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Reduction of Conservativeness in Thermal Stratification Analysis for LBB Application

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1. Introduction

Piping analysis, thermal stratification flowing analysis and piping stress analysis were performed for the surgeline heat-up operating condition which is reported that a thermal stratification has been found in the horizontal pipe. And efforts to optimize some conservativeness of previous analysis in LBB procedure were also tried in this paper to analyze a new LBB evaluation procedure in NUREG/CR-6765 which will form the basis of a future NRC Regulatory Guide for LBB application and to evaluate the effects of the new procedure on the previously applied components in the sites. To reduce conservativeness, exact temperature distribution should be calculated in the pipe during the given transient time. In this paper, 3-D FLUENT simulation has performed for the pressurizer heat-up transient condition and compared with the calculated results from Design Specification (DS).

2. Analysis methods and Load Combination

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 are consisted 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.

For normal operating condition load combination is taken as follows:

N = (deadweight) + (thermal) + (pressure)

$$F = F_{DW} + F_{TH} + F_P$$
$$M_Y = (M_Y)_{DW} + (M_Y)_{TH}$$
$$M_Z = (M_Z)_{DW} + (M_Z)_{TH}$$

For the normal operating condition plus SSE condition (N+SSE), load combination is as follows:

$$F = F_{DW} + F_{TH} + F_P + F_{SSE}$$
$$M_Y = (M_Y)_{DW} + (M_Y)_{TH} + (M_Y)_{SSE}$$
$$M_Z = (M_Z)_{DW} + (M_Z)_{TH} + (M_Z)_{SSE}$$

In the above equations, DW means dead weight, TH is thermal load and P represents internal pressure. An equivalent bending moment (M_O) can be calculate from the following equation:

$$M_O = [(M_Y)^2 + (M_Z)^2]^{0.5}$$

To obtain axial forces and moments at the critical locations, ADLPIPE code was used for the calculation of piping loads including dead weight and SSE seismic inertia. For thermal stratification flowing analysis, 3-dimensional transient analysis FLUENT code was used.

2. Piping Analysis

ADLPIPE code was used for piping analysis and detail engineering data for the pressurizer surgeline of Uljin unit 5/6 were used for piping geometries and material properties. Pipe material is SA-312 Type 347 stainless steel SCH160 with 12 in. diameter and nominal wall thickness 1.313 inches. The operating pressure is 2250 psia. The ratio of resultant moments calculated by ADLPIPE analysis to loads calculated from the values of DS for Ulchin unit 5/6 is as follows: 0.85 ~ 0.95 for deadweight, 0.32 ~ 3.22 for the normal operating temperature (NOT), 0.24~1.07 for OBE seismic inertia, and 0.19~1.07 for SSE seismic inertia.

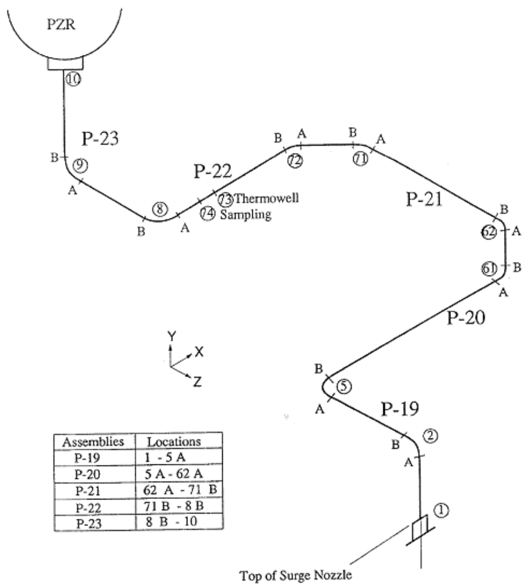

Figure 1. Surgeline pipe model for Uljin unit 5/6 surgeline

The piping load calculated from ADLPIPE results of deadweight loads was decreased 5-15% due to the small discrepancy of piping support boundary conditions. But the significant discord was obtained for the results of NOT loads, which is not only caused by the fully fixed boundary conditions at both ends of pipe, but also not considered seismic anchor motion at a side of hot leg.

3. Thermal Stratification Analysis

Finite element model used in DS for thermal stratification analysis is half symmetric model and assumed 320˚F temperature difference between upper part and lower part of the stratified flowing. A 3-dimensional time transient stratification flowing analysis has been done in this paper using FLUENT code to obtain more real temperature distribution in surgeline at the heat-up condition. Figure 2 shows temperature variation of Ulchin unit 5/6's pressurizer surgeline at the heat-up condition. The 3-D FLUENT results showed that the maximum fluid temperature difference between the top and the bottom of the horizontal pipe, Δ T=32˚F, was occurred at 19769 seconds. Compared to the results of DS, 3-D FLUENT results have decreased by 41~72 %.

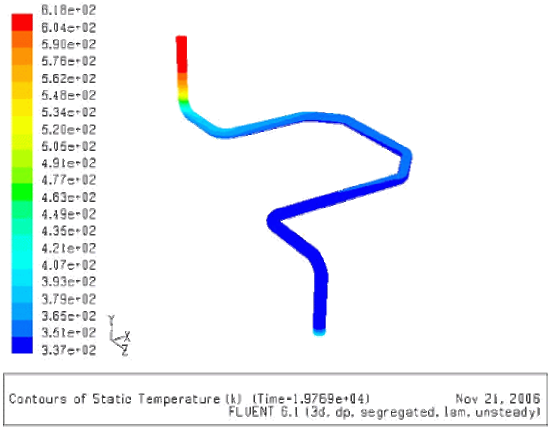

Figure 2. Temperature distribution of surgeline at heat-up transient 19769 sec

4. Stress Analysis

Stresses were calculated from the axial forces and the bending moments at each location at the normal operating condition (N), SSE condition, (N+SSE) condition, respectively. The locations which have the highest stress values, i.e. the highest N and SSE stresses, and the highest normal operating stress plus SSE stress to normal operating stress (N+SSE)/N, at each loading condition can be determined from the calculated stress values in this step and a postulated crack will be inserted for LBB assessment according to the NUREG/CR-6765 Level 1 LBB analysis.

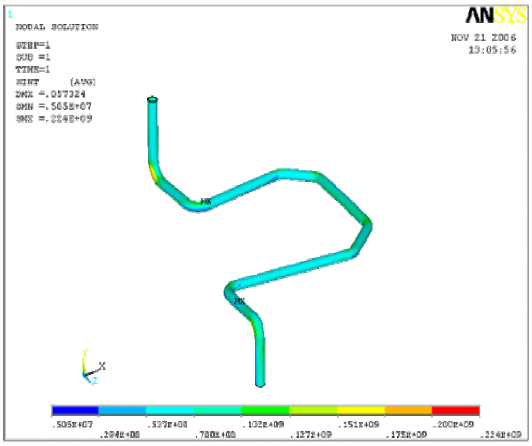

Figure 3. Stress intensity distribution of the surgeline at heat-up transient at 19769 seconds

First, the highest stress obtained from 3-D FLUENT analysis was 11.3513ksi at location 2A at the normal operating condition and 7.8225ksi at location 10 at the SSE condition. The highest ratio of (N+SSE)/N stress value was 1.7775 at location 72B. In case of Δ T=320˚F stratification in DS, the highest normal operation stress was 21.8155ksi at location 1 and the highest value of (N+SSE)/N ratio was 1.4309 at location 10. Because stresses calculated by using Δ T=320˚F stratification in DS were greater than those obtained by using 3-D thermal stratification analysis for heat-up transient, it is concluded that Δ T=320˚F stratification in DS gives LBB analysis results conservative estimation.

4. Conclusion and further study

The results of piping and stress analysis including thermal stratification flowing analysis with 3-D FLUENT simulation for heat-up condition of the surgeline have shown that stress values were reduced to 52% of the values of DS under normal operating condition and N+SSE. This result means that the 2-D thermal stress analysis in DS is more conservative than the 3-D thermal stratification flow analysis in this paper and conservativeness can be reduced with 3-D flow transient analysis.

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