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Fracture investigations on piping system having large through-wall circumferential crack

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In level-3 Leak-Before-Break (LBB) analysis, stability of a postulated through-wall circumferential crack is demonstrated by simplified fracture mechanics calculations. Detailed experimental studies, conducted by the authors, have revealed that the conventional assessment procedure used to demonstrate LBB is too conservative. There is a large factor of safety due to system indeterminacy. It was observed that the critical load of a cracked piping system (with even a large through-wall circumferential crack of about 120°) is of the order of 75–90% of the collapse load of the uncracked piping system. Reduction in load carrying capacity is even less for a piping system having an off-centre crack. This article discusses the above-mentioned aspects in detail. Detailed 3-D elastic-plastic finite element analyses of some of these tests were performed. The suitability of these numerical results to predict crack initiation load in light of the experimental data is discussed.

1. Introduction

Leak-before-break (LBB) has been widely accepted as a technical approach to eliminate pipe-whip restraints and jet-impingement shields in many nuclear power plants (NPPs). Concerns related to the application of this philosophical concept to nuclear reactors in United States were discussed by Wichman and Lee [1]. This alternative option is permitted by most regulatory bodies as long as it is ensured that all the 3 levels of LBB have actually been implemented in the plant. Level-1 is inherent in the design philosophy of ASME section III [2] which is generally followed to design the primary coolant piping. In level-2 analysis, fatigue crack growth calculations are performed for a postulated surface crack that would be permitted by the acceptance criteria of ASME section XI [3]. The surface crack is usually postulated at locations at which the highest stresses coincident with poorest material properties occur for base materials, weldments and safe-ends. The objective of level-2 analysis is to demonstrate that a small flaw that might have gone undetected in the non-destructive examination would not become through thickness during the life time of the component. Finally, in level-3 LBB analysis it is necessary to demonstrate, at the design stage, that a postulated through-wall circumferential crack, in a piping system, would not become unstable even under extreme loading conditions. The size of this postulated through-wall crack is such that, under normal operating loads, it would lead to a coolant leak rate well in excess of that detectable by the present leak detection systems. Typically, the leakage size crack (LSC) is defined as a crack that leads to a leak rate of 0.5 kg/s. Further details on the LBB philosophy is available in Ref. [4].

Safe-shut-down earthquake (SSE) is often considered as the design basis event for the primary coolant piping of many NPPs. Conventionally, applied moment at the postulated crack location is evaluated via linear elastic dynamic analysis, under SSE loads, assuming that the piping system is uncracked [5]. As discussed by Smith [5], simplified fracture mechanics calculations are then performed by assuming infinite compliance of the piping system. This essentially means that the connected piping system is offering no resistance to the deformation of component in which the crack is postulated. As a result, instead of undertaking detailed fracture analysis of a piping system fracture calculations are performed on the stand-alone component (see Fig. 1). In general, either the J–T analysis [6] or the net-section collapse (NSC) assessment is carried out to evaluate the critical/instability load of a piping component having a leakage size crack. Similar calculation is performed for a crack which is twice as large as the leakage size crack. The critical load obtained from such a simplified calculation is then compared

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