FINITE ELEMENT ANALYSIS OF CRACK PROPAGATION PROBLEMS FOR THE FRACTURE MECHANICS EVALUATION OF REACTOR VESSEL NOZZLE JUNCTION

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SUMMARY

The increased application of linear fracture mechanics methods, particularly in evaluating structural integrity of nuclear pressure vessels and piping, is well-known and has recently promoted a considerable research. Due to high concentration of local stresses associated with nozzle-to-vessel or pipe-to-shell junction, these areas deserve special concern in a fracture safety analysis, as is recommended by ASME-Code for protection against non-ductile failure of nuclear components. Concerning brittle materials, therefore, where plastic yielding in crack-tip regions is small, the conditions of cracked geometry are usually assessed on the basis of stress intensity factors at any instantaneous crack-tip position. High local stresses associated with these discontinuities enhance crack initiation and accentuate extensions, which usually assume the shape of quarter-ellipses. The complexities of both geometry and stress distribution at the junctions seem to exclude the possibility of deriving an exact analytical solution for the conventional stress intensity factors, (K_{I}, K_{II}, K_{III}), for three leading modes. For arbitrary configurations, therefore, the analyst has to invariably depend upon more sophisticated and efficient numerical techniques, such as 3-D finite element method of analysis. This method of analysis, despite high computational costs, offers the only mandatory approach associated with sufficiently reliable numerical results.

This paper describes a procedure involving a refined 3-D finite element method for analysing more realistic geometry, such as in the vicinity of a nozzle-shell intersection of a typical 920 MWe PWR vessel. The study involves deriving K-factors for a series of elliptical corner cracks for which computations have been carried out with nozzles of variable diameters, subjected to internal pressure and thermal loads. The method of analysis aims at computing stress intensity factors by employing efficient energy considerations to evaluate corresponding strain energy release rates (G_{I}, G_{II}, G_{III}) using variation of potential energy functional with an increasing crack-tip area and various crack lengths. The computational procedure considers various implementation techniques including optimization, multi-level recursive substructing as well as "Super-Element" concepts along the tip-front of a 3-D crack. Typical numerical examples have been investigated with aforementioned concepts to evaluate output data directly interpreted in terms of K-factors with sufficient accuracy.

The numerical results have indicated a considerable computational economy and promise the validity of a relatively simpler strain-energy-release-rate approach for analysing crack propagation problems, employing comparatively fewer but highly precise finite elements with coarser meshes. The influence of the geometry of the nozzle-to-cylinder configuration on the resulting K-factors for corner cracks has been illustrated. The accuracy of local K-values is found to be increased by using superior elements at the crack fronts and the choice of substructuring in mesh generation. It is also concluded that by using optimum substructuring techniques, calculation of strain energy release rate for 3-D thermo-elastic crack-propagation problem is economically feasible.