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Level Ⅰ LBB Assessment for Surgeline According to NUREG/CR-6765 Procedure

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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 future NRC Regulatory Guide for LBB. We performed a preliminary analysis i.e., piping analysis, thermal stratification flowing analysis and piping stress analysis for the surgeline heat-up operating condition which is reported that a thermal stratification has been found in the horizontal pipe [2]. And then the Level Ⅰ methodology was applied to determine the critical locations, to calculate postulated leaking crack length, and to assess a Level Ⅰ LBB acceptability using a limit load analysis described in NUREG/CR-6765.

2. Level Ⅰ LBB Analysis Procedure

A piping system that passes a general screening criterion can be elected to apply Level Ⅰ LBB procedure. Required input data for the Level Ⅰ LBB analysis are: physical dimensions, thermohydraulic conditions, yield and ultimate strength values, and elastically calculated normal operating and transient stresses, i.e., SSE (safe shutdown earthquake) or transient thermal expansion stress, from stress report.

Critical locations for the Level Ⅰ analysis were selected at each of the following locations: (a) the location with the highest normal operating stresses, (b) the location with the highest SSE or transient stresses, and (c) the location with the highest ratio of normal operating plus SSE stress (N+SSE) to normal operating stresses (N). In this study low toughness location along the piping system was not considered.

The maximum postulated leaking crack length (2c) for the Level Ⅰ LBB analysis can be calculated using the expression:

$$2c = (4/\pi)(A/COD) \tag{1}$$

where, A and COD are a leakage area and a crack-opening displacement (COD), respectively. In the Level Ⅰ LBB procedure the leakage area, A, can be calculated using a series of simple algebraic equations that incorporate pre-established influence functions. The COD can be estimated using the Paris–Tada approach which results in the most conservative predictions of COD, i.e., the Paris-Tada method predicts relative smaller COD values for austenitic steels which results in relatively large crack length for the same leak rate/crack opening area. In this study we calculated the postulated crack length and the COD using a VBA (visual basic application) in Microsoft Excel sheet.

The following four Level Ⅰ specific screening criteria were checked before proceeding further with the Level Ⅰ fracture analysis to check the appropriateness of the assumptions invoked in a Level Ⅰ LBB analysis: (1) check the ratio of the COD to the surface roughness, (2) check the thermo-hydraulic conditions of the water, (3) check the ratio of the postulated crack length to the pipe circumference, and (4) ascertain whether or not the piping system welds have been stress relieved or not.

For the fracture analysis in the Level Ⅰ LBB procedure a simplified limit load analysis is only used. The allowable stress index ($SI_{allowable}$) is first calculated for a flaw twice as long as the postulated leakage crack size at normal operating conditions using a simple limit load equations, and then compared with the applied stress index ($SI_{applied}$) at the faulted conditions. A piping system would pass the Level Ⅰ LBB criteria if the $SI_{applied}$ is less than the $SI_{allowable}$.

3. Level Ⅰ LBB Analysis Results and Discussion

For the calculation of a postulated leakage crack length and fracture analysis in LBB procedure, stresses at the critical location should be obtained from axial forces and bending moments under the reasonable loading combination. Piping loads consist of deadweight, temperature, pressure and transient load. Axial forces and bending moments were calculated at each location shown in the figure 1 at the normal operating condition including heat-up transient and safe shutdown earthquake (SSE) seismic condition.

Table 1 shows the critical locations selected from (a), (b) and (c) criteria described in the above chapter for Level Ⅰ LBB analysis. In the preliminary stress analysis [2], we calculated thermal stresses for thermal stratification with two different methods: using the moments and axial forces from design specification (indicated as DS in Table 1) and the values from 3-dimensional time transient analysis (indicated as 3D Transient in Table 1). Here DS results are the values based on the 2-dimensional analysis with assumption that temperature difference between top and bottom of the pipe is 320 ˚F, which is expected having a conservative result in the LBB stress.

Table 2 shows the calculated maximum leakage crack length (2c) compared with PICEP results at each critical analysis location. The great differences compared with PICEP results in Table 2 would be originated from the following two facts: (1) Dimension limit range of the ratio of inner radius to wall thickness (Ri/t) used in PICEP should be between 5 and 20 but Ri/t ratio of Uljin unit 5/6 surgeline is about 3.86, which brings about 10% differences in bending stresses in the stress analysis, and (2) Paris-Tada equation has derived from an influence function of the stress intensity factor for the pipe with that the ratio of mean radius to thickness (Rm/t) is 10, which has a little bit conservativeness even for this ratio, but the ratio Rm/t of Uljin unit 5/6 surgeline is about 4.4, in which value would contain great conservativeness.

The ratio of the calculated crack length to the pipe circumference is greater than one-eighth of the pipe circumference, thus the Level Ⅰ LBB analysis is not appropriate for this piping system because there is possibility that there may be restraint of the COD from the pipe system boundary conditions that need to be considered.

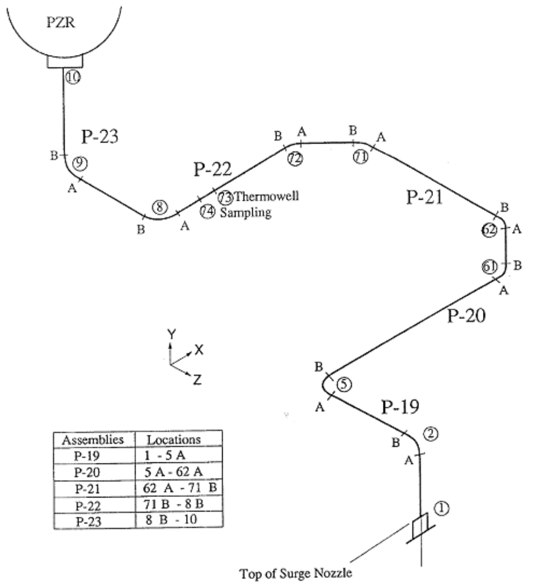

Figure 1. Surgeline pipe model for Uljin unit 5/6 surgeline

Table 1 Critical locations for Level Ⅰ LBB analysis

	Location	$\sigma_{bending}$ (ksi)	σ_{axial} (ksi)	σ_{total} (ksi)	Applied Criteria
DS	1	22.4178	-0.6	21.8155	(a)
	10	7.7742	0.0	7.8225	(b)
		25.4987	0.2	25.713	(c)
3D Trans -ient	2A	11.9655	-0.6	11.3513	(a)
	10	7.7742	0.0	7.8225	(b)
	72B	9.3413	0.2	9.4963	(c)

Table 2 Maximum leaking crack length (unit: in.)

	Location	Calculation	PICEP	Difference with PICEP (%)
DS	1	5.8629	1.6979	245.3
	10	6.3082	2.0446	208.5
3D Trans -ient	2A	7.2080	3.0031	140.0
	10	7.3489	3.1722	131.6
	72B	8.5193	4.6241	84.2

Table 3 shows the Level Ⅰ LBB fracture analysis results in this study. The applied stress indices are greater than the allowable stress indices at all the critical locations. Thus it is concluded that one needs to go on to a Level 2 or Level 3 analysis in order to demonstrate LBB.

Table 3 Level Ⅰ LBB fracture analysis results

	Location	$SI_{applied}$ (ksi)	$SI_{allowable}$ (ksi)
DS	1	43.83	26.40
	10	40.10	23.74
3D Transient	2A	23.95	18.41
	10	27.96	17.82
	72B	21.98	12.01

4. Conclusion

Level Ⅰ LBB analysis was performed according to the procedure described in NUREC/CR-6765 for Uljin unit 5/6 surgeline at heat-up conditions which is expected the appearance of maximum stresses due to thermal stratification flow. It was found that assumption of the traditional 2-dimensional thermal stratification flow has a great conservativeness compared with 3-dimensional transient analysis for thermal stratification flow. But both results can not satisfy the Level Ⅰ specific screening criteria and also Level Ⅰ LBB acceptability assessment. Therefore Level 2 or Level 3 analysis is required to demonstrate LBB for Uljin unit 5/6 surgeline.

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.
[3] Project Design Specification for Pressurizer for Uljin Nuclear Power Plant Units 5&6, NO696-ME-DS270-00,Rev.03 Korea Power Engineering Company, Jan. 2001