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

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1. Objective

Recently, through-deck fatigue cracks in trough to deck plate welded connections of orthotropic steel decks have found in orthotropic steel deck bridges in Japan as shown in Fig.1. The fatigue cracks initiate at the weld roots inside the trough ribs, and are thus invisible to visual inspections. They propagate into the deck thickness to form through-thickness cracks, which have caused some problems like deterioration of pavement surface, corrosion inside the trough ribs due to water penetration through the damaged pavement.

Fatigue strength of this welded connection regarding to through-deck crack is indispensable for fatigue assessment, but has not yet well defined. This paper briefly presents an investigation of the fatigue strength of this detail by a fatigue test on detail specimens under bending stress.

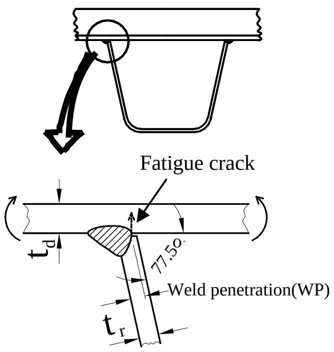


Fig.1 Fatigue crack in deck plate

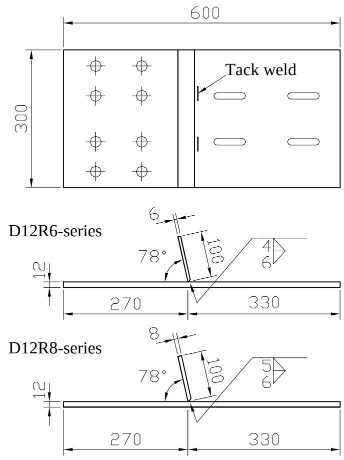


Fig.2 Test specimens

2. Fatigue test

1) Fatigue test specimens

The bending stress is produced in deck plate to simulate the bending stress resulted from the action of the truck wheel. With this stress, the fatigue test can be carried out on the detail specimens in the laboratory.

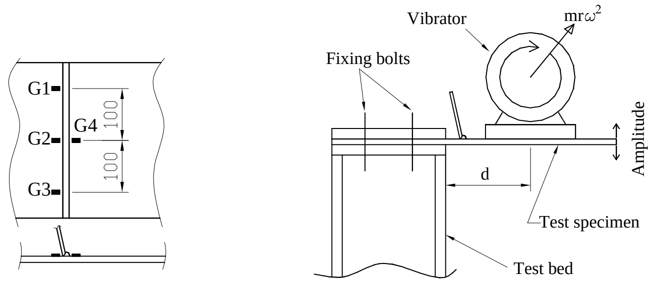
The test specimen is shown in Fig.2. They were 300mm wide and consisted of a main plate of 12mm and a rib of 6mm for D12R6-series and of 8mm for D12R8-series. The main plate and rib simulated a deck plate and a portion of trough rib, respectively. Yield strength of main plate was 281N/mm^2. Weld toes were ground to avoid toe cracking.

The fatigue tests were carried out with two levels of stress ranges around 175MPa and 150MPa. The applied stress ranges were monitored with 1mm long strain gages. The strain gages were glued to main plate and 5mm from the edge of the rib and 5mm from the weld toe as shown in Fig.3(a). The strains were monitored and recorded for 2seconds every 8 to 15minutes. Any change in strains was due to crack propagations

The specimen was installed on the test bed with the rib upward as shown in Fig.3(b). The bending stress was generated by a vibrator. The vibrator generated a centrifugal force due to the rotation of an unbalanced mass. Either rotation speed or unbalanced mass was controllable to obtain a desired stress range. This system produced stress wave at a particular point of R≒-1. The loading speeds were 18 or 19Hz.

2) Monitoring of fatigue crack propagation

As cracks were expected to initiate at the weld roots, the cracks could not be seen. The incidence of crack was indicated by variations in strains or strain ranges obtained from strain gages near the cracked region. A pattern of strain range variation pattern obtained from a strain monitoring is illustrated in Fig.4. The strain ranges at



(a) Strain gages (b) Test set-up

Fig. 3 Strain gage locations and bending fatigue test set-up

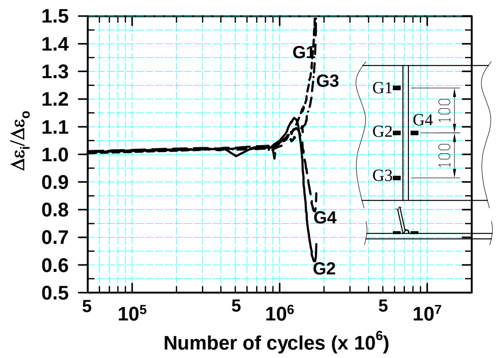


Fig.4 A pattern of variation in strain ranges for D12R6-1 specimen

gages G2 and G4 significantly increased from around 9x10^5 cycles then sharply dropped from 15x10^5 cycles. However, strain ranges from strain gages G1 and G3 sharply increased from 9x10^5 cycles. These indicated the incidence of a crack within region where the strain gage G2 was glued.

Beach marking tests were carried out several times to obtain the shapes and sizes of propagating cracks at various stages.

3. Fatigue test results

1) Crack propagation behaviors

The macro-sections of the representing test specimens containing weld root cracks are shown in Photo 1.

However, weld toe cracks also occurred on two of nine specimens. A typical fracture surface is shown in Photo 2. The crack seems to have initiated at multiple points along weld root line, propagated and coalesced to form a large and flat semi-elliptical crack. When the latter nearly reached the back surface, several small cracks initiated and propagated from the back surface. The test terminated when the cracks from both side joined to make a through-thickness crack which cut the copper wires attached on the back side of the main plate.

As both variation in strain ranges and crack shapes were monitored, their correlation can be established as shown in Fig.5. The abscissa is the ratio of a crack depth to the main plate thickness (a/t); the ordinate is the ratio of strain range just before the time of applying beach marking test to the initial strain range at G2—($\Delta\varepsilon_i/\Delta\varepsilon_o$). The fitted curve of the data is also plotted. The drops in strain ranges of 5% and 15% correspond to the depths of crack of 0.15t(=1.8mm) and 0.5t(=6mm), respectively.

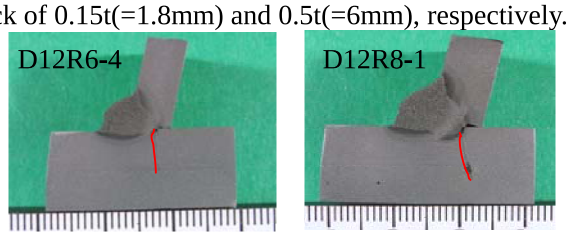


Photo 1 Macro-sections of weld root cracks

Photo 2 Beach marks left on a portion of main plate of a specimen

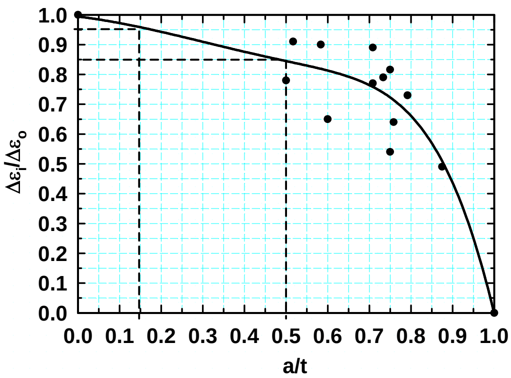


Fig. 5 Relationship between a/t and $\Delta\varepsilon_i/\Delta\varepsilon_o$

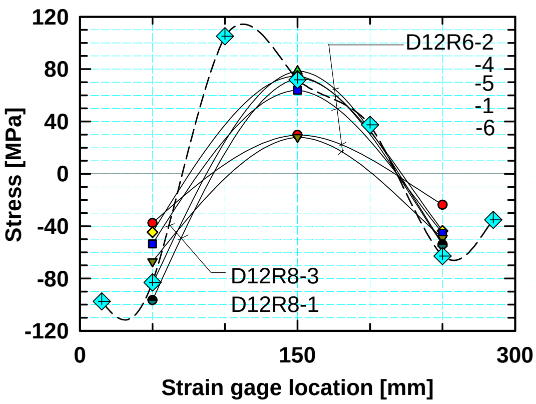


Fig. 6 Estimated residual stresses in weld root region

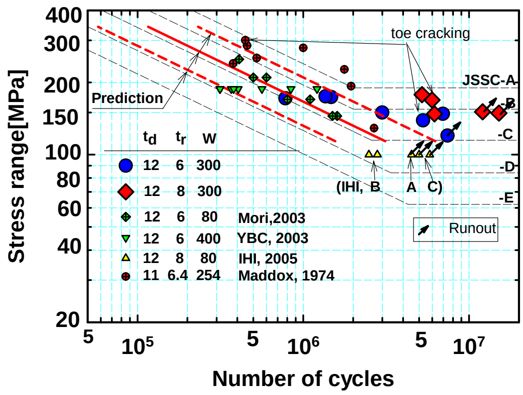


Fig.7 Comparison of test data and prediction

2) Estimation of residual stress pattern

It is assumed that the fatigue crack relieves some amount of residual stress caused by rib welding. Any changes in mean stress before and after the crack correspond to the residual stress. The estimated residual stress pattern in weld root region for specimens containing weld root cracks is shown in Fig.6. The tensile residual stress existed in middle part of specimens. Even though the data are scattered, many data shows its magnitudes of tensile stress was approximately 80MPa, which is around 1/3.5 of yield stress of main plate.

3) Fatigue test data in S-N diagram

The fatigue test results are plotted in the S-N diagram as shown in Fig.7. The fatigue lives of specimens are defined as the number of cycles corresponding to 15% drop in stress ranges relating to half-thickness cracks. The stress ranges are taken at cracked locations and computed from interpolations of stress ranges obtained from the strain gages on plate centerline in the weld toe and root sides. The fatigue test results obtained from other investigators are also plotted for comparison. The prediction scatter band of fatigue lives obtained from a one-millimeter stress method is plotted for comparison, too. Some specimens had fatigue lives comparable to that of the past studies and in a good agreement with the prediction. Some other specimens seem to have longer fatigue lives than predicted. There are two possible causes. One is the test specimens contained a low tensile residual tensile stress; the other is the test were performed with partial compressive stress.

4. Summary of findings, future works

Fatigue test results with R=-1 on 300m wide specimens of 12mm thick main plate and 6 or 8mm thick rib are comparable with the previous test and prediction results. Cracks had rather flat semi-elliptical shapes. Fatigue cracks were indirectly monitored with strain gages which showed that a drop in stress ranges can be correlated with a crack at a particular size. As some specimens have longer lives than expected, addition tests will be carried out with pulsating tension so as to eliminate the effect of compressive stress, if any, in tension-compression tests.

Reference:

Ya, S., Yamada, K., et al.: Fatigue tests of welded joint of trough rib to orthotropic steel deck plate, *J. Struct. Eng.*, Vol.53A, 2007 (submitted for publication)