Fatigue tests of welded joints of trough to orthotropic steel deck plate in bending

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1. Objective

Through-deck fatigue cracks from weld roots in trough to deck plate welded connections of orthotropic steel bridge decks, as shown in Fig.1, have recently been reported in Japan. This kind of fatigue cracks has received much attention as it has caused major concerns on performances of the bridge decks, for example, reduction in section of deck plate or deterioration of the surfacing.

The fatigue strength of this welded detail has to be investigated by fatigue test on detail specimen subjected to bending stress in deck plate. The results of the fatigue tests were partially presented elsewhere[1], and in this paper, discussions on the fatigue test set-up and test results are further given—background of fatigue test set-up, patterns of variation in strain range, and effects of tensile residual stress on applied stress and fatigue test results.

2. Fatigue test

1) Fatigue test specimens

The test specimens are shown in Fig.2. Each specimen was 300mm wide and consisted of a main plate of 12mm thick and a rib of 6mm thick for D12R6-series or 8mm thick for D12R8-series. The main plate and rib simulated a deck plate and a portion of trough rib, respectively. Yield strength of main plate was 281N/mm^2.

2) Fatigue test set-up

Presuming that bending stress in deck plate is of major importance in causing a through-deck crack and the bending stress acting in rib has an effect of least significance on the crack of this kind. Comparison of effects resulting from these stresses on the through-deck crack will be made to prove the presumption. The factors used for representing the effects of such loadings are one-millimeter stress range ($\Delta\sigma_{1mm}$) from either case above because one-millimeter stress is free from effects of local geometries of weld profiles[2]. FEA was used to compute the $\Delta\sigma_{1mm}$. A FEM model of deck plate 12mm and rib 6mm in plain strain was built and subjected to $\Delta\sigma_{bd}$ applied in deck plate and $\Delta\sigma_{br}$ applied in rib, as shown in Fig.3. It is confirmed that the applied $\Delta\sigma_{1mm}$ from $\Delta\sigma_{br}$ is smaller than one-tenth of that from $\Delta\sigma_{bd}$, meaning the presumption above proved correct.

As applied bending stress in rib has effect of least significance on the through-deck crack, thus it is possibly negligible in the fatigue test. Thus, fatigue test set-up giving only bending in deck plate (main plate) is suitable for fatigue strength investigation of the welded joint.

The test set-up giving main plate in bending with a reproduced bending stress by a vibrator and rib carrying no load is shown in Fig.4. The vibrator generates a centrifugal force as a built-in unbalanced mass rotates.

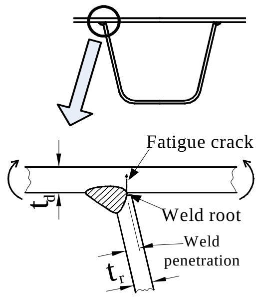

Fig.1 Through-deck fatigue crack

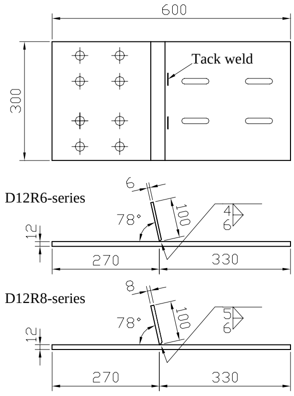

Fig.2 Test specimens

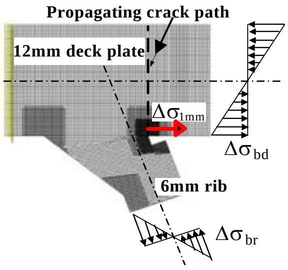

Fig.3 FEM model

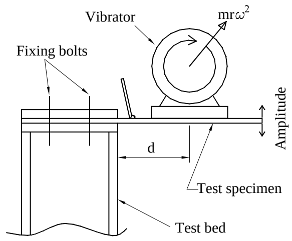

Fig.4 Test set-up

Either rotation speed or unbalanced mass is controllable to obtain a desired stress range. This fatigue test machine could only give an alternate loading condition, R≒-1.

3) Fatigue test procedure

Fatigue tests were carried out at two levels of applied stress ranges—around 175 and 150MPa. Stress ranges were monitored by strain gages attached around 7mm from weld root line. Weld toes were ground to avoid nonpreferable toe cracking in the test, so that only root cracking would be expected. The invisible root cracks were indirectly monitored by periodically recorded strains (i.e., record for 2 seconds for every 8 to 15 minutes). The incidence of fatigue crack was indicated by variation in recorded strains or strain ranges. Beach marks were inserted many times in a test. Strain records were used to estimate residual stress pattern in weld root region, to define fatigue life of specimen, and tell a relation in which such a drop in strain ranges corresponding to such a crack depth from beach mark tests.

3. Fatigue test results

1) Fatigue cracks and variation in stain ranges

Of nine specimens tested, seven had root cracking and two toe cracking. Macros-sections were taken on each series of specimens containing root cracks to observe their propagation paths, as shown in Fig.5.

Fig.6 shows the two patterns of variation in strain range observed throughout the fatigue test of strain gage G2. Note for the ordinate that the strain ranges recorded

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over time $\Delta\varepsilon_i$ were non-dimensionalized by the strain range recorded at the beginning of the test $\Delta\varepsilon_o$. Strain gage G2 gave larger variation in strain range and was thus more relevant to the root crack than other strain gages. The two patterns appear to have occurred, depending upon condition I or condition II. These conditions were characterized by locations of strain gages and propagating crack tips.

2) Residual stress pattern and its effects

The estimated residual stress patterns near weld root

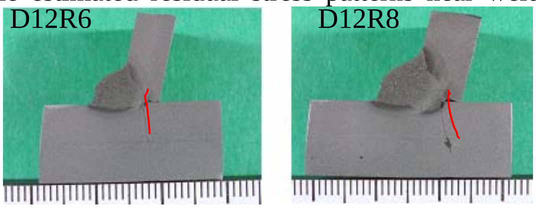

Fig. 5 Macro-sections of specimens containing root crack

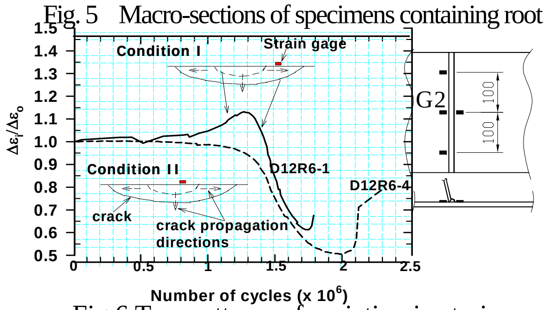

Fig.6 Two patterns of variation in strain ranges

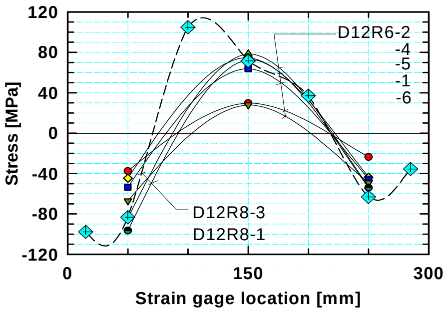

Fig. 7 Estimated residual stresses in weld root region

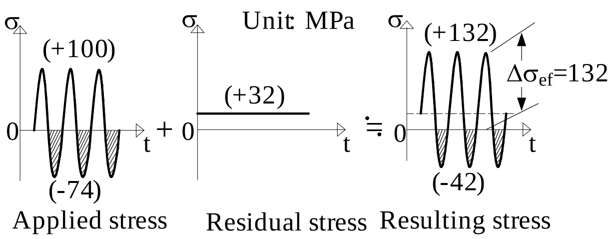

Fig.8 Effect of tensile residual stress on applied stress

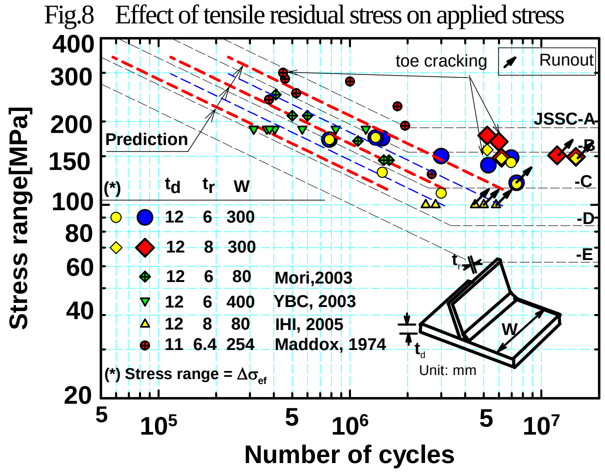

Fig.9 S-N diagram

regions for specimens containing root cracks are shown in Fig.7. Despite a scatter in data, major of data in center of plate appear to be confined to 60~80MPa, 1/3.5 of yield strength of main plate. Two data show low tensile residual stress. The tensile residual stress appears to form in middle part of the specimen. This is backed by the fact that fatigue cracks had initiated from center part of the plates in the fatigue test.

Effect of tensile residual stress on applied stress at center part of the specimen is illustrated in Fig.8 for a specimen D12R6-1 subjected to an intended applied stress range of 174MPa. The applied compressive stress –74MPa, hachured portions, was sifted up by an estimated tensile residual stress +32MPa, resulting an estimated actual tensile stress +132MPa. The resulting compressive stress was estimated –42MPa. Given that compressive stress is of no effect on crack propagation, the stress range effective in crack propagating would be $\Delta\sigma_{ef}$=132MPa, not 174MPa.

As amount of residual stress is different from a specimen to another, the amount of resulting compressive stress is different from one to another, too.

3) Test results and effect of residual stress

The fatigue test results are plotted in the S-N diagram as shown in Fig.9. The fatigue life of specimen was defined as the number of cycles corresponding to 15% drop in stress ranges, relating to a crack of half-main plate thickness. The stress range is simply the difference between the tensile and compressive stresses. The fatigue test results obtained from other investigators and the prediction of fatigue strengths of the welded detail by one-millimeter stress method are plotted for comparison. Some specimens had fatigue lives comparable to those of the past studies and are in a good agreement with the prediction. Some other specimens seem to have longer fatigue lives than predicted.

When $\Delta\sigma_{ef}$ is plotted, instead, for the data from this fatigue test, indicated by smaller circle and diamonds in Fig.9 some test results have become in good agreement of the prediction and the results from other investigations. Yet, some results are somewhat beyond the prediction.

4. Summary and future research

The fatigue test set-up proves suitable for fatigue test is backed by FEM analysis. The test set-up gave applied stress in tension-compression range. Variations in stress range had two patterns depending on locations of strain gage locations and fatigue crack tips. Tensile residual stress partially sifted the applied stress upward into tension range. However, applied compressive stress, ineffective in crack propagation, still largely existed as the magnitudes of tensile residual stress was low in some specimens. In the next research, the applied loading will be changed to tension-tension region, so that compressive stress effect can be eliminated.

References

1) YA, S., Yamada, K., Ojio, T.: Fatigue tests of welded joints between trough to orthotropic steel deck in bending stress, Proc. Annual meeting of JSCE Chubu Branch, pp.61-62, CD-ROM, 2007
2) Xiao, Z-G., Yamada, K., A method of determining geometric stress for fatigue strength evaluation of welded joints, *Int. J. atigue*, pp.1277-1293, 2004