Structural responses of orthotropic steel deck with through-deck fatigue crack

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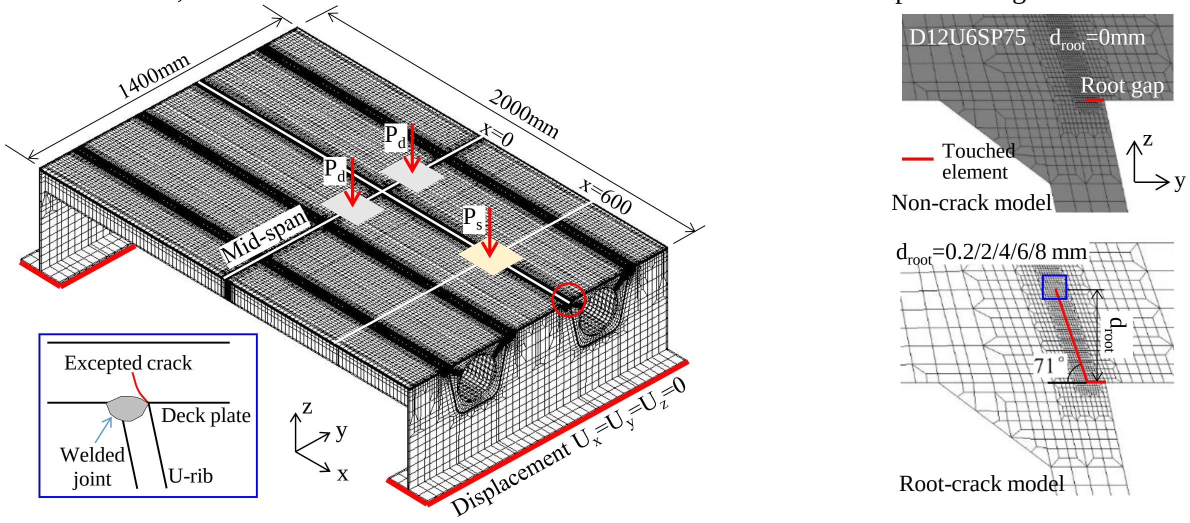
1 Introduction

Orthotropic steel bridge decks were widely applied to long-span bridges because of their characteristics such as light weight, high strength and durability, and rapid construction [1, 2]. However, fatigue problems always occurred in the welded connections after several years in service, especially a steel deck with closed ribs, as a consequence of high cyclic stresses by wheel loads. In Japan, the crack initiated at the weld root of the longitudinal fillet welding between deck plate and U-rib is the most common ones and of particular concern [3]. This study established the finite element models in a combination with stress analyses around the weld root. Various root crack depths were simulated in the crack models, the stress response at root tip during propagation stages, and the stress variations of half loading cycle were analyzed.

2 FE models

Three-dimensional elastic models were constructed by Marc mentat 2012, as shown in Fig.1(a). The models are denoted as D12U6SP75 with 12mm-thick deck plate, 6mm-thick U-ribs, and penetration of 75% of the rib thickness. The loading condition was included in static load P_s and dynamic load P_d (Double tire loading) in FE analysis, P_d = 13.5~135kN, P_s = 168kN, which contributed to the alternative stress at mid-span together. The primary nominal stress which 5mm away from weld toe was set from -160 to 20MPa. Fig.1(b) shows the welded joint details of non-crack model and 5 root-crack models with different projected crack depth. The root cracks were measured based on previous tested specimens, the measured average 71° is used for simulating root crack angle in all of the models, and the root cracks were located at -40 to 40mm from mid-span in longitudinal direction.



(a) FE models (b) Welded joint details

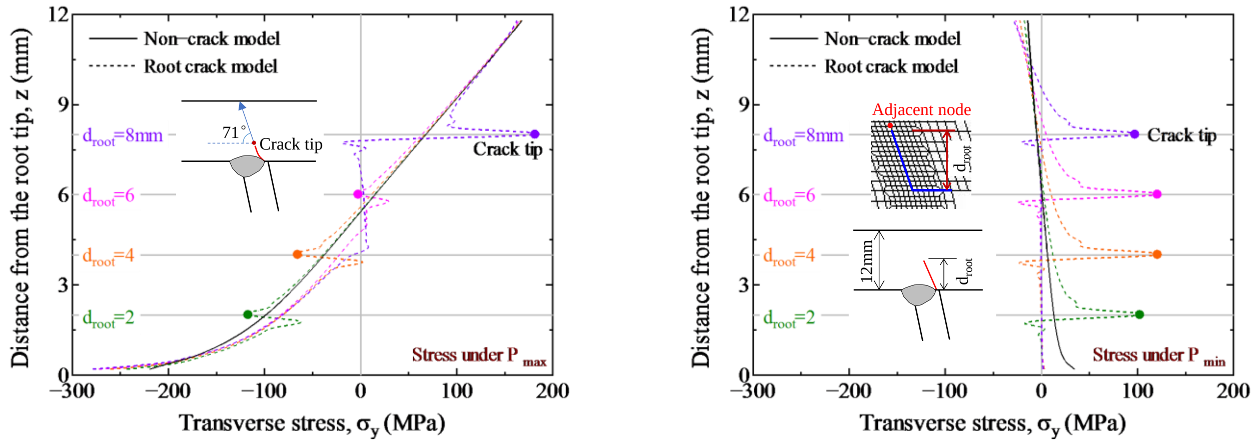
Fig.1 Definitions of FE models

3 Structural response analysis

In this paper, the stress distributions of crack models were based on the adjacent node of crack tip to upper surface of deck plate. The stress distributions including the node stress at cracked surface and the remaining sections are shown in Fig.2. For the models with root crack that projected depth between 0 to 6mm, their crack tip stresses shown to be compressive stress under P_{max}, as shown in Fig.2(a). The tendency for stress states was similar to compare with the non-crack and crack model. The neutral axis would not move because the crack closed in compression zone and the structural bearing capacity unchanged when the root crack propagated from 0 to 6mm. However, the stress concentration cannot avoid after the crack tip extend into tensile zone. Thus for 8mm-crack models, the crack tip and remaining section always under the tensile stress in loading cycles, whereas the cracked part in range of 4mm distance from bottom of deck plate were in a state of compression under any loading steps. On the other hand, a tensile stress zone existed below the neutral axis of deck plate when models under P_{min}, The stress at crack tip were significantly changed during the crack growth, as shown in Fig.2(b). In this case, cracked section cannot afford the tensile stress and crack tip tend to be open, thus the neutral axis moving up continues in cracking process, and stress redistribution in deck thickness.

Therefore, the stress distribution of 8mm-crack model is different compare with the other crack models in deck thickness direction, its crack tip zone is tend to be tensile stress under any loading conditions. The corresponding stress contours and deformation are shown in Fig.3. A tensile stress zone lead to the crack tip open, and the bottom one-third of deck plate thickness is under the compressive stress, which is consisted with the stress distribution in Fig.2(a).

Figure 4 shows the stress variations at crack tips of these crack models under the loading. In case of crack length from 0.2 to 6mm, the transverse compressive stress tend to reduce under P_{max}. However, the tensile stress has not changed much under P_{min}. 8mm-crack model shows the tensile stress always around its crack tip under the whole loading cycle. The tensile stress value for P_{max} on 8mm crack length is about 1.86-times larger than those of P_{min}. It was considered the crack tip would forms tensile stress under the whole cycle of loading when a root crack propagated over half of deck plate thickness. In this case, with the crack extending, the loading value P_{max} would be a dominant factor for crack propagation instead of P_{min}, and lead to a larger principal tensile stress at crack tip. The promoting effect between crack growth and principal stress might result in a significant reduction in the residual life of this structure.



(a) P_{max} (b) P_{min}

Fig.2 Stress distribution in cracking direction

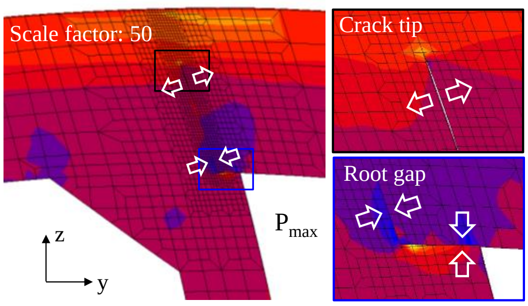


Fig.3 Stress contour of 8mm-crack model under P_{max}

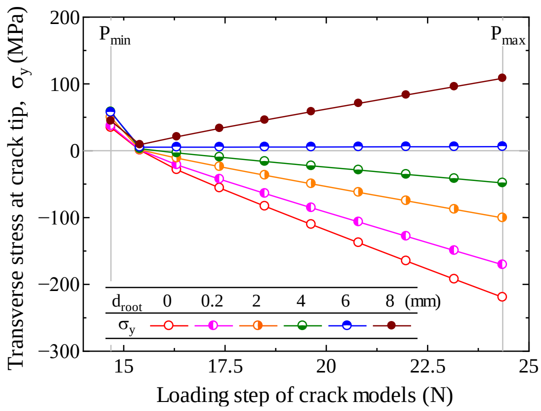


Fig.4 Stress variations of half loading cycle

4 Summary

1) Crack tip always tend to be open under P_{min} for this structure detail.

2) The crack tip forms tensile stress under the whole cycle of loading when a root crack propagated over half of deck plate thickness.

3) The large crack length (more than 1/2 thickness) has significant adverse impact on the root crack propagation.

Reference

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