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A STUDY ON THE SEISMIC ANALYSIS METHOD FOR INTERFACE PIPING SYSTEM MULTI-SUPPORTED BETWEEN BASE-ISOLATED BUILDING AND NON-ISOLATED BUILDING

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ABSTRACT

A study on the application of seismic isolation system has been widely researched in order to increase the seismic safety of SSCs (Structures, Systems, and Components) for nuclear power plant (NPP). In the design of base isolated NPPs, the seismic analysis of interface piping system multi-supported between base-isolated building and non-isolated building is one of the key issues. The main steam supply piping connected to the high pressure (HP) turbine of APR1400 (1400 MW-class advanced nuclear power plant in Korea) is a typical example of interface piping system multi-supported between base-isolated building and non-isolated building, and it is routed from the Containment building (base-isolated building) to the Turbine building (non-isolated building) via the Main Steam Isolation Valve House in the Auxiliary building (base-isolated building). In the seismic analysis of this piping system based on seismic inputs developed from the study for application of base isolation system to APR1400, using the Enveloped Response Spectrum (ERS) method, a commonly used methodology for seismic analysis of piping systems in the nuclear industry, generates overly conservative analysis results. This paper performs parametric research on combination effects of responses between support groups, damping effects and modal combination method with close modes in applying the Multiple Input Response Spectrum (Independent Support Motion : ISM) method to the analysis model of the main steam interface piping. Quantitative assessment and comparison with the analysis results of the ERS method and Time History Method (THM) are also carried out. As a result, it is shown that the analysis results of the ISM method together with the SRSS combination between support groups, 4% damping with ±15% spectrum peak broadening and modal response combination methods considering the contribution of closely spaced modes are remarkably similar to those of THM.

INTRODUCTION

An application of seismic isolation system to nuclear power plant (NPP) is not only to improve the seismic safety of SSCs (Structures, Systems, and Components) for NPP but also to resolve the issue about its site-unique seismic characteristics. Consequently, the Korea nuclear industry has conducted the study on the application of seismic isolation system to APR1400 (1400 MW-class advanced nuclear power plant in Korea). In the design of base isolated NPPs, the seismic analysis of interface piping system multi-supported between base-isolated building and non-isolated building is one of the key issues. During an earthquake, an interface piping system is prone to deform due to the large relative displacements between base-isolated building and non-isolated building, and at the same time it is apt to be excited by the two buildings with different vibration characteristics. For the seismic design of interface piping system, special consideration must be given to its rigidity to withstand the force of the inertia response generated by excitations from base-isolated building and non-isolated building but also to its flexibility to cope with the large relative displacements between two buildings. Applying the ERS method, a commonly used methodology for seismic analysis of piping systems in the nuclear industry, to the seismic analysis of interface piping system generates overly conservative analysis results. It is because all of the response spectra exciting each support location of the piping system at different elevations in the base-isolated building and non-isolated building are enveloped into one spectrum in each direction. Therefore, the nuclear industry has been studying the multiple input analysis method such as Multiple Input Response Spectrum (Independent Support Motion: ISM) method and THM in order not only to eliminate unnecessary conservatism but also to get the analysis result with mathematic logicality [1, 2, 3, 4, 8, 11]. THM provides the most mathematically accurate and realistic results because it is possible to consider excitation characteristics of individual support. However, THM has a limitation to use common analysis method because it requires considerable amount of manpower and time in the perspective of applicability. In spite of numerous study results that the ISM method provides the mathematic logicality and preferable applicability to resolve this issue, commonly agreed guidelines for the consistent and general use of the ISM method in the nuclear industry have not been proposed yet. The nuclear industry and USNRC have held different positions in applying the ISM method to combination effects of responses between support groups, damping effects between PVRC and 4% damping per RG (Regulatory Guide) 1.61, and closely spaced modes effects. USNRC Piping Review Committee still demands additional verification to secure reliability of analysis results based on the PVRC damping (ASME Code Case N411-1) and combination of SRSS between support groups in applying the ISM method through NUREG-1061, Vol.4 and Standard Review Plan [9]. And it recommends RG 1.61 damping and absolute sum (ABS) combination of support groups. But there are some exceptions of USNRC's conceding the application of PVRC damping and ABS combination of support groups for Limerick Unit 2, South Texas Units 1&2 and Vogtle Units 1&2 and the application of RG 1.61 damping and SRSS combination of support groups for San Onofre. It is determined based on quantitative assessment and comparison with the analysis results of the ERS method and THM method for some specific power plants [10].

In order to commonly use ISM method as seismic analysis method of interface piping system, using the seismic inputs developed from the study for the application of base isolation system to APR1400, this paper performs parametric research on the combination effects of responses between support groups, damping effects and modal combination method with close modes in applying the ISM method to the analysis model of the main steam interface piping multi-supported between base-isolated building and non-isolated building. Quantitative assessment and comparison with the analysis results of the ERS method and Time History Method (THM) are also carried out.

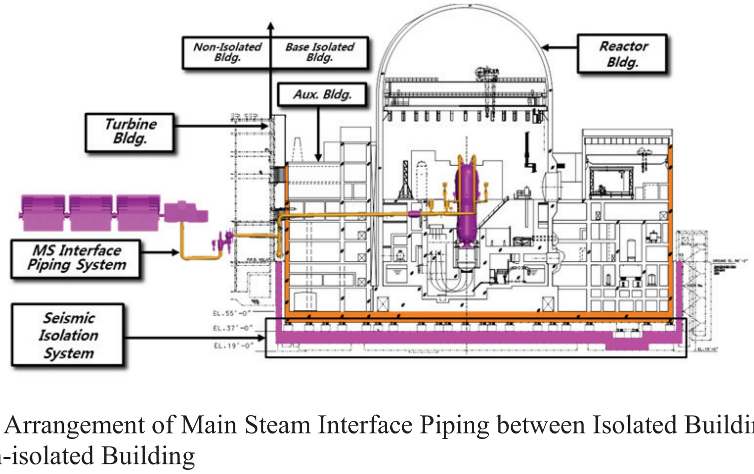


Figure 1. General Arrangement of Main Steam Interface Piping between Isolated Building and Non-isolated Building

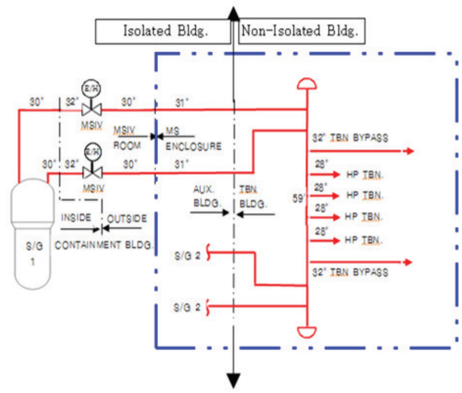


Figure 2. Subsystem Boundary of Main Steam Interface Piping

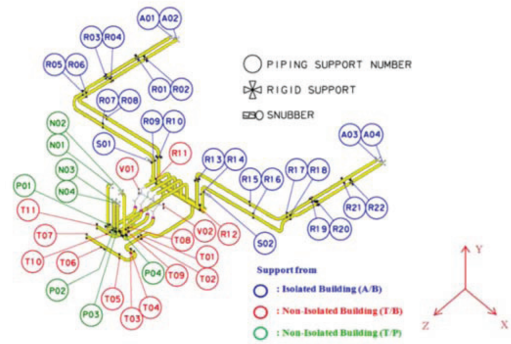


Figure 3. Analytical Model for Main Steam Interface Piping Subsystem III

DESCRIPTION OF INTERFACE PIPING SUBSYSTEM

In the study for the application of seismic isolation system to APR1400, the main steam interface piping passes through the Main Steam Isolation Valve (MSIV) room and main steam enclosure in the Auxiliary building (base-isolated building), and it is connected to the steam supply nozzle of the HP turbine in the Turbine building (non-isolated building) as shown in Figure 1. It is, however, divided into the three piping subsystems for the purpose of piping analysis, and the boundary of the piping subsystem is illustrated in Figure 2 [5]. The first piping subsystem (Subsystem I in Figure 2) in the Containment building (base-isolated building) starts from the steam generator nozzle and ends at the flued-head penetration anchor in the Containment building. The second piping subsystem (Subsystem II in Figure 2) in the MSIV room starts from the flued-head penetration anchor in the Containment building and ends at the flued-head penetration anchor in the MSIV room. Subsystems I and II are classified as seismic category I piping. The third piping subsystem (Subsystem III in Figure 2) inside the dashed line in Figure 2 starts from the flued-head penetration anchor in the exterior wall of the MSIV room, passes through the main steam enclosure in the Auxiliary building (base-isolated building) and the turbine pedestal structure in the Turbine building, and ends at the steam supply nozzle of the HP turbine in Turbine building (non-isolated building).

Especially, Subsystem III is a typical example of multi-supported piping subsystems which is reviewed in this paper. The piping in Subsystem III is classified as non-safety related, but defined as seismic category II for the piping portion in the main steam enclosure area and seismic category III in the Turbine building. Moreover, the piping portion of Subsystem III in the Auxiliary building needs to be designed to eliminate the postulation of intermediate break in order to protect the Auxiliary building from the pipe whip loads. To eliminate the postulation of intermediate breaks on this piping, the piping stresses caused by deadweight, thermal expansion, and operating basis earthquake (OBE) must be less than 80% of the Code specified allowable.

DESCRIPTION OF ANALYTICAL PIPING AND SUPPORT MODEL

Figure 3 shows the analytical piping model of main steam interface piping. Supports A01 thru A04 (flued-head type penetration sleeves attached to the exterior wall of the MSIV room in the Auxiliary building) and N01 thru N04 (HP turbine nozzles) are modeled as anchors (six degrees-of-freedom restrained). Supports S01 and S02 (snubbers), V01 and V02 (turbine stop valves supports), R01 thru R22 (struts), P01 thru P04 (supports installed on the turbine pedestals) are modeled as rigid restraint which are laterally and/or longitudinally restrained. Supports T01 thru T11 are designed for seismic load to separate turbine bypass piping from the subsystem according to the 3-restraint rule. Table 1 shows support information such as their identifications, locations for installation and applied response spectral group.

Table 1. Support Information for Analytical Model

Support ID	Support Location		Spectral Group	Support ID	Support Location		Spectral Group
	Building	Elevation			Building	Elevation	
R07,R15	Aux.	150‘	A-1	R11,R12	Turbine	118‘	T-1
A01,A02,A03,A04	Aux.	142‘	A-1	V01,V02	Turbine	136‘	T-1
R01,R02,R03,R04	Aux.	138‘	A-2	T01,T08	Turbine	98‘	T-2
R19,R20,R21,R22	Aux.	138‘	A-2	T02,T09	Turbine	97‘	T-2
R05,R06,R17,R18	Aux.	138‘	A-2	T03,T05,T07,T11	Turbine	96‘	T-2
R08,R16	Aux.	138‘	A-2	T06	Turbine	93‘	T-2
R10,R13	Aux.	132‘	A-2	T04,T10	Turbine	93‘	T-2
R09	Aux.	124‘	A-3	N01,N02	Pedestal	149‘	P-1
R14	Aux.	123‘	A-3	N03,N04	Pedestal	136‘	P-1
S01,S02	Aux.	122‘	A-3	P01,P02,P03,P04	Pedestal	107‘	P-2

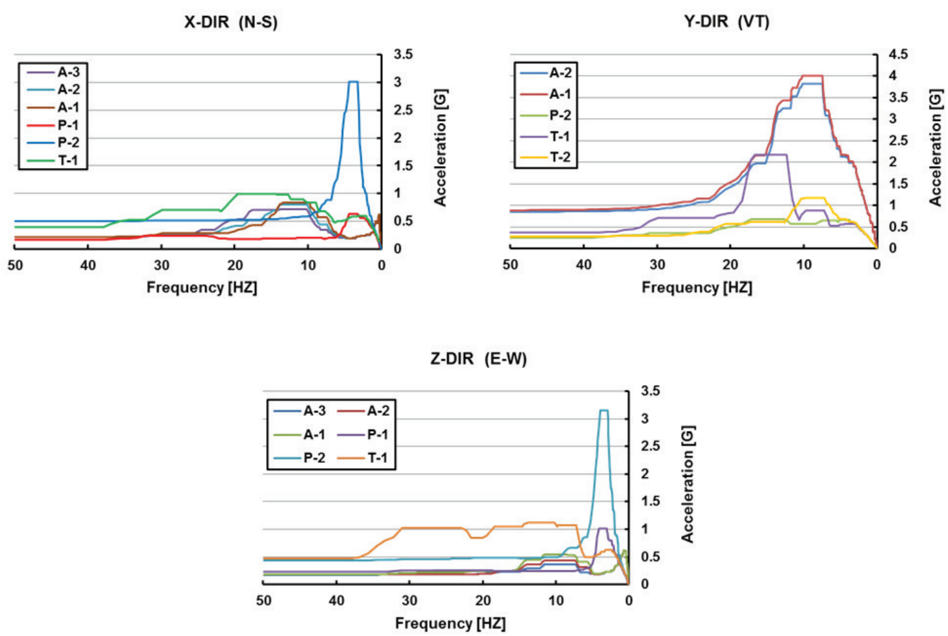


Figure 4. Acceleration Response Spectra of Supports attached to A/B and T/B

DESCRIPTION OF SEISMIC INPUT DATA

Figure 4 shows acceleration response spectra of supports attached to A/B (Auxiliary building) and T/B (Turbine building) listed in Table 1. Input acceleration response spectra are SSE spectra with ±15% peak broadening to comply with Appendix N, Section N-1226.3(d) of 2007 edition of ASME Boiler and Pressure Vessel Code with 2008 addenda and with Section C.2 of USNRC Regulatory Guide 1-122.

Figures 5 and 6 show acceleration time history at anchor points (node A01 and node N01) in A/B and T/B, respectively. From the Figure 4 through Figure 6, it is confirmed that the seismic isolation system applied to APR1400 can reduce seismic force in the only horizontal direction.

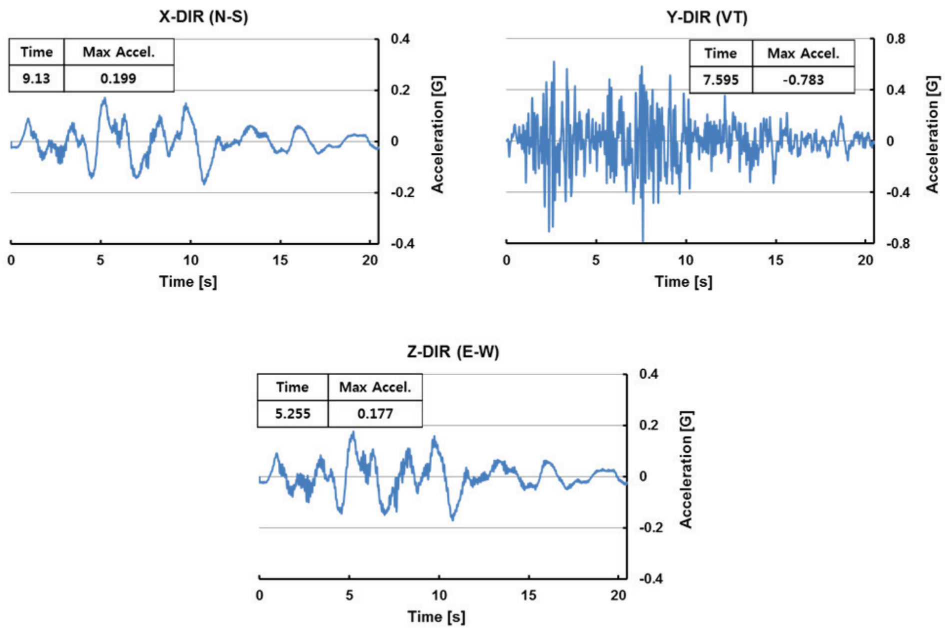


Figure 5. Acceleration Time History at A/B anchor point (Node A01)

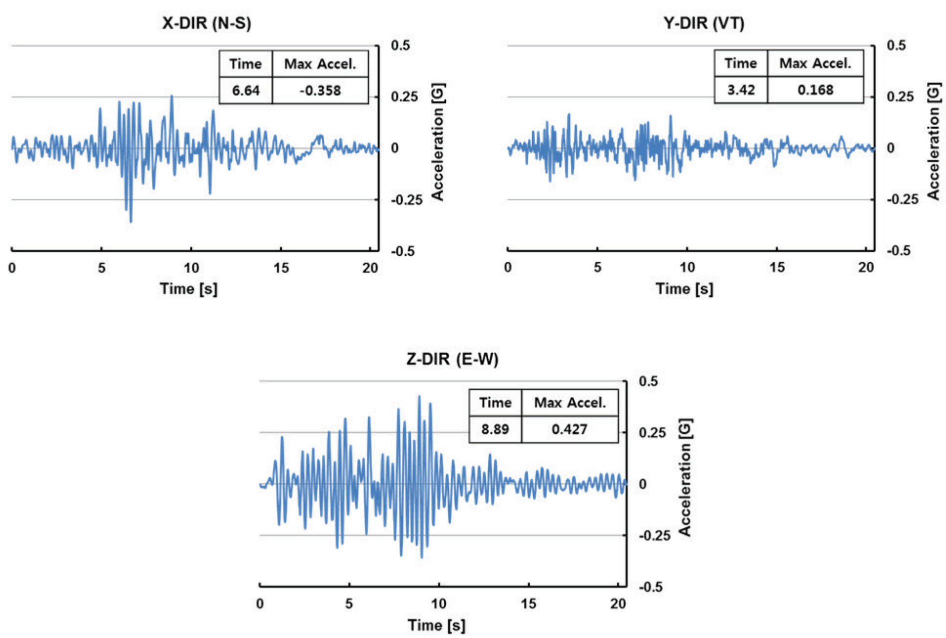


Figure 6. Acceleration Time History at T/B anchor point (Node N01)

PARAMETRIC STUDIES OF THE MULTIPLE INPUT RESPONSE SPECTRUM METHOD

Piping System Damping and Response Combination Between Support Groups

In applying the Multiple Input Response Spectrum (Independent Support Motion: ISM) method to piping seismic analysis, Piping system damping and combination method of responses between support groups are the major factors affecting directly on the ISM analysis results of the piping system. Therefore, it is necessary not only to perform parametric research on SRSS and ABS combination effects of response between support groups and damping effects between PVRC and 4% damping per RG (Regulatory Guide) 1.61 in applying the ISM method to the main steam interface piping but also to fulfill the quantitative comparison and assessment with analysis result of ERS method and THM method to assure the adequacy of the ISM method applied to the main steam interface piping. Six combination cases are studied as shown in Table 2 to evaluate the effects of combination between groups, damping values and ISM or ERS response spectrum (RS) analysis method [6]. Time history analysis based on the information of support locations shown in Table 1 is added in this study. The results of the THM are used as a baseline for the comparison with the six combination cases. To consider the effect of the time step variation due to the uncertainty by the approximation of modeling and material characteristics of structures, with the notion of time history broadening, as stated in the 2007 ASME BPVC Code, Appendix N, paragraph N-1222.3, time history of each piping support used in THM is applied to the piping subsystem using the ±15% time step variation [0.00425(-15% time step shift), 0.005(building time step) and 0.00575(+15% time step shift)]. Figure 7 depicts time history broadening with ±15% time step variation. Table 3 shows analysis combination for time history analysis of the main steam interface piping to comply with the concept of time history broadening. The response spectrum analyses for the six different combination groups and the time history analysis using the modal superposition are performed by PIPESTRESS [7], a commercial piping stress analysis program. For an effective review on analysis results, three response locations such as snubber support (S01, S02), valve body support (V01, V02) and A/B anchor points (A01, A02, A03, A04) are selected, and all responses of each analysis case shown in Table 2 are compared with those of the most conservative analysis case (TH) among analysis cases for time history analysis shown in Table 3.

Table 2. Combination between Groups and Damping for Response Spectrum Analysis

Analysis Case	Damping	Combination Between Groups	Analysis Method
H-1	4%	ABS	ISM
H-2	PVRC	ABS	ISM
H-3	4%	SRSS	ISM
H-4	PVRC	SRSS	ISM
H-5	4%	-	ERS
H-6	PVRC	-	ERS

Figure 8 presents comparison ratios of responses on support S01, S02, V01 and V02 for all six combination cases to those of the most conservative analysis case (TH) among time history analysis. Figure 9 compares responses on A/B anchor point A01 for all six combination cases with those of analysis case TH. Also, piping stresses on A/B anchor points (A01, A02, A03, A04) for H-1 thru H-6 are compared with those for analysis case TH as shown in Figure 10. The results of analyzing Figure 8 through Figure 10 show that H-3 analysis case which performs ISM analysis by applying 4% damping and SRSS combination between support groups, provides the response results which are the closest to the response results of analysis case TH. Analysis cases (H-3 and H-4) which perform ISM analysis using SRSS combination between support groups generate much lower responses than analysis cases (H-1 and H-2) which perform ISM analysis using ABS combination between support groups. Analysis cases (H-1, H-3 and H-5) using 4% damping generate slightly lower responses than analysis cases (H-2, H-4 and H-6) using frequency dependant PVRC damping. Therefore, it is confirmed that ISM with SRSS combination between groups and 4% damping provides the closest response to time history analysis, and reduces the conservatism as well. Also damping effects between PVRC and 4% damping per RG (Regulatory Guide) 1.61 are not significant in the seismic analysis of the main steam interface piping.

However, specifically, responses on A/B anchor points for analysis cases (H-1 and H-2) with ISM analysis using ABS combination between support groups reveal more conservative results than those for analysis cases (H-5 and H-6) using ERS as shown in Figure 9, 10. This contradicts to the fact that ISM has been developed to reduce the unnecessary conservatism of ERS for seismic response analysis of structural systems subjected to multiple support excitations.

Table 3. Combination for Time History Analyses

Analysis Case	A/B Δt [s]	A/B % Broadening	T/B Δt [s]	T/B % Broadening
1	0.005	0	0.005	0
2	0.00425	(-)15	0.005	0
3	0.00575	(+)15	0.005	0
4	0.005	0	0.00425	(-)15
5	0.00425	(-)15	0.00425	(-)15
6	0.00575	(+)15	0.00425	(-)15
7	0.005	0	0.00575	(+)15
8	0.00425	(-)15	0.00575	(+)15
9	0.00575	(+)15	0.00575	(+)15

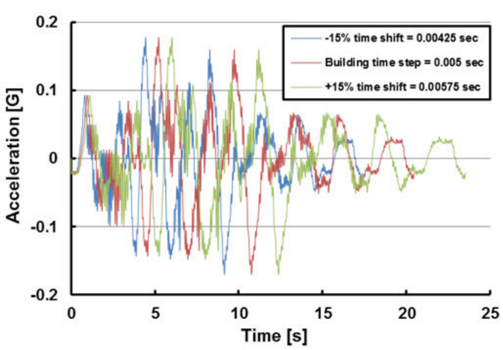


Figure 7. Time History Broadening

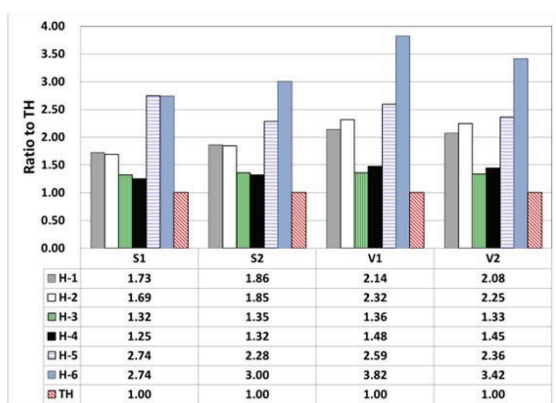
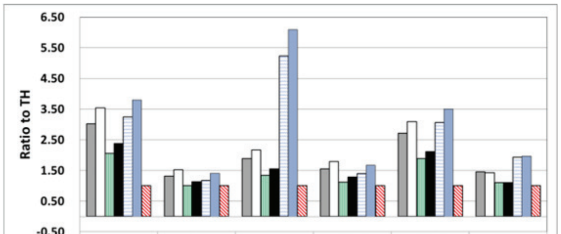
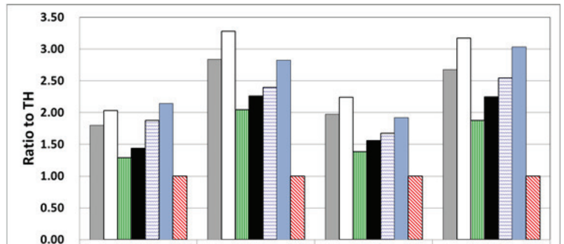


Figure 8. Comparison of Support Loads per Combination Case



	FX	FY	FZ	MX	MY	MZ
H-1	3.02	1.32	1.90	1.56	2.72	1.46
H-2	3.54	1.53	2.18	1.79	3.09	1.42
H-3	2.05	1.00	1.34	1.12	1.88	1.11
H-4	2.39	1.14	1.56	1.28	2.11	1.10
H-5	3.24	1.17	5.23	1.39	3.06	1.93
H-6	3.80	1.41	6.09	1.67	3.51	1.97
TH	1.00	1.00	1.00	1.00	1.00	1.00

Figure 9. Comparison of Loads at A/B Anchor Point(A01) per Combination Case



	A01	A02	A03	A04
H-1	1.80	2.84	1.98	2.67
H-2	2.03	3.28	2.24	3.17
H-3	1.29	2.04	1.39	1.87
H-4	1.44	2.26	1.56	2.25
H-5	1.87	2.39	1.67	2.54
H-6	2.15	2.82	1.92	3.04
TH	1.00	1.00	1.00	1.00

Figure 10. Comparison of Pipe Stresses at A/B Anchor Points(A01~A04) per Combination Case

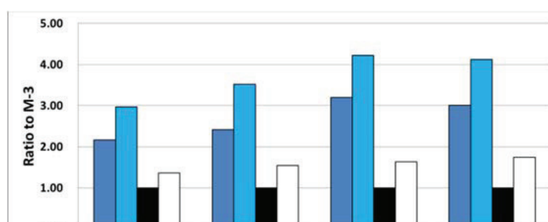
Effect of Closely Spaced Modes

In response spectrum modal dynamic analysis, two consecutive flexible modes are defined as closely spaced if their frequencies are differed each other by 10 percent or less of the lower frequency. If there are some closely spaced modes in flexible modes, modal combination by algebraic summation may give too conservative results. Regulatory Guide 1.92 regulates by adding several modal response combination methods to reflect the effect of closely spaced modes. Mode analysis is performed to verify the existence of closely spaced mode in the main steam interface piping subsystem, and the result confirms that a lot of closely spaced modes exist. As a further comparison of various combination studies, four combination cases are considered as shown in Table 4 based on with and without contribution of closely spaced modes [6]. Analyses are performed respectively using SRSS method for without contribution of closely spaced modes and grouping method for with contribution of closely spaced modes.

Figure 11 presents comparison ratios of responses of supporting loads on nodes of S01, S02, V01 and V02 for four analysis cases to those for case M-3. In Figure 11, M-2 analysis case using ERS with 4% damping and Grouping of flexible modes shows the highest responses. In other hand, M-3 analysis case using ISM with PVRC damping, SRSS combination between groups and SRSS of flexible modes shows the lowest responses. Specifically, Grouping combination (M-2, M-4) shows more conservative results by 1.36~1.75 times than SRSS combination modes (M-1, M-3) if other combinations such as support grouping method and damping are assumed as being equal in Response spectrum analyses. This means that the effect of closely spaced modes is somewhat significant for the seismic analysis of main steam interface piping subsystem.

Table 4. Consideration of Closely Spaced Modes

Analysis Case	Damping	Response Spectrum Analysis	Combination Flexible Modes
M-1	4%	ERS	SRSS
M-2	4%	ERS	Grouping
M-3	PVRC	ISM	SRSS
M-4	PVRC	ISM	Grouping



	S1	S2	V1	V2
M-1	2.17	2.42	3.20	3.01
M-2	2.97	3.52	4.22	4.12
M-3	1.00	1.00	1.00	1.00
M-4	1.36	1.54	1.63	1.75

Figure 11. Comparison of Support Load per Combination Case

CONCLUSIONS

For the application of the Multiple Input Response Spectrum (Independent Support Motion: ISM) method to seismic analysis of the main steam interface piping system multi-supported between Auxiliary building (base-isolated building) and Turbine building (non-isolated building), the following conclusions are obtained by parametric study:

1) ISM method is effective and accurate method for seismic analysis because it reduces unnecessary conservatism of ERS analysis method and provides the closest response to the analysis results of THM method.
2) Damping effects between PVRC damping (ASME Code Case N411-1) and 4% damping per RG (Regulatory Guide) 1.61 are not significant in the seismic analysis of the main steam interface piping.
3) If there are some closely spaced modes in flexible modes, ISM method with modal response combination methods considering the contribution of closely spaced modes must be used for combination of flexible modes.
4) ISM method with 4% damping and SRSS combination between support groups provides the best results which are closer to the results of THM method than 4% damping and ABS combination recommended by USNRC because the latter shows so conservative responses that overly excessive design could be anticipated.

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