Numerical analysis for fatigue crack penetration of gusset welded joint using FRANC3D

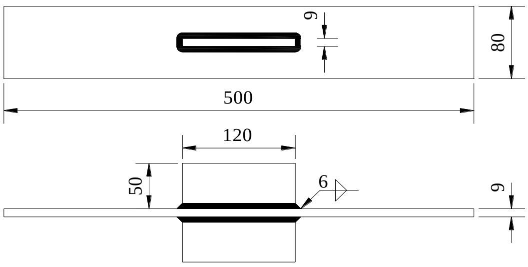
Kyushu University Regular member ○Y. S. Jeong Fellow member S. Kainuma
Mitsui Engineering & Shipbuilding Regular member D. Uchida N. Yagi

1. Introduction Importance of maintenance in steel structures is emphasized according to increase of their service time. Fatigue crack can be a controlling factor in the life of some welding components, such as vertical and horizontal stiffener. In this study, fatigue tests were carried out on the both side welding and one side welding for out-of-plane gusset fillet welded joint. In addition, investigations of three-dimensional fatigue crack penetration of gusset welded joint using the finite element analysis of FEMAP with NX NASTRAN and FRANC3D. The 3D crack growth simulations can be performed to compute stress intensity factor(SIF), which are used to determine crack propagation cycles.

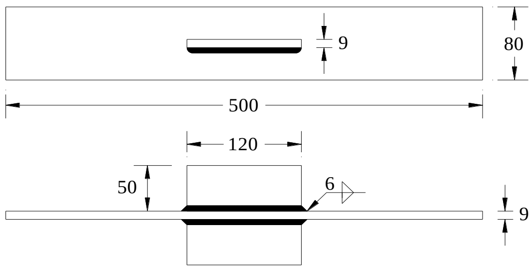
2. Fatigue test program Fatigue tests were carried out on the both side welding and one side welding out-of-plane gusset fillet welded joint. Figure 1 shows the geometry and dimension of the test specimens. The test specimens were made of structural steel plates conforming to JIS SM400A and the flux core arc welding (FCAW) process was used to joint attachments to the main plates for gusset weld by 2 pass. All the gusset welding starts and stops were located in the end of the longitudinal gussets.

Constant amplitude sinusoidal stress cycles were applied to the specimens. Uniaxial tension stress cycles were applied in the longitudinal direction of the specimens and stress ratio was 0.1. The fatigue tests were continued until the specimens failed, and the number of loading cycles to failure was defined as the fatigue life.

Fracture surfaces of specimen with stress range of 120N/mm^2 were shown in Fig. 2. Fatigue cracks occurred in weld toe, combined into a multi-crack and propagated with semi-elliptical shape toward thickness direction. The crack depth can be reconstructed from beach-marked remained on fracture surface. From the crack size of observable minimum crack size, the initial crack depth can be assumed as 0.34mm, and then the fatigue life can be divided into fatigue crack initial life and propagated.

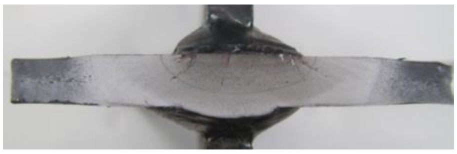


(a) Both side welding specimen

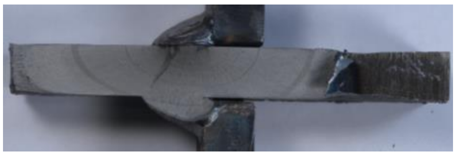


(b) One side welding specimen

Figure 1 Shape and dimension of specimens (unit:mm)



(a) Both side welding specimen



(b) One side welding specimen

Figure 2 Fracture surface of tested specimens

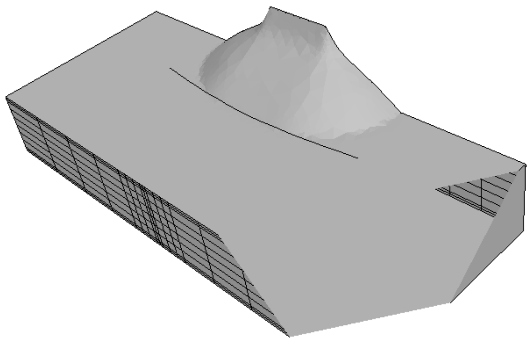


Figure 3 Crack penetration model

Keywords: fatigue, crack penetration, welded joint, out-of-plane gusset, FRANC3D
744, Motooka, Nishi-ku, Fukuoka 819-0395 Kyushu University

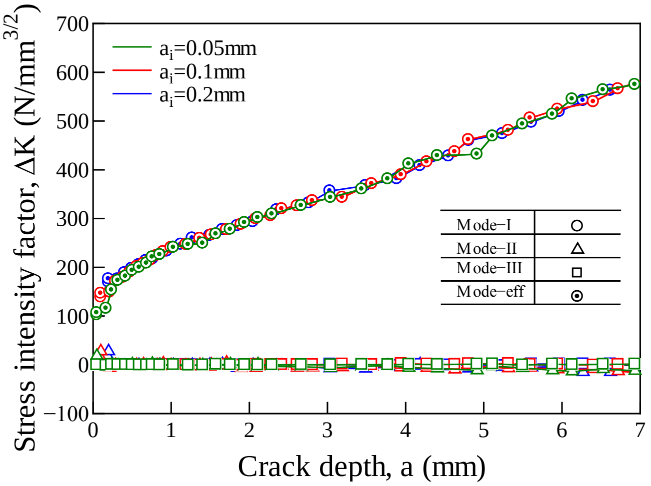


Figure 4 Comparison of SIFs to initial crack size

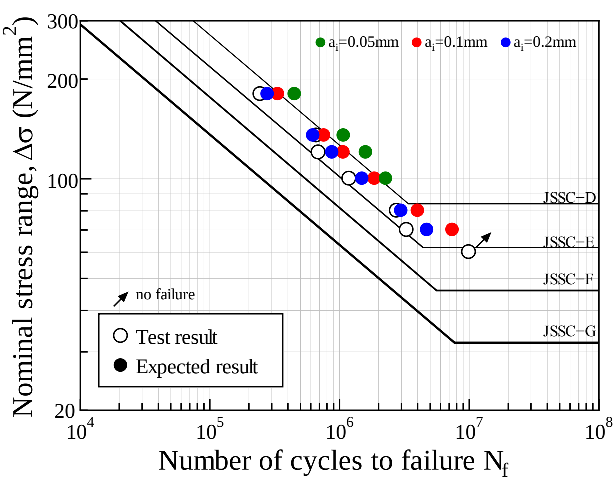


Figure 5 Fatigue test results and design S-N curves

3. Fatigue crack penetration analysis Fundamental concepts and practical applications of the fracture mechanics approach to fatigue crack propagation was demonstrated by Paris[1]. In this study, fracture analysis simulations was used in FEMAP with NX NASTRAN Ver.7.1 and FRANC3D Ver.6.0.5. It was illustrated by first analyzing a surface crack in a cube on weld toe. Second, determined crack geometry was extended and third, insert crack into portion of weld toe and re-mesh. The fatigue growth algorithm uses a fatigue crack growth rate model (*da/dN* vs. Δ*K*) in conjunction with the computed stress intensity factors in order to predict the relative amount of crack growth. The stress intensity factor (SIF) can be calculated using Paris law and C and n are used in Fatigue Design Recommendations for Steel Structures(JSSC)[2] shown in Eq.(1).

$$da/dN = C\Delta K^n \tag{1}$$

where C and n are material parameter, *da/dN* : mm/cycle, Δ*K* : N/mm$^{3/2}$, C=1.1×10^{-12} and n=2.75

FRANC3D computes separate stress intensity factors for all three modes of fracture (K_I, K_{II}, and K_{III}). In this study, the effective stress intensity factor on the crack growth models was calculated using strain energy release rate criterion shown in Eq.(2).

$$K_{eff} = \sqrt{K_I^2 + K_{II}^2 + 1.43 \cdot K_{III}^2} \tag{2}$$

The semi-elliptical surface crack is inserted at weld toe and crack penetration model shown in Fig. 3. It was based on test specimens but welded joints was created in turnaround weld. To consider the effect of initial fatigue crack size, the SIFs (K_I, K_{II}, K_{III} and K_{eff}) were compared based on analysis results with gusset welded joint, as shown in Fig 4. The SIFs were shown to be similar at propagation process, but initial process is different because of the crack size. In addition, the fatigue life based on SIFs for gusset welded joint was expected and it was verified by comparing fatigue test result. From the results, the expected fatigue life were shown to be similar with test result. Therefore, the fatigue crack propagation by the FRANC3D can be examine the fatigue problem of steel structures.

4. Summary

In this study, numerical analysis for fatigue crack penetration was conducted using FRANC3D. The three-dimensional numerical analysis results on gusset welded joint were developed considering the initial crack size and aspect ratio. From analysis result, SIFs behaviors of gusset welded joint were shown to be similar at propagation process. In addition, the fatigue life was expected.

References

1)T. L. Anderson: Fracture Mechanics: Fundamentals and Applications, Third edition, New York, Taylor & Francis, 2005.
2)Japanese Society of Steel Construction (JSSC) : Fatigue Design Recommendations for Steel Structures, Second edition, Gihodo, 2012.
3) FRANC3D Version 6.0 : http://www.cfg.cornell.edu/.