

EFFECT OF DECK PLATE THICKNESS OF ORTHOTROPIC STEEL DECK ON FATIGUE DURABILITY

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Abstract

The effect of thickness of deck plate on fatigue durability of OSDs was also discussed from experimental and analytical results to improve fatigue durability of the structural details for the deck plate cracks. Wheel running fatigue tests were performed for full-scale test specimen with combination of 16/19mm thickness deck plates and 6/8 mm thickness ribs. Finite element analyses were also conducted in order to clarify the effect of thickness of deck plate on local stress at rib-to-deck welded joints.

Introduction

Orthotropic steel deck (OSD) bridges have been widely used for long-span bridge and urban viaducts for reducing dead load. OSDs consist of many thin steel plates, stiffened by a series of closely spaced longitudinal ribs supported by transverse floorbeams (see Fig. 1). As they support vehicle wheel loads directly as deck system, considerations for fatigue has to be supposed to be required in the design of OSDs. With rapid increase of vehicle weight and traffic volume in Japan, various types of fatigue cracks shown in Fig. 2 have recently been observed in existing OSDs under severe traffic condition, resulting from the complicated welded details combined with local stresses that can be difficult to quantify in the design. Among such fatigue damages, two types of severe cracks have been observed at the rib-to-deck welded joints. They initiate at the root of the one-sided fillet weld. One type of them propagates into the deck plate and finally reaches its surface (deck plate cracks), while the other propagates through the weld (bead cracks). Among them, the deck plate cracks have potential to threaten safety of traffic due to cave-in of road surfaces if they reach a certain length. Focusing on the two types of cracks, especially the deck plate cracks, the research projects have been conducted for the following objectives:

- 1) Identification of the causes of fatigue cracking and proposal of appropriate structural details to improve fatigue durability for newly constructed bridges
- 2) Development of an ultrasonic inspection method which can detect invisible cracks initiating in the weld root
- 3) Performance evaluation of applicability of steel fiber reinforced concrete (SFRC) overlays as a measure to retrofit existing damaged OSDs

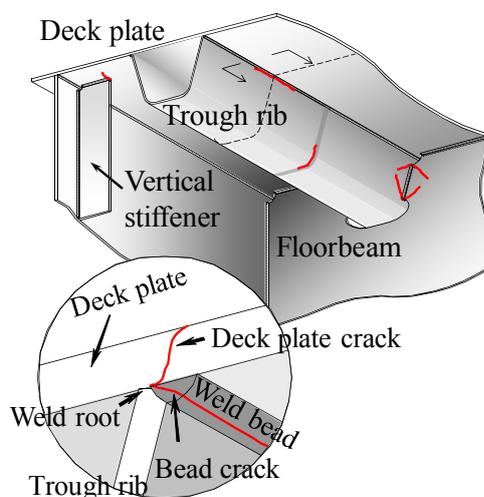
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Fig. 1 View of orthotropic steel deck box girder bridge



【Section of the rib-to-deck weld connection】

Fig. 2 Major fatigue cracks observed in OSDs

Major findings of the research were summarized in PWRI Technical notes. In this paper, the experimental and analytical results regarding the first objective were discussed based on results.

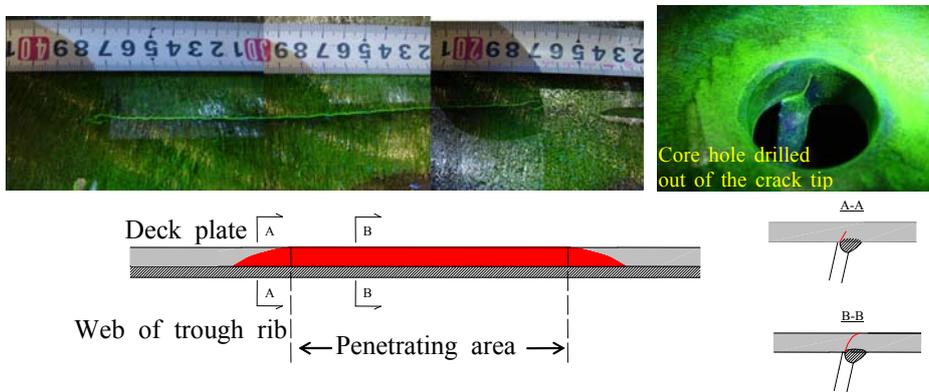
Features of Deck Plate Cracks

Fig. 3 shows detailed inspection for a deck plate crack. According to investigation of existing damaged OSDs, the tendencies of deck plate cracking are listed below.

- 1) Cracks have been observed in about 10 to 30 years after construction under heavy traffic route. In terms of cumulative traffic volume of heavy vehicles estimated roughly by multiplying the current volume of heavy vehicle traffic and service years, cracks have been detected when it exceeded around 12million vehicles/lane.
- 2) Cracks have been observed both at the rib-to-floorbeam (RF) connections and the other parts in the rib-to-deck (RD) weld line under the wheel running position, initiating in the weld root.



(a) Visual observation of deck surface after removal of asphalt layer



(b) Description of observed crack

Fig. 3 Detailed inspection for deck plate crack

- 3) While the thicknesses of the damaged deck plate were mostly 12mm and the floorbeam spacings were 2.0 to 2.85m and the thicknesses of the rib were 6 or 8mm, the tendency of cracking is not clear in relation with detailing dimensions except for the deck plate thickness.

Current Fatigue Design

Fatigue Design Guideline for Steel Highway Bridges was issued in 2002. Requirement for standard structural details of OSDs is specified to ensure fatigue resistance. In the Fatigue Design Guideline, the minimum deck plate thickness is 12mm. As to the RD one-sided fillet weld, 75 percent minimum penetrations of rib thickness are required for preventing weld bead cracks. After identifying deck plate cracks, from long-term performance point of view, the minimum deck thickness has been increased to 16mm at wheel load running position in case of use of closed ribs in the latest design code, which was revised in 2012. The results of the present research were reflected in the revision.

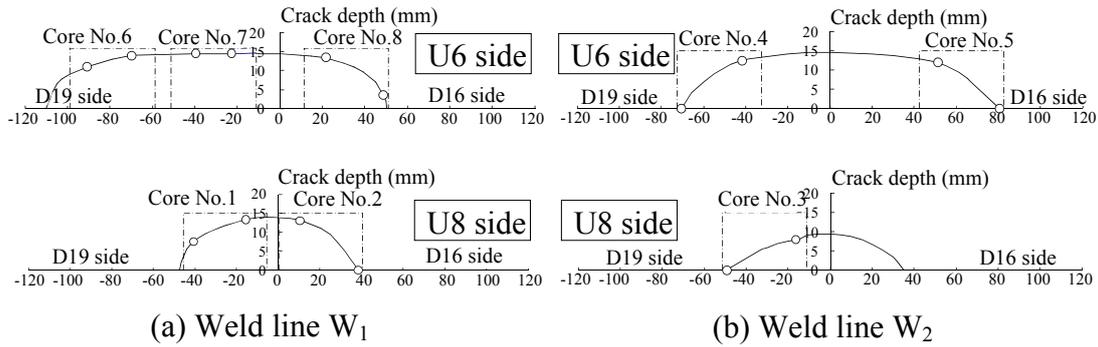


Fig. 6 Shapes of deck cracks in the weld root at the rib-to-floorbeam connections(D19)

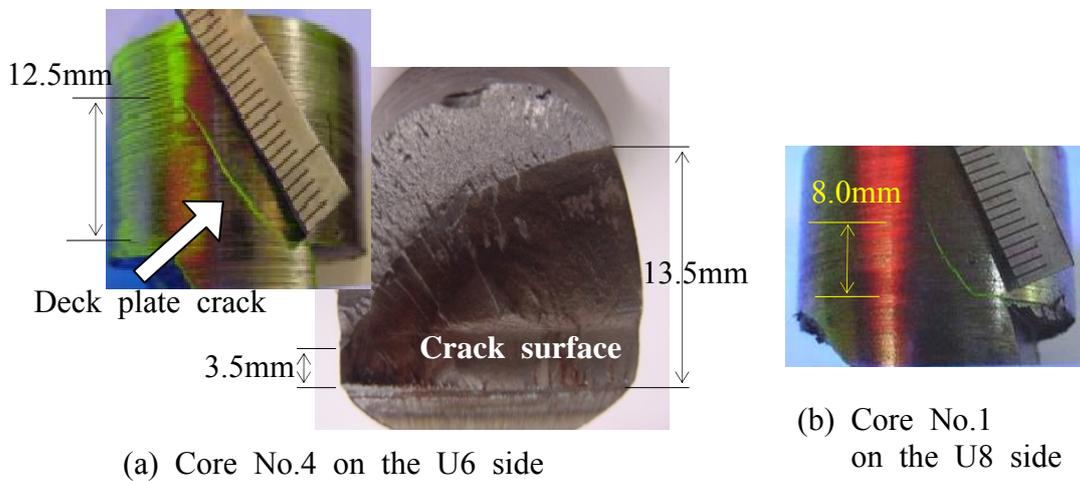
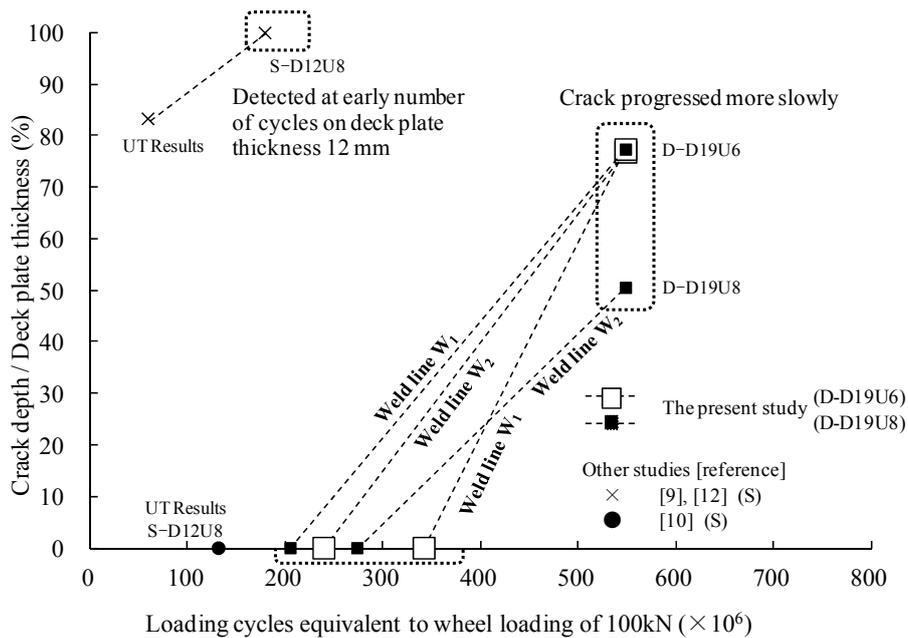


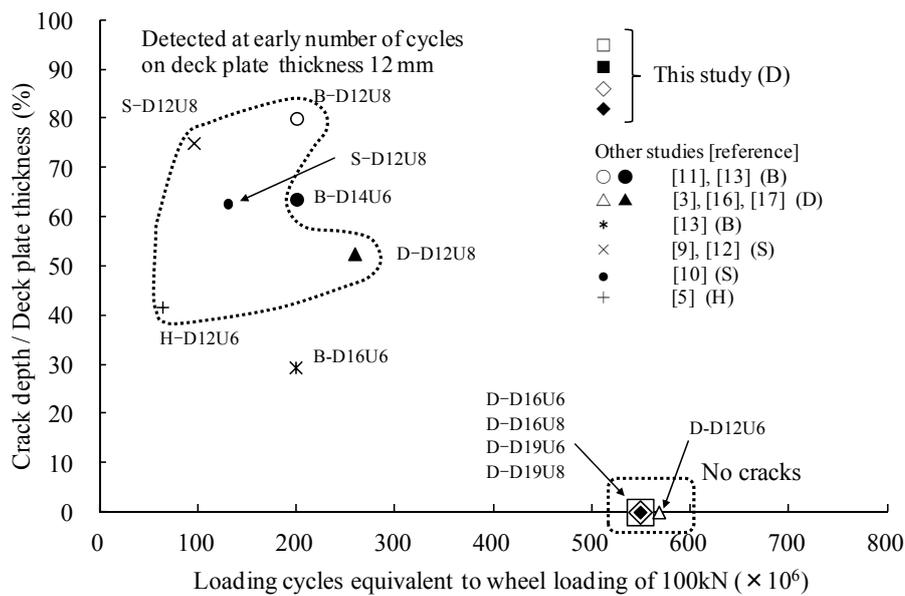
Fig. 7 Cracks observed on the core surfaces

addition, two trapezoidal ribs with thickness of 6mm and the other two with thickness of 8mm, four in total, were used to investigate the effect of difference of rib thickness. Therefore, wheel running test can be conducted for different details at a time under two loading cases. Steel grade is SM490Y. Structural details were designed by the Fatigue Design Guideline. The partial penetration of 75% rib thickness was ensured for the RD weld. One-pass CO₂ gas shielded arc welding was applied with natural groove for U6. Two-pass CO₂ gas shielded arc welding was applied with 35° groove and 2mm edge for U8.

The test was conducted at 4million cycles each on U6 and U8 rib side of the test specimen. The wheel running test machine owned by PWRI was used for the test (see Fig. 5). Wheel load was set to 150kN based on the measured truck axle load observed in the past field measurements, referred to the Fatigue Design Guideline. Running length of wheel load was set to 3m, two rubber sheets with the width of 200mm and the thickness of 22mm were set on the deck surface to simulate rubber dual-tire wheel load. Above them, steel blocks with the width of 500mm and the length of 200mm were set along longitudinal direction, and a steel plate with the width of 560mm and the thickness of 16mm was placed over them for running the steel wheel of the test machine.



(a) Cracks in weld parts of RD connections at rib-to-deck weld



(b) Cracks in other parts at rib-to-deck weld

Fig. 8 Ratio of crack depth to deck thickness versus loading cycles equivalent to 100kN wheel load

Ultrasonic testing (UT) was performed every 0.25million cycles during the test. In order to observe directly the initiation and propagation behavior of cracks after the test, drilled cores were taken with the diameter of 40mm locations showing a large change of measured strains or those where high ultrasonic echoes were measured by UT.

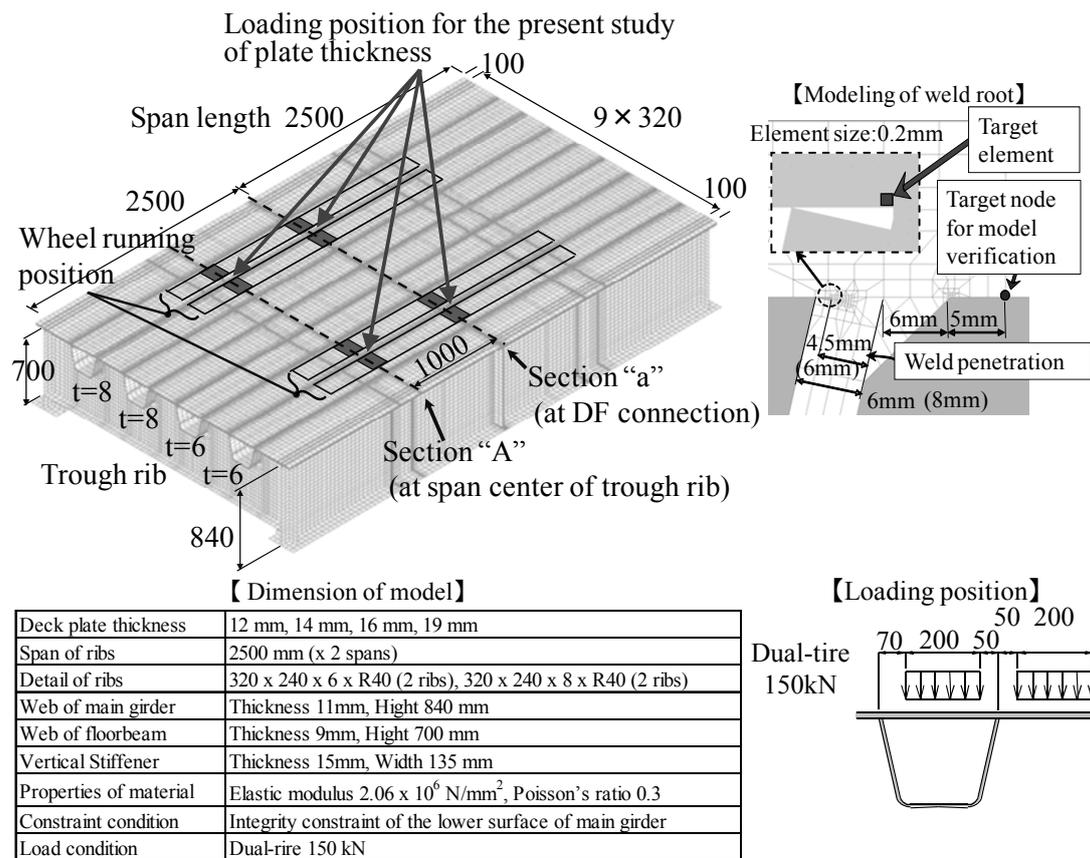


Fig. 9 Analysis model of test specimen

Test Results

Locations of drilled cores taken from the deck plate were shown in Fig. 4. Black symbols and white symbols in the figure denote cores where crack were detected or not respectively. As results of UT conducted during the test, cracks were observed only at four locations of RF connections of weld lines W_1 and W_2 both on U6 and U8 sides. Fig. 6 shows shapes of all observed cracks initiating in the weld root. Intersections of the crack tip and the core surface are also shown with white symbols in the figure. Fig. 7 shows photos of cracks observed on the surface of core No.4 on the U6 side and the core No.1 on the U8 side. Cracks initiated in the weld root and propagated semi-elliptically at an angle of approximately 50 degrees to the deck plate surface. The direction of crack is similar to that of actual cracks in damaged OSD bridges. As the results, progress of deck plate cracks is possible even if the deck thickness is increased to 19mm.

Fig. 8 shows the relation between the ratio of crack depth to deck thickness and the number of loading cycle equivalent to 100kN wheel load. The results by the authors and those by other studies are plotted in the figure. The equivalent loading cycles were calculated based on the linear cumulative damage rule ($m=3$). Crack depths estimated from UT are also plotted. Although the variation in data is large, crack growth tended to progress relatively slowly with increase of the deck thickness.

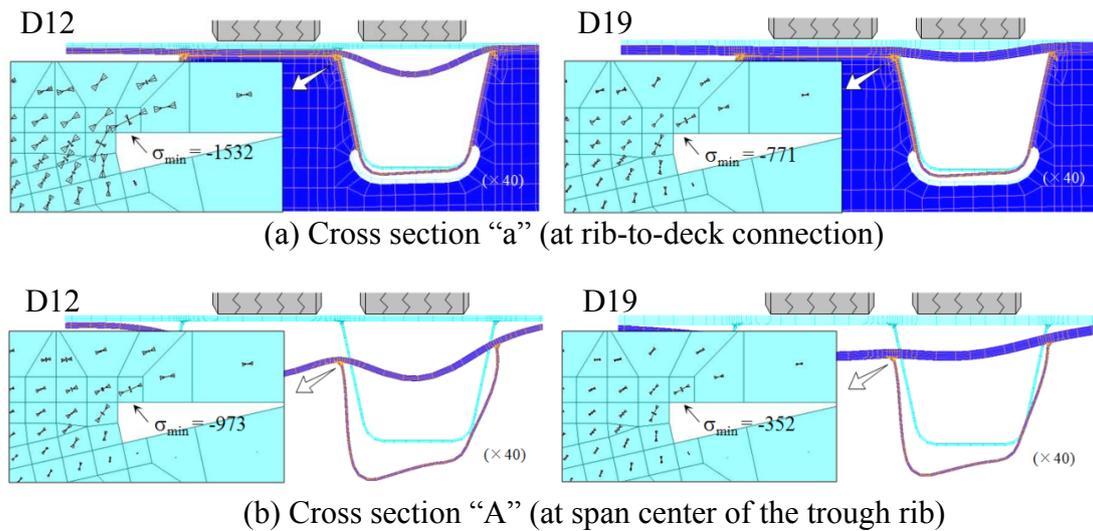


Fig. 10 Deformation and principal stress vector diagrams for D12U6 and D19U6

Finite Element Analysis on Local Stress of Structural Details

Analysis Method

FE analyses were conducted for the full-scale test specimen focusing on the local stresses in the weld root where cracks initiated. Fig. 9 shows outline of the analysis model. In modeling, the minimum dimensions of elements of the target weld root were set to $0.2\text{mm} \times 0.2\text{mm} \times 0.5\text{mm}$. Although local stresses of the weld root are affected by element dimensions in the analysis model, relative comparison of local stresses by using the same detail modeling is considered to be appropriate. The elastic modulus of E and Poisson's ratio ν for steel material were set as $E=206,000\text{N/mm}^2$ and $\nu=0.3$, respectively. The contact point between the bottom surface of deck and the inner surface of rib at the RD connection was modeled as separated node. Dual-tire wheel loads of 150kN were applied above RD weld line, same as that in the wheel running test. Especially in this paper, the results of loading patterns at section "a" at DF connection and section "A" at span center of trough rib were discussed.

Analysis Results

Fig. 10 shows the deformation and the principal stress vector diagrams for the combination of D12U6 and D19U6 at cross section of "a" (rib-to-deck connection)" and "A" (span center of the trough-rib). Relative high peak compressive stresses occurred at the weld root due to local bending of deck plate. Deformation of the deck and the rib and local stress of target element in the weld root decreased with increase of the deck thickness. Absolute values of the minimum principal stress are larger than those of the maximum principal stress in the weld root. As to target element, the direction of minimum (compressive) principal stress corresponds almost perpendicularly to the direction of crack propagation.

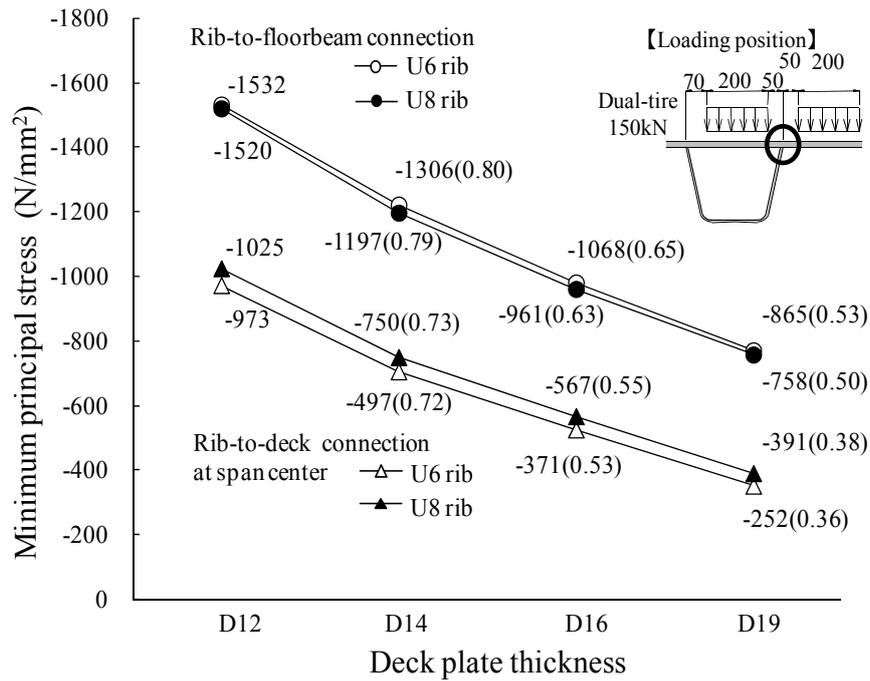


Fig. 11 Minimum principal stress versus deck plate thickness

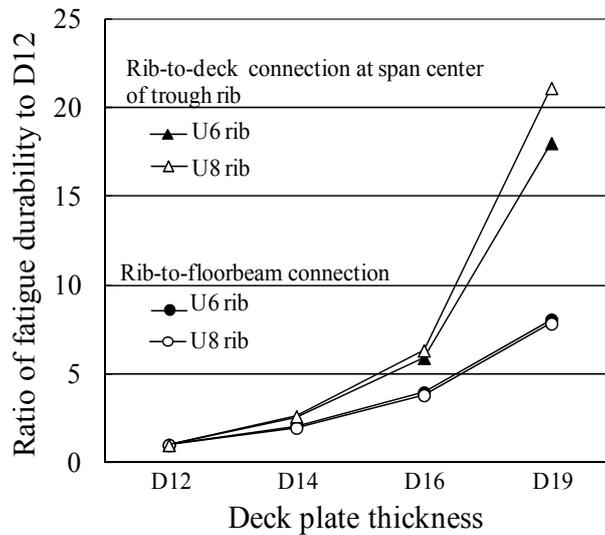


Fig. 12 Ratio of Fatigue durability to D12 versus deck plate thickness

Fig. 11 shows the minimum principal stress for the target element in the weld root by deck thickness. The ratios to the stresses for D12 are indicated in parentheses. The effect on fatigue durability of deck thickness was evaluated on the basis of relative comparison of minimum principal stress since compressive principal stress is dominant in the local stresses at the weld root under wheel loading. Increase of deck thickness can significantly reduce the minimum principal stress. The minimum principal stress at RF connection part for D19 is larger than that at RD connection part at the span center of the trough rib for D16 and D19, which corresponds to tendency

of fatigue cracking observed in the test. Rib thickness does not significantly affect the local stresses in the weld root.

Fig. 12 shows the relative comparison of fatigue durability by deck plate thickness. Fatigue durability was assessed based on the local stresses in the weld root by cumulative damage rule. As to the weld root at RF connection, where is under more severe fatigue condition, estimated fatigue durability for OSD with D14, D16 and D19 against local stress are about 2, 4 and 8 times as long as that with D12, respectively.

Conclusions

Wheel running fatigue tests were performed for full-scale test specimen with combination of 16/19mm thickness deck plates and 6/8 mm thickness trapezoidal ribs. Finite element analyses were also conducted in order to clarify the effect of thickness of deck plate on local stresses in the weld root at the rib-to-deck connections. The major findings are summarized as follows.

- 1) Deck plate cracks occurred at the rib-to-floorbeam connections even in the deck thickness 19mm. However, based on the test results of the present study and other studies, the crack growth tended to progress relatively slowly with increase of deck plate thickness.
- 2) Relative high peak stresses occurred at the weld root due to local bending of deck plate. The extent of reduction of the stresses in the weld root was evaluated for increase of the deck plate thickness.

Acknowledgment

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