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Modal analysis of main steam line piping under high energy line break condition

Tae-Jin Kim [a], Seung Hyun Kim [a], Sang-Yun Je [a] and Yoon-Suk Chang [a*]
[a]*Dept. of Nuclear Engineering, Kyung Hee University, 1732 Deokyoungdae-ro, Yongin, Kyunggi, 17104, Korea*
[*]*Corresponding author: yschang@khu.ac.kr*

1. Introduction

If HELB (High Energy Line Break) occurs in NPPs (Nuclear Power Plants), not only environmental effect like release of radioactive material but also secondary structural defects should be considered. Jet impingement phenomenon caused by sudden pipe rupture may lead to severe damage on neighboring safe-related components and other structure. Thereby, understanding the dynamic characteristics of SG (Steam Generator) and MSL (Main Steam Line) piping is important when analyzing the design basis accidents.

Lots of studies have been conducted to assess dynamic behaviors of the SG and MSL piping [1] while pipe whip restraints and jet impingement shields are taken into account during design stage. Arroyo *et al.* [2] performed modal analyses of a simple square component to examine the jet impingement phenomenon. Also, structural characteristics were predicted to assure structural integrity against the HELB [3, 4].

In this study, we examined dynamic characteristics of SG and MSL piping in a typical 1000MWe NPP. Simulation was performed by using two commercial computational softwares [5, 6]. In particular, modal analyses were conducted to determine mode shapes and natural frequencies of the structure and maximum displacements. The data obtain from each software were compared and observation was discussed in relation to the jet impingement phenomenon.

2. Analysis Methods

2.1 Analysis model

Fig. 1 represents a representative combined FE (Finite Element) model of the SG and MSL piping used for structural analyses. The relevant information such as element type, mesh and material behavior is summarized in Table I.

Table I: FE models information of the SG and MSL piping

	Element type	No. of elements	No. of nodes	Material behavior
Code-A	Hughes -Liu	22,413	27,820	Bi-linear plastic
Code-B	Solid 187	22,069	44,030	

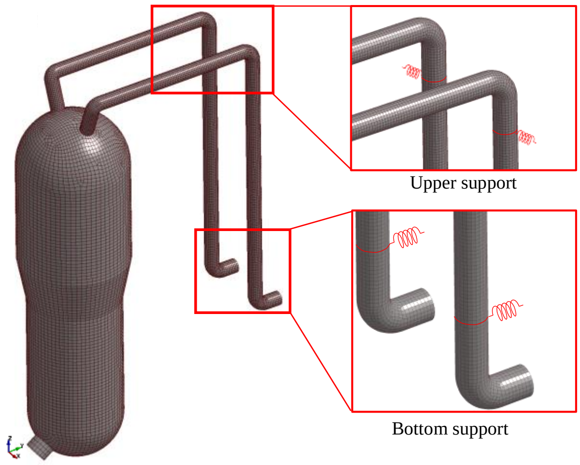


Fig. 1. Combined FE model of the SG and MSL piping.

2.2 Analysis condition

As boundary conditions, bottom side of the SG was fixed according to local coordinate system so that the DOFs (Degree Of Freedoms) along the vertical direction were restrained. Also, since each MSL piping was supported by two supports, x- and y-directional spring stiffness values were assigned [1]. All the boundary conditions for modal analysis were equally applied to the FE models developed by different softwares.

2.3 Modal analysis

Modal analyses were carried out to investigate dynamic characteristics of the structures. The Block-Lanczos method was employed to resolve large symmetric eigenvalue problems.

The generalized eigenvalue problem for modal analysis can be solved by

$$[\mathrm{M}]\{\ddot{U}\} + [\mathrm{C}]\{\dot{U}\} + [\mathrm{K}]\{U\} = \{P(t)\} \qquad (1)$$

where, $[\mathrm{M}]$ is the mass matrix, $[\mathrm{C}]$ is the damping matrix and $[\mathrm{K}]$ is the stiffness matrix of the structures. Also, $\{U\}$ is the displacement vector, $\{\dot{U}\}$ is the velocity vector and $\{\ddot{U}\}$ is the acceleration vector of each node. $\{P(t)\}$ is the applied force vector. Through equation (1), we can get a dynamic equilibrium equation:

$$[\mathrm{M}]\{\ddot{U}\} + [\mathrm{K}]\{\mathrm{U}\} = 0 \qquad (2)$$

Also, by taking $[\mathrm{U}(\mathrm{t})] = \{\phi\}\sin\omega t$, the following differential equation is derived.

$$([\mathrm{K}] - \omega^2[M])\{\Phi\} = 0 \qquad (3)$$

Subsequently, natural frequencies of the structures $\omega_i (i = 1, 2, \cdots, N)$ and the mode shape function $\{\Phi_i\}(i = 1, 2, \cdots, N)$ can be obtained from equation (3). The Material considered in this modal analysis is SA508 Gr.3 and its properties are summarized in table II.

Table II: Material property used in dynamic analysis

Material	Elastic modulus (GPa)	Poisson's ratio	Yield strength (MPa)	Density (kg/m^3)
SG and MSL piping	183.08	0.3	303.36	7,830

3. Analysis Results and Discussion

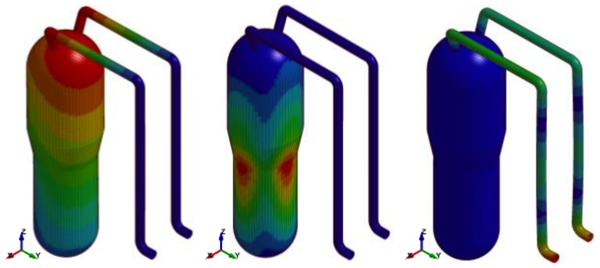
Natural frequencies of the SG and MSL piping were predicted as shown in table III. The difference between two models at the first mod was 7% approximately.

Table III: Summary of representative modal analysis results

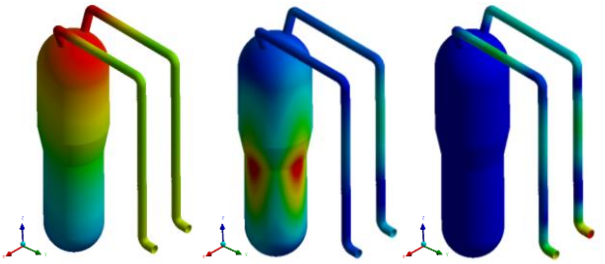
Mode	Frequency (Hz)		Max. resultant displacement (mm)	
	Code-A	Code-B	Code-A	Code-B
1	1.68	1.69	142.4	138.5
2	2.20	2.30	142.1	139.1
3	6.14	6.86	177.1	175.5
4	6.18	6.92	141.6	142.6
5	7.72	7.83	145.0	144.4
6	10.35	11.02	143.7	135.8
7	10.42	11.15	161.2	155.5
8	11.32	12.81	152.8	151.5
9	12.43	12.84	127.6	122.5
10	13.04	12.86	128.0	124.7

Fig. 2 compares typical mode shapes of the SG and MSL piping. As depicted in the figures, y-directional bending mode shapes appear at the first mode. The maximum resultant displacements and the difference between two models was less than 1% at the third mode.

The FE model and modal analysis technique will be used as technical bases for further dynamic research such as power-spectrum density analysis and random response analysis under HELB conditions with the jet impingement phenomenon.



(a) Mode #1 (b) Mode #3 (c) Mode #6



(d) Mode #1 (e) Mode #3 (f) Mode #6

Fig. 2. Dynamic mode shapes of the SG and MSL piping with Code-A [(a) - (c)] and Code-B [(d) - (f)].

4. Conclusions

In this research, modal analyses on the SG and MSL piping were carried out to get natural frequencies, vibration mode shapes and maximum displacements. Thereby, the following key finding was observed.

(1) Maximum displacement was calculated at the top of SG outlet nozzle with y-directional bending at the third mode.

(2) The differences between two models were respectively 7% in natural frequencies and less than 1% in maximum displacements.

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