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Technical Note

Crack detection with strain gages and the body force method

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1. Introduction

We proposed the concept called "Pseudo-3-D problem" and developed a stress estimation method based on this concept (Yoshimura *et al.* 2004). In this method, the observed domain, a surface of a notched region of 3-D stress field, is treated as a pseudo-3-D plate without thickness. Stress fields on the surface are estimated using a few surface strain data by strain gages and the body force method (BFM) (Nisitani and Cheng 1994).

In this study, we apply the above method to detecting a crack near a notch of 3-D structures.

2. Crack detection with stress contour maps

2.1 Models for crack detection

We use the results of elastic FEM analyses instead of the outputs of strain gages to bring correct boundary conditions in stress estimation (refer to Harada and Noguchi 1999) on the effect of strain gage's noise).

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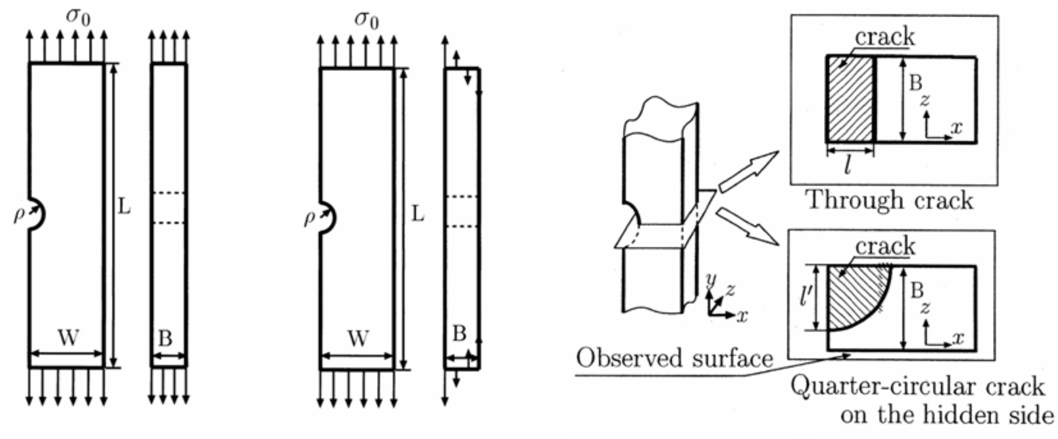


(a) Tension (b) Bending (c) Crack configuration

Fig. 1 Model for crack detection ($L/\rho = 18$, $W/\rho = 5$)

The models of FEM analyses are shown in Fig. 1. A through crack or a quarter-circular hidden crack on the back face is introduced at the root of a unilateral notch. By the way, the stress field near a notch (Nisitani 1994) and the stress gradient in the plate thickness direction (Kawai and Endoh 1986) depend on a notch root radius, ρ. Accordingly, dimensions of models are made dimensionless numbers at a notch root radius, ρ. The ratio of plate thickness and a notch root radius, B/ρ determines 3-D effect for stress fields near a notch (Kawai and Endoh 1986). The value is made to be 0.5, 1.0 and 2.0 in order to investigate the 3-D effect, stress gradient in the plate thickness direction for the crack detection. Though the models of a through crack are loaded tension or antiplane bending, those of a quarter-circular hidden crack are loaded only tension.

2.2 Crack detection method

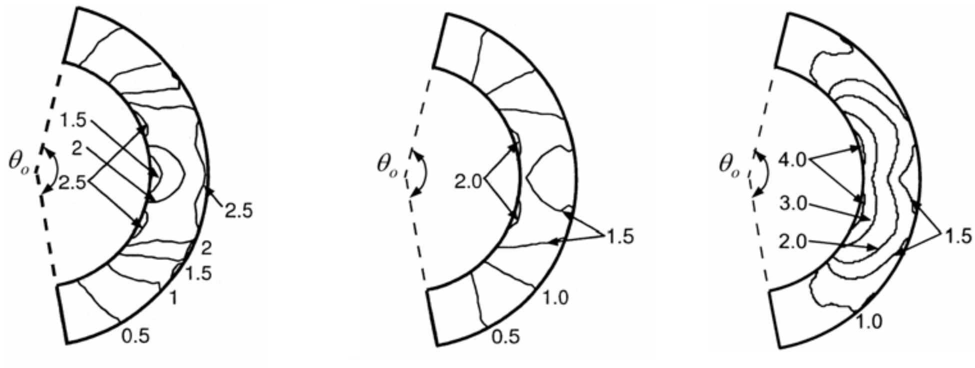
In a notched plate with a crack, the maximum stress generates not at the notch edge but at the crack tip. The present method cannot satisfy free boundary conditions on the crack surface. However, it is expected that a characteristic stress field appears because of the existence of the crack (Harada and Noguchi 2003). The crack detection can then be carried out based on the characteristic stress field.

The angular range of the observed domain, θ_0, is 160°. The width of the observed domain is 0.5ρ and the division number of the observed domain is eight. The positions of collected stress values are same as those of stress estimation (Yoshimura *et al.* 2004).

3. Results of crack detection and consideration

3.1 Results of crack detection

Some stress contour maps estimated in the observed domain are shown in Fig. 2. In these stress contour maps, two stress concentrations exist along the notch edge, which is the characteristic stress



(a)Through crack under tension ($B/\rho=1.0, l/\rho=0.3$)

(b)Through crack under bending ($B/\rho=1.0, l/\rho=0.3$)

(c) Quarter-circular crack ($B/\rho=1.0, l'/B=0.6$)

Fig. 2 Contour maps for σ_θ/σ_0 by the present method near a through crack and a quarter-circular crack on the hidden side of Fig. 1

Table 1 Results of crack detection of model in Fig. 1

○: Success, ×: Failure

B/ρ	Through crack (tension or bending)					Quarter-circular crack (tension)				
	l/ρ					l'/B				
	0.1	0.2	0.3	0.4	0.5	0.3	0.6	0.7	0.8	0.9
2.0	×	×	○	○	○	×	×	○	○	○
1.0	×	×	○	○	○	×	○	○	○	×
0.5	×	×	○	○	○	×	×	×	×	×

field. It means that crack detection is possible. However there are some cases where two stress concentrations do not exist and crack detection is impossible. Table 1 shows the conditions regarding whether crack detection is possible.

3.2 Limits of crack detection

From Table 1, crack detection is successful under the following condition in through cracks:

$$l/\rho \geq 0.3 \tag{1}$$

In quarter-circular hidden cracks, it is impossible to determine detection limits using the parameters, l'/B and B/ρ. In the hidden cracks, two stress concentrations along a notch edge occur due to compressive stress at the notch root. The compressive stress generates because of the following two factors:

3.2.1 Antiplane bending due to crack opening

Antiplane bending occurs on the plane containing the hidden crack due to the nonconformity of

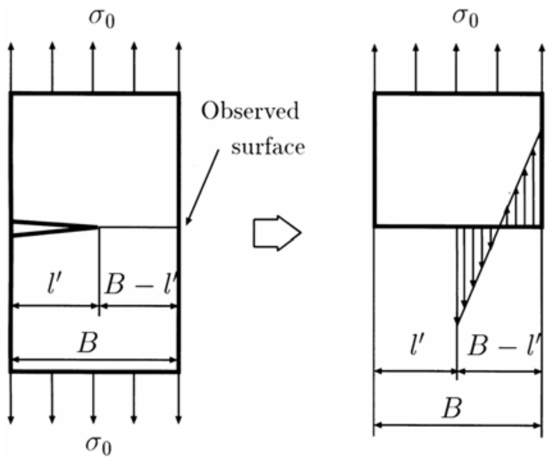


Fig. 3 Bending effect attributable to a hidden crack

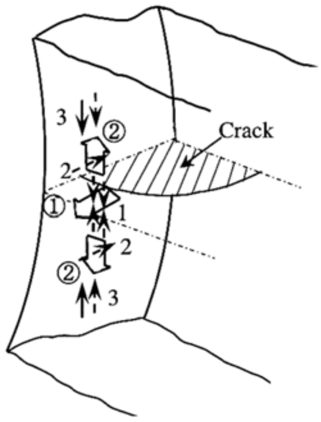


Fig. 4 Strain restraint effect characterizing the stress fields near a notch

the centers of the tension and the ligament. The antiplane bending causes compressive stress at the notch root of the face as shown in Fig. 3. Though stress near a notch is large because of stress concentration, the compressive stress decreases the stress near a notch root of the face and makes the two stress concentrations. The dimensionless parameter, $(B-l')/B$ expresses the effect of the antiplane bending from Fig. 3. When $(B-l')/B$ is small, the effect of the antiplane bending is large. Moreover the two stress concentrations needs that the compressive stress field is located only inside the stress concentration domain, too. Namely, the large stress concentration domain is necessary. The area depends on a notch root radius, ρ (Nisitani 1994). Accordingly, a small value of $1/\rho$ tends to bring the stress field characteristic. Consequently, we use $(B-l')/\sqrt{B\rho}$ as a parameter for the factor of antiplane bending. But a small value of this parameter means the large effect.

3.2.2 Strain restraint along thickness direction

The above compressive stress due to antiplane bending (the arrows of the broken lines 1 in Fig. 4) and the Poisson's effect bring antiplane deformation near the notch root (the thick arrow ①). In a thick plate, shear stress preventing the antiplane deformation brings compressive forces inside the plate (the arrows of the broken lines 2). The forces and the Poisson's effect generate secondary deformation of the thick arrow ②. It causes secondary compressive stress of the arrows 3. The compressive stress appears also on the face. In a thin plate, the processes after antiplane deformation of the arrow ① do not occur. To be brief, this factor is based on strain restraint along thickness direction and is concerned with relative thickness of a plate to a notch root radius, B/ρ (Kawai and Endoh 1986). Accordingly we use B/ρ as a parameter for this factor.

Table 2 is the rearrangement of detection result of quarter-circular cracks on the hidden side in Table 1 using these two parameters. The range in which the crack detection is possible is surrounded in the bold line. From Table 2, the hidden crack can be detected under the following conditions:

$$B/\rho \geq 1.0 \quad \text{and} \quad 0.14 \leq (B-l')/\sqrt{B\rho} \leq 0.42 \tag{2}$$

Table 2 Rearrangement of Table 1 (Quarter-circular hidden crack under tension)

B/ρ	$(B-l')/\sqrt{B\rho}$										○: Success, ×: Failure		
	0.071	0.100	0.141	0.200	0.212	0.283	0.300	0.400	0.424	0.495	0.566	0.700	0.990
2.0	-	-	○	-	-	○	-	-	○	-	×	-	×
1.0	-	×	-	○	-	-	○	○	-	-	-	×	-
0.5	×	-	×	-	×	×	-	-	-	×	-	-	-

In the cracks of $B/\rho = 0.5$, the effect of strain restraint is not enough. The effect of the antiplane bending is insufficient in $(B-l')/\sqrt{B\rho} \geq 0.495$. In the crack of $B/\rho = 1.0$ and $(B-l')/\sqrt{B\rho} = 0.1$, the very large tensile stress due to the superfluously small ligament ($(B-l')/B = 0.1$) decreases the effect of antiplane bending relatively.

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