Recent Studies on Fatigue of Orthotropic Steel Deck at PWRI

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1. Introduction

Orthotropic steel deck system is widely used in long-span bridges and urban viaduct bridges to help reduce self-weight of superstructure. Orthotropic deck is composed of thin plate members connected by welds and bolted splices, and subjected to direct wheel load of vehicles. With rapid development of large vehicle weight and traffic volume, fatigue cracks have been reported for some welded connection details, such as rib-to-deck connection, rib-to-diaphragm connection, cutout details (Figure-1) of orthotropic steel decks subjected to heavy wheel load. Recently, two severe types of fatigue crack have been reported at rib-to-deck connection. Both are root cracks which initiate at the root of the one-side fillet weld. As shown in Figure-2, one type propagates to the rib-to-deck weld bead while the other is propagated inside the deck plate.

We have just started studying how to repair and retrofit fatigue damaged orthotropic deck, especially focusing on the crack propagating to the deck plate. The objectives of our research program are as follows.

(1) To investigate field non-destructive measurement techniques for detecting cracks

This crack can not be detected by visual close inspection because it initiates at the weld root inside the closed U-rib and then propagated to the deck plate.

Non-destructive measurement methods using ultrasonic waves commonly used are investigated.

(2) To understand fatigue behavior of orthotropic decks subjected to wheel loads

Connection details between U-shape rib and deck plate are ordinary details among typical closed rib system.

In order to investigate fatigue behavior and cracking mechanism of orthotropic decks, FE analytical studies, full-scale static/fatigue experiments and field studies of damaged bridges are conducted.

(3) To investigate and establish repairing and retrofitting techniques

Repair and retrofit techniques which is effective to improve fatigue durability of damaged bridges and practical under in-service traffic condition are investigated.

This paper first introduce an example of the fatigue cracks in a damaged bridge briefly and then outlines the present main results of fundamental studies on ultrasonic measurements for detecting the cracks and FE analytical parametric studies to investigate local stress behavior around the details.

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2. Example of the fatigue damage

Examples of cracks that have penetrated a deck plate have been recently reported. As shown in Figure-2(b), on those spots, cracks have propagated along the weld lines, severely damaging the pavement. If those cracks propagate more, a cave-in may occur in the road surface.

As far as we know, the deck penetrating cracks have been observed on three bridges in Japan. Table-1 shows the sectional dimensions and rib-to-deck connection details of these bridges. There are several similar points: under heavy traffic; combination of 12mm thickness deck plate and 8mm thickness U-rib; and damaged U-rib directly under the wheel load and adjacent to the main girder web. As for Bridge-B, a 3-span continuous box-girder bridge, the thickness of the deck plate varies from 12mm to 20mm in the longitudinal direction, and fatigue cracks are found only in areas of 12mm thickness deck plate.

3. Fundamental studies on application of ultrasonic measurement

Non-destructive inspection methods using ultrasonic waves are being investigated to detect fatigue cracks propagating to the deck plate. So far, three methods with different ultrasonic waves, which are considered to be useful for scanning and detecting surface crack, have been selected and are being tested.

Figure-3 shows images of scanning by three ultrasonic waves: commonly used SV wave (angle beam technique), creeping wave and surface SH wave. Laboratory tests on application of three ultrasonic measurements are being conducted with small specimens that simulate U-rib-deck connection details (Figure-4). Fatigue loading tests were conducted to generate root cracks at the weld root of the specimens, and during the tests, ultrasonic measurements are conducted to investigate the crack detectability for each measurement method, meanwhile their applicabilities to field measurement are being investigated on actual damaged deck (Photo-1). As a result, it has been found so far that with the angle beam technique, we can detect and measure crack depth of more than about 6mm depth (more than half the deck plate) with almost practical accuracy (Figure-5).

4. FE analytical studies

FE analyses on local stress at the weld root have been conducted to investigate fatigue behavior around the rib-to-deck connection details by several researchers in Japan. We are also conducting FE analytical study focusing on the local stress behavior around the root of one-side fillet weld between U-rib and deck plate.

FE analytical model was set up for a full scale test specimen that simulates the dimensions of Bridge-B. The whole model consists of 376,866 solid elements and 472,043 nodes, with the same connection geometry and almost the same size and shape of the weld as those of Bridge-B. The element sizes around the weld root were adjusted to see the local stresses. FE analytical parametric studies are being conducted in various wheel load positions, focusing on the local stress of the weld root. Figure-6 shows the FE analytical model without deck pavement and applied wheel loads on the model. These wheel loads represent a pair of front tire (single tire) and rear tire (double tires) of a short-body heavy truck. The static loading test of a full scale orthotropic deck specimen was also conducted to ensure the accuracy of FE modeling around the connection details. It was confirmed that the FE modeling is accurate enough to give good agreement between measured strain values and analytical values.

Figure-7 shows the principal stresses of the weld root just directly under the wheel load on the center line between the cross-beams (L/2 line). Those wheel load transverse positions in Figure-7 are the same as those estimated in Bridge-B. The front tire gives a tensile stress in the direction that tears the weld bead, and the rear tire gives a high compressive stress in the back surface of the deck plate. It seems that the stress variation created by the front tire and the rear tire is related with the generation of root cracks propagating to the deck plate.

Figure-8 shows the longitudinal variation of the principal stress of the weld root under the same rear tire loading as those shown in Figure-7. As mentioned previously, the wheel load gives high compressive stress to transverse direction on the back of deck plate just under the load. But when the wheel load moves to longitudinal direction, it gives low tensile stress, which influences crack propagation to the deck surface to some extent after occurrence of cracking.

It is considered from these results that the high compressive stress directly under the wheel loads (which is considered to cause severe tensile stress range at weld root with combination of high tensile residual stress) and the variation of stress by repetitive loading of front tire and rear tire generate the crack, and that the local stress behavior when moving wheel load is related to the propagation of the crack.

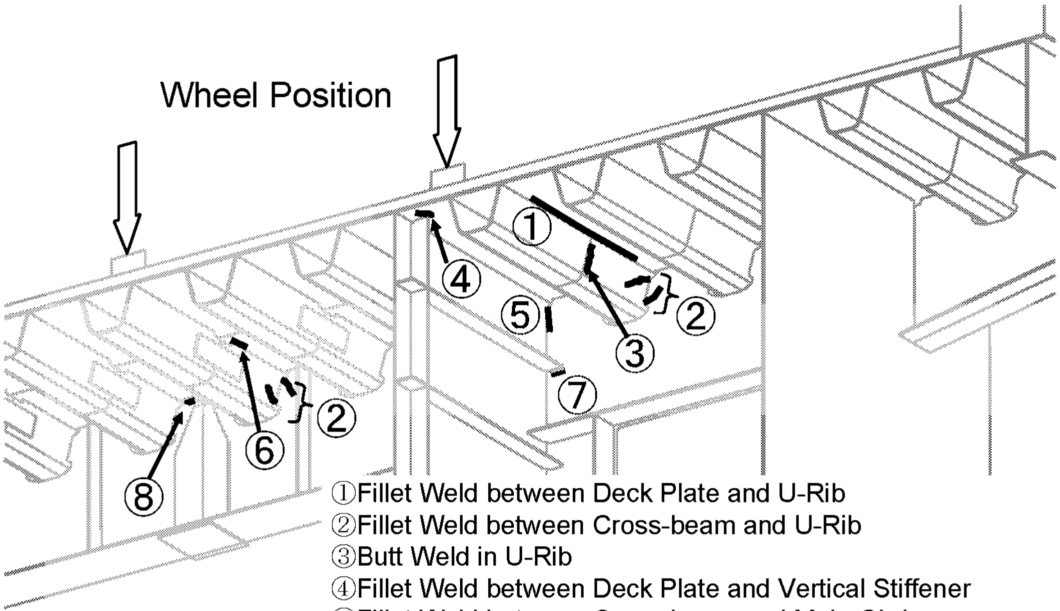
5. Summary

Recent studies on fatigue of orthotropic steel deck at PWRI was outlined in this paper.

As to ultrasonic measurement methods, applicabilities of the three methods are being studied further to investigate the characteristic of ultrasonic reflection from crack surface/tip and to propose a practical measurement method. As to repair and retrofit techniques, strengthening by bolted thick steel plate after removing crack tips is now considered to be a countermeasure to repair and retrofit damaged deck. For a newly constructed bridge, Steel Fiber Reinforced Concrete (SFRC) was applied to deck surfacing instead of ordinary asphalt pavement, to reduce effectively the local stresses with its high rigidity. Fatigue behavior and durabilities of such countermeasures are being studied further to establish effective/practical repair and retrofit methods with FE analytical studies and full scale wheel running fatigue tests.

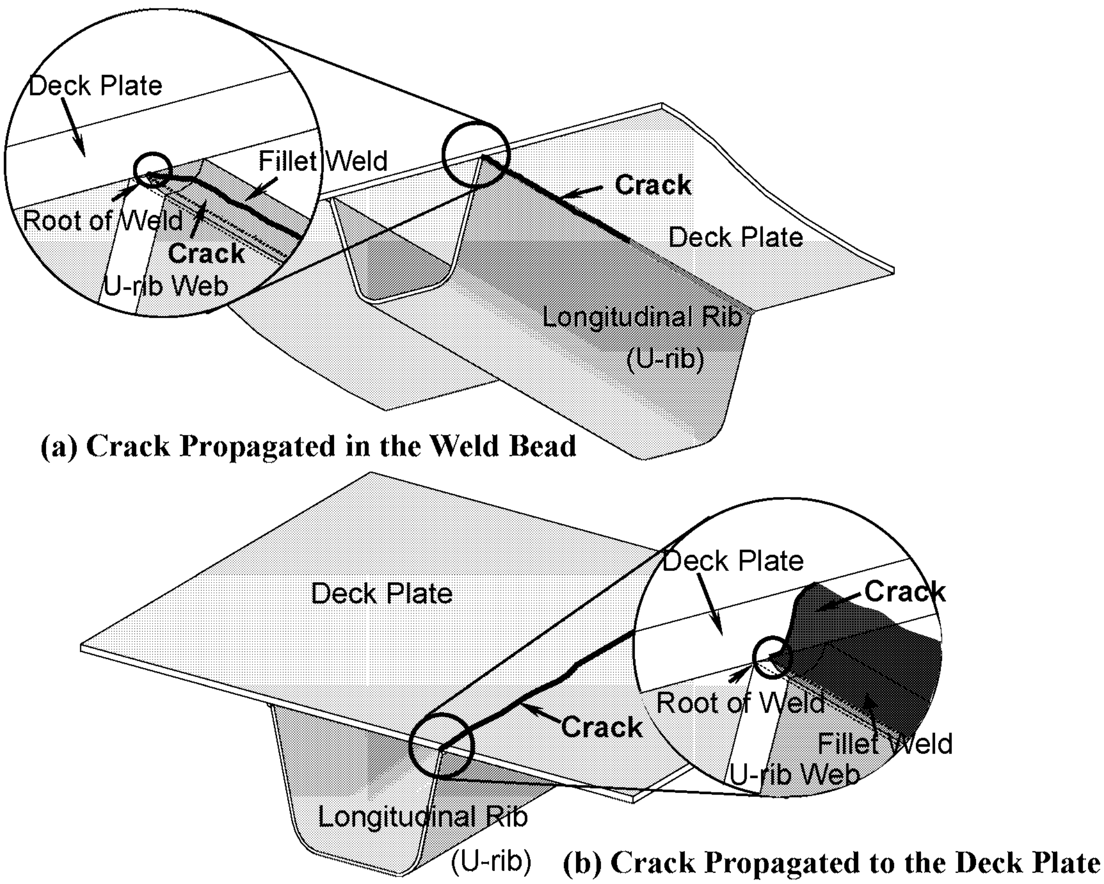
References

1) Fatigue of Steel Bridges, Japan Road Association, 1997.



①Fillet Weld between Deck Plate and U-Rib
②Fillet Weld between Cross-beam and U-Rib
③Butt Weld in U-Rib
④Fillet Weld between Deck Plate and Vertical Stiffener
⑤Fillet Weld between Cross-beam and Main Girder
⑥Fillet Weld between Deck Plate and U-Rib
(Cutout at U-Rib Field Connection)
⑦Fillet Weld between Horizontal Stiffener and Cross-beam
⑧Fillet Weld between Deck Plate and Cross-beam
(Cutout at Cross-beam Connection)

Figure-1 Fatigue Damages of Orthotropic Deck Bridge

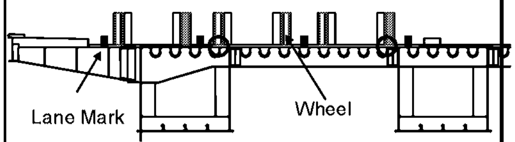
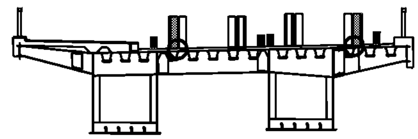
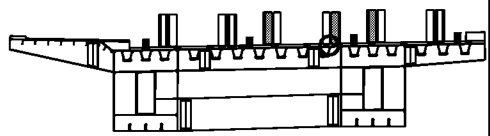


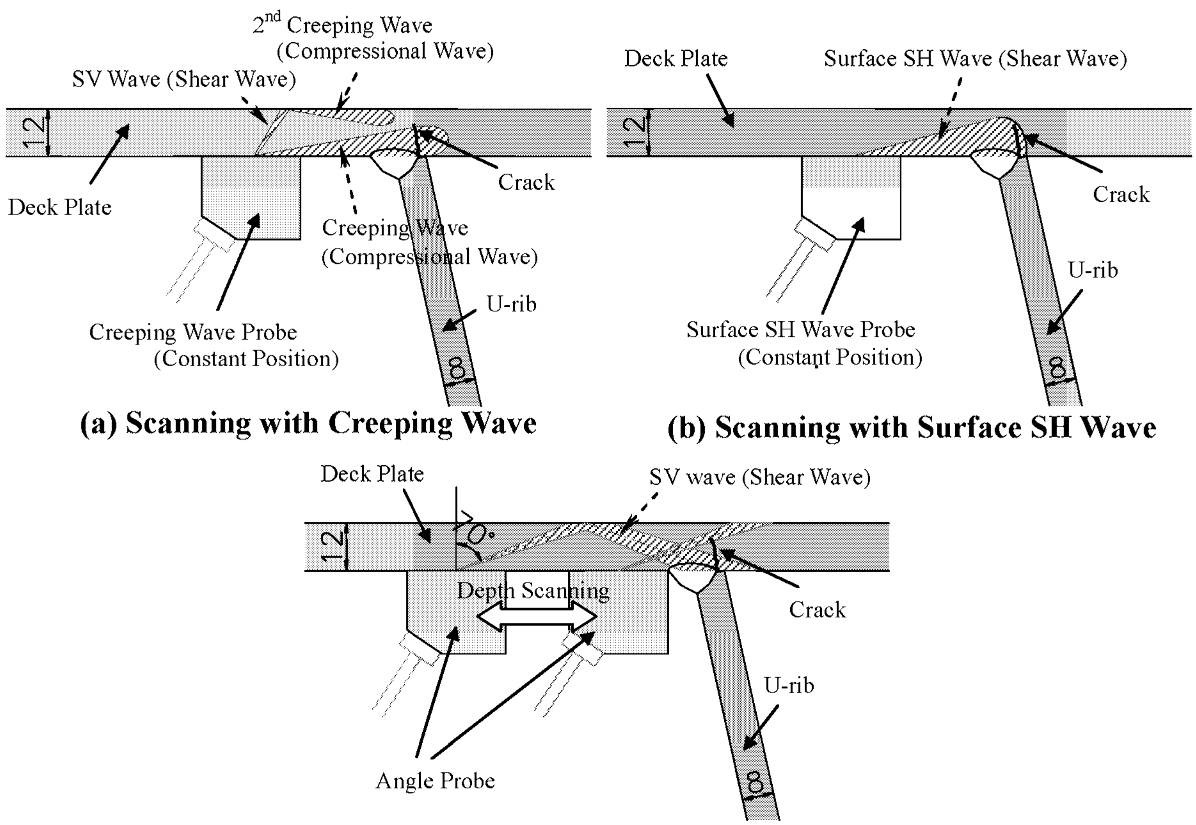
(a) Crack Propagated in the Weld Bead

(b) Crack Propagated to the Deck Plate

Figure-2 Fatigue Crack at the Weld between U-rib and Deck Plate

Table-1 Damaged Bridges

Bridge	Service Year	Dairy Truck Traffic	U-rib Section	Crack Location(○), Wheel Load Position
A	25 Years	7,634 vehicle/ day	Pavement thickness 70mm; Deck 12mm; 310; 274; U-Rib 8mm	
B	13 Years	3,124 vehicle/ day	Pavement thickness 70mm; Deck12-20mm; 320; 250; U-Rib 8mm	
C	24 Years	2,903 vehicle/ day	Pavement thickness 80mm; Deck 12mm; 340; 280; U-Rib 8mm	



(a) Scanning with Creeping Wave

(b) Scanning with Surface SH Wave

(c) Scanning with SV Wave (Angle Beam Technique)

Figure-3 Scanning with Ultrasonic Waves

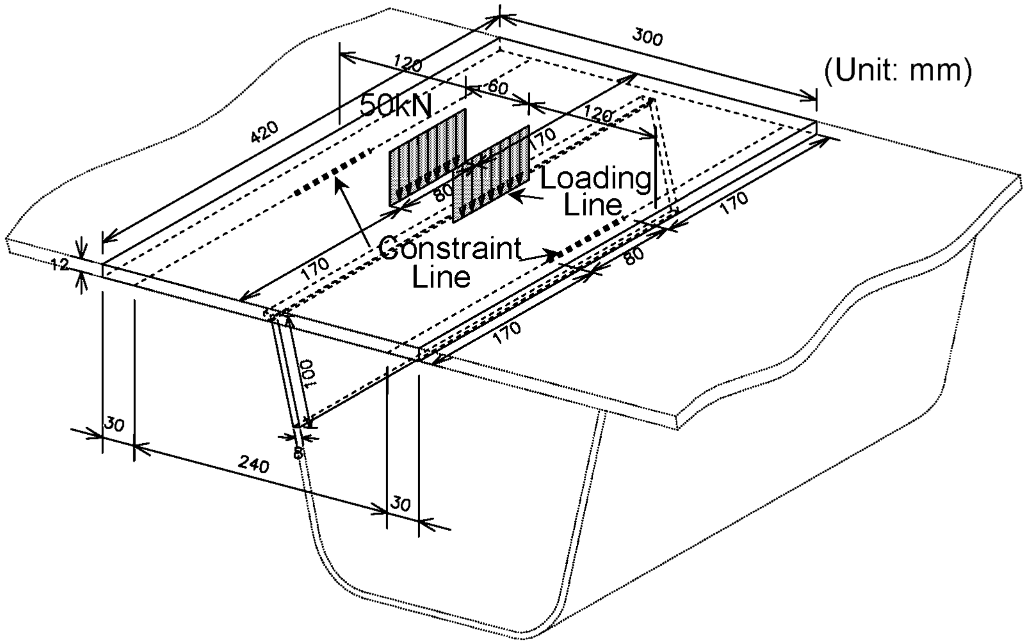


Figure-4 Small Test Specimen

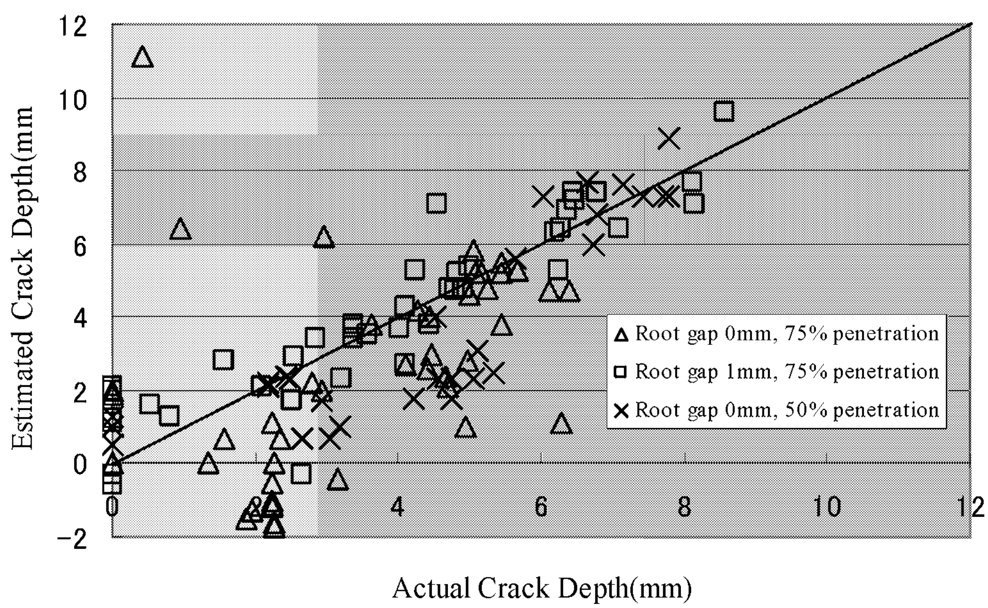


Figure-5 Comparison between Real and Estimated Depths of cracks with Angle Beam Technique

Photo-1 Field Measurement in a Damaged Bridge

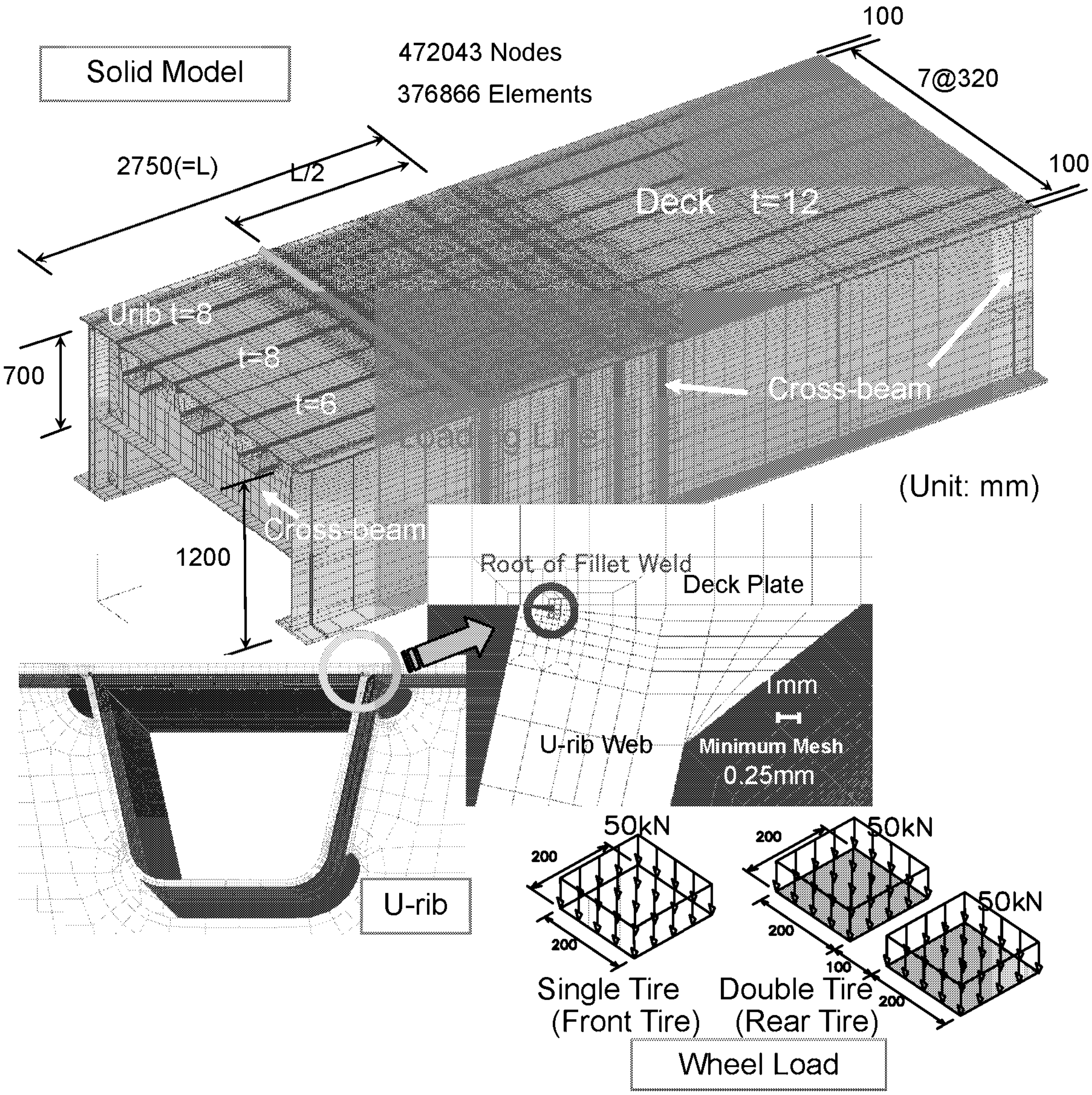


Figure-6 FEM Analytical Model

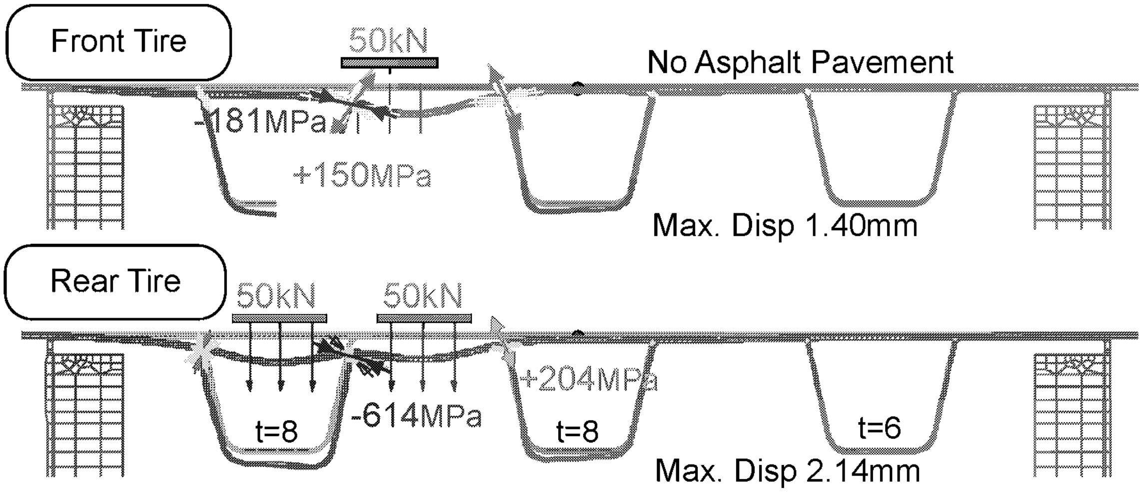


Figure-7 Principal Stresses at the weld root under Loading (L/2 cross section)

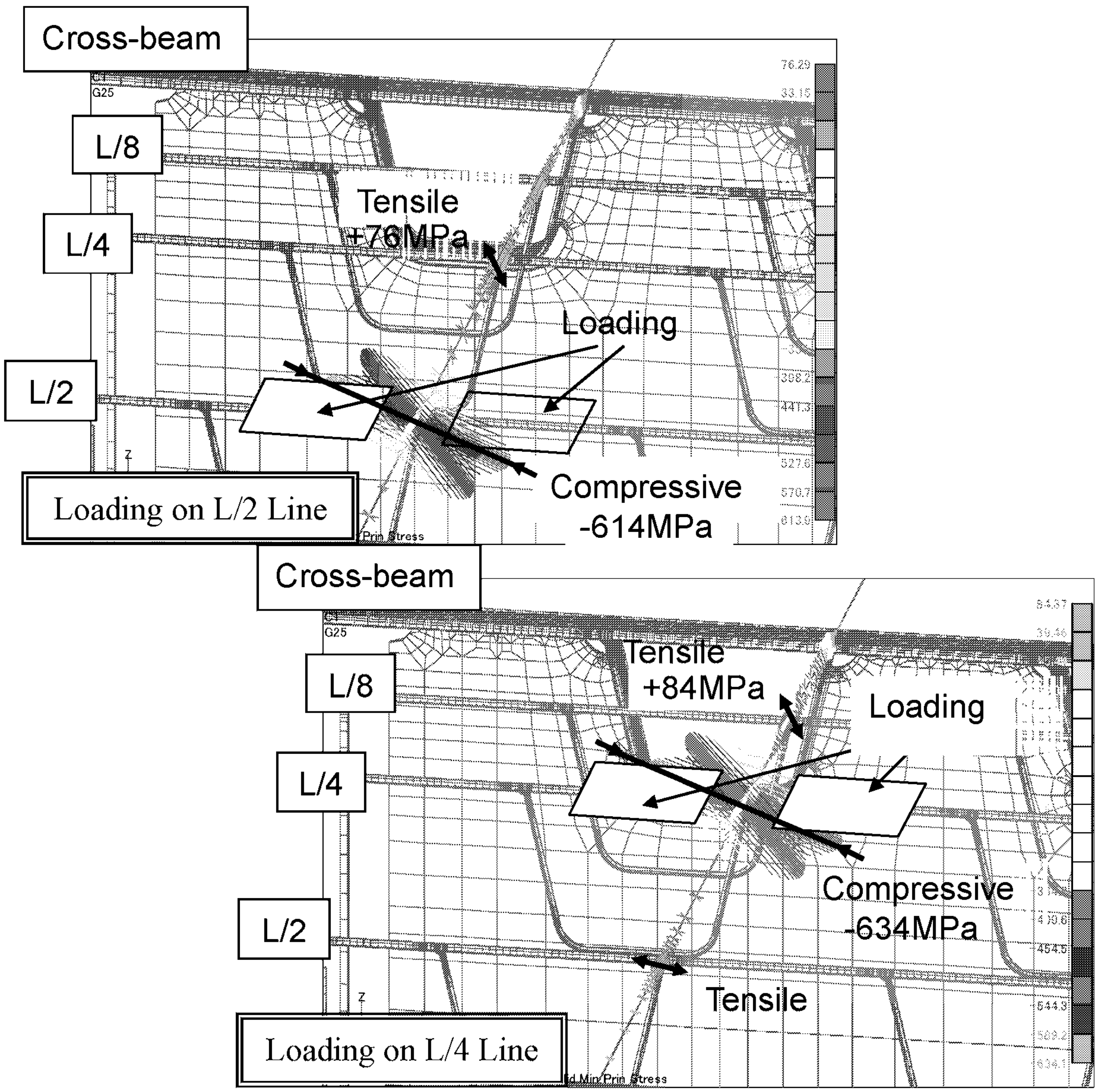


Figure-8 Longitudinal Distribution of Principal Stresses at the Weld Root