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RESULTS OF A NONLINEAR GAPPED SUPPORT ANALYSIS ON A PIPING SYSTEM IN A BASE ISOLATED PLANT

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ABSTRACT

A novel concept for nuclear power plants in high seismic regions is to provide base isolation for the nuclear island. Nuclear power plants designed as base isolated plants face many difficult design problems. The Nuclear Island (containment building and auxiliary building) are base isolated while the balance of the plant is not. As a result, the piping systems that initiate in the nuclear island and terminate in adjacent buildings are subjected to extremely high relative seismic anchor displacements at the building boundaries. In this case, classic linear elastic design methods may result in extremely complex and overly conservative design solutions. One possible solution to this issue for some systems is the use of gapped supports. These can be utilized in order to simplify the design and reduce overall complexity. This paper details the design process and resulting benefits of utilizing a minimal amount of gapped supports in order to dampen safe shutdown earthquake (SSE) seismic anchor motions for a main steam line of a base isolated nuclear power plant. The analysed piping line initiates in the auxiliary building and terminates in the turbine building, crossing over the boundary between the base isolated part of the plant and the non-base isolated part of the plant. Utilizing the ANSYS software program, results of an analysis including gapped supports are compared to the results of a typical linear elastic time history analysis.

ANALYSIS BACKGROUND

A novel concept for nuclear power plants in high seismic regions is to provide base isolation for the nuclear island. Base isolated nuclear power plants face unique design challenges where piping systems cross between the base isolated portion and the portion that is not base isolated. This is due to the extremely high relative seismic anchor displacements at the building boundaries. When analysing such a system, classic linear elastic design methods may result in extremely complex designs. In an effort to avoid these complex design solutions, a study was completed to determine if the use of gapped pipe supports and a non-linear analysis approach could be used to streamline the design process and reduce complexity.

The main steam line was chosen as the piping system to be analysed for this study. The analysed piping line initiates in the auxiliary building and terminates in the turbine building after crossing over the boundary between the base isolated part of the plant and the non-base isolated part of the plant. Thus, the system is subject to the high seismic anchor displacements between sections due to the base isolation. The model of this piping system is shown in Figure 1 below. An initial linear elastic ANSYS analysis of this section of piping resulted with Primary pipe stresses failing to qualify under Subsection NC of the ASME BPVC. Using a traditional linear elastic design method, the next step would typically be to try rerouting piping or adding and modifying pipe supports to try and qualify the pipe stresses. However, for the purposes of this study, the goal was to qualify the pipe stresses utilizing only the addition of gapped piping supports.

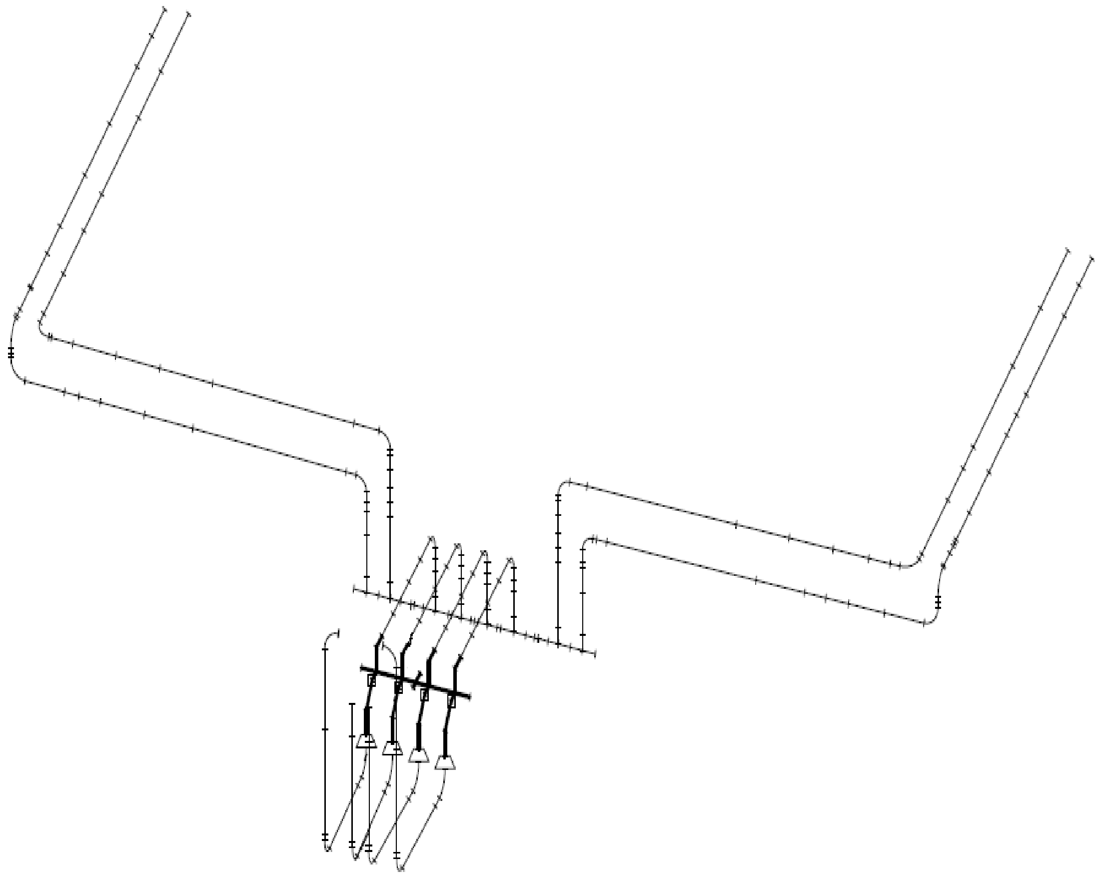

Figure 1. Main Steam Piping Model

METHODOLOGY

The nonlinear time history analysis performed on the main steam model for this study includes seismic inertial loads, seismic anchor motion loads, and fluid transient loads. The seismic inertial loads and seismic anchor motion loads are expressed as a single displacement time history representing both portions of the SSE event. The fluid transient loads are represented by a set of force time history data applied at specified points along the main steam piping. In order to get the true movements at the gapped supports, the primary loads must be run simultaneously with the secondary loads. This method more accurately shows the effects the gapped supports have on the overall system. However, because of this, the resulting stresses from the analysis are a combination of primary and secondary stresses. While the Code permits separate evaluation of primary and secondary stresses, it is not possible to separate theses stresses when using gapped supports. This is because the gap of any particular support may close due to the combination of primary and secondary loading, but not one or the other considered individually. The behaviour of the system may therefore not be accurate if considered individually.

To determine the placement of gapped supports, an iterative approach was taken. The initial placement of the gapped supports was based on a review of the linear elastic time history analysis. Locations of maximum resultant displacements were chosen, and gapped supports were strategically placed at these locations using COMBIN40 support elements to dampen some of the inertial loads. The gapped size was also based on the linear elastic time history run, as the gap size was based on the SAM displacement at each given location.

This results of this initial nonlinear ANSYS run were then reviewed to determine the behaviour and effect of the gap support configuration. Based on these results, the gap support locations and gap sizes were varied until an ideal configuration was obtained. Figures 2 and 3 show the final locations of the gapped supports in the main steam piping system, while Table 1 gives the location, direction, and gap size of each of these supports.

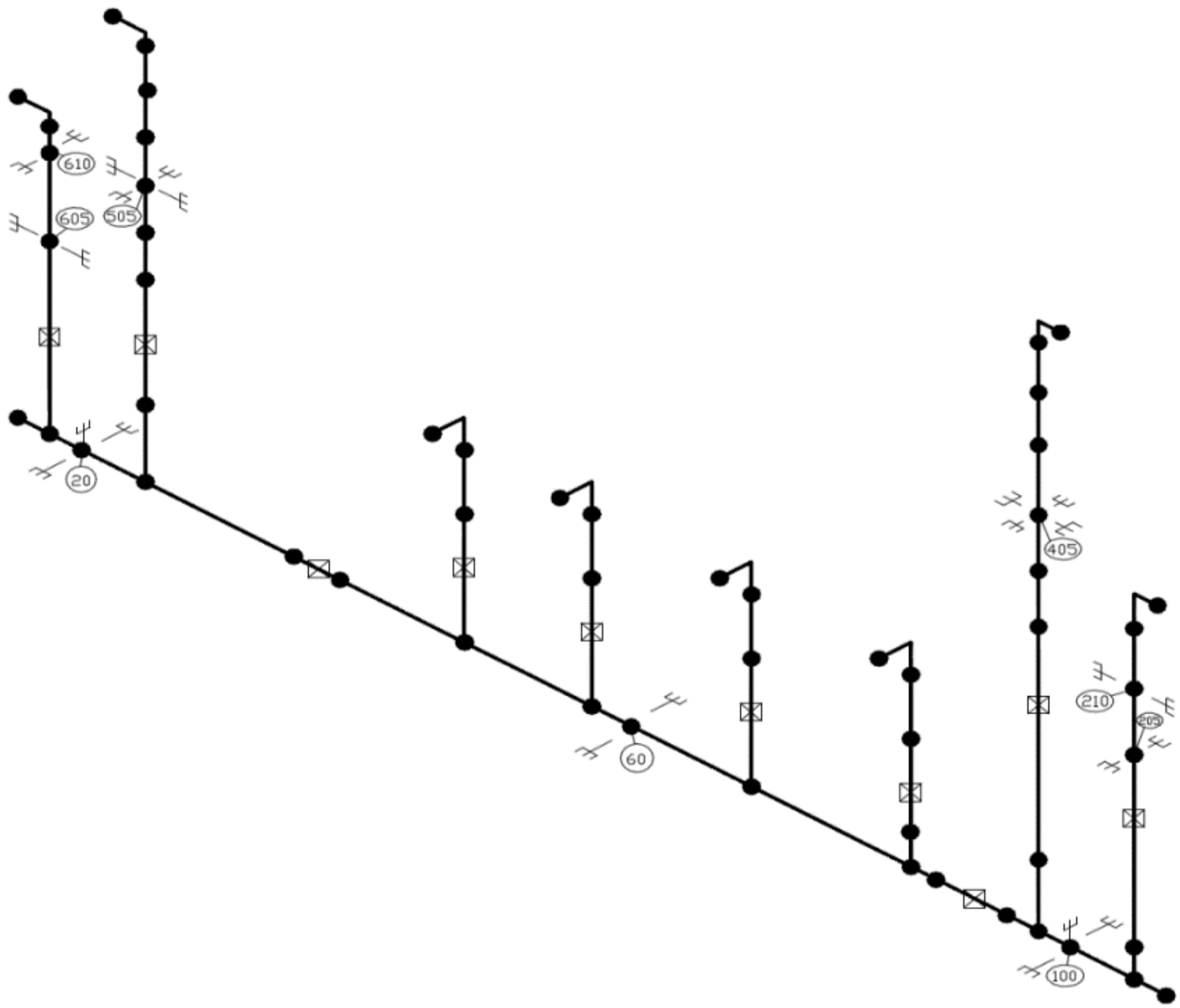

Figure 2. Gapped Support Locations Part 1

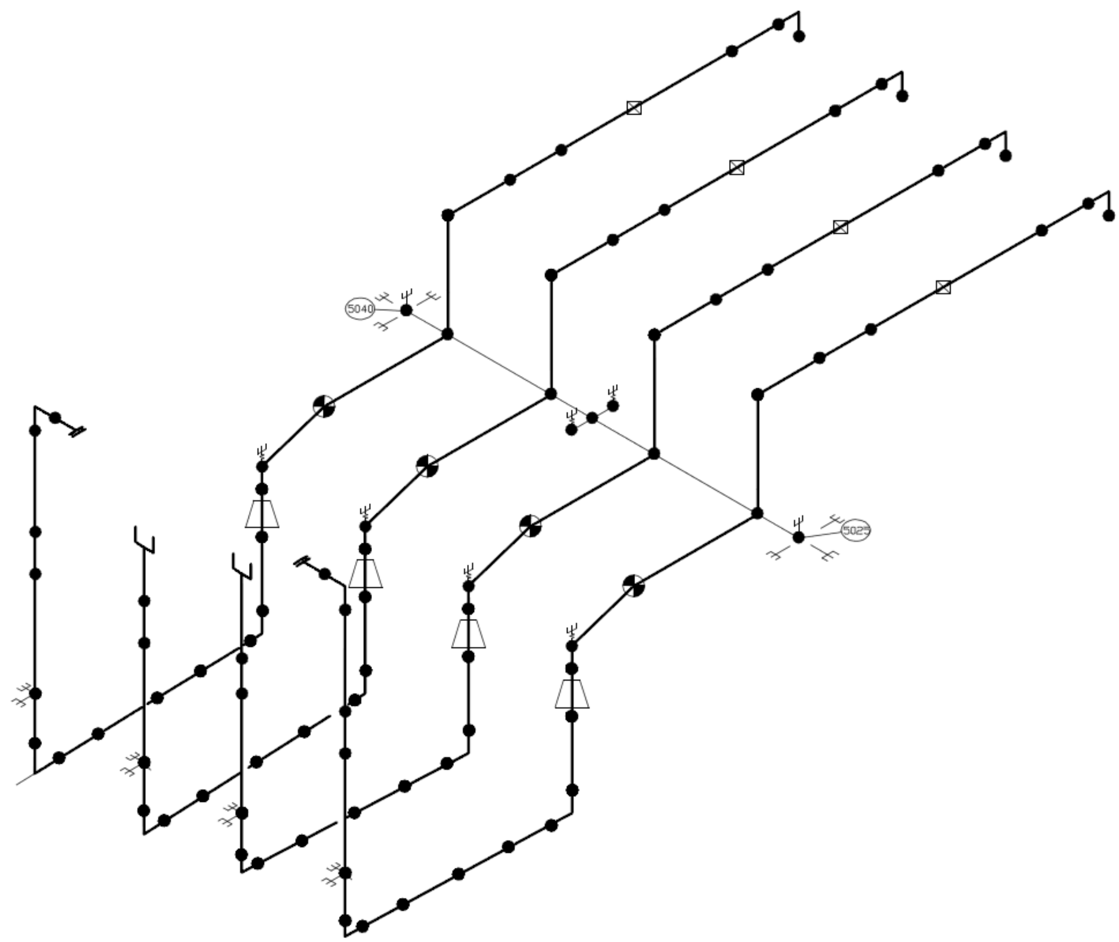

Figure 3. Gapped Support Locations Part 2

Table 1: Gap Supports in Nonlinear Time History Main Steam Model

Point	Building	Direction	Total Gap
20	Aux Building	Z	2”
60	Aux Building	Z	2”
100	Aux Building	Z	2”
5025	Turbine Building	Z	3.5”
5040	Turbine Building	Z	3.5”
5025	Turbine Building	X	2.25”
5040	Turbine Building	X	2.25”
605	Aux Building	X	1.5”
210	Aux Building	X	1.5”
405	Aux Building	X	1.5”
505	Aux Building	X	1.5”
610	Aux Building	Z	1.5”
205	Aux Building	Z	1.5”
405	Aux Building	Z	1.5”
505	Aux Building	Z	1.5”

ACCEPTANCE CRITERIA

The seismic event being considered for this study is a Level D SSE event, to which can be applied the elastic analysis criteria of ASME BPVC Appendix F. Appendix F states that for Ferritic steel, the general primary membrane stress intensity Pm shall be less than .7Su, and that the primary membrane plus bending stress intensity shall be less than 150% of the primary membrane stress limit. This leads to equations (1) and (2) below.

$$P_m \leq 0.7S_u \tag{1}$$

$$P_m + P_b \leq 1.5(0.7S_u) \tag{2}$$

Where P_m is the primary membrane stress, S_u is the tensile strength of the material, and P_b is the primary bending stress.

The non-linear ANSYS results are therefore post-processed to generate the Pm (Primary Membrane) and Pm+Pb (Primary membrane plus bending) stresses, and include the effect of Pressure, weight, seismic inertial loads, fluid transient loads, and seismic anchor motion effects.

The study does include seismic anchor motion effects, which are secondary stresses and typically evaluated separately from primary stresses. However, since both the seismic inertial and seismic anchor motion effects are represented by a single time history, there is not an effective way to separate the results into primary and secondary stresses. However, if the combined primary and secondary stresses meet the Pm and Pm+Pb limits, the higher primary plus secondary stress limit for P_m+P_b+Q would be met. It is also important to note that Appendix F only requires evaluation of Primary stresses. Secondary stresses are not required to be evaluated.

ANALYSIS RESULTS

Table 2 below contains a summary of the top 5 pipe stresses for the inertial load case of the original linear ANSYS model against Code allowable values. Note that the linear ANSYS run was performed as part of a previous related project, and not directly as part of this study. Therefore, this table is presented for reference only to show that without any modifications the base model failed to qualify inertial pipe stresses.

Table 2: Main Steam - 5 Highest Pipe Stresses for Lv. D Primary Inertial Stress Case: ANSYS Linear Results

Rank	Keypoint[1]	Location of Highest Stress	Stress Ratio Actual/Allowable
1	55	Tee 59.75”x28.85”	1.253
2	1015	Elbow 28.9”	1.252
3	4015	Elbow 28.9”	1.249
4	1015	Elbow 28.9”	1.248
5	65	Tee 59.75”x28.85”	1.248

For the non-linear ANSYS run of this study, Table 3 below contains a summary of the top 5 Primary Membrane stress intensities (Pm) evaluated for the main steam analysis against the limit of 0.7Su found in the Mandatory Appendix for Level D. Table 4 below contains a summary of the top 5 total stress intensities (Pm+Pb+Q) conservatively evaluated for the main steam analysis against the limit of 1.5(0.7Su). Note that because the non-linear analysis SAM stresses cannot be separated out, the stress intensities from SSE inertial, water hammer, and SAM are evaluated together in both tables.

Table 3: Main Steam - 5 Highest Primary Membrane Stress Intensities (Pm): ANSYS Non-Linear Gapped Time History Results

Rank	Keypoint[1]	Location of Highest Stress	Stress (psi)	Stress Ratio Actual/Allowable
1	26 (1010)	Elbow 28.9”	9416	0.224
2	1015	Elbow 28.9”	9416	0.224
3	1020	Straight Pipe 28.85”	9390	0.224
4	1022	Straight Pipe 28.85”	9358	0.223
5	1024	Straight Pipe 28.85”	9321	0.222

Table 4: Main Steam - 5 Highest Total Stress Intensities (Pm+Pb+Q) : ANSYS Non-Linear Gapped Time History Results

Rank	Keypoint[1]	Location of Highest Stress	Stress (psi)	Stress Ratio Actual/Allowable
1	26 (1010)	Elbow 28.9”	71805	1.140[2]
2	1015	Elbow 28.9”	71602	1.138[2]
3	28 (2010)	Elbow 28.9”	65120	1.034[2]
4	2015	Elbow 28.9”	65027	1.032[2]
5	95	Tee 59.75” x 31.6”	62804	0.997

1 During meshing, ANSYS creates Keypoints beyond those which are specified and shown in the isometrics. The number in parentheses is the closest keypoint labeled on the isometrics to the ANSYS keypoint where the associated high stress is found.

2 The above overstresses are found at different points along 2 elbows, with the maximum being 14% over the allowable for primary stresses. If a more refined analysis were performed utilizing separate inertial and secondary inputs, the primary stresses alone would meet the primary allowable. Therefore they were judged as being acceptable.

CONCLUSION

This study showed that gapped supports can be used to reduce the stresses in a piping system and qualify the system to code requirements. The results of the analysis showed that by only adding new gapped supports or converting existing supports to gapped supports, the Main Steam system design could be qualified to the criteria of the Appendix F of ASME Section III. There is a level of conservatism built into the analysis because the SAM stresses (secondary stresses) were evaluated with the inertial stresses as primary stresses in the nonlinear analysis. This is when compared to the linear model of the same system without gapped supports, which failed to qualify even inertial stresses independently.

REFERENCES

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