LBB Assessment of Pressurizer Surgeline Using NUREG-CR/6765 Level 3 Approach

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1. Introduction

NUREG/CR-6765 [1] proposed a new three-tiered approach to LBB, which will form the basis for the development of a future NRC Regulatory Guide for LBB. The Level 3 methodology is the most complex and accurate of the three levels. Level 3 assesses the locations at which LBB cannot be demonstrated using a Level 2 approach and uses the postulated leakage crack size calculated at Level 2. While Linear elastic calculated stresses are used in the 1 and 2 methodologies with nonlinear fracture mechanics analysis, the inherent margins can be taken from nonlinear stress calculation in the Level 3 analysis. The Level 3 procedure is described in detail in NUREG/CR-6765 Appendix C.

In this study, Level 3 LBB analysis has been performed at heat-up operating conditions for surgeline where a thermal stratification was reported [2].

2. Level 3 LBB Procedure Used in This Study

The Level 3 analysis looks for additional margin in the nonlinearity of the crack, the piping system, or both. Since such nonlinearities consume energy, this energy is not used for driving a crack. Therefore, there may not be a large enough crack driving force to reach the critical crack load, and, hence, LBB is satisfied. For the Level 3 analysis, a finite element model of the piping run from anchor to anchor contains the hypothesized flaw, a complete characterization of the loading as a function of time, a load-displacement description of the crack behavior, the stress-strain behavior of the pipe at the operating temperature, and a nonlinear finite element analysis program.

In this study, the following three different types of nonlinear analysis were considered, their results were compared with linear stresses and the Level 2 results:

Type 1: an uncracked nonlinear pipe analysis with temperature-dependent material properties, Here, material properties are just changed from elastic to temperature-dependent material properties taken from ASME Code Section II, Part D.

Type 2: a linear pipe analysis with nonlinear crack behavior, Here, the material properties are elastic, but a simple crack is inserted at the assessment location in the full piping model. A circumferential crack was inserted, and the orientation for the crack was chosen to the normal to the axial direction in the section of the assessment location .

Type 3: a nonlinear pipe analysis with nonlinear crack behavior, Here, both Type 1 and Type 2 analyses are considered at once.

For the Level 3 analysis, the finite element model should be built including all boundary conditions (supports, anchors, snubbers, etc.) with time history and all loads must be known as a function of time during the SSE event combined with a heat-up and a cool-down thermal stratification. In this study, to simplify the time domain variables, we consider only a thermal stratification load occurring during heat-up transient event. The time transient temperature data were taken from the author's previous study [2,3] for Ulchin unit 5/6 surgeline shown in Fig. 1 and applied to the finite element model as a thermal loading. This finite element model can take into consideration either elastic or temperature-dependent material properties.

The reduced bending moment values at the cracked section in the pipe represent the additional margin in Level 3. As shown in Fig. 2, this can be achieved by inserting a simple crack of which is the same length as the leakage crack length used in the Level 2 assessment [4]. The crack was modeled by reconstructing the node connectivity of the elements for the surgeline. Since the exact stress values at the vicinity of the crack tip were not considered in the crack modeling, the crack tip singularity element was not employed in the finite element model.

Once axial forces and moments were obtained from the above three nonlinear analyses for the thermal stratification event, they were combined with those of dead weight and SSE load by SRSS to calculate the axial forces and equivalent moments to be used in the fracture analysis. Material properties for fracture analysis were taken from the literature [5]. The assessment locations of 72A, 72B, and 10 are given in Fig. 1

3. Results and Discussion

Table 1 shows the reduced axial forces and moments predicted from the three nonlinear analyses at 72B. Compared to the elastic case, the reduction level in bending moment appeared in the following order: Type 1 < Type 2 < Type 3. Table 2 shows the LBB loads for the faulted condition, where the data in Table 1 were combined with dead weight and SSE loads. Internal pressure was applied in the finite element model including end-cap load. Here 2c in Table 2 means postulated crack length. Figure 3 sdepicts J-T analysis results. J-T analysis was performed for the Type 1 problem only and for twice the postulated leakage crack length (2a). The arrows designate the crack length equivalent to 2a. These points were located in the upper right region of the material J-T curve in the Level 2 analysis [4]. From the Fig. 3, it can be seen that a consideration of temperature-dependent material nonlinearity can reduce conservativeness in the LBB process.

4. Conclusion

Level 3 LBB analysis was performed in accordance with the procedure described in NUREC/CR-6765 for the Ulchin unit 5/6 surgeline at heat-up conditions. As a results of the three nonlinear analyses, the additional margin in the LBB load could be obtained. From the J-T analysis, the Level 3 LBB acceptance criterion was satisfied at all critical locations.

References

[1] NUREG/CR-6765, Development of Technical Basis for Leak-Before-Break Evaluation Procedure, 2002.
[2] B.S. Kim, Y.H. Jang and C.K. Moon, “Reduction of Conservativeness in Thermal Stratification Analysis for LBB Application,” Transactions of the Korean Nuclear Society Spring Meeting, Cheju, Korea, May 9-11, 2007.
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[4] M.W. Kim, Y.J. Kim and Y.H. Jang, “Level 2 LBB Assessment of A Pressurizer Surgeline in accordance with NUREG/CR-6765,” 2008 annual conference of the Korean Society of Pressure Vessels and Piping, pp. 185-186, 2008.

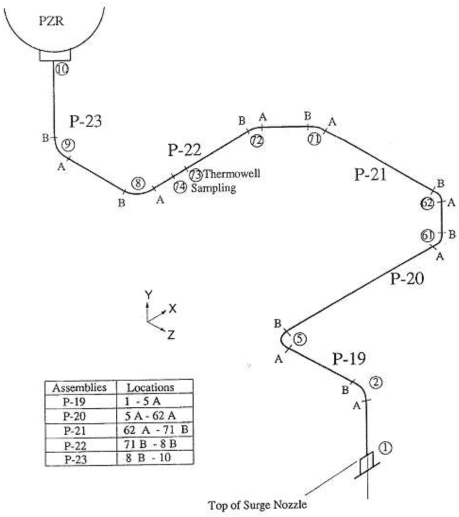

Figure 1 Surgeline pipe model for Ulchin unit 5/6 surgeline

[5] Stress-Strain (σ −ε) and Static Fracture Resistance (J-R) Characteristics of the Primary Piping Base Materials for Ulchin 5/6 Nuclear Power Plants, Doo-San Heavy Industrial, 2001. 9.

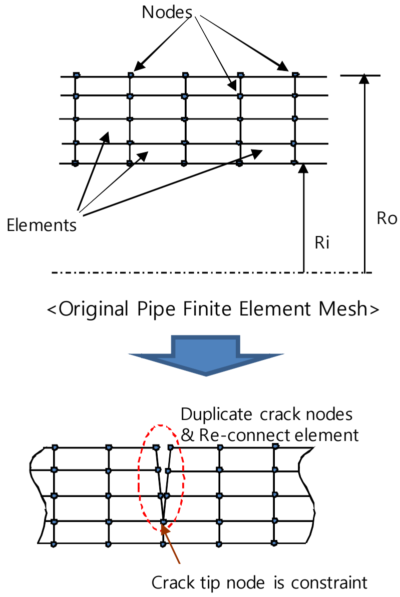

Figure 2 A schematic diagram for a simple crack modeling

Table 1 Comparison of nonlinear analysis results at 72B

[redacted]

Table 2 Applied LBB load (N+SSE) for fracture analysis

[redacted]

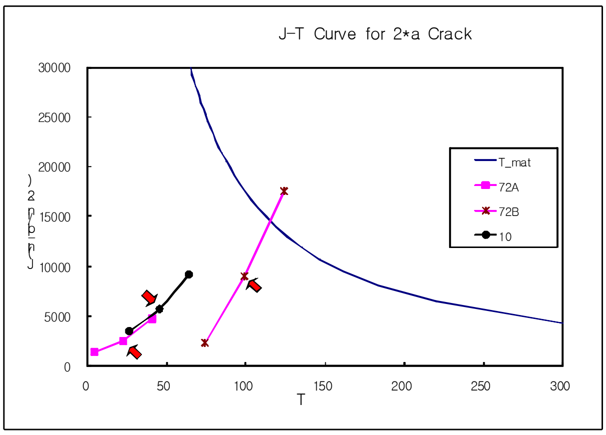

Figure 3 J-T Curve for twice the postulated leakage crack length (2a). The arrows designated the crack length equivalent to 2a.