Preliminary Seismic Analysis of the Elevated Temperature IHTS Piping of a Sodium-Cooled Fast Reactor

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1. Introduction

The advanced reactor concepts are needed to meet the waste management, further enhanced safety, nonproliferation, and resource challenges that must accompany the deployment of increasing numbers of nuclear power plants. The ABTR(Advanced Burner Test Reactor) has design features of a pool-type, sodium coolant, 30 years plant life with the expectation of life extension[1]. In this study, the structural integrity of the IHTS hot leg piping is evaluated for mechanical loads including the seismic load and thermal transient load of the enveloped cycle events.

2. Structural Integrity Evaluation

2.1 IHTS Concept

The IHTS piping of ABTR reactor is primarily consisting of the main system hot and cold legs which make the necessary connections between the IHX and the PCHE. The hot leg piping connects to the secondary sodium outlet of the IHX directly to the PCHE sodium inlet. The cold leg piping connects the sodium outlet from the PCHE to the secondary pump tank inlet and then from the pump tank discharge to the secondary cold sodium inlet to the IHX. The IHTS piping is constructed from 40.6cm outer diameter, 1.27cm thick-walled(16 inch Schedule 30) 304 stainless steel piping because of the lack of corrosion issues for sodium and the ease of fabrication with this material.

2.2 Primary Load

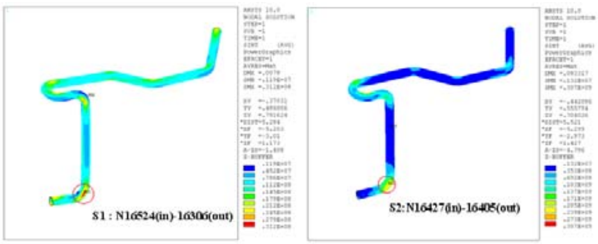
The representative primary loads include the coolant pressure and dead weights of piping and coolant. The coolant pressure inside the piping is assumed to be 0.5MPa and is exerted on the inner surface of the piping. Fig. 1(a) shows the stress distribution by primary load at the full power steady state condition. The maximum stress intensity including membrane, bending and peak stress components is 31.2MPa at the lower elbow section. To evaluate the structural integrity, a critical section(S-1) having a maximum stress intensity value is selected from the stress distribution.

2.3 Thermal Transient Load

For the structural integrity evaluation, two duty cycle event types for the thermal transient operations are considered as representative design thermal loads as follows in this study;

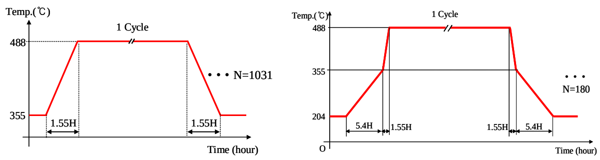
- Cycle Type 1 (CT-1) : heatup from a hot standby to a full power and a reverse operation with a hold time at full power operation
- Cycle Type 2 (CT-2) : heatup from a refueling to a full power and a reverse operation with a hold time

The assumed coolant temperatures at the refueling, hot standby and normal operation are 204℃, 355℃ and 488℃ respectively. Fig. 2 shows the temperature histories of CT-1 and CT-2 event, respectively. The design frequencies of CT-1 and CT-2 are 1031 and 180, respectively corresponding to the ABTR 60 years plant lifetime and 4-months refueling cycle. The additional critical section(S-2) for structural integrity evaluation is selected as shown in Fig. 1 through the thermal stress intensity analysis.



(a) Primary stress (b) Thermal stress

Fig. 1. IHTS hot leg piping layout and critical sections for structural integrity evaluation



(a) CT-1 event (b) CT-2 event

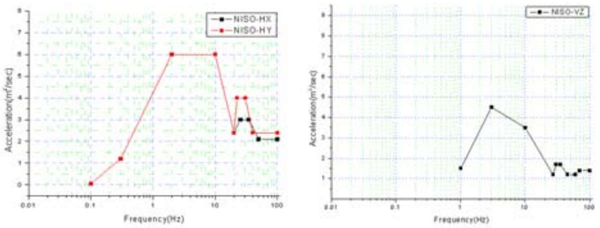
Fig. 2. Hot leg coolant temperature histories of cycle events

2.4 Modal Analysis

The mode extraction method used for the modal analysis is Block Lanczos method[4]. The natural frequency of the 1st mode is 2.85Hz and formed within the range of general seismic frequency (2Hz~10Hz). If it is considered that the natural frequencies of the reactor building is generally about 4.5Hz and the horizontal seismic isolation frequency is about 0.5Hz, the current piping layout might be weakened from the seismic load.

2.5 Seismic analysis

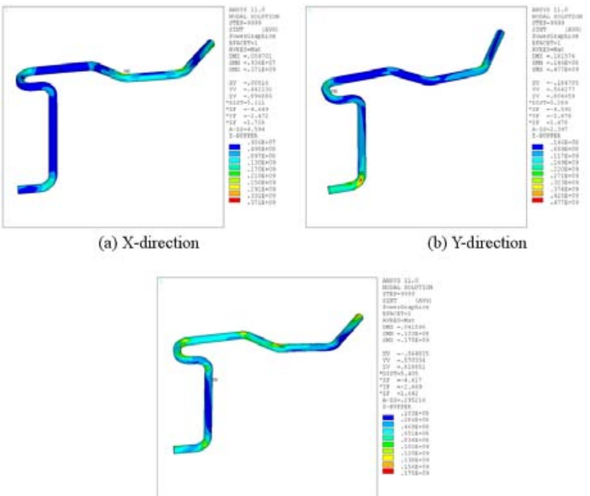
The Floor Response Spectra(FRS) should be provided for the structural integrity evaluation against the system loading including the seismic load. The FRS are obtained from the seismic response analysis which was carried out with lumped-mass beam model. The FRS used in this study are provided for the seismically non-isolation model(NISO). Fig. 3 shows the design FRS of the IHTS piping for the seismic analysis under the Operating Basis Earthquake (OBE) condition. In the Fig. 3, the VZ means the gravity(vertical) direction but HX and HY do the ground(horizontal) direction.



(a) Horizontal-NISO (b) Vertical-NISO

Fig. 3. OBE floor response spectra

The seismic analysis is performed for the initial 13 modes below 50Hz natural frequency. The spectrum type used in this analysis is a single point excitation response spectrum of ANSYS and the combination method is a SRSS which is a Square Root of Sum of Squares mode combination method of the directions provided in ANSYS[4]. Fig. 4 shows the stress intensity distribution for the three directional FRS of NISO model. As shown in Figures, the seismic stresses are too excessive comparing with the primary mechanical stress.



(a) X-direction (b) Y-direction

(c) Z-direction

Fig. 4. Stress intensity distribution of NISO model by the mode combination

2.6 Evaluation Result of Structural Integrity

Table 1 shows the structural integrity evaluation result for the enveloped cycle event of IHTS hot leg piping by using the SIE ASME-NH program from the stress analysis results including the seismic analysis. The primary stress increases remarkably and thus the design margins for membrane and membrane plus bending stress can not be secured. The proposed current hot leg piping layout without intermediate energy absorbers can not satisfy the inelastic strain limit by the elastic analysis method of the ASME-NH rule. For the creep ratchet strain and creep-fatigue damage, they are evaluated from the normal operating cycle event without seismic load because the seismic load works only for a very short time about 30 seconds and the number of OBE seismic event for the plant lifetime is very limited.

Table 1. Structural integrity evaluation result

Evaluation Items		Section-1		Section-2	
		Calculated	Limit	Calculated	Limit
Primary stress limits	Membrane	462.1	90.4	440.0	90.4
	Membrane + Bending	533.8	145.4	421.5	145.4
Inelastic strain limits	Elastic approach	4.99	1.0	4.52	1.0
	Creep ratchet	0.031%	1.0%	0.097%	1.0%
Creep-Fatigue damage	Fatigue damage	0.26e-3	0.172	0.30-3	0.105
	Creep damage	0.597	0.999	0.756	0.999

3. Conclusion

The structural integrity of the IHTS hot leg piping is evaluated for mechanical loads including the OBE seismic load and thermal transient loads of the enveloped cycle events. The proposed initial piping layout satisfies the Design Limits. Two elbow sections are selected as the critical sections from the primary and secondary stress analyses. The structural integrity is evaluated by using SIE ASME-NH program to decrease the calculation time and induce an exact calculation compared with a manual calculation. The seismic load is regarded as a primary loading. From the seismic analysis of the non-isolated seismic model without energy absorbers, the hot leg piping layout can not satisfy the structural integrity of the Level B Service due to the excessive primary stress caused by the seismic load. Therefore, modification of the piping layout and support structure of energy absorber such as a snubber should be followed to resist the seismic and other dynamic displacements by all means.

REFERENCES

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