SENSITIVITIES OF TWO-DIMENSIONAL FRACTURE PROBLEMS TO THE NEAR-TIP MESH PARAMETERS

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Abstract. Using the displacement correlation technique, near-tip mesh-parameter sensitivity studies are performed for cracks that cover most basic two-dimensional load-controlled problems. Stress intensity factors computed from two different mesh models for different settings of mesh parameters are compared with other solutions. The corresponding sensitivity graphs are plotted to visually see the parameters which affect results the most. Conclusions are drawn and settings of mesh parameter values are recommended.

Keywords: Mixed-Mode, Displacement Correlation Technique, Finite Element Method.

1. Introduction. The finite element method has become the most commonly used technique to solve complicated fracture mechanics problems with no analytical solutions. There is a variety of sub-methods also within the finite element method as applied to fracture mechanics. In the mid 1970s, Barsoum (1974) and Hensell and Shaw (1975) discovered that by moving the mid-side nodes of a quadratic element at the crack tip to quarter point of element side, the singular stress field which occurs at a crack tip could be simulated. To determine stress intensity factors (SIFs), the Displacement Correlation Method with a linear extrapolation from two nodes at each crack face was used by Mi (1996) and Shih et al. (1977). Fehl and Truman (1999) also employed displacement correlation technique. Later, Park and Lee (2004) developed a finite element modeling approach for the mixed-mode 2D linear elastic crack propagation analysis based on the displacement correlation method.

Despite its relatively old discovery, the Displacement Correlation Technique (DCT) with quarter-point elements is still one of the most commonly used methods to compute SIFs. Depending on the element sizes and distribution of the mesh near the crack tip, the method can yield some variation on the computed SIFs. Thus, in this study, detailed sensitivity studies are performed for different two-dimensional cracks. As the numerical tool, the finite element software ANSYS™ (2008) is used and its KCALC™ command is employed. The sensitivities of computed SIFs from two types of mesh models, “KSCON™ Model” and “Circular Zone Model”, are presented and conclusions are drawn.

2. The Displacement Correlation Technique. Moving the mid-side nodes of a quadratic element into the quarter-distance points measured from the crack tip allows accurately modeling the radial distribution of the analytically known strain and displacement fields of
an elastic crack. However, no guarantee exists that the “true” variation of strains and displacements in angular direction are introduced into the element. Therefore, in an effort to simulate angular variation of displacements and strains, typically “enough” refinement is used in this direction. In Fig. 1, singular triangular elements surrounding the tip of a two-dimensional crack are shown, in which the solid edge lines are on the crack surfaces.

Figure 1: Singular quarter-point elements on top and bottom crack faces.

In this study, the DCT is applied via the usage of ANSYS™'s KCALC command. The SIFs are computed using the analytically known displacement fields as evaluated on the crack faces and nodal displacements on the crack face elements at the crack tip and are given by,

\[
K_1 = \frac{G}{\kappa+1} \sqrt{\frac{2\pi}{L}} (8\Delta V_{24} - \Delta V_{35}) \quad \text{and} \quad K_2 = \frac{G}{\kappa+1} \sqrt{\frac{2\pi}{L}} (8\Delta u_{24} - \Delta u_{35}).
\] (1)

In (1), \(L\) is the element edge length in radial direction and terms in the parentheses are differences of nodal displacements for nodes 2-4 and 3-5 in different directions. \(G\) is the shear modulus, \(\kappa = (3 - 4\nu)\) for plane strain, \(\kappa = (3 - \nu)/(1 + \nu)\) for plane stress. It is observed from (1) that the extracted SIFs depend on the element edge size, \(L\) and nodal displacements obtained from the finite element solution. Thus, element edge length, \(L\), affects (1) and the overall finite element solution since it also controls the mesh size at the crack tip. Moreover, other mesh details at the crack tip, such as number of elements in the circumferential direction and neighboring element sizes and distributions, will also affect the finite element solution. In what follows, the mesh sensitivity studies are described and the related applications along with their results are presented.

3. Models for Mesh Sensitivity Studies. Two different mesh models are considered.

The Circular Zone Model: In an effort to produce a focused mesh in a “more controlled” manner, the Circular Zone Model (CZ model), is developed (Fig. 2a, 2b). It can be seen in Fig. 2 that, the model consists of two main zones in the radial direction. In the first zone (Fig. 2a), three radial layers of elements are always used that have equal radial edge length. Therefore, radial edge sizes in this region are equal to the radial edge size of the first-row elements (\(r_{\text{first}}\)) that touch the crack tip. Next a second radial zone (Fig. 2b) exists in