Fatigue cracking behavior of a through-thickness crack under out-of-plane bending

Nagoya University ○Xiao-Chen JU, Kazuo TATEISHI and Sung-Min CHOI

1. Introduction

Through-thickness crack is a typical fatigue crack observed in steel structures. Among them, some through-thickness cracks arise due to the repeated out-of-plane bending stress. Some researchers have suggested the estimation method of stress intensity factor (SIF) at crack front under out-of-plane bending by assuming that the crack front shape is straight[1), 2)]. However, under out-of-plane bending conditions, the crack front shape may not be straight because SIF is non-uniform along plate thickness due to the stress gradient and crack closure in the compression side as shown in Fig.1.

In this study, fatigue cracking behavior of through-thickness cracks under out-of-plane bending was investigated by fatigue tests. Moreover, an estimation method of SIF has been suggested based on numerical studies.

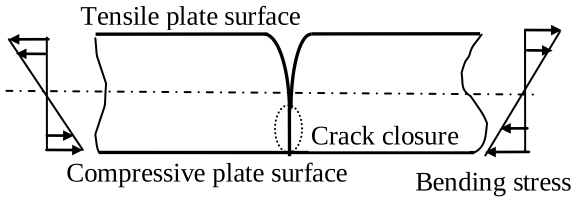

Fig. 1 Through-thickness crack under out-of plane bending

2. Experimental study

Test program The geometry configurations of the specimen are illustrated in Fig. 2. The thickness of plate is 15mm. Four through-thickness notches which are 8 mm in length with a 0.2 mm gap were installed to introduce through-thickness fatigue cracks. The nominal stress on the surface was calculated from measured strain at 35 mm away from the notch tip. In order to introduce out-of-plane bending, the middle part of the specimen was connected to the fatigue testing machine, and the two ends of the specimen were supported by circular steel bars welded on end plates as shown in Fig. 3.The test conditions are shown in Table 1. In order to investigate the shape of crack front, beach mark tests were also carried out.

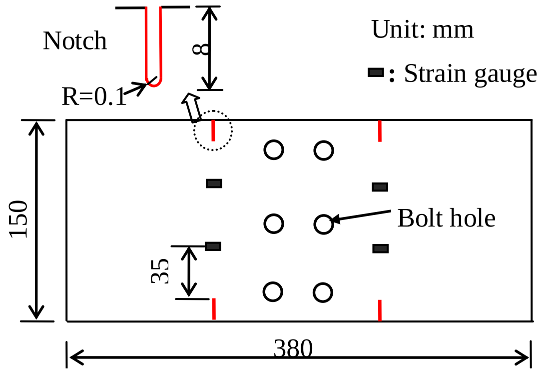

Fig. 2 Geometry configurations of specimen

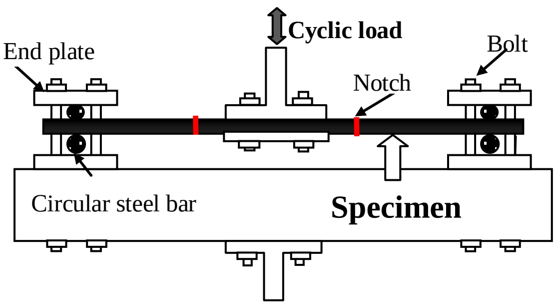

Fig. 3 Loading device

Test results Fig. 4 shows the fracture surface for each stress ratios (R). In R=0, fatigue crack has a quarter-ellipse shape which is the typical crack shape of surface crack. Except R=0, fatigue cracks were observed on both surfaces of plate. However, taken as a whole, the crack shapes in R=-0.25, -0.5, and -0.75 are similar to that in R=0. On the other hand, in R=-1, fatigue crack has a symmetrical V shape which is unique crack front shape compared with the other stress ratios. That is, it is difficult to estimate SIFs based on the theoretical considerations on a crack with a straight crack front in case of the fatigue crack under out-of-plane bending. This study mainly focused on the through-thickness cracking behavior for R=-1.

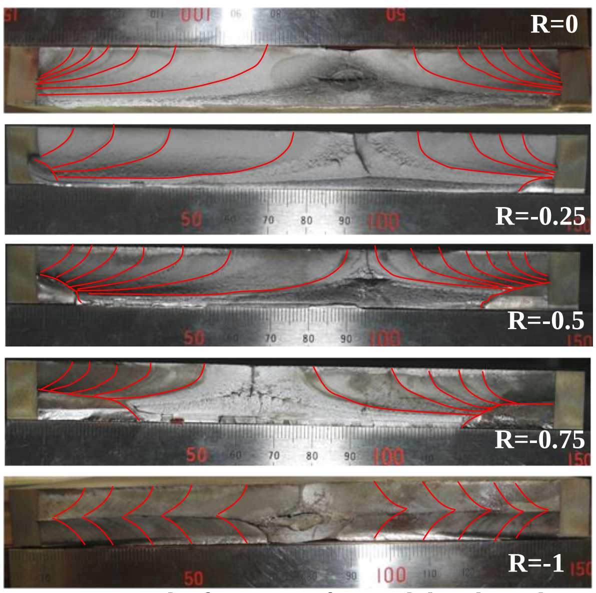

Fig. 4 The fracture surface with beach marks

3. Numerical analysis

FE model A quarter of the specimen with a through -thickness crack was modeled using twenty-node solid elements. Fig. 5 shows the analysis model and boundary conditions. Young's modulus and Poisson's ratio are set to be 210 GPa and 0.3. The symmetrical V shape crack observed in test was

Keywords Out-of-plane bending, Stress intensity factor, Crack front shape
Department of Civil Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan TEL 052-789-4620

Table 1 Test condition

General load (KN)		Load for beach mark(KN)		Stress ratio(R)
Max.	Min.	Max.	Min.	
19.2	-19.2	9.6	-9.6	0
30	0	30	15	-0.75
28	-21	21	-14	-0.5
28	-14	21	-10.5	-0.25
32	-8	24	-6	-1

modeled in the FE model. Contact elements were employed on the crack surfaces.

4. Results and discussions

Since SIF is an important factor to identify the crack propagation behavior, the SIF distributions along the crack front were investigated. Mode I SIF was calculated by J-integral method. Fig. 6 shows the SIF distributions along the crack front for different crack lengths. Regardless of the crack length, SIFs in the tensile region are roughly uniform, decline drastically around the interface of tensile compressive sides, and eventually become zero at the compressive side. Since the stress ratio is -1, a symmetric distribution must be presented when inversed loading is applied. As an example, Fig.7 represents the SIF range (K_{max}-K_{min}) when crack length at plate surface is 33.1mm. In the graph, the dotted line is calculated SIF ranges, and the solid line indicates crack front. As shown in the figure, the SIF ranges remain approximately uniform along the V-shaped crack front.

In order to calculate Mode I SIF for a through-thickness crack under of out-of-plane bending ($K_{bending}$), a correction factor α is introduced to Mode I SIF for a through-thickness crack under tension is given as explained below[1), 2)]:

$$K_{bending} = \alpha\sigma\sqrt{\pi a}\sqrt{\frac{2B}{\pi a}\tan\frac{\pi a}{2B}} \qquad (1)$$

Where, σ is stress at plate surface, a is crack length, B is half width of the plate, and α means correction factor.

The proposed values of α are 0.45 and 0.5 based on the theoretical considerations on a crack with a straight crack front. Fig.8 shows correction factors for crack length calculated in this study. The correction factor decreases slightly with the increase of crack length. The range of the correction factor is about 0.45-0.49, and the mean value of the correction factor is 0.465.

5. Conclusions

This study investigated fatigue cracking behavior of through-thickness cracks under out-of-plane bending and proposed a simple estimation method of SIF.

References

1) Erdogan et al., A comparative study of crack propagation in plates under tension and bending, *Proc. 1th Inter. Conf. Fracture*, pp. 341-362, 1965.

2) Kanazawa et al., A study of crack propagation and brittle fracture in plate with penetrating crack under combined stress, *The symposium of Japan Society of Naval Architects*, No.136, pp. 191-205, 1974.

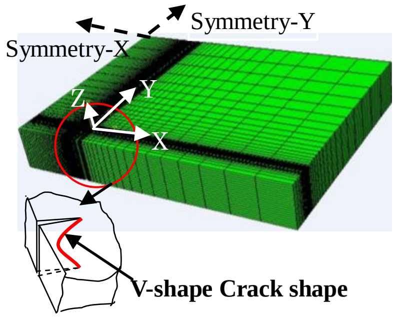

Fig. 5 FE model

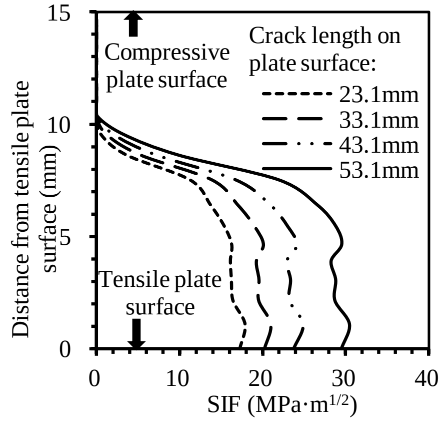

Fig. 6 SIF along V shape crack front

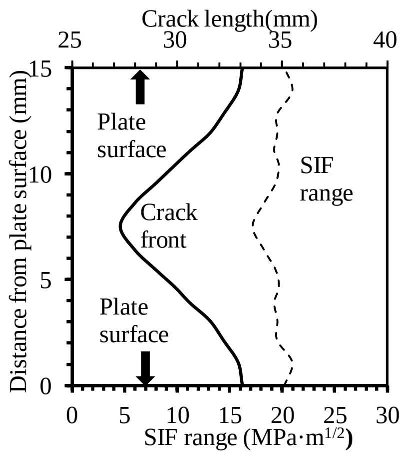

Fig. 7 SIF range along V shape crack front

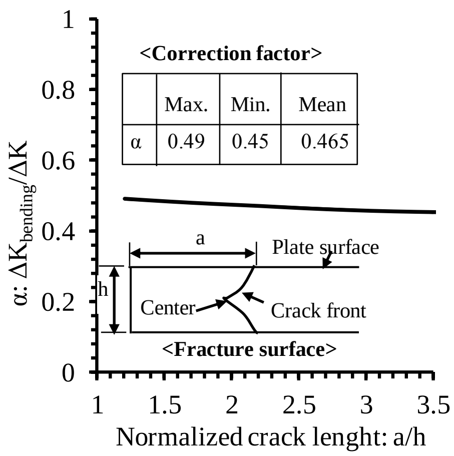

Fig. 8 Correction factor