DEVELOPMENT OF A NOVEL ‘CRACK’ FINITE ELEMENT FOR PROPAGATION SIMULATION

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Summary In this paper, we propose a 2D ‘crack’ element for the simulation of propagating crack with minimal remeshing. A regular finite element containing the crack tip is replaced with this novel crack element, while the elements which the crack has passed are split into two transition elements. Singular elements can easily be implemented into this crack element to represent the crack-tip singularity without enrichment. Both crack element and transition element proposed in our formulation are mapped from corresponding master elements which are commonly built using the moving least-square (MLS) approximation only in the natural coordinate. In numerical examples, the accuracy of stress intensity factor K_I is demonstrated and the crack propagation in a plate is simulated.

INTRODUCTION

It is well known that FEM has still shortcomings especially in simulating propagating cracks due to the intricacy of continual remeshing procedures. In order to avoid this difficulty of remeshing, enriched meshfree methods have been developed and applied to the crack growth problems. These method do not employ meshes in function approximations, and thus can have advantage in the simulation of moving discontinuity. However, meshfree methods do require the enrichment of basis to accurately represent the singular behavior of strain field around a crack tip, which may lead to immense load of computation. More recently developed is the extended finite element method (XFEM) [1,2] which is based on FEM and does not need the remeshing though. In order to represent the discontinuity, XFEM employs the modification of shape functions for the elements involving crack surface, as well as the enrichment around the crack tip. In this paper, we present a novel ‘crack’ finite element. Instead of modifying the shape function for discontinuity, we replace cracked elements with two or more transition elements and thus the crack surface naturally fulfills the traction-free boundary conditions, which makes the conventional formulation of FEM unaltered. Furthermore, our approach does not require the enriching procedure because our crack element itself reproduces the singular strain field by the typical FEM way of constructing singular element. These implies that we are able to calculate all the shape functions simply by the mapping from the parent or master elements to the physical elements. We construct the master elements for crack and transition elements by using the moving least-square (MLS) approximation. It means we adopt the MLS approximation in natural coordinates, not in physical coordinates, which are obviously different from the meshfree methods and XFEM. Furthermore, the present methodology is fundamentally different from the interface element method (IEM) recently reported [3] in that no interface elements are introduced nor adaptive meshing is required as crack tip moves. Therefore, it appears to be far more effective for simulating crack propagation than any other methods ever reported.

NUMERICAL EXAMPLES

First of all, a center cracked plate as shown in Fig. 1(a) is demonstrated for calculating stress intensity factor, K_I. The model is constituted with 25 elements including a crack element. The plate is subjected to a uniform tension, $\sigma_0 = 2\times10^4\ \mathrm{N}$ in the y direction at bottom and top of the plate. The dimensions and properties are $H = 12.0\ \mathrm{m}$, $W = 12.0\ \mathrm{m}$, $a = 3.0\ \mathrm{m}$, $E = 1\times10^6\ \mathrm{Pa}$ and $\nu = 0.25$. The contour plots of σ_{yy} are shown in Fig. 1(a). The errors for stress intensity, $100 \times \frac{K_{\mathrm{exact}}-K_{\mathrm{num}}}{K_{\mathrm{exact}}}\ \%$, at the tip of crack is 2.809 $\%$. K_{exact} is the exact value of mode I stress intensity factor and K_{num} is the numerically calculated value of mode I stress intensity factor. The exact value of stress intensity is $K_{\mathrm{I}} = 1.325\sigma_0(\pi a)^{\frac{1}{2}}$. The mode I stress intensity factor K_{I} is computed from J-integral using domain integration. For simulation of crack propagation, we consider half the plate of Fig. 1(a), as shown in Fig. 2(a). The loading is applied on the upper left corner in the form of a concentrated force, which is oriented 45 degree from the top surface as shown in Fig. 2(a). The bottom edge is simply supported while the remaining edge is free from traction except the upper left loading point. We utilize the maximum circumferential stress criterion with the aid of the two-state conservation integral, which are known to be very effective for the mode decomposition [4-7]. Fig. 2(b)-(g) show the configuration of the crack propagation as the load increases. As shown in this figure, the modification needed for accommodating the varying configuration due to the crack propagation is just to add the nodal points on the crack faces that have been created. So far the present method appears to be far more effective than other existing schemes for modelling moving discontinuity such as a propagating crack.

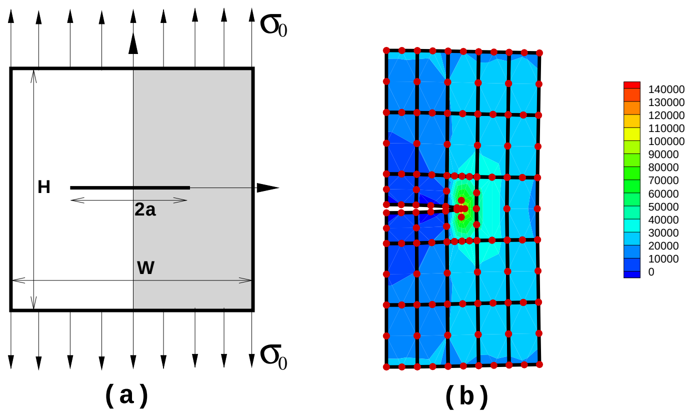

Figure 1. (a) A center cracked plate model, (b)Contour plot of σ_{yy} at the crack tip.

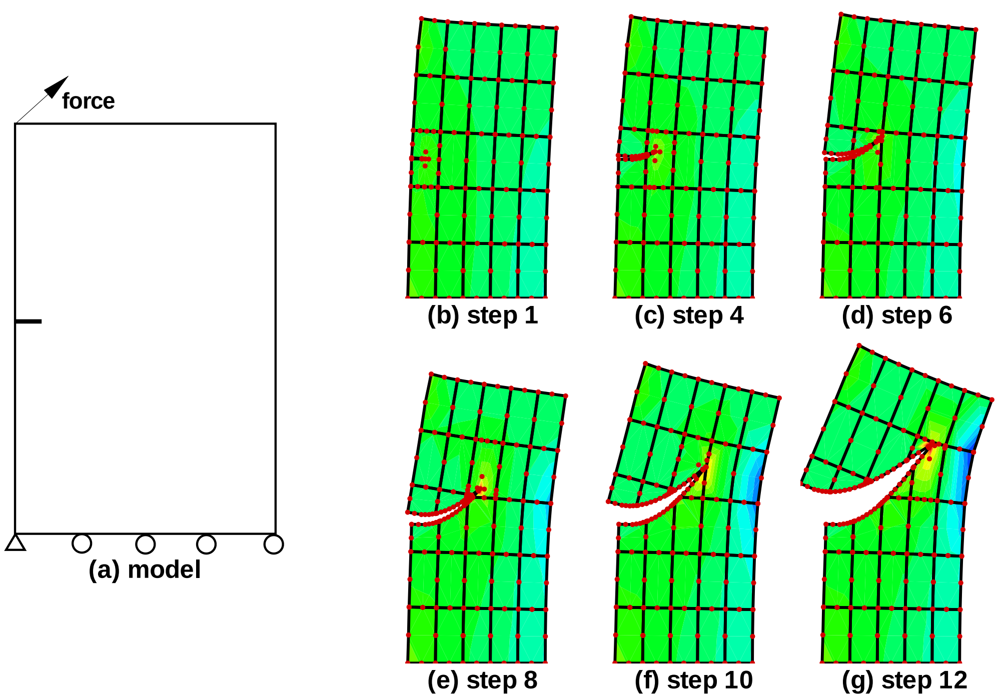

Figure 2. Crack propagation using the proposed method.

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