International Journal of Solids and Structures 48 (2011) 492–505

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Three-dimensional fracture analysis using tetrahedral enriched elements and fully unstructured mesh

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ARTICLE INFO

Article history:
Received 28 April 2010
Received in revised form 7 October 2010
Available online 20 October 2010

Keywords:
Three-dimensional crack
Stress intensity factor
Enriched elements
Mixed mode
Unstructured mesh

ABSTRACT

In the absence of automated and customized methods and tools, some of today's existing methods for solving three-dimensional fracture problems require comprehensive finite element meshing, labor-intensive analysis and post-processing efforts. In this study, a tetrahedral enriched element method and related applications are presented that demonstrate employment of fully unstructured tetrahedral meshes for general mixed-mode three-dimensional fracture problems. As in the case of hexahedral enriched elements, the tetrahedral enriched elements also alleviate the needs of pre- and post-processing the finite element model, allowing direct computation of stress intensity factors in the solution phase. In addition, when tetrahedral enriched elements are used, the crack front region can also be meshed using unstructured elements allowing direct use of automatic free-meshing programs. The applications presented are plane-strain central crack problem, mode-I surface crack in a plate, inclined penny-shaped crack, edge-cracked bar under constant heat flux and lens-shaped crack embedded in a large elastic body. The results obtained are in good comparative agreement with those available in the literature. Thus, it is concluded that the enriched tetrahedral elements can be applied efficiently and accurately on a general three-dimensional fracture problem allowing usage of fully unstructured finite element meshes.

1. Introduction

The earliest analyses of three-dimensional cracks start with the works of Sneddon (1946), Green and Sneddon (1950) that dealt, respectively, with a pressurized penny-shaped crack and an elliptical crack contained in an infinite solid. An early approach to the analysis of part-through wall cracks that is still often used is that given by Irwin (1962). Irwin (1962) introduced approximate correction factors to account for the free-surface and crack-tip plasticity to the solution of an elliptical crack embedded in an infinitely large elastic body given by Green and Sneddon (1950), Kanninen and Popelar (1985). Starting from this point, increasingly higher consideration has been given to the surface and other three-dimensional crack problems and a variety of numerical and experimental methods have been developed to solve such problems. The numerical methods developed and used for three-dimensional fracture problems so far include alternating methods (Hartranft and Sih, 1973; Kobayashi and Moss, 1969; Liao and Atluri, 1989; Shah and Kobayashi, 1972; Smith et al., 1967; Smith, 1972; Thresher and Smith, 1972), the boundary integral method (Cruse, 1972, 1973), virtual crack extension method (Blackburn and Hellen, 1972; deLorenzi, 1985), the line-spring method (Erdogan, 1986; Rice and Levy, 1972), the boundary element method (Carter et al., 2000; Mi and Aliabadi, 1994) and suitably modified finite element techniques, which include singular quarter-point 3-D elements (Barsoum, 1976; Raju and Newman, 1979; Tracey, 1974). In the last two decades, the coupled domain integral-finite element methods (Gosz and Moran, 2002; Shivakumar and Raju, 1991; Ural et al., 2005) have also been used widely. Some of the techniques listed so far require special near-crack tip finite element mesh and post-processing to compute stress intensity factors (SIFs), which, in the absence of customized tools, are somewhat laborious efforts. Considerable research and development have also been undertaken in the last decade to develop methodologies and customized tools for analysis of three-dimensional fracture and crack growth simulations using the numerical techniques. Although, the analyses using the boundary element technique (Mi and Aliabadi, 1994; Riddell et al., 1997) can be cited as the earliest works in this category, most studies focused on usage of finite elements. Dhont (1998) presented an algorithm for simulation of planar crack growth in mode-I conditions. FRANC3D (Carter et al., 2000; Barlow and Chandra, 2005) is capable of performing crack growth simulation in conjunction with the finite elements. In ZENCRACK™ (Hou et al., 2001; Zentech, 2008), a crack-block approach, in which a collection of brick elements stored as a unit cube, is used to introduce

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doi:10.1016/j.ijsolstr.2010.10.012