Fatigue Durability Assessment of Tough-to-deck Welded Joint of Orthotropic Steel Deck Bridge

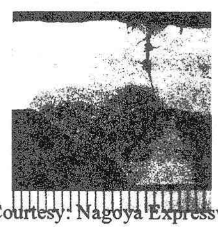
Kentaro YAMADA, Professor, Department of Environmental Engineering and Architecture, Nagoya University
○ Samol YA , Graduate student, Department of Environmental Engineering and Architecture, Nagoya University
Zhi-Gang XIAO, Pacific Consultants Co., LTD. Ushijima-cho, Nishi-ku, Nagoya, Japan

1. Introduction:

Orthotropic steel decks are advantageous due to their good inherent properties, and thus they are extensively used for long span bridges and elevated urban highway bridges. They are subject to wheel loads directly; this may be one of the key factors causing fatigue cracks at various welded joints. Their fatigue assessments are required when a large number of heavy wheel loads is anticipated. Photo 1 depicts a crack emanating from weld root of trough-to-deck detail and propagates into the deck plate. Welding U-ribs to deck plate is executed from one side.

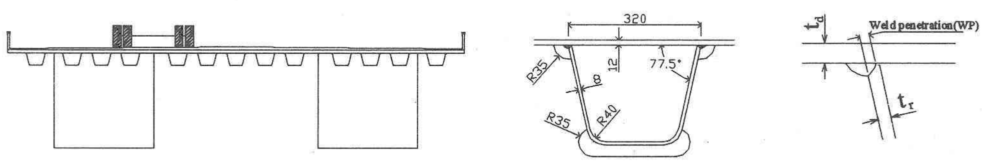
Fig. 1 schematically shows a typical cross section of box girder with orthotropic steel deck, a trough rib, and a trough-to-deck plate joint. Shown in Fig.1(c) is the object detail of which fatigue strength is being investigated.

The procedure for fatigue durability evaluation consists of three main parts. First part involves in evaluation of fatigue strength of the welded detail. Second part deals with computation of stress range for fatigue assessment of the joint by FEA on an orthotropic steel deck model. The last part presents a fatigue life evaluation on the joint of the model using.



Courtesy: Nagoya Expressway

Photo 1: crack from weld root



(a) Typical cross section of orthotropic steel deck (b) A U-rib cross section (c) Object detail with relating parameters

Fig. 1: Orthotropic steel deck and joint to be considered

2.Fatigue strength evaluation of trough-to-deck plate welded detail

To obtain fatigue strength of the detail, a so-called one-millimeter stress method was used. One-millimeter stress method involves in calculation of one-millimeter stress on the detail to be investigated by FEA. A number of parameters covering actual detail conditions were considered in the FEA stage on object detail. They included: deck plate thickness (t_d) of 12,14, 16, and 18mm; trough rib thickness (t_r) of 6,8 and 9 mm; level of weld penetration (WP) of 100, 80 and 60 % with respect to rib thickness; and irregularity of weld root tip modeled with 77.5° and 90° with deck plate. Various combinations of these parameters were made for particular purposes. A rather wide cruciform joint with thin plates were selected and assumed to be the reference detail, and fatigue test data on foregoing joints with comparable dimensions were used. It is found from application of the method that: (1) Irregularity of the weld root had little effect on fatigue strength, (2) Full penetration gave the lowest fatigue strength among the three levels, (3) The same fatigue strength was obtained for using a deck plate with a trough rib of 6 or 8mm thick, and (4) Thicker deck plate of 18 mm lowered fatigue strength by 30% compared with deck pate of 12 mm. Fig.2 shows the evaluated S-N curves of a model of deck plate of 12mm thick, rib of 6 or 8mm, with full weld penetration together with fatigue test data of comparable details from other sources. The plot shows that the test data fall within the predicted range, indicating the adequacy of the one-millimeter stress method as well as the reference detail in this case study.

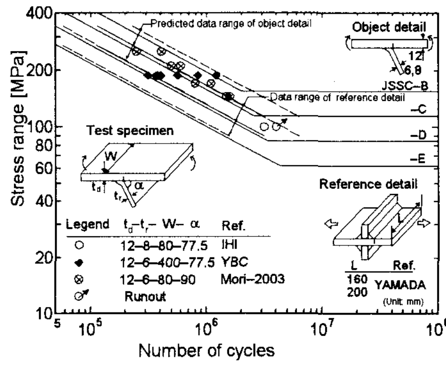


Fig.2: Predicted S-N curves with fatigue test data

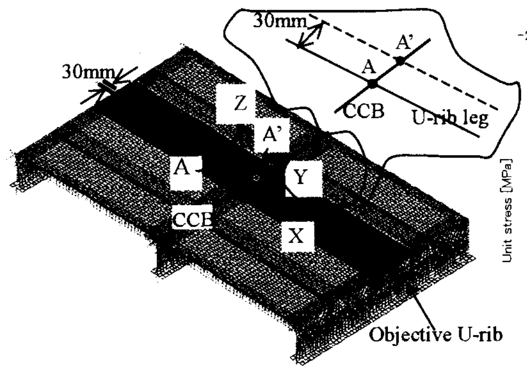


Fig.3: two-pane deck plate model

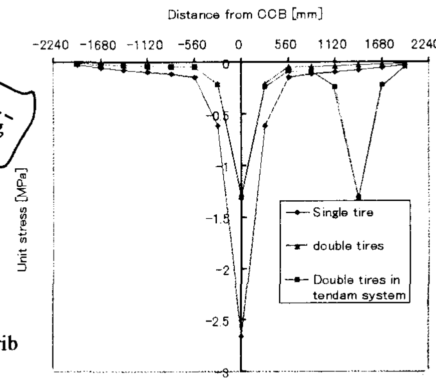


Fig.4: stress wave at point A'

2. Stress range calculation by FEA

Two-deck panel consisting of 4 ribs of 8mm and 12mm thick deck plate spanning over three crossbeams placed 2240mm apart was generated using 4-node shell elements, as shown Fig.3. For ease in calculating stresses in the deck at a particular point under a wheel load at a particular magnitude, a concentrated load of 1KN was used applying on a contact area. The contact areas was considered in both case of neglecting pavement effect and case of considering pavement effect for single and double tire. Pavement effect was used to mean that load is distributed due to stiffness of pavement. A single tire of 200x200 mm, and a double tire of two single tire placed 100mm apart, that is 200x500 mm were considered as contact area in the first case. The second case was considered with only two factors: asphalt pavement of 75 mm thick and a lateral load distribution pavement of 45°; the contact areas of 350x350 mm for single tire, and 350x650 mm for double tire were resulted. A movement of a wheel load on the deck model was simulated by a series application of contact pressure due to a unit load in longitudinal bridge direction. In transverse bridge direction, only one case was presented here as illustration. That is, the contact pressures were applied on a U-rib for single, across the leg of that U-rib for double tire. The stress in transversal bridge direction, and on a section 30mm apart from the leg was selected as the stress for fatigue durability evaluation of the connection at point A. Fig.4 schematically shows stress waves at point A', used for fatigue durability evaluation at point A, in the case of neglecting pavement, plotted versus distance relative to central cross beam (CCB). Unit stress ranges and their number of cycles, for a single passage of each wheel, in case of neglecting pavement effect, are obtained as following: 2.66 MPa and 1cycle for a single tire; 1.28 MPa and 1 cycle for double tire; and 1.31 MPa for tandem system of double tire. In case of considering pavement effect, corresponding stress ranges reduce to 1.41MPa, 0.71MPa, and 0.74MPa, respectively. The distance between wheels in tandem system was selected as 1.4m for ease in calculation.

3. Fatigue life Assessment

Results of stress measurement on trunk loads around Nagoya indicated that the equivalent axle load was around 110KN, and its equivalent number was somewhat scattered. In this study, number of equivalent axle load was assumed to be 1500 per day. The equivalent wheel load would be 55KN. By assumed that the equivalent loads were all double tire, stress range was 55x1.28= 70.4MPa, the fatigue life at point A would be **11** years in case of neglecting pavement effect. Similarly, the stress range and the fatigue at point A would be 55x0.71 =39 MPa, and **69** years in case of considering pavement effect.

Reference:

1. Ya, S.,Yamada, K., Xiao, Z-G., Fatigue Assessment of trough-to-deck plate detail of orthotropic steel deck, proceeding of the eighth Japan-Korea joint Seminar on steel bridges, 2005

2. Yamada, K., Ojio, T., Yagi. T., Nakano, T. " Service load monitoring by BWIM using reaction force method on National Road 19", internal report, 2004