A COMPATIBLE SMALL-SCALE YIELDING SINGULAR ELEMENT AND ITS APPLICATION TO LWR FUEL ROD ANALYSIS

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SUMMARY

A small-scale yielding singular element which is compatible with modified eight-node quadratic isoparametric elastic singular element has been developed. This element is based on previous formulation by D.M. Tracey ("On the Fracture Mechanics Analysis of Elastic-Plastic Materials Using the Finite Element Method," NASA NGL 40-002-080/11, February 1973) and has a triangular shape with two mid-side nodes at quarter points on the two sides radiating from the crack tip and one mid-side node at the far side where regular elements are adjoining. A computer program has also been developed to incorporate this element together with other two elements, namely, elastic singular isoparametric element (R.S. Barsoum, "On the Use of Isoparametric Finite Elements in Linear Fracture Mechanics," Int. J. for Numerical Methods in Eng., Vol. 10, 25-37, 1976) and Tracey's small-scale yielding power hardening element. For treating more general geometric configurations, the newly developed element and Tracey's element are modified for general orientations.

This newly developed small-scale yielding element is qualified by comparing the results of analyzing the same structure using Tracey's original element. Crack opening displacements, J-Integral and propagation of plastic zones are evaluated. Numerical aspects of the integration rules are also studied. It is shown that the compatibility between the elastic singular isoparametric element and the currently developed small-scale yielding singular element enables a smooth elastic-plastic fracture mechanics analysis and gives satisfactory solution accuracy.

The application of this newly developed element to LWR fuel clad with assumed existing flaws is demonstrated through two illustrative examples. The first presumes the existence of three longitudinal flaws symmetrically distributed 120° apart with the flaw depth being one eighth of the clad thickness. Plane strain condition is imposed on the model. The second example considers an additional thermal gradient through the clad thickness for the problem considered in the first example. The stress-strain distribution around the crack tip, the J-Integral and the crack opening displacement are obtained for both cases. In addition to fuel clad applications these cases demonstrate the utility of this element in the analysis of general two-dimensional problems in fracture mechanics.