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Seismic Analysis of Gas Delivery Cabinet

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***Abstract*— Seismic safety is a paramount concern in industries reliant on gas delivery systems to safeguard critical infrastructure and ensure uninterrupted operations. This gas delivery systems are enclosed within an enclosure called Gas Delivery Cabinets. These systems introduce unique safety challenges, with potential gas leaks during seismic events posing grave risks to personnel and the environment.**

This project thoroughly investigates the seismic behavior of gas delivery cabinet. A comprehensive comparison between the widely adopted Equivalent Lateral Force (ELF) method and the Response Spectrum Method (RSM) aims to provide insights for optimizing seismic safety protocols. The ELF method estimates seismic forces efficiently by approximating cabinets as equivalent single-degree-of-freedom systems. Conversely, the RSM offers a detailed dynamic response representation, incorporating site-specific seismic input through response spectra, particularly relevant in regions with varying ground motion spectra.

Following ASCE standards, the analysis employs Ansys Workbench for numerical simulations, considering realistic material properties, boundary conditions, and seismic input data.

The study recommends prioritizing the RSM for cabinets in higher seismic zones, where accurate analysis is vital due to their high seismic importance. In lower seismic zones, the ELF method may be suitable for its simplicity and computational efficiency. The results of this project provide seismic safety guidelines for gas delivery cabinets, thereby enhancing their seismic resilience.

Keywords*— *Seismic Analysis, Gas Delivery Cabinets, Equivalent Lateral Force Method, Response Spectrum Method, Site-specific seismic input, American Society of Civil Engineers (ASCE) standard.

I. INTRODUCTION

Earthquakes are natural phenomena that can cause severe damage to buildings and infrastructure. Structural engineers design buildings to withstand earthquakes. But what about the lights, storage tanks, tall machines and enclosures, HVAC systems, Mechanical, Electrical and Plumbing (MEP) systems, fire protection systems etc.? These components are also significantly impacted by earthquakes, and the failure of these components also poses a significant risk. According to the ASCE standard [1], they are classified as non-structural components. Non-structural components may fail if their attachments fail, making it necessary to design them to withstand seismic forces.

This project work specifically focuses on a non-structural component known as the Gas Delivery Cabinet (a sheet metal enclosure for the gas delivery system) as shown in Fig.1. Seismic analysis involves analyzing how systems and structures respond to seismic forces. Its goal is to predict the behavior, deformations, and stresses that a structure might experience during seismic events. Seismic analysis can be conducted analytically, experimentally, or through numerical simulation. Numerical simulation, such as Finite Element Analysis, surpasses the complexity of analytical methods and costly experimental techniques [3]. It rapidly and efficiently models intricate scenarios, accelerates design iterations, and optimizes seismic resilience by reducing time and resource consumption.

Fig. 1. Gas Delivery Cabinet

These gas delivery systems introduce unique safety challenges, as they may contain hazardous or flammable gases. Potential gas leaks during seismic events pose grave risks to personnel and the environment, highlighting the importance of conducting seismic analysis for such systems. Seismic analysis becomes a crucial tool for engineers, aiding them in simulating the impact of these seismic forces on the cabinet and helps in identifying potential weaker regions. Seismic analysis can be conducted using four different methods: Equivalent Lateral Force (ELF) method, Response Spectrum (RS) method, Push-Over method, and Time history method. Among these, the ELF or RS methods are more suitable for analyzing non-structural components [1].

A. Equivalent Lateral Force Method:

The ELF method simplifies seismic analysis by estimating building lateral forces during earthquakes as shown in Fig.2. It treats the structure as a single-degree-of-freedom system, concentrating forces at the center of mass. The ELF method is necessary because conducting a detailed dynamic analysis for every structure can be computationally intensive and time-consuming [3]. This method is carried out by estimating base shear load and distributed using code-specified formulas. The

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application of this method is also limited concerning seismic zones [4] [5]. This method is not applicable to structures with irregularities, such as weight/mass irregularity (disproportionate weight at different levels), out-of-plane offset irregularity (misaligned vertical elements), and torsional irregularity (which causes twisting when subjected to lateral forces) [6]. Since the gas delivery cabinet doesn't exhibit any of these irregularities, we can use this ELF method to conduct the seismic analysis.

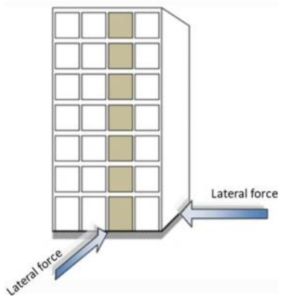

Fig. 2. Equivalent Lateral Force (ELF) method [6]

B. *Response Spectrum Method:*

A RS analysis is primarily employed in lieu of a time history analysis to determine the response of structures exposed to the short, non-deterministic, time-dependent loading conditions, such as earthquakes and shock events. Steps performing seismic analysis using the Response Spectrum (RS) method, as per ASCE standards [1] are as follows:

- Response Spectrum Generation: The method begins by choosing a set of ground motion records that correspond to the expected seismic activity at the site. These records could be sourced from historical data, simulated data, or a combination of both [7]. A response spectrum is generated for each selected ground motion record. The response spectrum graphically represents the maximum response (often displacement, velocity, or acceleration) of a structure as it varies with different frequencies. Fig.3 shows a detailed procedure to generate response spectrum curve.

- Modal Analysis: The structural system is broken down into its individual vibration modes through modal analysis. Each mode represents a distinct way in which the structure can vibrate when subjected to dynamic loads. Often, a few dominant modes predominate in the structure's response.

- Combining Modes: Individual mode response spectra are combined to derive the overall response spectrum of the structure. Various mode combination methods, such as the square root of the sum of squares (SRSS), complete quadratic combination (CQC), and Rosenbluth (ROSE), can be used in order to account for damping and the interaction of closely spaced modes. The SRSS method is used for mode combination when the successive modes are far apart (not closely spaced), as there will be less interaction effect between the modes. [8].

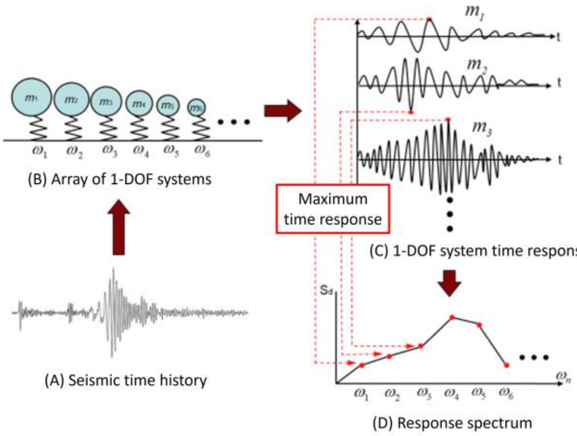

Fig. 3. Response Spectrum method (RSM) [9]

II. PROBLEM DESCRIPTION

Gas delivery systems are essential for handling hazardous and flammable gases in industries, but their vulnerability to seismic-induced gas leaks raises serious safety issues. To address this, this project seeks to comprehensively investigate the seismic behavior of a gas delivery cabinet. Overall aim of this project is to ensure the structural integrity of a gas delivery cabinet under standard seismic conditions.

Specific objectives of this project are as follows:

- Perform seismic analysis for a gas delivery cabinet using the ELF method and RSM considering different seismic zones.

- Assessment of structural integrity against seismic standards.

- Critical comparison of results obtained by ELF method and RSM.

III. METHODOLOGY

A. *Input Study*

Firstly, the study commenced with a meticulous analysis of the Gas Delivery cabinet, scrutinizing its structural attributes and design intricacies to establish a strong foundation for subsequent seismic analyses. A comprehensive literature survey explored seismic analyses for non-structural components, while ASCE 7 Chapter-13 provided essential guidelines for conducting seismic analyses using the ELF and RS methods.

B. *Model Preparation/Geometry defeaturing:*

Geometry clean-up prior to simulation enhances the accuracy and efficiency of analyses. During the geometry clean-up process, meticulous efforts are invested in removing any extraneous details or flaws. The geometry needs to be thoughtfully simplified in this phase while retaining its important components, ensuring the model remains relevant to the goals of the seismic study. It involves modeling the Cold Rolled Steel (CRS) sheet metal cabinet of 12-gauge thickness using Siemens NX software with the appropriate dimensions as

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per industry standards. The geometry and material properties of the sheet metal are shown in Fig.4 and Table 1 respectively.

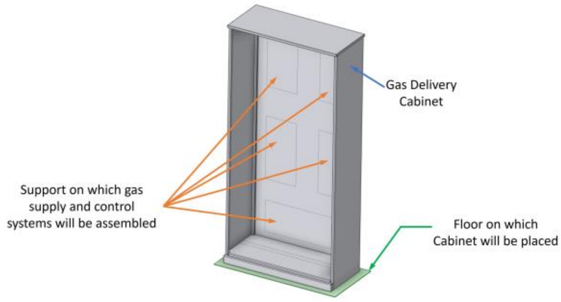

Fig. 4. 3D Model of Gas Delivery Cabinet

Properties	Value
Young's Modulus	2×10^{11} N/m^2
Poisson's Ratio	0.3
Density	7860 kg/m^3
Yield Strength	145×10^6 N/m^2
Ultimate Tensile Strength	360×10^6 N/m^2

TABLE I. MATERIAL PROPERTIES

C. *Perform static structural analysis:*

Static analysis is performed on the gas cabinet to assess its structural integrity, as conducting seismic analysis would be pointless if the cabinet fails during static analysis. Factor of safety for the Von-Mises stress should be greater than 3, which is the accepted criterion according to industry standards. The gas sticks assembly constitutes a sub-assembly of gas flow and control components. It has been modeled as a point mass and has been affixed to the support, as illustrated in Fig. 5

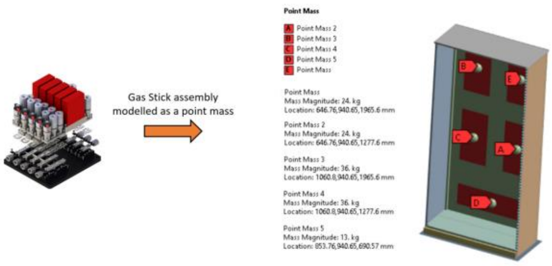

Fig. 5. Gas Stick Assembly modelled as a point mass

A mid-surface meshing of the sheet metal is performed using second order 2-D Quad elements (Parabolic Quad 8 elements). To ensure compliance with industry standards, a mesh convergence check is conducted by subsequently refining the element size (H-refinement) of the mesh to ensure that the stress variation is below 10%. Boundary conditions for static structural analysis as shown in Fig. (6).

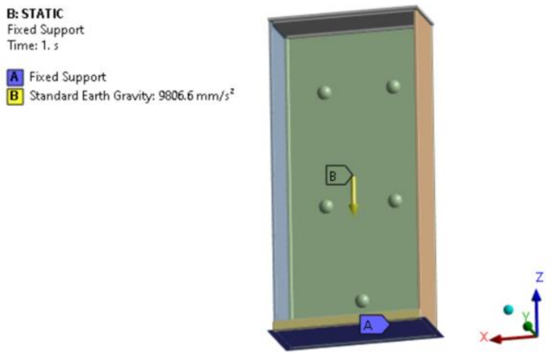

Fig. 6. Boundary Conditions for Static Structural Analysis

D. *Perform Modal analysis:*

Conduct a modal analysis to ascertain the structure's natural frequency and predominant modes. Modal analysis is performed by fixing the bottom facing of the floor while having frictional contact is given between the floor and base of the cabinet. The number of modes is selected such that the combined participating mass is at least 90% of the total effective mass in the structure [10]. Modal analysis is performed to classify whether the structure is flexible/rigid. Structures with fundamental natural frequency $f_n < 17$Hz (T > 0.02s) is considered as flexible structure and $f_n > 17$Hz is considered as rigid structure [1].

E. *Perform Seismic analysis:*

Seismic analysis is conducted on the gas cabinet using both ELF and RS methods, considering cabinet placement in different seismic zone areas. The structural integrity of the gas cabinet is assessed, and a comparison is made between the results obtained from both methods.

1) *Seismic analysis by ELF method:*

ELF method is founded on the concept of applying static lateral force to a structure to simulate the effects of dynamic forces. Therefore, acceleration values of 3.6g in horizontal (X & Y) direction and +3.6g and -1.6g in vertical (Z) direction. There will be 8 loading cases as shown in Fig. 7.

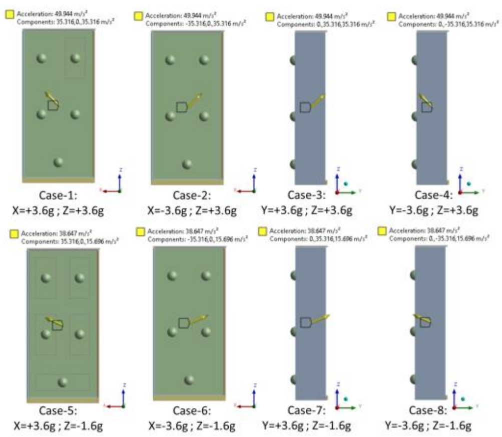

Fig. 7. Loading cases for ELF method

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2) Seismic analysis by RS method:

Response spectrum analysis measures pseudo-spectral acceleration, velocity, or displacement as a function of time period for a specific amount of damping. This information can be utilized to understand the dynamic behavior. First step of RS analysis would be to generate the RS curve. Here, four different locations such as San Francisco, California; Phoenix, Arizona; Santa Clara, California and Seattle, Washington is considered as these are the primary customer locations. These locations are classified as Site A, B, C and D respectively as per ASCE-7 standard. Example of RS curves obtained for different location is shown in Fig. 8.

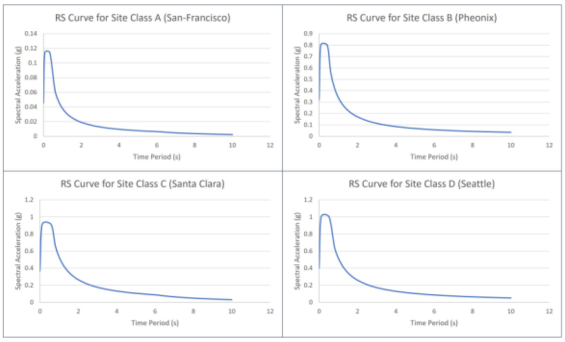


Fig. 8. Response Spectrum Curves for different locations.

IV. RESULTS AND DISCUSSION

A. *Results of Static structural & Modal Analysis*

1) Static Analysis:

A static analysis was conducted on the Gas Delivery Cabinet, revealing a maximum stress of approximately 37MPa as shown in Fig. 9 with a Factor of Safety (FOS) of 3.92 with respect to the yield strength of the CRS material, which is 145MPa. Thus, in accordance with industry standards, the cabinet is safe under static conditions, as the FOS is ≥ 3.

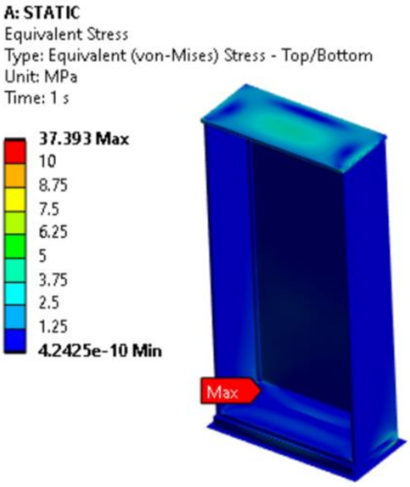


Fig. 9. Results of Static Analysis

2) Modal Analysis:

Modal analysis was performed for up to 100 modes in order to ensure that the participating mass is atleast 90% of the total effective mass of the structure as shown in Fig.10. The fundamental natural frequency obtained is around 8.7Hz, which is less than 17Hz. Therefore, according to ASCE 7 standard [1], we classify it as a flexible structure.

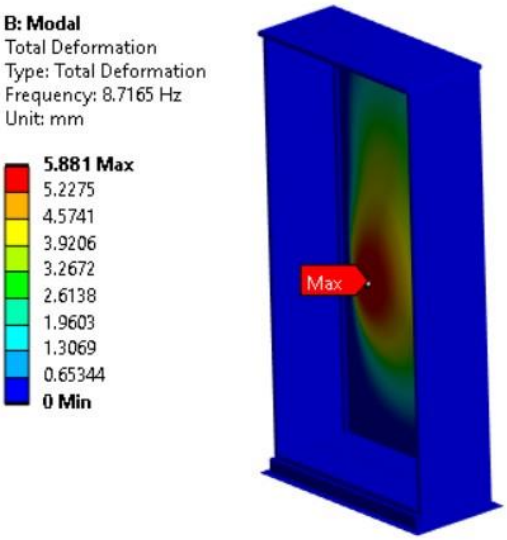
For response spectrum analysis, this modal analysis is a prerequisite. It gives us inputs like,

a) Mode combination method to be used:

List of modal frequencies shows that the modes are not closely spaced, indicating that we need not consider the interaction effect between the modes. Thus, we can use the Square Root of Sum of Squares (SRSS) method for mode combination in response spectrum analysis.

b) Direction in which spectral acceleration has to be applied for the structure:

We observe that the fundamental mode in dominant in Y-direction and hence we apply spectral acceleration along the Y-direction of the Global Coordinate system.



***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION

MODE	FREQUENCY	PERIOD	PARTIC.FACTOR	RATIO	EFFECTIVE MASS	CUMULATIVE MASS FRACTION	RATIO EFF.MASS TO TOTAL MASS
1	8.71653	0.11472	-537.54	1.000000	288950.	0.445296	0.369064
2	10.6190	0.94171E-01	-290.62	0.540651	84461.1	0.575458	0.107879
3	17.4310	0.57369E-01	-19.601	0.036464	384.198	0.576050	0.490721E-03
4	18.7813	0.53244E-01	-12.155	0.022612	147.747	0.576278	0.188711E-03
5	23.8597	0.41912E-01	-75.688	0.140805	5728.71	0.585106	0.731706E-02
6	35.8937	0.27860E-01	27.552	0.051256	759.127	0.586276	0.969604E-03
7	48.1644	0.20762E-01	65.812	0.122431	4331.18	0.592951	0.553205E-02
8	50.8425	0.19669E-01	-1.4428	0.002684	2.08172	0.592954	0.265890E-05
9	53.8674	0.18564E-01	130.84	0.243413	17120.3	0.619338	0.218671E-01
10	55.5033	0.18017E-01	-18.254	0.033958	333.198	0.619851	0.425581E-03
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
sum					640217.		0.941169

Fig. 10. Results of Modal Analysis

3) Results of Seismic Analysis using ELF method

Seismic analysis was conducted using the ELF method for all eight loading cases, as illustrated in Fig. 7. Corresponding stress values were recorded, but only the results for Case-1 and Case-3 are presented in Fig. 11 & 12. The results for the remaining cases have been tabulated in Table II.

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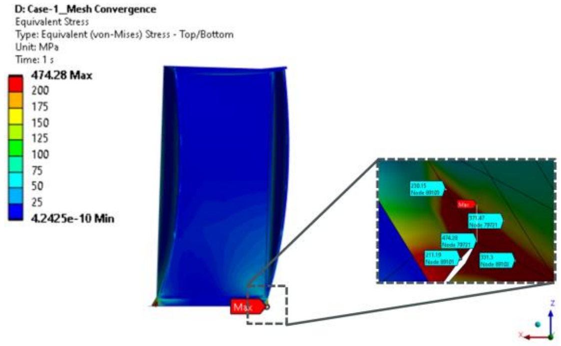

Fig. 11. Results of Case-1: X=3.6g & Z=3.6g

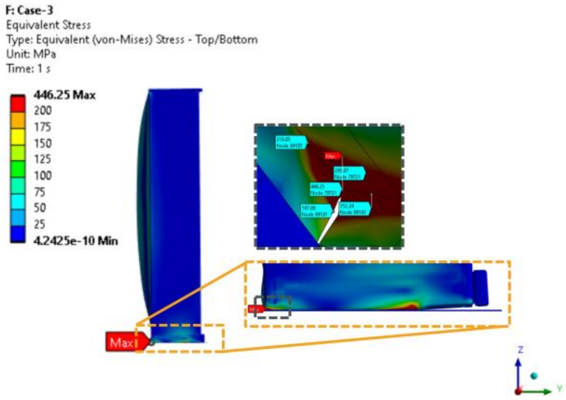

Fig. 12. Results of Case-3: Y=3.6g & Z=3.6g

Loading Cases	Max. Von-Mises stress (MPa)	UTS (MPa)	FOS
Case-1	324	360	1.112
Case-2	312	360	1.153
Case-3	300	360	1.201
Case-4	321	360	1.120
Case-5	328	360	1.099
Case-6	318	360	1.132
Case-7	303	360	1.187
Case-8	315	360	1.144

TABLE II. RESULT SUMMARY OF SEISMIC ANALYSIS USING ELF.

B. *Results of Seismic Analysis using RS method*

The results of the Response spectrum analysis show that the cabinet experiences max. stress when placed in site class D, which represents soft soils or extremely deep soil deposits. The least stress is developed when the cabinet is placed in site class A, which represents the hard rocky surfaces.

Max. stress is developed near the bolting regions of the back plate and side plate as shown in Fig.13. Since the direction of application of spectral acceleration is same for all the site classes (i.e., in the Y-direction), the maximum stress is developed at the same point, with the only difference being the magnitude of the stress developed.

Figure 13 displays the outcomes of the seismic analysis conducted using Response spectrum analysis method.

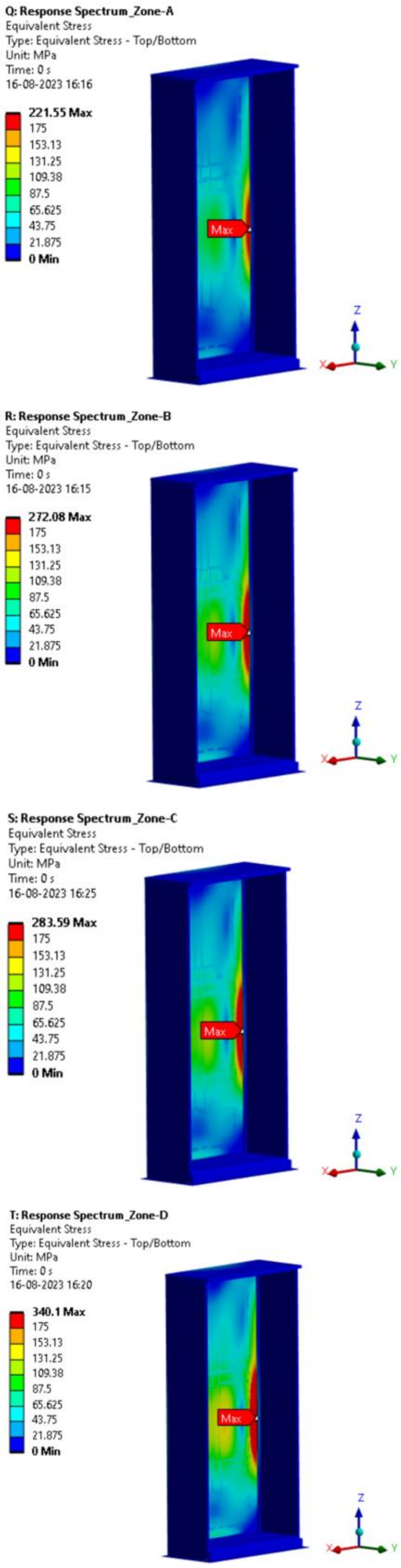

Fig. 13. Results of Seismic Analysis using RS method

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Type of Site Class	Max. Von-Mises stress (MPa)	UTS (MPa)	FOS
Site Class-A	221	360	1.629
Site Class-B	272	360	1.324
Site Class-C	283	360	1.272
Site Class-D	340	360	1.059

TABLE III. RESULT SUMMARY OF SEISMIC ANALYSIS USING RS METHOD

V. CONCLUSIONS:

In this project, a cabinet used in gas delivery systems was modeled, and a seismic analysis was performed to understand the structural integrity of the cabinet. The results obtained during the analysis are as follows:

- During static analysis, the maximum stress developed is around 37 MPa, and an observed Factor of Safety (FOS) of 3.92 was well within the accepted limit.
- Modal analysis resulted in a fundamental natural frequency of the structure at 8.7 Hz, with the fundamental natural frequency being dominant along the Y-direction. Hence, in response spectrum analysis, spectral acceleration is applied along the Y-direction.
- In the Seismic analysis using the Equivalent Lateral Force (ELF) method, higher stresses are developed in the X-directional loading due to the location of the seismic brackets. The maximum stress developed is around 328 MPa in case-5 with an FOS of 1.10, which also falls within industry standards.

In Seismic analysis using the Response Spectrum (RS) method, the maximum stress developed is around 340 MPa for site class D, with an FOS of 1.05, which falls within industry standards. As expected, higher stresses are developed in site class D which represents the soft soil with deep deposits and hence it amplifies ground motions resulting in more significant shaking during earthquakes compared to other site classes.

It can be concluded that for less significant seismic zones, such as locations with site classes A, B, and C, the ELF method can be used to perform seismic analysis for non-structural components, as it is computationally efficient.

However, for critical seismic zones, such as those classified as site class D, ELF method predicts conservative behavior. Therefore, it is better to perform RS analysis and reconfirm the results, as failures of structures in these critical zones are very common.

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