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A structural integrity evaluation of the IHTS hot piping for PGSFR

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1. Introduction

This paper provides structural integrity evaluation results of the IHTS (Intermediate Heat Transfer System) hot piping system, which is required to be designed with consideration of the elevated temperature services, of the PGSFR (Prototype Gen-IV Sodium Fast Reactor). To evaluate the structural integrity of the high temperature piping per ASME Subsection NH rules, the structural analysis should be carried out first by using a 3-dimensional structural model.

2. Finite element analysis

2.1 Geometry

The IHTS hot piping is 559 mm outer diameter and 15.88 mm thick-walled 9Cr-1Mo-V piping. The front and top views are shown in Fig. 1. A reinforced straight tee for IHTS piping is shown in Fig. 2.

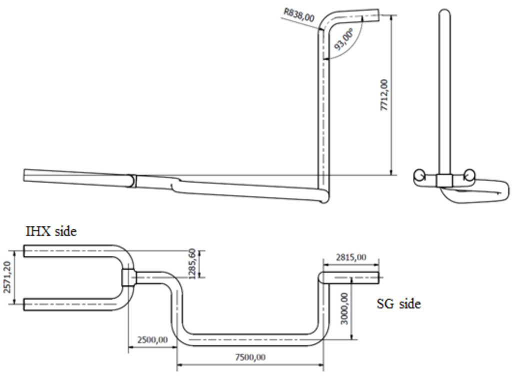

Fig. 1. Front and top views of the hot leg

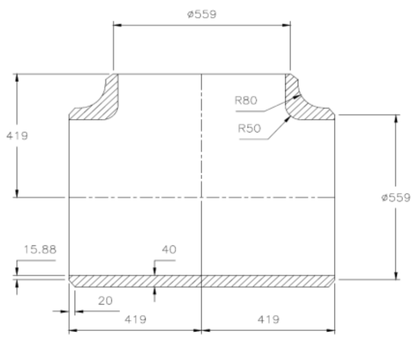

Fig. 2. Front and top views of the hot leg

2.2 FE analysis

Elastic numerical simulations were performed using the finite element software package ANSYS v.14.5 [1]. Fig. 3 illustrate a typical FE mesh for analysis. Three-dimensional eight-node structural solid elements (SOLID185) were used and the small strain assumption was employed in the elastic analyses. The number of elements and nodes in FE mesh is 126192 and 161358, respectively.

FE result for gravity is shown in Fig. 4. Maximum stress intensity is 37.8 MPa at the end of piping next to the steam generator. FE result for inner pressure (3.5 MPa) is shown in Fig. 5. Maximum stress intensity is 112 MPa at straight tee.

3. Structural integrity evaluation

To evaluate the structural integrity for IHTS hot piping, the ASME-NH [2] rules are used in this paper. The structural integrity is evaluated using the SIE ASME-NH computer program, which implements the ASME Subsection NH rules at elevated temperature service [3]. Linearized stresses for evaluation for design and service level A condition are summarized in Table I and II. Structural integrity evaluation results for design and service level A condition are summarized in Table III and IV. Minimum margin for design and service level A condition are evaluated to be 0.38 and 0.31, respectively.

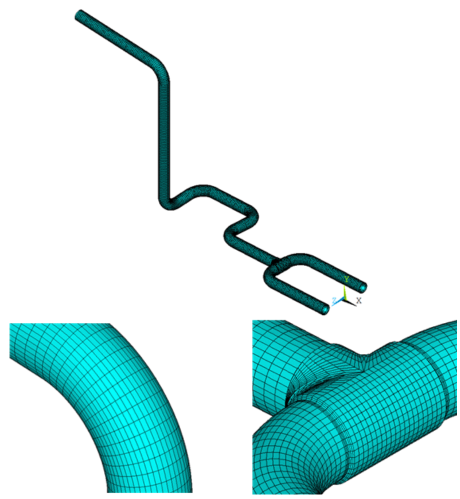

Fig. 3. Typical FE mesh for FE analyses for IHTS hot piping

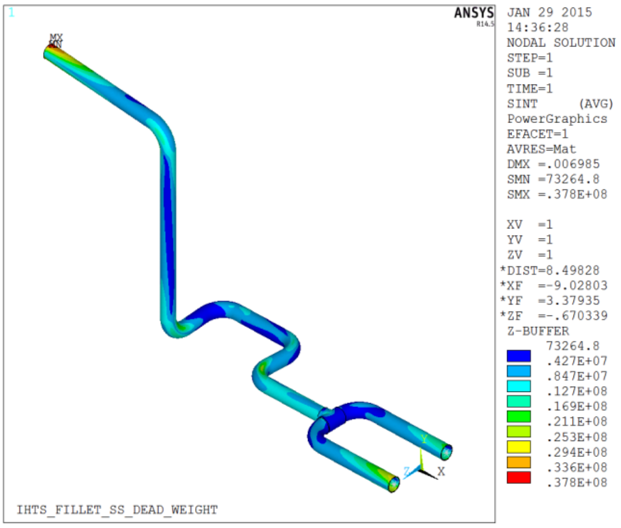

Fig. 4. FE result for gravity

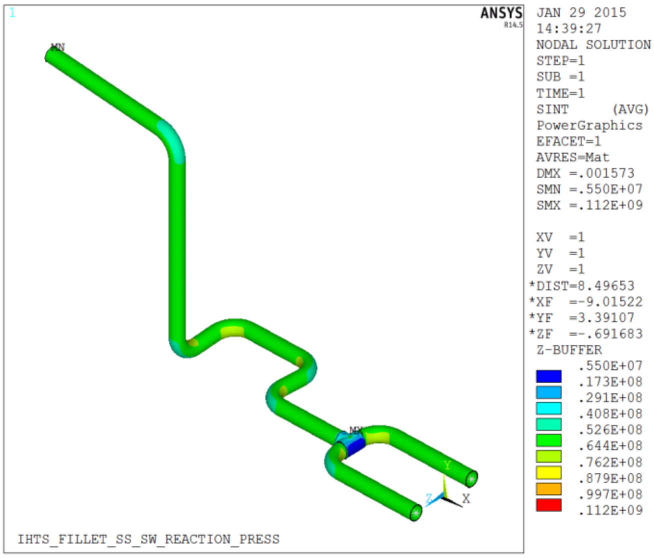

Fig. 5. FE result for inner pressure

4. Conclusions

A structural integrity evaluation by utilizing elastic FE analysis for IHTS hot piping per ASME-NH was performed. The evaluation results give enough margin of design and service level A conditions. The transient and seismic load conditions will be considered in future work.

Acknowledgement

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Table I: Linearized stress for design condition

Sections	Node	Stress (Pa)	SX	SY	SZ	SXY	SYZ	SXZ	Temp. (°C)
DW	Inner 64735	Pm	6.38E+07	-2.74E+05	5.75E+07	-7.23E+06	6.96E+06	2.38E+06	555
		Pb	-1.62E+06	-1.25E+06	1.34E+06	1.02E+04	2.97E+05	1.52E+04	
		Pp	9.24E+03	9.00E+04	5.33E+04	5.92E+03	-4.15E+03	-7.70E+02	
	Outer 64205	Pm	6.38E+07	-2.74E+05	5.75E+07	-7.23E+06	6.96E+06	2.38E+06	555
		Pb	1.62E+06	1.25E+06	-1.34E+06	-1.02E+04	-2.97E+05	-1.52E+04	
		Pp	-3.04E+04	-1.30E+05	7.21E+03	-3.58E+03	1.59E+04	2.47E+02	
SW	Inner 165	Pm	3.61E+06	5.99E+07	4.85E+06	1.03E+06	3.25E+06	-5.99E+06	555
		Pb	5.83E+05	4.30E+07	-2.77E+05	1.01E+06	3.40E+06	-3.56E+06	
		Pp	-3.66E+06	3.20E+06	-3.88E+06	-3.05E+05	1.75E+05	3.59E+06	
	Outer 32	Pm	3.61E+06	5.99E+07	4.85E+06	1.03E+06	3.25E+06	-5.99E+06	555
		Pb	-5.83E+05	-4.30E+07	2.77E+05	-1.01E+06	-3.40E+06	3.56E+06	
		Pp	-8.54E+05	6.08E+06	-1.08E+06	1.69E+05	4.96E+05	2.66E+06	

Table II: Linearized stress for service level A

Sections	Node	Stress (Pa)	SX	SY	SZ	SXY	SYZ	SXZ	Temp. (°C)
DW	Inner 64735	Pm	3.88E+07	3.93E+05	8.38E+06	-5.82E+06	1.18E+06	2.05E+06	528
		Pb	-1.47E+06	-5.51E+04	9.60E+03	6.43E+04	5.62E+03	-5.89E+03	
		Pp	5.51E+04	3.70E+04	5.86E+04	7.18E+02	2.57E+03	-3.77E+02	
	Outer 64205	Pm	3.88E+07	3.93E+05	8.38E+06	-5.82E+06	1.18E+06	2.05E+06	528
		Pb	1.47E+06	5.51E+04	-9.60E+03	-6.43E+04	-5.62E+03	5.89E+03	
		Pp	-5.67E+04	-3.91E+04	-5.51E+04	2.57E+03	-1.77E+03	-6.28E+02	
SW	Inner 165	Pm	2.96E+05	8.25E+06	4.00E+05	-3.54E+05	7.79E+04	-7.56E+05	528
		Pb	4.24E+05	6.91E+06	3.71E+05	-3.13E+05	9.90E+05	-9.48E+05	
		Pp	-6.09E+05	4.69E+05	-6.38E+05	1.42E+05	1.28E+05	6.62E+05	
	Outer 32	Pm	2.96E+05	8.25E+06	4.00E+05	-3.54E+05	7.79E+04	-7.56E+05	528
		Pb	-4.24E+05	-6.91E+06	-3.71E+05	3.13E+05	-9.90E+05	9.48E+05	
		Pp	-1.20E+05	1.00E+06	-1.69E+05	2.28E+05	1.03E+05	5.09E+05	

Table III: Evaluation results for design condition

Sections	Node	Stress (MPa)	Calculated	Allowable	Margin	Temp. (°C)	C&S
DW	Inner 64735	Pm	6.69E+01	9.78E+01	0.46	555	ASME Sec. III Div.5-HBB
		PL+Pb	6.69E+01	1.47E+02	1.19		
	Outer 64205	Pm	6.69E+01	9.78E+01	0.46	555	
		PL+Pb	6.72E+01	1.47E+02	1.18		
SW	Inner 165	Pm	6.20E+01	9.78E+01	0.58	555	
		PL+Pb	1.09E+02	1.47E+02	0.35		
	Outer 32	Pm	6.20E+01	9.78E+01	0.58	555	
		PL+Pb	1.55E+01	1.47E+02	8.48		

Table IV: Evaluation results for service level A

Sections	Node	Stress (MPa)	Calculated	Allowable	Margin	Temp. (°C)	C&S
DW	Inner 64735	Pm	4.05E+01	9.35E+01	1.31	528	ASME Sec. III Div.5-HBB
		PL+Pb	3.91E+01	2.03E+02	4.18		
		PL+Pb/kt	3.94E+01	9.35E+01	1.37		
		UFS(t/tm)	5.26E+05	1.72E+06	0.31		
		UFS(t/tb)	5.26E+05	1.74E+06	0.30		
	Outer 64205	Pm	4.05E+01	9.35E+01	1.31	528	
		PL+Pb	4.19E+01	2.03E+02	3.84		
		PL+Pb/kt	4.16E+01	9.35E+01	1.25		
		UFS(t/tm)	5.26E+05	1.72E+06	0.31		
		UFS(t/tb)	5.26E+05	1.69E+06	0.31		
SW	Inner 165	Pm	8.68E+00	9.35E+01	9.76	528	
		PL+Pb	1.62E+01	2.03E+02	11.47		
		PL+Pb/kt	1.47E+01	9.35E+01	5.35		
		UFS(t/tm)	5.26E+05	2.44E+06	0.22		
		UFS(t/tb)	5.26E+05	2.30E+06	0.23		
	Outer 32	Pm	8.68E+00	9.35E+01	9.76	528	
		PL+Pb	2.32E+01	2.03E+02	86.35		
		PL+Pb/kt	3.00E+00	9.35E+01	30.14		
		UFS(t/tm)	5.26E+05	2.44E+06	0.22		
		UFS(t/tb)	5.26E+05	2.56E+06	0.21		

REFERENCES

[1] ANSYS user's manual for revision 14.5, ANSYS Inc., 2014

[2] ASME boiler and pressure vessel code, Section III Rules for Construction of Nuclear Facility Components, Division 1 – Subsection NH, Class 1 Components in Elevated Temperature Service, 2010.

[3] G.-H. Koo and J.-H. Lee, "Development of an ASME-NH program for nuclear component design at elevated temperatures", International Journal of Pressure Vessels and Piping, Vol.85, pp.385-393, 2008.