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◆특집◆ 가공과 진동

Analytical Structural Integrity for Welding Part at Piping Penetration under Seismic Loads

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지진하중이 적용되는 배관 관통부의 용접에 대한 구조 건전성 해석

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ABSTRACT

The purpose of this paper is to assess the structural integrity of piping penetrations for nuclear power plants. A piping qualification analysis describes loads due to deadweight, pressure difference acts normal to the plate, thermal transients, and earthquakes, among other events, on piping penetrations that have been modeled as an anchor. Amodel was analyzed using a commercial finite element program. Apiping penetration analysis model was constructed with an assembly of pipe, head fittings and sleeves. Normally, the design load, thus obtained, will consist of three moments and three forces, referred to a Cartesian coordinate system. When comparing the stress analysis results from each required cutting position, the general membrane stress intensities and local membrane plus bending stress intensities during a structural evaluation cannot exceedthe allowable amount of stress for the design loads. Therefore, the piping penetration design satisfies the code requirements.

Key Words : Piping penetration(배관 관통부), Nuclear power plant(원자력 발전소), Seismic(지진)

1. Introduction

Currently, the likelihood of the occurrence of an earthquake that exceeds the design basis of nuclear power plants in South Korea is very small. However, an accident due to leakage of radioactive matter can inflict catastrophic damage on the environment nearby. Therefore, more rigorous and precise seismic analysis in comparison to other industrial facilities was required. To resist large vibrations such as those that occur from earthquakes during normal operation and transient operation status, the piping penetration inside

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structures of nuclear power plants need to conform to the guidelines of the design seismic qualifications[1]. This paper describes the thermal-hydraulic conditions experienced at various locations inside the safety injection system during design basis events. The results presented provide a conservative basis for the plant component design.

The nuclear steam supply system performance and safety related design bases events with the associated frequencies of occurrence are presented in Table 1. The frequency of occurrence is based on operating plant histories and engineering judgement and is intended for design purposes only. The values presented may exceed the actual expected number of operational occurrences. A steam line break, for example, is included as a design basis event but is not expected to occur in the life of the plant. A turbine power step change of about 10% is included as a weekly event although the actual frequency is expected to be significantly less than this value. The design frequency of occurrence reflects estimates of the yearly 40, monthly 500, weekly 2,000, daily 15,000 or three times per hour 1,000,000 operations over a 40-year plant life. Based on the frequency of occurrence the events are divided into normal, upset, emergency and faulted categories as defined in Table 1.

Table 1 Frequencies of occurrence

Categories	Thermal/Pressure mode description	Number of occurrences
Normal event	System shutdown conditions following plant normal/upset event	1100
Upset event	System shutdown conditions following plant normal/upset event	54
Emergency event	System conditions following plant emergency event	20
Faulted event	System conditions following plant faulted event	30

ASME Section III defines the relationship between the alternating stress and the allowable number of cycles for specific materials. The specified number of operational cycles divided by the allowable number of cycles is defined as the usage factor for a particular event. The sum of the usage factors for all normal, upset, emergency and faulted categories must be less than one over the design life of the component. The purpose of this paper is to assess the structural integrity for the piping penetration for the safety injection system for the nuclear power plant unit.

2. Structural analysis method

2.1 Modeling

The model was analyzed using the ANSYS finite element (FE) computer program [4]. The model was divided into elements as shown in Fig. 1 and Fig. 2. The element types used in this analysis were SOLID185 (3-dimensional 8-node structural solid) and MPC184 (multipoint constraint elements: rigid link/beam) elements. The SOLID185 elements were used in the pipe, head fitting and sleeve model. The MPC184 elements were used for applying pipe loads.

For the boundary conditions, supporting conditions of the piping penetration assembly were represented

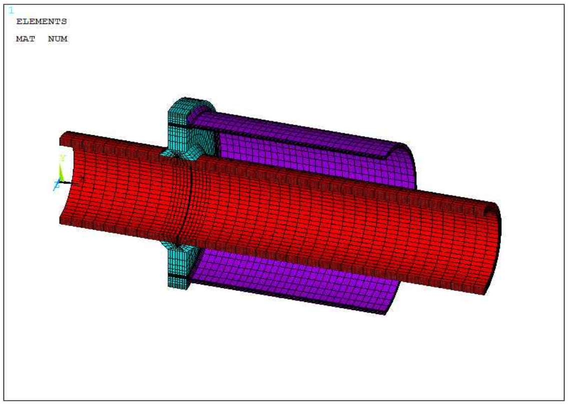


Fig. 1 FE modeling image of piping penetration

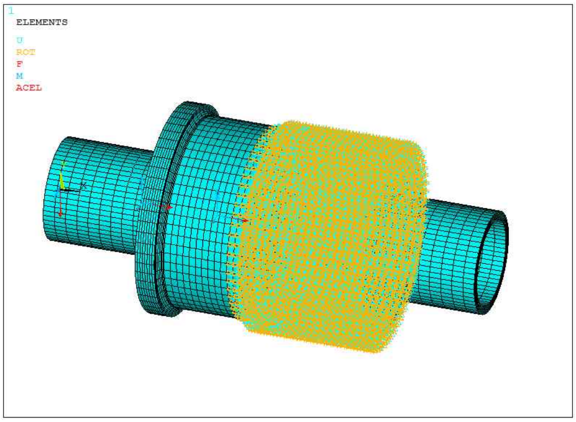


Fig. 2 Boundary conditions image of piping penetration

Table 2 Piping Loads

Loading conditions	Normal (A)	Upset (B)	Emergency (C)	Faulted (D)
Fx(kgf)	824	420	1612	1691
Fy(kgf)	350	291	555	600
Fz(kgf)	1737	332	3362	3407
Mx(kgf)	639	136	1287	1286
My(kgf)	1707	352	3431	3536
Mz(kgf)	624	359	1205	1233

Table 3 System Criteria

Loading conditions	General membrane (PM)	Local membrane + Secondary(PL+PB)
Nornal (A)	Sm	1.5Sm
Upset (B)	1.1Sm	1.65Sm
Emergency (C)	Larger of 1.2Sm or Sy	Larger of 1.8Sm or 1.5Sy
Faulted (D)	Larger of 0.7Su or Sy+(Su-Sy)/3	Larger of 1.05Su or 1.5Sy+(Su-Sy)/2

by translational (UX, UY, UZ) and rotational (ROTX, ROTY, ROTZ) constraints for the boundary conditions in the numerical analysis.

2.2 Piping loads

The piping stress analysis describes loads due to thermal expansion, dead weight, thermal transients and earthquake, etc. on a seal plate that has been modeled as an anchor. If the line continues to the other side of the anchor and becomes a part of another piping system, the anchor loads from the second system must be combined with the first set of loads in the appropriate manner. This gives us resultant loads on the anchor due to thermal expansion of piping, deadweight and earthquake, etc. These loads, then, should be lumped together to give the worst possible combination of loads on the anchor. Normally, the design load, thus obtained, will consist of three moments and three forces referred to as a Cartesian coordinate system. The x-axis is from centerline of a component to the pipe, the y-axis is perpendicular to the x-axis in the vertical plane positive upward and the z-axis is perpendicular to the x-axis in the horizontal plane to form a right hand coordinate system. The piping loads are shown in Table 2. The piping loads in Table 2 are maximum absolute values of each condition. However, if the designed thickness of the seal plate is abnormally high, or if the designer finds it difficult to meet the Code allowable stress values, the seismic loads can be considered separately. In that case, stresses due to seismic loads only satisfy the requirements of Subsection NE of ASME Section III.

2.3 Stress evaluations

The general membrane stress intensities (P_M) and the local membrane plus bending stress intensities (P_L+P_B) are linearized at the maximum stress location using the ANSYS postprocessor "POST1". The results are summarized below at the location shown in Fig.

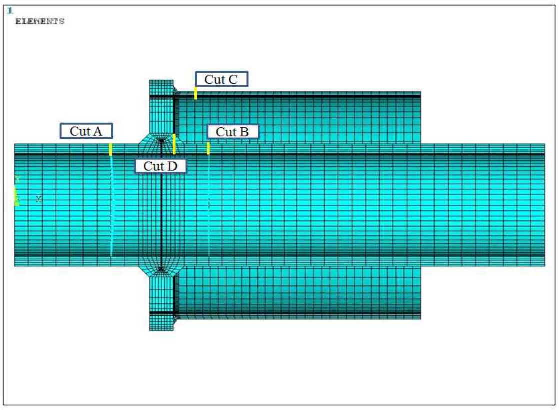
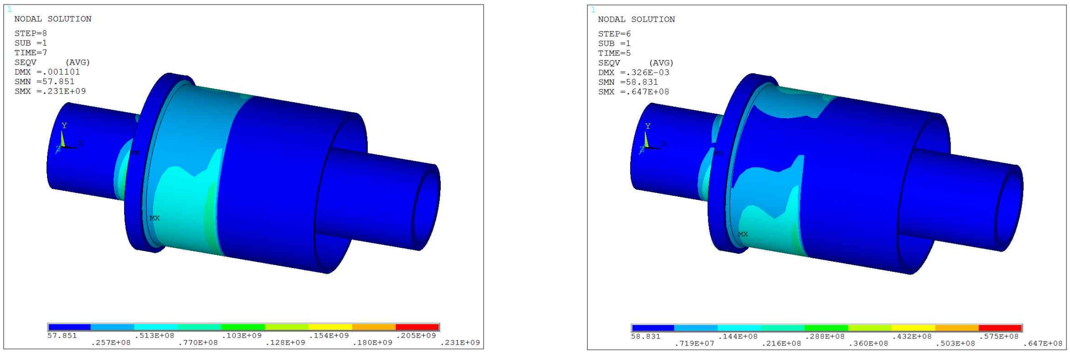


Fig. 3 Cutting locations of piping penetration

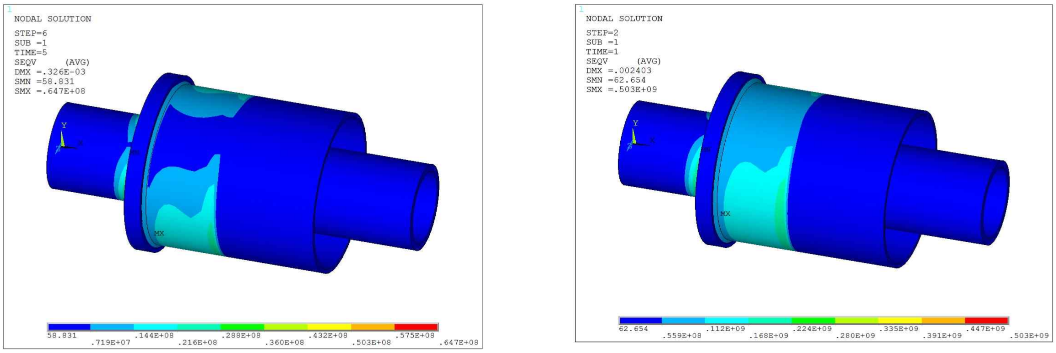
Table 4 Stress evaluation of normal event

Cut	Max. stress location		Calculated stress (MPa)	Allowable stress(MPa)
A	P_M		9.026	140.3
	P_L+P_b	Inside	6.065	210.5
		Outside	12.27	
B	P_M		34.10	140.3
	P_L+P_b	Inside	37.47	210.5
		Outside	31.28	
C	P_M		43.27	140.3
	P_L+P_b	Inside	40.76	210.5
		Outside	45.85	
D	P_M		58.94	140.3
	P_L+P_b	Inside	31.70	210.5
		Outside	111.0	



(a) Normal event

(b) Upset event



(c) Emergency event

(d) Faulted event

Fig. 4 Stress distributions

Table 5 Stress evaluation of upset event

Cut	Max. stress location		Calculated stress (MPa)	Allowable stress (MPa)
A	P_M		5.003	140.3
	P_L+P_b	Inside	3.517	210.5
		Outside	6.535	
B	P_M		9.676	140.3
	P_L+P_b	Inside	9.148	210.5
		Outside	10.64	
C	P_M		13.98	140.3
	P_L+P_b	Inside	12.49	210.5
		Outside	15.50	
D	P_M		14.81	140.3
	P_L+P_b	Inside	18.87	210.5
		Outside	25.58	

Table 6 Stress evaluation of emergency event

Cut	Max. stress location		Calculated stress (MPa)	Allowable stress (MPa)
A	P_M		18.57	140.3
	P_L+P_b	Inside	12.49	210.5
		Outside	25.30	
B	P_M		71.73	140.3
	P_L+P_b	Inside	79.18	210.5
		Outside	65.35	
C	P_M		89.92	140.3
	P_L+P_b	Inside	84.73	210.5
		Outside	95.25	
D	P_M		106.2	140.3
	P_L+P_b	Inside	71.68	210.5
		Outside	197.5	

3. The stress distributions are presented in Fig. 4 through Fig. 7, and the stress evaluations are linearized at each cut as shown in Table 4 through Table 7.

2.4 Fatigue analysis

The stress concentration factor is applied to the linearized stresses at appropriate locations, that is cut A, B, C and D outside. The cumulative fatigue usage factor (U) is calculated at both sides of each cut as required by ASME Code Sec. III. The fatigue analysis procedure is described by the following steps and is shown in Fig. 5. Step 1: Repeated the number of times of each form of stress cycles, n1, n2, ⋯ nn. Step 2: The alternative stress intensity, Salt1,Salt2,⋯,

Table 7 Stress evaluation of faulted event

Cut	Max. stress location		Calculated stress (MPa)	Allowable stress (MPa)
A	P_M		18.57	140.3
	P_L+P_b	Inside	12.67	210.5
		Outside	25.32	
B	P_M		72.97	140.3
	P_L+P_b	Inside	80.60	210.5
		Outside	66.43	
C	P_M		90.41	140.3
	P_L+P_b	Inside	85.10	210.5
		Outside	95.87	
D	P_M		108.7	140.3
	P_L+P_b	Inside	73.43	210.5
		Outside	202.7	

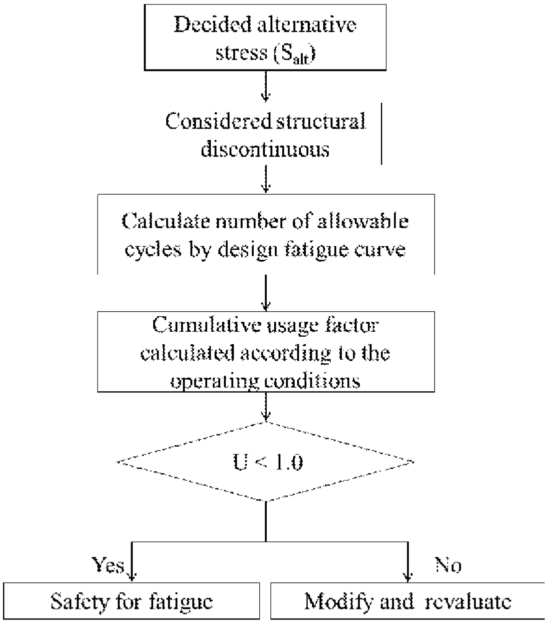


Fig. 5 Fatigue analysis procedures

Table 8 Stress evaluation of faulted event

Cut	Node No.	Cumulative usage factor			
		Normal	Upset	Emergency	Faulted
A	32295	0.00110	0.00225	0.00002	0.00003
	32087	0.00110	0.00225	0.00002	0.00004
B	34658	0.00175	0.00225	0.00006	0.00009
	34450	0.00153	0.00225	0.00005	0.00007
C	18784	0.00189	0.00225	0.00006	0.00009
	16832	0.00206	0.00225	0.00007	0.00010
D	905	0.00205	0.00259	0.00007	0.00010
	34047	0.00405	0.00298	0.00013	0.00020

Saltn for each stress cycle form calculated as in the procedure above. Step 3: (N1,N2,...,Nn) the maximum allowable number of iterations for Salt1, Salt2, ⋯, Saltn using the appropriate design fatigue curves. Step 4: Usage factors,

$$\left(u_1 = \left(\frac{n_1}{N_1}\right), u_2 = \left(\frac{n_2}{N_2}\right), \ldots, u_n = \left(\frac{n_n}{N_n}\right)\right)$$

are obtained from each stress cycle form. Step 5: The cumulative usage factor U calculated with the following formula.

$$U = \sum_{S_{alt}} (n/N) < 1.0 \tag{1}$$

n : Design lifetime occurrence for Salt
N : Allowable occurrence
Salt : Alternative Stress Intensity (Salt=(1/2)αSp)
Sp : Range of Peak Stress Intensity
α : The ratio of the modulus of elasticity defined by NB-3219

The number of occurrences is shown in Table 1. The cumulative fatigue usage factors are shown in Table 8. A summary of the cumulative fatigue usage factors is given below:

3. Conclusion

The general membrane stress intensities and local membrane plus bending stress intensities at the structural evaluation do not exceed the allowable values for all conditions, and the cumulative usage factors do not exceed unity 1.0. Therefore, all structural and fatigue requirements were satisfied.

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