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2-DIMENSIONAL DYNAMIC CONTACT FRACTURE ANALYSIS FOR PARTIALLY OPENED CRACK

K.T. Chen[1], C.H. Chen[1] and K. Ting[2]

[1]Dept. of Applied Mathematics, National Chung-Hsing University, Taichung, Taiwan, R.O.C.
[2]Dept. of Nuclear Regulatory Atomic Energy Council, Taipei, Taiwan, R.O.C.

ABSTRACT

When a 2-dimensional structure is subjected to in-plane dynamic loading, the faces of a pre-existing crack are pressed together over some part of their surface, a non-linear contact crack closure problem ensues. Without consider the crack face contact and slide effects, an application of a finite element approach will be yield solutions in which overlap of the crack face is implied. When a crack tip actually lie in its overlap zone, a negative K_I value is obtained. In the present work, we examine the above problem using an iterative procedure in conjunction with a well developed 2-D dynamic finite element contact analysis program. It is used to predict dynamic behavior and variations of stress intensity factors for two examples which involves the center crack and mixed mode slant crack plates whose tips experience mode I and II loading. In addition, we bring the frictional force to the stress intensity factor K_{II}. We obtain the frictional force between crack surfaces affects greatly on the value of K_{II}. When coefficient of the friction reaches some specific value, K_{II} can almost be neglected. This justified that it is reasonable that stress intensity factor can be neglected under static pressure for cracked materials with rough crack faces. But it is wrong for smooth crack face, such as: crack in oil pipe etc..

1. INTRODUCTION

There is much literature describing various analytical and numerical approaches for determining fracture parameters such as stress intensity factors, J-integral and open crack tip displacement. Most of majority of their work is concerned with situations where the faces of the pre-existing cracks are deemed either to open (mode I behavior) or to slide over each other (mode II and mode III). When a structure is loaded in such a way that the faces of a pre-exist cracks are pressed together over some part of their surface, a nonlinear boundary value problem ensues. A finite element approach will yield solutions in which overlap of the crack face is implied. When a crack tip actually lies in this overlap zone, a negative value is obtained for K_I. While studies on the analysis of crack with closure effects are limited in recent years. Chen & Wang [1980] have analyzed the dynamic tension problem of a strip plate with a center crack. They used the hybrid displacement finite element method. The analysis method is to adopt singular element near the crack tip region and the regular elements in the remain region. Chen & Wu [1981] have analyzed the dynamic tension problem of the bimaterial strip plate with a center crack. Their analysis method considered the impact effects of crack faces. Karami & Fenner [1986] have used boundary element method to analyze the closure effects of the strip plate with a single edge crack under static bending.

In present work, we exam the above crack contact problem utilizing an iterative procedure in conjunction with a well-developed 2-D dynamic finite element contact analysis program. It is used to predict dynamic behavior and variation of stress intensity factors for a partially opened crack plate whose tips experience mode I and mode II.

2. FINITE ELEMENT FORMULATION

The method of analysis employed in the present work is the dynamic finite element transformation matrix method original developed by Chen & Yeh [1988,1991]. On the basis of on the works of Chen & Yeh [1991] , a modified and simplified finite element procedure for partial closure crack contact problem was derived and described. The main difference between the one body contact problem treated by present and the multiple body contact problem treated by Chen & Yeh is in the assembling of the global stiffness matrix. After doing the Gaussian Upper-triangle partition, our matrices will have two decoupled terms that are closely similar to the full matrix form at the up-right and down-left parts of stiffness matrix.

According to the principle of virtual work, the incremental nodal displacement. $\left\{\Delta q_{(k)}\right\}$ with kth iteration can be obtained from the following simultaneous ordinary differential equations for dynamic crack contact problem with friction:

$$\left[G_{(k-1)}^T + \mu_d S^T n_{(k-1)}^T I\right]\left(\begin{bmatrix} M_{AA} & M_{AB} \\ M_{BA} & M_{BB} \end{bmatrix}\begin{bmatrix} G_{(k-1)} \\ I \end{bmatrix}\left(\Delta\ddot{q}_{(k)}\right)\right.$$

$$\left.+\begin{bmatrix} K_{AA} & K_{AB} \\ K_{BA} & K_{BB} \end{bmatrix}\begin{bmatrix} G_{(k-1)} \\ I \end{bmatrix}\left(\Delta q_{(k)}\right)\right)$$

$$=\left[G_{(k-1)}^T + \mu_d S^T n_{(k-1)}^T I\right]\left(\begin{Bmatrix} P_A^{(N+1)} \\ P_B^{(N+1)} \end{Bmatrix} - \begin{bmatrix} M_{AA} & M_{AB} \\ M_{BA} & M_{BB} \end{bmatrix}\begin{pmatrix} \ddot{q}_A^{(N+1)}{}_{(k)} \\ \ddot{q}_B^{(N+1)}{}_{(k)} \end{pmatrix}\right.$$

$$\left.-\begin{Bmatrix} Q_{A(k-1)}^{(N+1)} \\ Q_{B(k-1)}^{(N+1)} \end{Bmatrix} - \begin{bmatrix} M_{AA} & M_{AB} \\ M_{BA} & M_{BB} \end{bmatrix}\begin{pmatrix} h_{(k-1)} \\ 0 \end{pmatrix} - \begin{bmatrix} K_{AA} & K_{AB} \\ K_{BA} & K_{BB} \end{bmatrix}\begin{pmatrix} h_{(k-1)} \\ 0 \end{pmatrix}\right)$$

In which, $[G]$ is the matrices assembled from $\{N\}$ and $\{t_1\};\{t_2\}$. $\{N\}$ is the assembly matrix of the local area coordinates of the triangle contact element. $\{t_1\};\{t_2\}$ are two perpendicular unit tangential vectors that are arbitrarily chosen on the triangular target surface. $[I]$ represents the global unit matrix. The gap vector $\{h\}$ is prescribed from the geometry of the contact surface. $\{P_A^{(N+1)}\}$ is the resultant global contact nodal force for the instant $t^{(N+1)}$. $[M]$ is the mass matrix. $[K]$ is the stiffness matrix. In order to solve these ordinary differential equations, the modified Newmark direct integration method [Hallquist,1983] is adopted.

3. RESULTS AND DISCUSSIONS

The first example is solved to verify the partial crack closure effect on mode I situation. A strip plate with a center crack, is subjected to uniform dynamic tension loading represented by Heaviside function. We adopt the material properties as follows: Young's modulus $2.1\times10^{12}\,dyne/cm^2$, Possion's ratio 0.3, material density $5.0\,g/cm^3$ and Heaviside function loading is $P_0 = 4\times10^9\,dyne/cm^2$. We use "quarter-point" eight-node isoparametric quadrilateral elements near the crack tip region and the eight-node convection elements in the remaining part. In the present work, we denote the portion above the crack surface as deformable contactor and the lower portion as the rigid targetas shown in Fig.1. Fig. 2 show the computed dynamic stress-intensity factor $\overline{K}_I(t)$ normalized by $P_0\sqrt{\pi a}$ for plane strain case. Also show in Fig.2 the time integration is completed with 130 steps at $0.2\,\mu s$ each. It appears that excellent agreement between results from the present study and that given in referenced paper [Chen,& Wang, 1981] and [Chen, 1975]. before the crack surface contact . When the crack impact happened, the upper crack surface and the lower crack surface are no more overlap in the present analysis. The maximum $\overline{K}_I(t)$ value of the dynamic case is more than double of the value of the static $\overline{K}_I(t)$ case.

Often, the crack angle of the material with crack is not equal to zero degree. In such case , situations are more general where mixed mode of I and II partial crack closure may occur. The model we have adopted is a strip plate with center slanted crack angle ($\theta = 30^0$). The material properties and the loading condition are considered as same as those used in the above example. The total number of 71 elements and 252 nodes are taken and the time integration is complete with 200 steps at time increment 2 μs. We consider surfaces as two deformable bodies so that there will have sticking displacement. Fig.3 displays the relationship of stress-intensity factor $\overline{K}_{II}$ with different friction coefficients under static pressure. Fig.3 vividly indicates that when the coefficient of friction is equal to 0.6, $\overline{K}_{II}$ will be zero. This justifies that it is reasonable that the stress-intensity factors $\overline{K}_{II}$ can be neglected under static pressure for cracked materials with rough crack surface, But it is wrong for smooth crack faces. When the time is 248 μs , a part of crack surfaces near crack tip 1 will open and the part away from the tip 1 be closed as shown in Fig.4. At the tip 2 , the time variation of the dynamic stress-intensity factor $\overline{K}_I$, $\overline{K}_{II}$ are show in Fig.5 & Fig.6 , in which the theoretic value of $\overline{K}_I = 0.8453$ and $\overline{K}_{II} = 0.4490$ under uniform static tension loading are shown by the dash line. The results we computed for dynamic stress-intensity factors $\overline{K}_I$, $\overline{K}_{II}$ are over twice as much as the results under static loading.

4. CONCLUSION

In the present work, we have derived and modified the contact transformation matrix method to compute the stress-intensity factor $\overline{K}_I$, $\overline{K}_{II}$ of the cracked structure under dynamic impact loading. We can efficiently evaluate the crack contact effects of the fracture parameters, concerning stress wave arrival at crack surfaces and the stress-intensity factors after stress wave rebounding. The results that we have obtained match very well with practical fracture problems.

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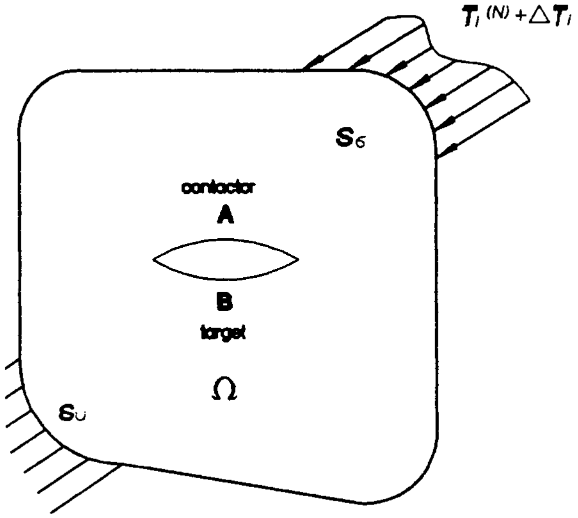

Fig.1 One body crack contact configurations.

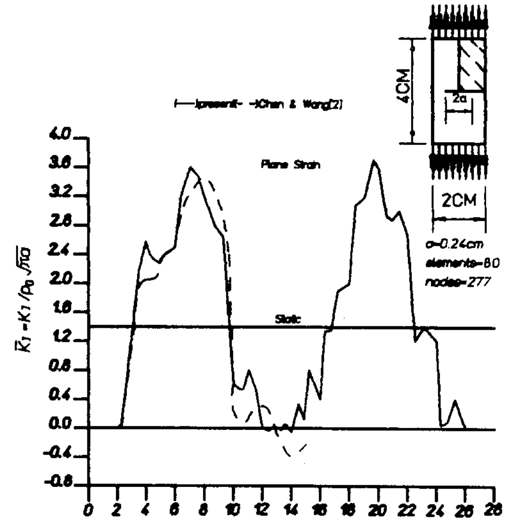

Fig.2 The time variation of $\overline{K}_I(t)$ for central-crack plate.

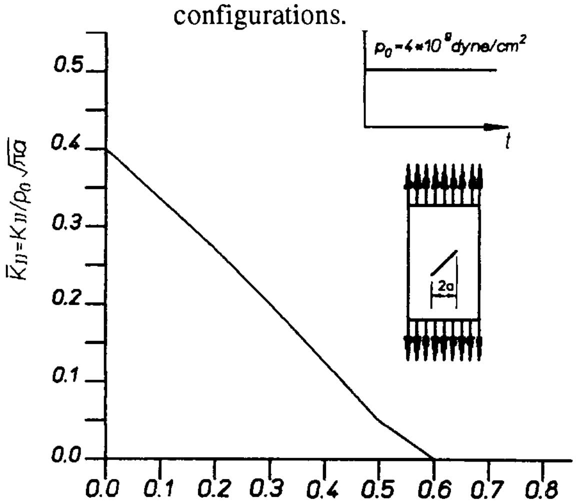

Fig.3 The relation curve of $\overline{K}_{II}$ & μ_d under uniform loading.

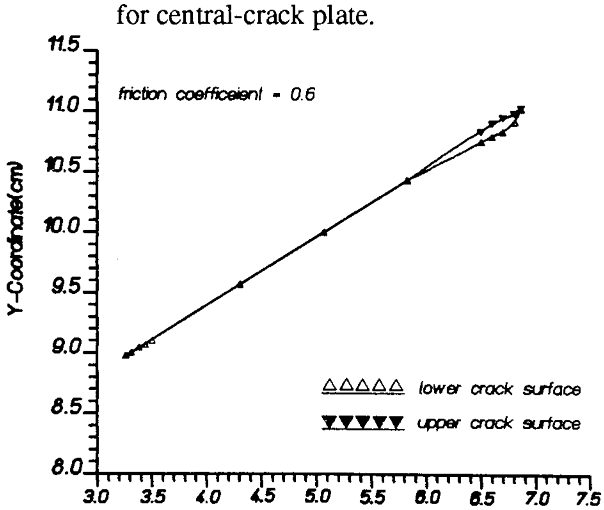

Fig.4 Partially open crack effects at time 248 μs

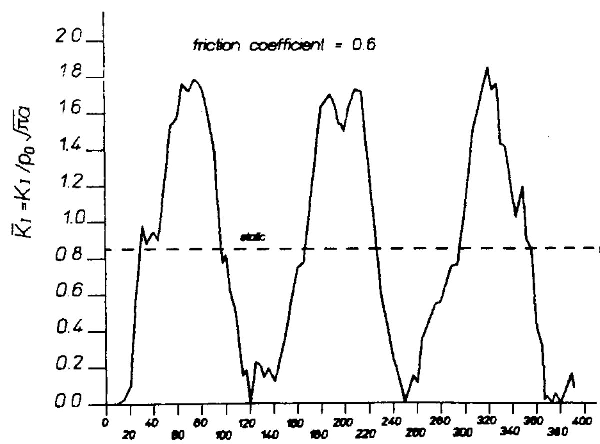

Fig.5 The time variation of $\overline{K}_I(t)$ for slant-crack plate with friction.

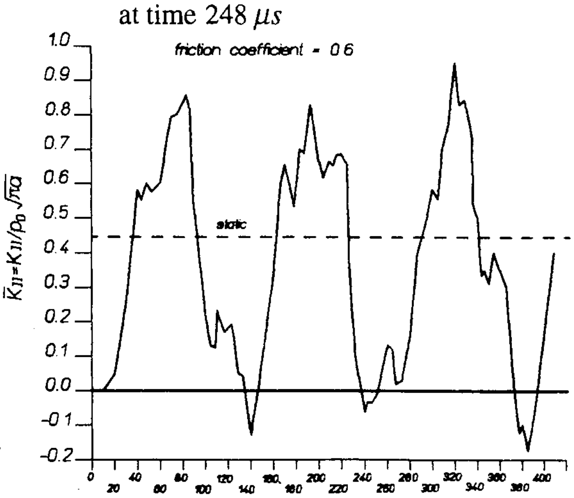

Fig.6 The time variation of $\overline{K}_{II}(t)$ for slant-crack plate with friction.