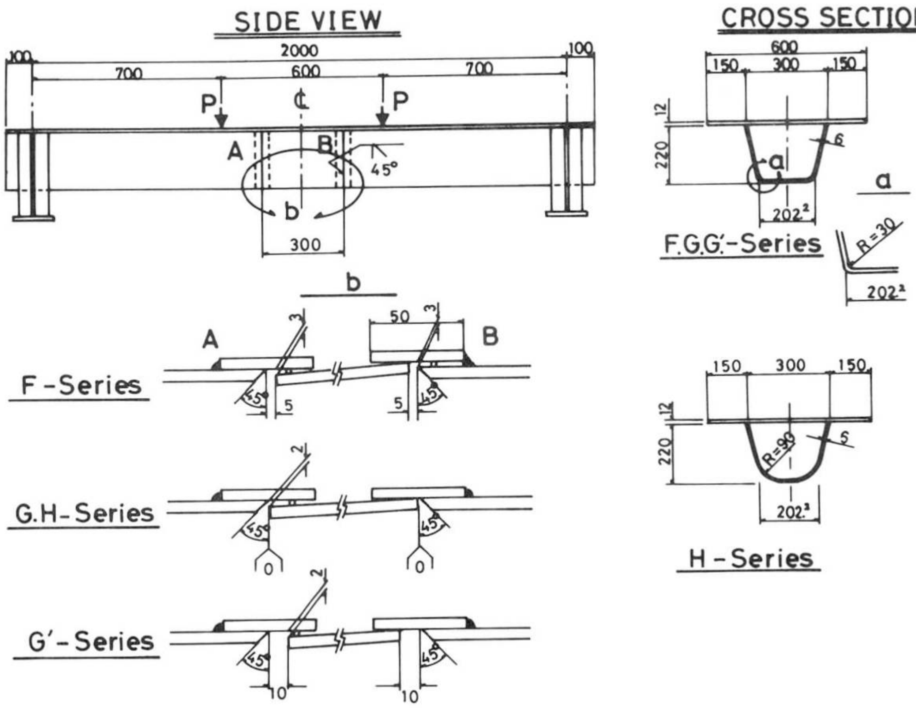


Figure 2: Bending fatigue specimens of decks with trapezoidal trough ribs.

The bending deck specimens with trapezoidal trough ribs are shown in Figure 2. The trough ribs are cold-formed from a flat plate of 6 mm thick by press. The radius of the corner of 30 mm (5 times the rib thickness) is used for the specimens F, G and G', while that of 90 mm (15 times the rib thickness) is used for the specimens H. Butt welding is carried out with low hydrogen type electrodes of 3.2 mm diameter in overhead position with engine driven welding machine. The welding process simulates the field welding. The specimens are first fabricated in the designated form. The center part of the ribs is left open. The ends of the ribs are bevelled to 45 degrees. Then the connecting ribs of 300 mm long is placed at the position to fill the gap with the tack welding. The out-of-fitness and the root opening, which are intentionally introduced to each specimen, are shown in Figure 2. The steels used to fabricate the specimens conform to JIS SS41 steel, equivalent to ASTM A36. The test set-up for the bending fatigue tests is shown in Photo 1.

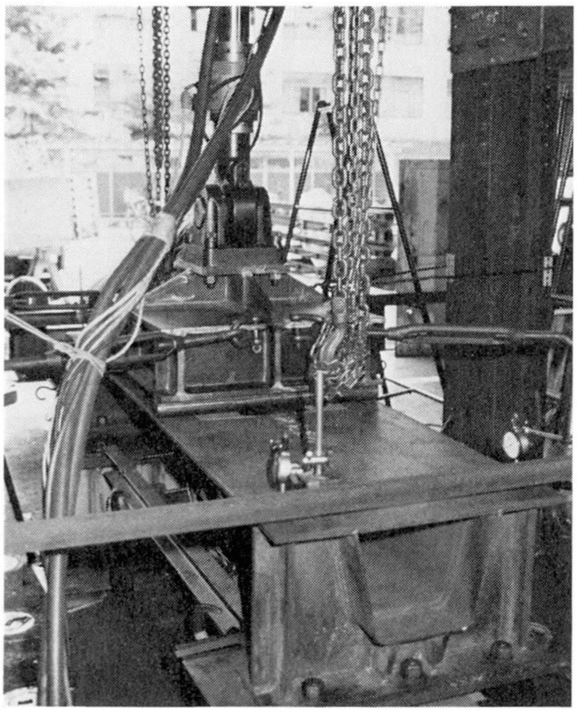


Photo 1: Test set-up for bending fatigue test.

3. FATIGUE TEST RESULTS

3.1 Fatigue Test Results of Tensile Specimens

Fatigue test results of all 44 tensile specimens are plotted in Figure 3. Fourteen (14) specimens did not fail over 3 million cycles and the fatigue tests are discontinued. The data is shown by the symbols with arrow. The fatigue crackings mainly initiate at the weld root of the specimens A, B and D, as shown in Fig. 6. This is due to the unfavorable root condition introduced by the welding in overhead position. Specimens E are also welded in overhead position, but the fatigue cracks initiate from the toe near the stop and restart posision.

Although wide scatter of the data is observed for all types of the specimens, the specimens D show the lowest fatigue strength. The mean regression line of the specimens D is plotted by the dotted line in Figure 3, while that of the specimens A, B, C and E together is plotted by the solid line for comparison. The average fatigue strength at $2 \cdot 10^6$ cycles of the specimen D is about 90 MPa, while that for the specimens A, B, C and E together is about 115 MPa.

Prior to the fatigue tests of the tensile specimens, all specimens are examined through X-ray radiography. The observation is then classified according to the Japanese Industrial Standards (JIS Z-3104), as shown in Figures 4 and 5. First, Figure 4 shows the type of defects observed in the tensile specimens. About 80 percent of the specimens A, B and D welded in overhead and vertical positions show some sorts of weld defects, while only 20 percent of the specimens show the defects when welded in flat position. It is speculated that the unfavorable welding conditions, which must be reluctantly accepted for welding the trough rib joint in the field, leave more or less weld defects.

Then the specimens are also classified into four degrees of severeness of weld defects depending upon the number and the size of the internal defects. The welded joints with the third and fourth degree of weld defects are not acceptable, and must be repaired, for tension members of the highway bridges [2]. As shown in Figure 4, the acceptability of the weldments is greatly affected by the welding position. About half of the specimens D show the weld defects more than third degree and are not acceptable for welding the trough rib joints.

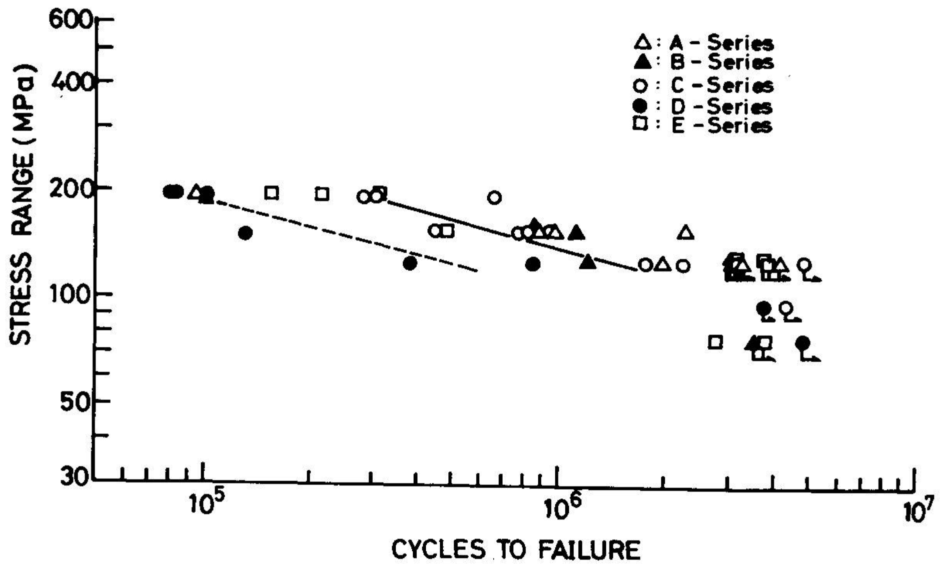


Figure 3: Fatigue test results of tensile specimens.

It should be noted that the radiographic examination of the field welded trough rib joints is not applicable. Therefore, the soundness of the welds may be achieved through the quality control of the welding process, such as controlling the out-of-fitness of the backing strip, cleaning the surface, controlling the root opening, training the welders, and so on.

Fatigue test results are replotted in accordance with the degree of the internal defects in Figure 6. It seems that the degree of the severeness of the internal defects affect little to the fatigue strength of the specimens. This may be due to the fact that the fatigue cracks mainly initiate and propagate from the weld toes or from the weld roots, as shown in the insert of Figure 6. The fatigue crackings from these places are supposed to be almost independent from the existance of internal defects.

Similar groove-welded tensile specimens with backing strips are also tested at the Public Works Research Institute, Ministry of Construction [3]. The parameter of the tests include the qualification of the welders, the shape of the groove face, the out-of-fitness of the backing strips, the unfavorable welding positions and the weld defects. Out of 22 specimens tested, ten (10) specimens have the root opening of 5 mm and the bevel angle of 45 degrees, comparable to the present study. These fatigue test results are also plotted by the inverse triangular in Figure 6. As the results of the X-ray radiography, eight specimens show the fourth degree of weld defects, while two others show the first degree. The effect on the degree of the severeness of the weld defects on the fatigue life also seems negligible, and the data is generally in good agreement with the present test results.

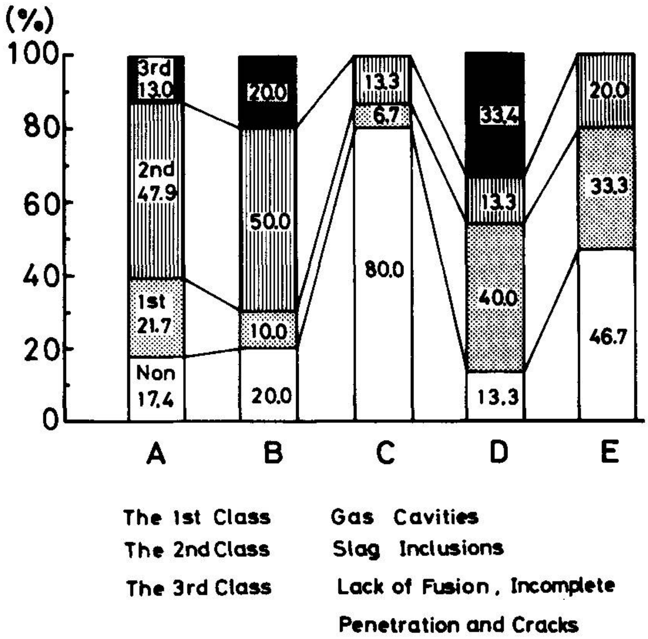


Figure 4: A kind of weld defects observed by the X-ray radiography.

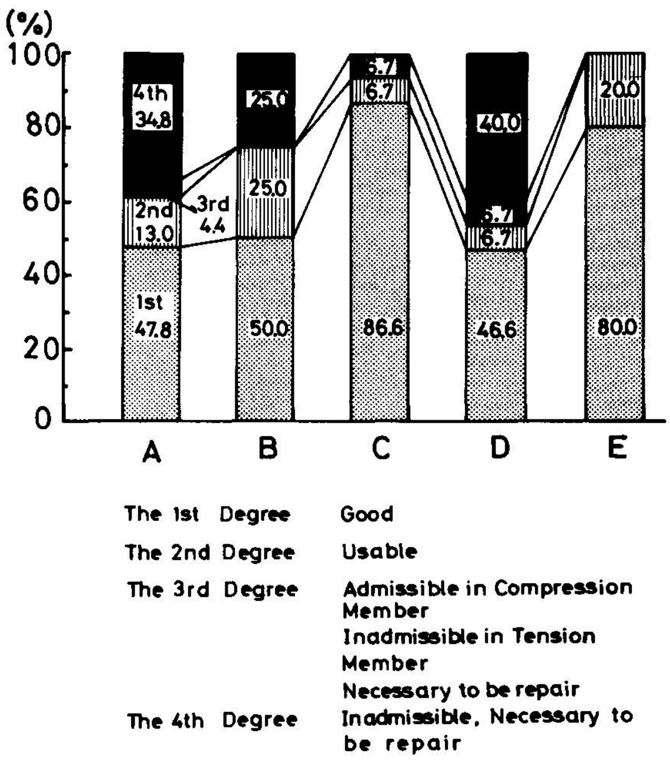


Figure 5: Classification of the severeness of the weld defects for each type of specimens.

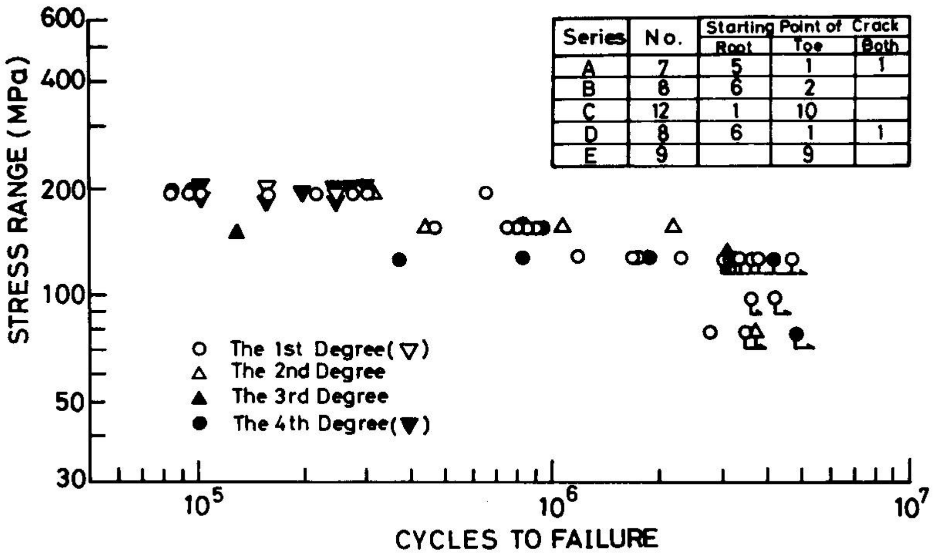


Figure 6: Summary of tensile fatigue test results according to the severeness of the weld defect.

3.2 Bending Fatigue Test Results of Decks with Trough Ribs

Fatigue test results of decks with trough ribs are plotted in Figure 7. Stress ranges correspond to the nominal stress at the bottom fiber of the ribs, and the number of cycles to failure corresponds to the cycles at the complete separation of the rib joints.

Total of 17 specimens are tested. The specimen H tested at the stress range of 83 MPa shows no fatigue cracking after 4 million cycles, and the test is discontinued. For one specimen G tested at 59 MPa, fatigue cracks are observed at $3.45 \cdot 10^6$ cycles, and the test is continued up to 5 million cycles. The cracks propagate to almost half the bottom flange of the rib.

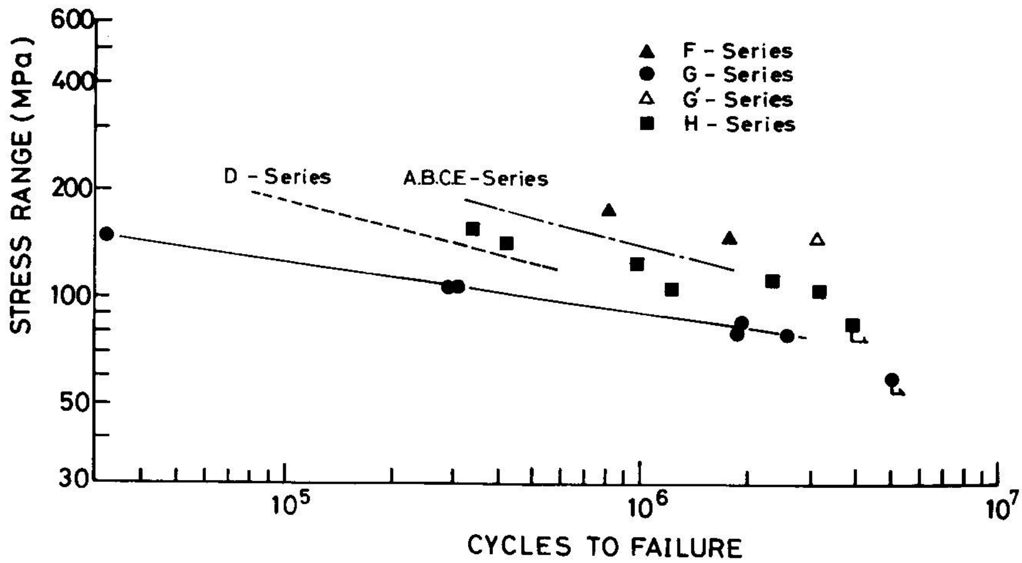


Figure 7: Bending fatigue test results of all 17 specimens of decks with trough ribs.

The fatigue cracks initiate and propagate from the root of the groove welds in 14 specimens. A typical fatigue fracture surface of the specimen is shown in Photo 2. The cracks penetrate the groove welds from inside to outside and are first observed at the surface of the groove welds at the bottom of the trough ribs. Then the cracks propagate gradually in two directions to separate the bottom flanges of the trough ribs completely. The specimen F tested at the stress range of 147 MPa shows the fatigue cracking from the toe of the tack welding of the backing strip.

As shown in Figure 2, the root opening of the specimens G and H is zero, so that it seems difficult for the welders to achieve the complete penetration of the groove welds, especially in overhead position. For six specimens G and four specimens H, fatigue failures occur from the incomplete penetration of the side B (see Figure 2), where no misalignment of the trough ribs is introduced. The incomplete penetration of about 1 mm deep is clearly found at some of the fatigue fracture surface.

Two specimens tested at the stress ranges of 125 MPa and 147 MPa have fatigue cracking from the side A, where 2 mm of misalignment of the trough ribs is maintained (see Figure 2). Fatigue cracks initiate and propagate from the root of the groove welds, where the sudden change of the section due to the misalignment exists. No incomplete penetration is visible on the fracture surface of these specimens. Fatigue cracks of the specimens F and G' also initiate and propagate from the weld root of the side A. It seems that the weld roots near the backing strips is still the initiation point of the fatigue cracks due to incomplete penetration or defects. Fatigue life is, however, prolonged for these specimens probably because the root opening of more than 5 mm make it easy to groove-weld and also reduces the degree of sudden change of the section, compared with the specimens G and H.

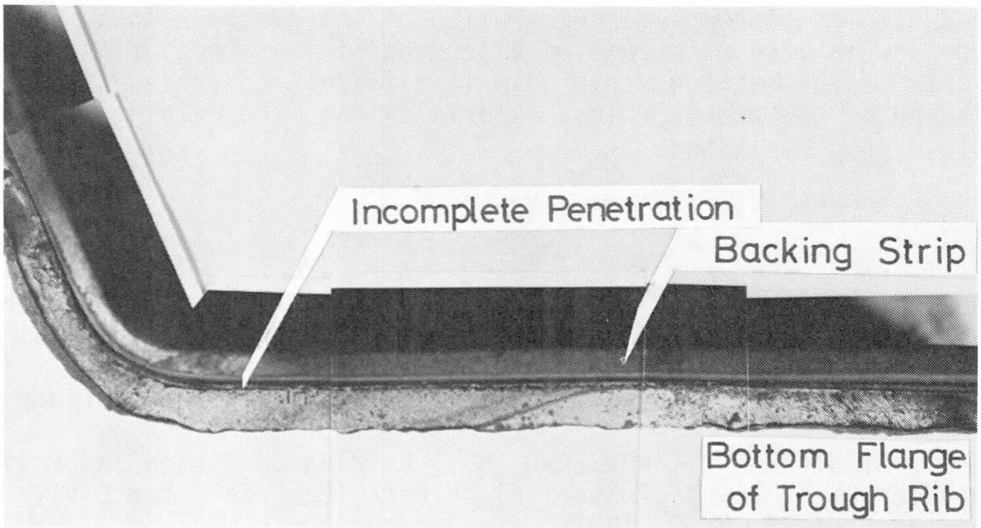


Photo 2: Typical fatigue fracture surface of trough rib joints.

Obviously the incomplete penetration of the groove welds can be the initiation point of fatigue cracking, or can be almost initial cracks as it is. This lowers the fatigue strength of this detail. Consequently, the specimens G show the lowest fatigue strength, as shown in Figure 7. A mean regression line of the specimens G is computed and plotted by the solid line for comparison. The average fatigue strength at $2 \cdot 10^6$ cycles is about 80 MPa. This is even lower than that of the tensile specimens D plotted by the dotted line. When the full penetration of the groove welds is maintained with sufficient root opening, such as for the specimens F, the fatigue strength is even longer than that of the tensile specimens A, B, C and E together.

The fatigue strength is somewhat higher when the radius of 90 mm is used at the corner of the trough ribs, such as for the specimens H. The specimens G and H are fabricated at two different occasions by the different welders. From visual inspection of the fatigue fracture surfaces, the specimens H are found to have less amount of the incomplete penetration than the specimens G. The radius of 5 times the thickness of the ribs (or 30 mm for the 6 mm thick ribs) is normally used for the corner of the trough ribs [4].

4. SUMMARY

The fatigue tests of the butt-welded tensile specimens and the bending specimens are carried out to obtain the fatigue strength of the field-welded trapezoidal trough ribs of the orthotropic steel decks. The groove welds with the backing strips in overhead position simulate the field welding conditions of this type of details. The followings summarize the findings.

1) The fatigue tests of the groove-welded tensile specimens show that the specimens failed from either weld toe or weld root. The specimens D, which contain the misalignment of about 1 mm and are welded in overhead position with rusted backing strips, show the lowest fatigue strength.
2) As the results of the X-ray radiography of the tensile specimens, the internal defects are introduced to the joints largely by the unfavorable welding position, and/or the rusted backing strips.
3) However, the internal defects seems to have little effect on the fatigue strength of the tensile specimens.
4) From the bending fatigue tests of the decks with trough ribs, fatigue crackings are observed mainly from the root of the groove weld. Reduction of the fatigue strength is significant when root opening is zero. This may be due to the incomplete penetration of the groove welds. When the root opening is zero with some misalignment of the trough ribs and out-of-fitness of the backing strips, it is difficult to achieve the complete penetration of the groove welds, especially when the welding is carried out in overhead position.

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