Computaiton of SIF of Corner Crack in Interior Wall for Nozzle of Nuclear Vessel

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1 INTRODUCTION

The fracture evaluation for nuclear pressure vessel is on the basis of the linear elastic fracture mechanics now. So the solution of I type stress intensity factor K_I is a key for this case. The computation of SIF K_I of corner crack in interior wall for nozzle is a complicated 3-D case. The finite element method is a powerful tool for this case. Since the isoparametric singular element with quarter-points was given by Barsoum 1976[1], this method has been applied extensively. In the early 1980's, this method were extended to a 3-D case with a curved crack front by Hussain[2] and Manu[3]. However, there were some places which would be improved in their methods.

In this paper, an improved 3-D isoparametric singular element with quarter-points was presented. The trasitional element[4] and the method of computing K_I by the Williams formula[5] were extensively used to 3-D case. SIF of corner crack in interior wall for nozzle of RPV of a typical 300 MW nuclear power station was computed with aforementioned elements and method. The results were verified by 3-D photo-elastic test and diffusion of light test[6].

2 THE METHOD OF COMPUTING K_I

At first, the improved 3-D collapsed isoparametric singular element with quarter-points was presented as follows. Without losing any degree of generality, on the plane of crack the O-XYZ coordinate system was established (figure 1). The middle plane of the element was in parallel with OXY plane. The two side surfaces of the element were perpendicular to OXZ plane. The X, Z coordinates of the nodes on the two side surface were symmetrical about the middle plane of the element.

The coordinates of nodes 10 and 11 were:

$$X_{10}=X_3+X_9 \qquad Y_{10}=(Y_3+Y_{15})/2 \qquad Z_{10}=C_0+C/2 \qquad (1)$$
$$X_{11}=X_5+X_9 \qquad Y_{11}=(Y_5+Y_{15})/2 \qquad Z_{11}=C_0+C/2$$

The rest of the requirements for the coordinates of nodes of the element were the same as common isoparametric singular element with quarter-points.

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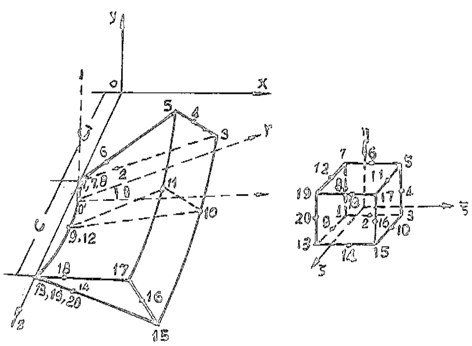

Fig.1 The improved singular element and OXYZ coordinate system.

The required singularities of the presented element were driven as follows. In the 3-D isoparametric element with 20 nodes we had:

$$X=\sum_{i=1}^{20} N_i X_i \quad Y=\sum_{i=1}^{20} N_i Y_i \quad Z=\sum_{i=1}^{20} N_i Z_i \qquad (2)$$

In the expression (2) the expressions of shape functions $N_i(\xi,\eta,\zeta)(i=1,2,---,20)$ were shown in paper[7]. Substituting these values of X_i, Y_i, Z_i and the expression of N_i, into the expression (2) we could see that the third expression of (2) was a expression of a plane which was perpendicular to OXZ and passed a point O' of the front of crack when $\zeta=\zeta_c(-1\leq\zeta_c\leq 1)$. In this plane the polar coordinate systen O'rθ was established. In this coordinate system the expression (3) could be driven from the first and the second expression of (2):

$$\eta=\eta(\theta,\zeta)$$
$$\xi=F(\theta,\zeta)\sqrt{r}-1 \qquad (3)$$

and then we could obtain:

$$\varepsilon_r=G_1(\theta,\zeta)+G_2(\theta,\zeta)r^{-1/2}$$
$$\varepsilon_\theta=G_3(\theta,\zeta)+G_4(\theta,\zeta)r^{-1/2} \qquad (4)$$
$$\varepsilon_{r\theta}=G_5(\theta,\zeta)+G_6(\theta,\zeta)r^{-1/2}$$

In the expression (4), $G_1(\theta,\zeta)$--$G_6(\theta,\zeta)$ were the definite functions. From (4) it could be seen that in these vertical planes of the crack plane the strains and shearing strain ε_r, ε_θ, $\varepsilon_{r\theta}$, in or vertical the ray direction from O', had the required inverse square root singularity.

The size of the elements at the front of crack had an effect on computing accuracy. Hence, the conception of the transitional element[4] were extensively used to 3-D case. In the extensional area of the improved 3-D isoparametric singular element the transitional element was constructed. The requirements of it's nodes coordinates were similar to the improved isoparametric singular element except that the transitional nodes defined by paper [4] were used instead the quarter-points.

The SIF could be computed from the displacement field near the front of crack. The Williams formula[5] was extensively used to 3-D case. When the high powers were negelected and gave n=3 we obtained:

$$K_I^{\prime} = K_I - \sqrt{2\pi} A_3 r$$
$$K_I^{\prime} = E[V(r,\pi)-V(r,-\pi)]/[8(1-\nu^2)] * \sqrt{2\pi/r} \quad (5)$$

In the expression (5) A_3 was a constant, E, ν were Young's modulus and Poisson ratio respectively. From the first expression of (5) it could be seen that K_I was the cut of $(K_I'-r)$ linear equation. We could solve K_I by node's displacements near the front of crack with the least square linear fitting method [8].

The example which was an infinite body with a circle crack under uniform tensile stresses at remote region was solved. All together 12 models, with three different relative size of singular element (r_s/a) and five different number of layers of transitional element (n), were computed and compared with the exact solutions $(\tilde{K}_I)$. The results were shown in table 1.

Table 1 $K_I/\tilde{K}_I$ $(r_s/a, n)$

r_s/a	n				
	0	1	2	3	4
0.2	1.01754	1.01750	1.01748	/	/
0.1	1.01740	1.01738	1.01734	1.01731	/
0.05	1.01703	1.01703	1.01699	1.01692	1.01688

3 THE COMPUTION OF K_I OF CORNER CRACK IN INTERIOR WALL FOR NOZZLE

There was a complicated construction in the nozzle of the nuclear pressure vessel. Under internal pressure there was a high stress field in the fillet for the nozzle [9]. The key of fracture analysis and evaluation was here too. The engineering requirment was satisfied when to cut a quarter nozzle and one twelfth cylinder vessel as computing model [9]. A circle crack was assumed in the interior wall. The finite element mesh was constructed using aforementioned 55 improved 3-D isoparametric singular elements, 110 transitional elements (two layers) and a number of common isoparametric elements. In whole model there were 1390 nodes and 516 elements. In order to analyse the effect of fillet radius (R) and relative deep of crack (a/t) on K_I, the displacement fields of twelve models with three different R and four different (a/t) were computed. Then according to the expression (5) the SIF K_I could be computed with the least square linear fitting method. The relation between $(K_I)_{max}$ and deeps of crack was shown as figure 2(a). In the range of crack deeps in this paper K_I were near linear increased with the crack deeps. K_I of the model (R=124) varied along with the front A_0B_0 of crack shown as figure 2(b). The maximun of K_I took place near the middle of the front of crack and inclining to nozzle side when the crack was shallow, but the change of K_I value along with the front of crack was not obvious when the crack was deep.

The aforementioned results would give a reference to these nuclear pressure vessels with the same type as it in this paper.

4 IN COMPARISON TO THE ENGINEERING METHOD AND THE RESULT OF TEST

An engineering method for computing K_I of corner crack in interior wall for nozzle of pressure vessel was given in paper [10] and recommened by ASME(Ⅲ). In order to make a comparison the corres-

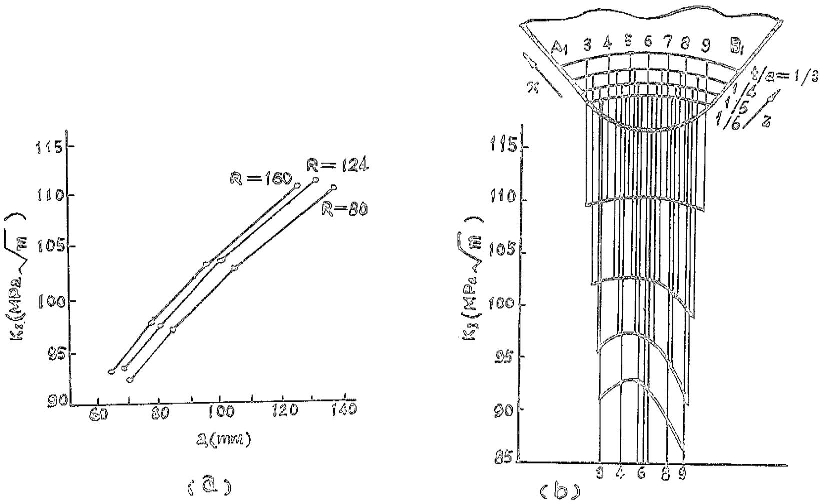

Fig. 2(a) $(K_I)_{max}$ vs. crack deeps
(b) The changes of K_I along with the front of crack

ponding factor F defined in [10] were computed according to the K_I values of point 6 on the front of crack (figure2) and shown by symboles '+' as figure 3. The values of factor F in this paper were 0.79--0.82 of the values of F in paper [10] . These results were verified by 3-D photo-elastic test and diffusion of light test [6] .

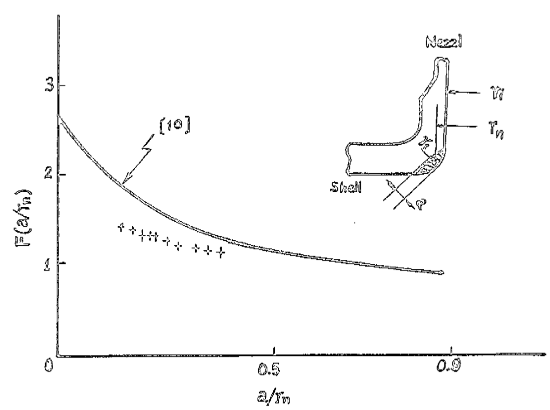

Fig. 3 The comparison between the two F values

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