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SEISMIC ACCELERATION PROFILE FOR CONTAINMENT ANALYSIS

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ABSTRACT

The purpose of this paper is to evaluate a concrete containment structure when large openings exist in different bays and to investigate the acceptability of obtaining an equivalent static acceleration profile when the structure is subjected to earthquake load. To analyze the structural behavior of this containment under seismic loads when large openings exist in the cylindrical wall, a three-dimensional (3D) finite element (FE) model of the containment is created using GTSTRUDL. Two cases of openings (3-bay opening and 2-bay opening) are considered in different bays of the cylindrical walls. Response spectrum analysis is performed for these two cases to provide a seismic acceleration profile to be used in the subsequent structural evaluation of the containment.

INTRODUCTION

The selected containment is a concrete structure with a cylindrical wall, a flat foundation mat, and a shallow dome roof. The inside surface of the reactor building is lined with a steel liner to ensure a high degree of leak tightness during operating and accident conditions. The foundation mat is supported by competent bearing material, and is 12’-6” thick. There are six exterior concrete buttresses equally spaced around the cylindrical wall (60° apart) and the buttress is 70” thick. The cylindrical wall has an inside diameter of 130’-0”, wall thickness of 3’-6”, and a height of 157’-0” from the top of the foundation mat to the dome spring line. The shallow dome has a large radius of 110’-0” and a thickness of 3’-0”. The construction opening size considered in the containment wall during replacement varied, approximately about 80ft x 60ft. The hoop and vertical tendons in the containment wall are considered to be detensioned/removed in the study of this paper.

To analyze the behavior of this containment under repair loading conditions, a three-dimensional (3D) finite element (FE) model is created using GTSTRUDL. First, a modal analysis of the intact containment is performed for benchmarking. Second, the GTSRUDL model is modified for the two cases considered in this paper to simulate the proposed concrete removal and replacement sequence; then the response spectrum analyses are performed to obtain the spectral seismic acceleration profiles (both horizontal and vertical) to be used in a subsequent equivalent static seismic evaluation. Finally, comparisons between the equivalent static analysis and response spectrum analysis are conducted.

GTSTRUDL MODEL

To analyze the structural behavior of this containment under seismic loads when large openings exist in the cylindrical wall, a three-dimensional (3D) finite element (FE) model of the containment is created using GTSTRUDL (See Figure 1). Two cases of openings (3-bay opening & 2-bay opening) are considered in different bays of the cylindrical walls (see Figures 2) to simulate two concrete removal and replacement options. Elevations defining the concrete removal for the 3-bay opening case are shown in Figure 3. A 3D isometric view of the containment model for the 3-bay opening case is shown in Figure 4.

The containment cylindrical wall, major portion of dome, ring girder, and buttresses are modeled with GTSTRUDL element type SBHQ6, which is a 4-node quadrilateral element with six degrees-of-freedom at each of four corner nodes, and is suitable for analyzing thin to moderately thick shell structure.

Apex of the dome is modeled with SBHT6, which is a 3-node triangle element with six degrees-of-freedom at each of three corner nodes. The element size is ~ 3.5' x 3.5' in the cylindrical wall and gradually reduced when approaching the dome apex.

The GTSTRUDL model is created using a coordinate system with its origin at the center of the containment cross section and at the base of the cylindrical wall. As shown in Figure 2, the global Z axes aligns with 1.50 degree from the centerline of buttress #3, and the global Y-axis is oriented in vertical direction (positive up). Different colors in Figure 1 correspond to different shell element thickness. The containment was assumed to be fixed at its base and the actual foundation mat of the containment was not modeled.

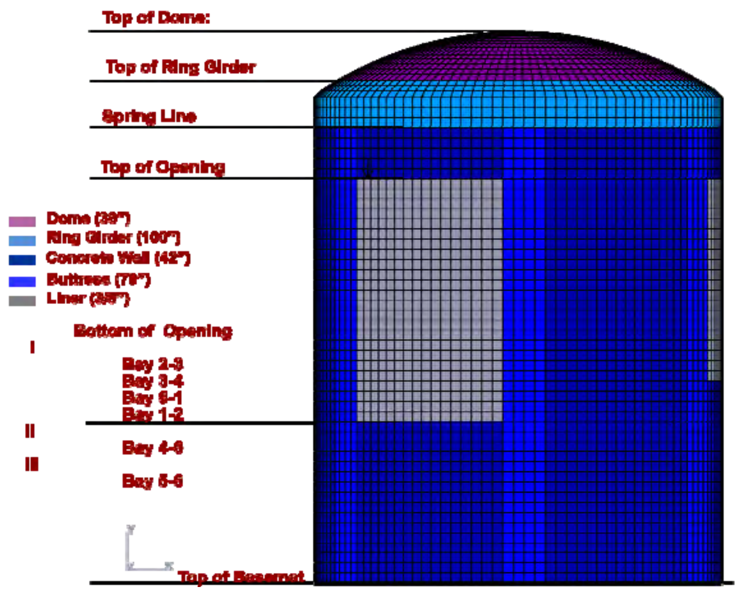


Figure 1. Elevation View of Containment Finite Element Model

Case 1 – 3 Bay Opening

Case 2 – 2 Bay Opening

Figure 2: Proposed Concrete Openings

Note: Bay in Red: new concrete
Bay in Black: existing concrete
Bay in White: Removed concrete

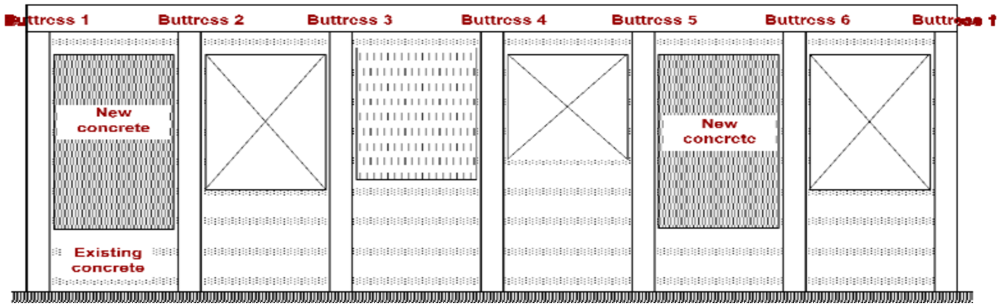


Figure 3. Elevation View of 3 Bay Opening Case (unfolded)

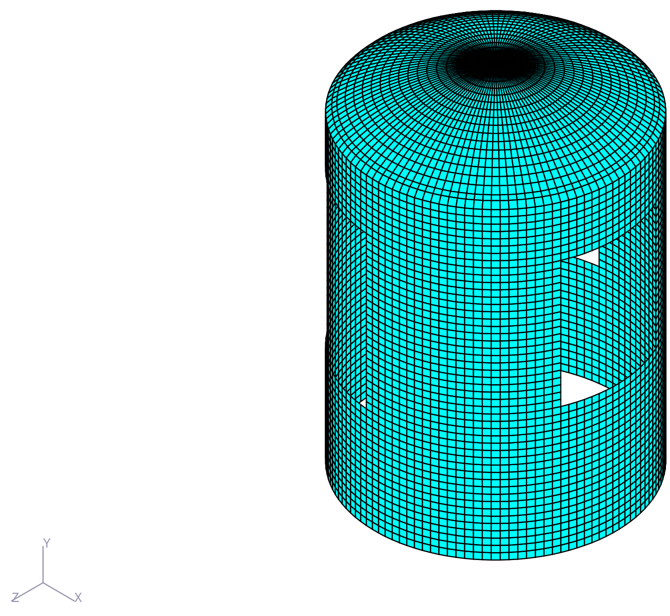


Figure 4. 3D Isometric View of 3 Bay Opening Case

ACCELERATION PROFILE USING RESPONSE SPECTRUM ANALYSIS

A typical seismic evaluation approach, but very conservative for most practical cases, is to apply the peak ground acceleration with a 1.5 multi-mode factor as an equivalent static load to the structure. However, the resulting seismic demands using this approach make the structural evaluation very challenging due to resulting high seismic demands. Therefore, a refined seismic acceleration profile is developed in order to reasonably reduce the seismic demands on this containment.

Finite Element Benchmarking

First, a modal analysis of the intact containment is performed and the natural frequencies and total weight of containment as obtained directly from GTSTRUDL are compared with those obtained from an ANSYS model and those from the original containment analysis (FSAR) for benchmarking. Refer to Table 1 for the comparison results.

Table 1 Finite Element Benchmarking

COMPARISON ITEM	FSAR	GTSTRUDL		ANSYS	
		GTSTRUDL	(GT-FSAR) /FSAR	ANSYS	(ANSYS-FSAR) /FSAR
Fundamental Frequency (Hz)	4.4	4.29	-2.50%	4.3	-2.27%
Total Weight (kip)	58,631	54,570	-6.93%	57175	-2.48%

As shown in Table 1, the fundamental frequency from GTSTRUDL model is within 3% of the original containment data and the total weight is within 7% of the original containment data.

The mass participation factor in GTSTRUDL shows that more than 97% of mass participation is achieved for the horizontal directions and more than 95% for the vertical direction when 300 modes are included in the analysis.

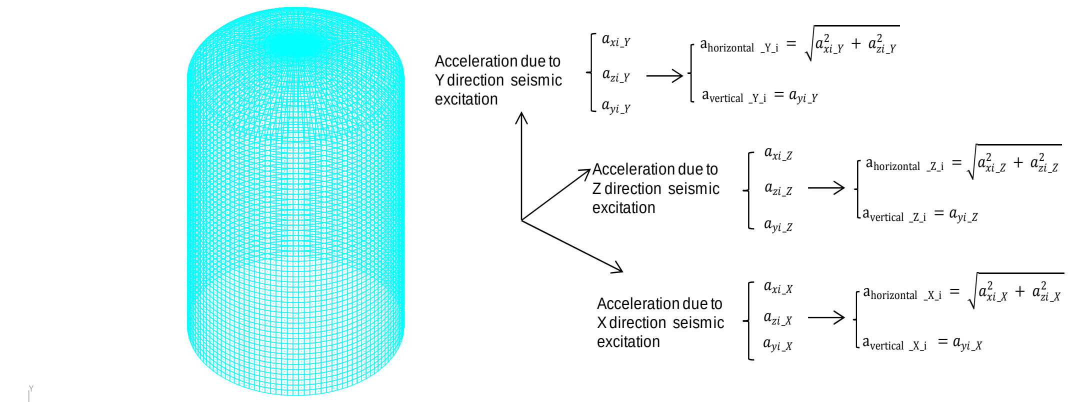
Response Spectrum Analysis

Second, the GTSRUDL model is modified for the two cases considered in Figure 2 to simulate the structure when multiple openings exist in the cylindrical wall. The response spectrum analyses for safe-shutdown earthquake (SSE, 5% damping) are performed for the two cases to obtain the spectral seismic acceleration profile (both horizontal and vertical) to be used in a subsequent equivalent static seismic evaluation. This is a two-step method:

Step 1: Perform Response Spectrum Analysis and obtain equivalent seismic acceleration profile.

Step 2: Apply the equivalent seismic acceleration from Step 1 into the structure to perform equivalent static analysis.

The flowchart in Figure 5 described the steps for obtaining the seismic acceleration profile in this paper. The obtained horizontal and vertical acceleration profiles along the containment height, respectively, for the two cases and their envelope are provided in Figure 6. Please note a 10% margin has been added into the enveloped value due to the unforeseen modifications in the containment model. Figure 7 provides the final horizontal and vertical acceleration profile along the height.



$$a_{horizontal\_X} = \frac{\sum_0^n a_{horizontal\_X\_i}}{n}, \quad a_{horizontal\_Z} = \frac{\sum_0^n a_{horizontal\_Z\_i}}{n}, \quad a_{horizontal\_Y} = \frac{\sum_0^n a_{horizontal\_Y\_i}}{n} \longrightarrow a_{horizontal} = 1.1 \times \{\max(a_{horizontal\_X}, a_{horizontal\_Z}) + a_{horizontal\_Y}\}$$

$$a_{vertical\_X} = \frac{\sum_0^n a_{vertical\_X\_i}}{n}, \quad a_{vertical\_Y} = \frac{\sum_0^n a_{vertical\_Y\_i}}{n}, \quad a_{vertical\_Z} = \frac{\sum_0^n a_{vertical\_Z\_i}}{n} \longrightarrow a_{vertical} = 1.1 \times \{\max(a_{vertical\_X}, a_{vertical\_Z}) + a_{vertical\_Y}\}$$

Figure 5. Flowchart for Obtaining Acceleration Profile

Note:

a_{xi_X}, a_{yi_X}, a_{zi_X} are the nodal acceleration responses for node "i" obtained in global x, y, z axis respectively due to the seismic excitation at X direction.

a_{xi_Y}, a_{yi_Y}, a_{zi_Y} are the nodal acceleration responses for node "i" obtained in global x, y, z axis respectively due to the seismic excitation at Y direction.

a_{xi_Z}, a_{yi_Z}, a_{zi_Z} are the nodal acceleration responses for node "i" obtained in global x, y, z axis respectively due to the seismic excitation at Z direction.

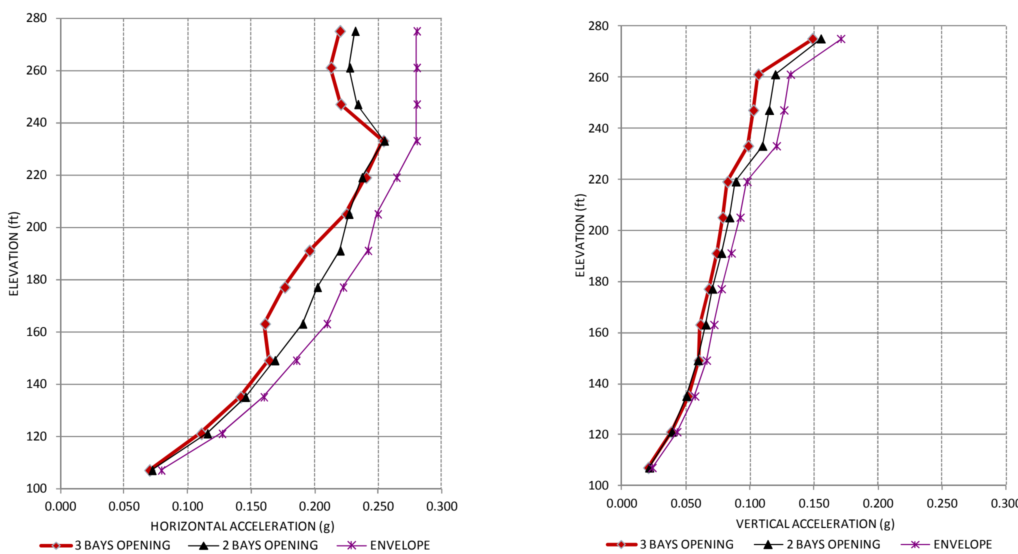


Figure 6. Seismic Acceleration Profile Plots (Horizontal and Vertical)

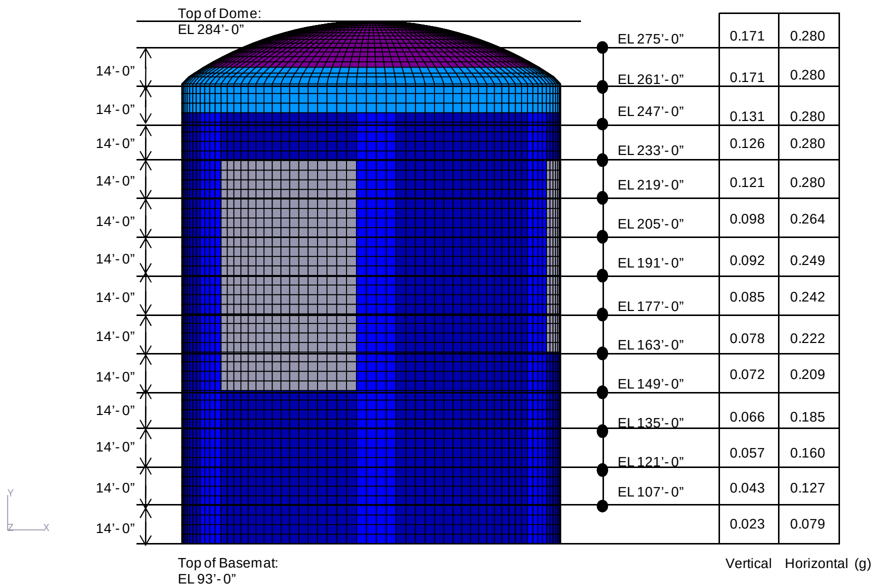


Figure 7. Seismic Acceleration Profile (Horizontal and Vertical)

Analysis Results Comparison

In order to validate the acceleration profile obtained in Figure 7, equivalent static analyses are performed by applying the acceleration profile provided in Figure 7 and comparison between the equivalent static analysis and response spectrum analysis are conducted.

The horizontal displacement, the total base shear and “story” shear at every 14’ along the height, and the overturning moment at every 14’ along the height from Response Spectrum Analysis are compared with the results from equivalent static analysis. The comparison results are plotted in Figures 8 ~ 13 respectively. In the Figures, H0 and H90 represent the two horizontal directions and V represents the vertical direction. RS refers to Response Spectrum Analysis and Static refers to Equivalent Static Analysis.

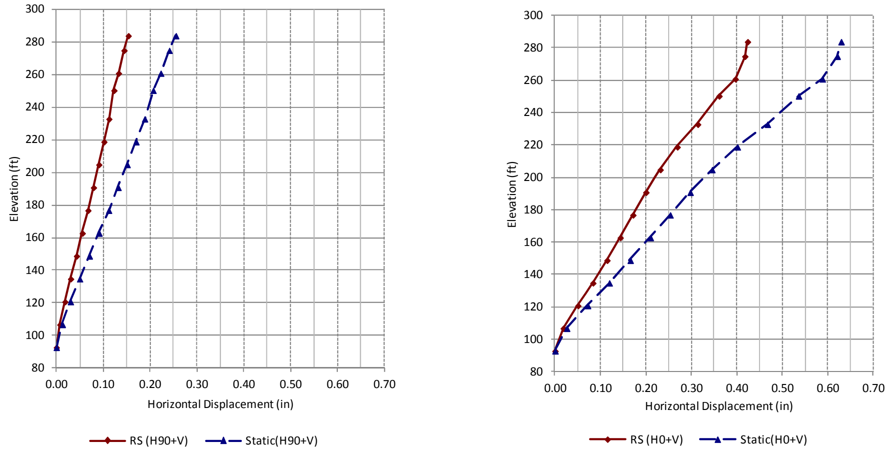


Figure 8. Displacement Comparison for Loading H90+V & H0+V (2-Bay Opening)

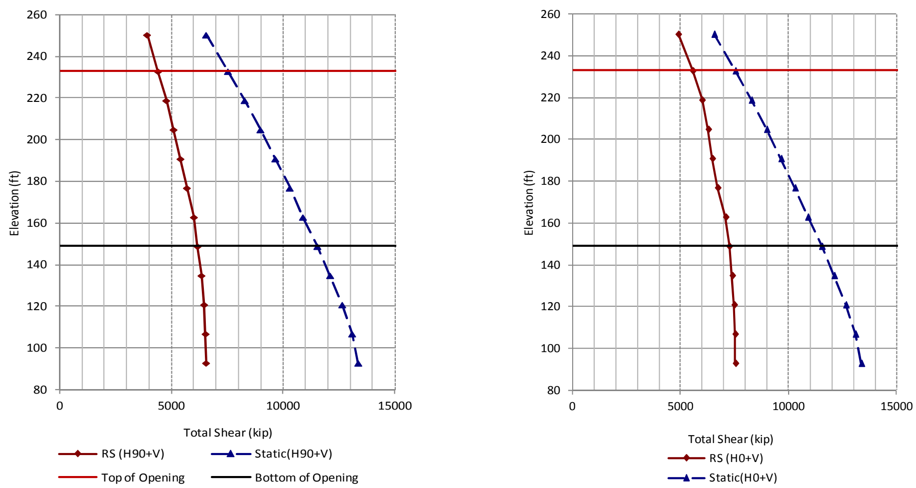


Figure 9. Total Shear Comparison for Loading H90+V & H0+V (2-Bay Opening)

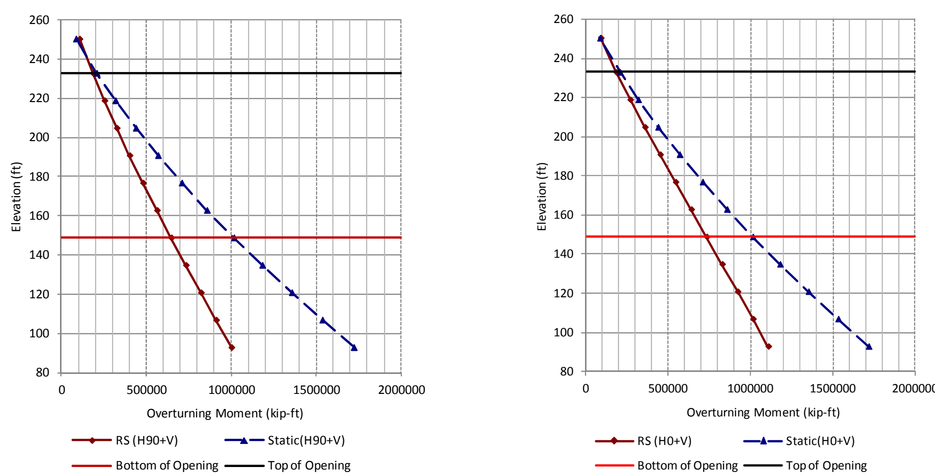


Figure 10. Overturning Moment Comparison for Loading H90+V & H0+V (2-Bay Opening)

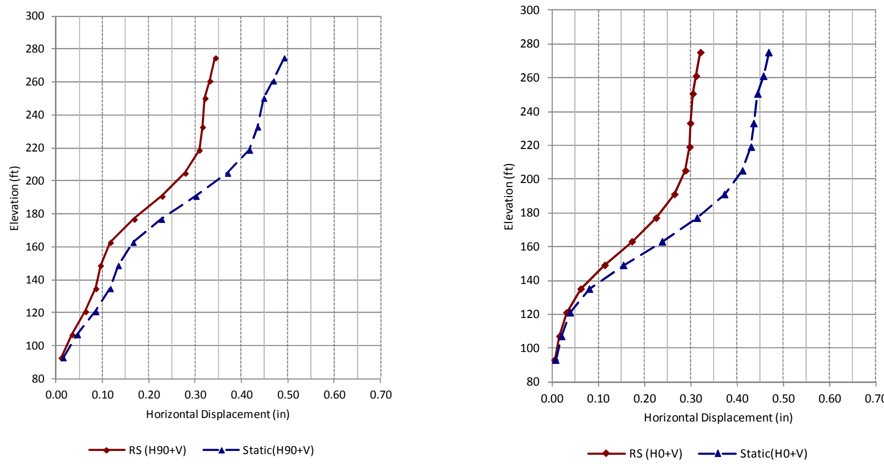


Figure 11. Displacement Comparison for Loading H90+V & H0+V (3-Bay Opening)

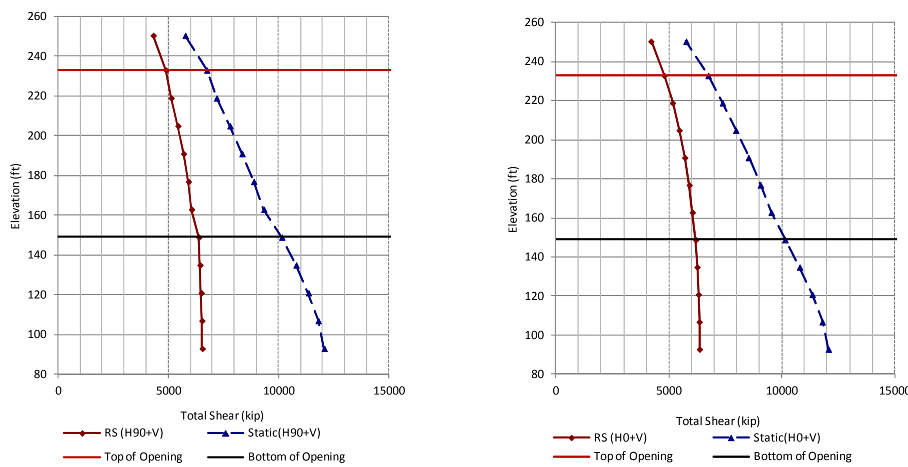


Figure 12. Total Shear Comparison for Loading H90+V & H0+V (3-Bay Opening)

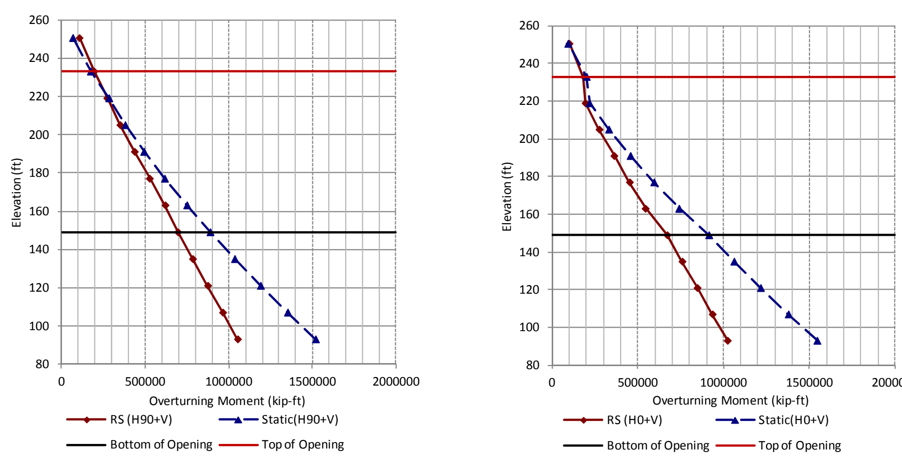


Figure 13. Overturning Moment Comparison for Loading H90+V & H0+V (3-Bay Opening)

Below are the conclusions from the comparisons shown in Figures 8 ~ 13:

1. The horizontal displacements along the height of containment from equivalent static analysis envelop those from response spectrum analysis.
2. The base shear and story shear along the height of containment from equivalent static analysis envelop those from response spectrum analysis.
3. The overturning moment at base from equivalent static analysis is ~50% more than that from the response spectrum analysis, and they reach almost the same level above EL 233'-0" (the highest elevation where concrete is removed in the GTSTRUDL model).

The base shear and base moment for the two cases obtained from response spectrum analysis (RS) and equivalent static analysis (Static) are listed in Table 2.

Table 2 Result Comparison

3 BAY OPENING					
Weight	C.G (Y)	RS		Static	
		Base Shear	Base Moment	Base Shear	Base Moment
(kip)	(ft)	(kip)	(kip-ft)	(kip)	(kip-ft)
53584	113.97	6538	1022273	12066	1544656

2 BAY OPENING					
Weight	C.G (Y)	RS		Static	
		Base Shear	Base Moment	Base Shear	Base Moment
(kip)	(ft)	(kip)	(kip-ft)	(kip)	(kip-ft)
56335	114.65	7534	1105869	13360	1715296

The comparisons confirm that the acceleration profile obtained in this paper is adequate and reasonably conservative to be used as the seismic input in equivalent static analysis of the containment for the concrete removal condition.

CONCLUSION

The methodology to obtain the acceleration profile presented in this paper is practical and the final acceleration profile is reasonably conservative to be used as input for the equivalent static analysis of this containment when the two cases of openings considered exist in different bays of the cylindrical wall.

REFERENCES

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Regulatory Guide 1.61, *Damping Values for Seismic Design of Nuclear Power Plants*, Revision 1, 2007

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