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Structural Integrity Assessment of Genset Structure for Earthquake Loads

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***Abstract*—** Structural integrity assessment is aspect of engineering which deals with the ability of a structure to support operating loads (such as weight, engine generated forces, etc.) without failure, and also includes the study of past structural failures in order to prevent failures in future designs. Integrity of a structure is the ability, to hold together as a single or group of structures, under various operating non-operating loads, including its own weight, without deforming excessively. Sometimes earthquake loads might be responsible for the structural failure of the Genset Structure. Primarily Genset is used as emergency power source but in some cases it needs to be used in rescue operations after earthquake events, so its structure needs to be assessed for Earthquake loads, as it can be used in rescue operations after earthquake events.

***Keywords*—** Genset, Earthquake loads, FEA, Response Spectrum, Structural integrity, Seismicity.

I. INTRODUCTION

All the machineries are designed to withstand various loads, operating and non-operating, without any structural failure. Seismic analysis is the analysis of the structure of Genset for equivalent seismic loads to be withstood. There are two ways to carry out Seismic analysis, Static analysis method and Response Spectrum Analysis method. This paper is based on the Seismic Analysis by Static Analysis method. The motivation to carry out seismic analysis of Genset is that the Genset shall remain in operating conditions even after undergoing an Earthquake. For the post-earthquake rescue operations, the emergency power source will be essentially needed. So, to serve the purpose, it is necessary to ensure safety of a Genset structure during an earthquake. The paper gives idea about Equivalent earthquake load calculation and load combinations for seismic analysis with reference to standard IS 1893 Part 1 and 4. The FEA software used for the analysis is Ansys.

The paper is organized in different sections. Section I introduces the work carried out. Section II contains the derivation of equation of motion for SDOF system. Section III gives idea about the seismic zones of India. Section IV contains methodology of the work carried out. Section V contains the conclusion of the whole work carried out.

II. EQUATION OF MOTION FOR SDOF SEISMIC VIBRATIONS

Consider a SDOF system as shown in **Figure 1**, subjected to an earthquake acceleration, $\ddot{x}g(t)$. Let m, k and c represent the mass, stiffness, and damping, respectively of the SDOF

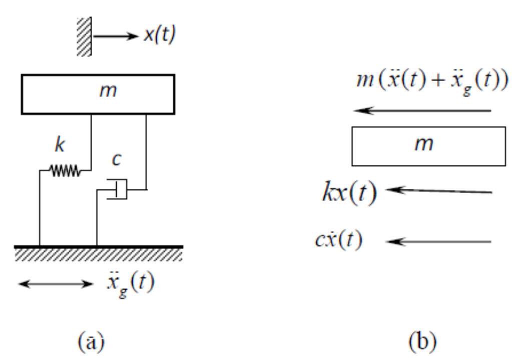

Figure 1: (a) SDOF system (b) Free body diagram. [10]

system undergoing relative displacement, velocity and acceleration of x(t), $\dot{x}(t)$ and $\ddot{x}(t)$ respectively. The various forces acting on the system will be inertial force, stiffness force and damping force. Consider the equilibrium of the various forces acting on the mass, as shown in **Figure 1(b)**, we get,

$$m\ddot{x}(t)+ \ddot{x}_g(t)) +c\dot{x}(t) + kx(t) = 0 \quad (1)$$

$$m\ddot{x}(t)+ \ddot{x}_g(t)) +c\dot{x}(t) + kx(t) = 0 \quad (2)$$

Where, $\ddot{x}(t)$= relative acceleration of mass with respect to ground, $\ddot{x}g(t)$ = earthquake ground acceleration [10].

III. Seismic Zones in India

Depending upon the vulnerability of the earthquake the geographical zones are formed, which are known as seismic zones. They are classified as Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, Zone 6. Indian geographical region is divided in four seismic zones viz. Zone 2, Zone 3, Zone 4, Zone 5 as shown in Fig. 6.5.1 [8,9].

Zone 1 is concerned with low seismicity whereas zone 6 is associated with high seismicity.

Classification of Indian regions into various seismic zones is shown in **Figure 2** [8]. Most of the geographical regions of India fall under zone II and zone III, which indicates the intermediate vulnerability to earthquake.

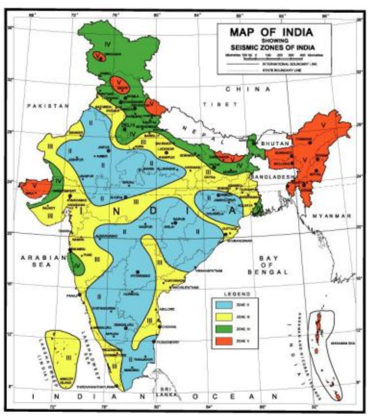

Figure 2: Seismic Zones of India [8]

IV. Methodology

The seismic analysis can be carried out by following steps:

4.1. Calculation of base shear force and Equivalent Earthquake Loads

The base shear force is the horizontal seismic force prescribed by this standard that shall be used to design a structure for earthquake loads. The force is calculated with reference to IS 1893 Part-1: 2016 [8].

4.2. Earthquake Load combination

The load combinations shall be considered as specified in respective standards due to all load effects mentioned therein. It needs to consider Load Combinations to account for three directional earthquake ground shaking. The effects due to vertical earthquake shaking shall be considered when any structure is located in Seismic Zone IV or V [8]. All possible combinations of three components (EL_X, EL_Y, and EL_Z) including variations in sign (plus or minus) shall be considered [8]. Thus, the structure should be designed for the following sets of combinations of earthquake load effects:

a) $\pm EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$, b) $\pm EL_Y \pm 0.3\ EL_Z \pm 0.3\ EL_X$ & c) $\pm EL_Z \pm 0.3\ EL_X \pm 0.3\ EL_Y$,

Where X and Y are orthogonal plan directions and Z vertical direction [8].

This implies that the sets of load combinations involving earthquake effects to be considered shall be as given below:

Table 1: Earthquake Load Calculations

Direction	X	Y	Z	unit
Deformation	27.97	2.86	13.55	mm
Base Shear	2726	1817.33	2726	N
Earthquake Load	4089.00	3452.93	4089.00	N
Dead Load	6057.77			N

1) 1.2 [DL + IL ± ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$)] and 1.2 [DL + IL ± ($EL_Y \pm 0.3\ EL_X \pm 0.3\ EL_Z$)];
2) 1.5 [DL ± ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$)] and 1.5 [DL ± ($EL_Y \pm 0.3\ EL_X \pm 0.3\ EL_Z$)]; and
3) 0.9 DL ± 1.5 ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$) and 0.9 DL ± 1.5 ($EL_Y \pm 0.3\ EL_X \pm 0.3\ EL_Z$).

Where DL= Dead Load, IL= Imposed Load, EL= Earthquake Load in X, Y and Z direction [8].

All the load sets need to be applied in both the horizontal directions, one at a time as per Cl. 6.3.2.1.

Directional deformations in X (horizontal), Y (vertical) and Z (horizontal) directions under the load applied equal to the weight of the structure i.e. 1g load are Shown in **Table 1**.

Base shear in each direction and earthquake loads in X (horizontal), Y (vertical) and Z (horizontal) directions are also Shown in **Table 1**.

As per IS 1893 Part 1: 2016, it is recommended to use maximum of all the three earthquake loads to calculate combined load to be used for the analysis [8].

The possible load combinations using values in **Table 1** are shown in Table 2.

Table 2: Possible Load Combinations

Sr. No.	Load Combination Formulae	Calculated Values	Unit
1)	1.2 [DL + IL ± ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$)]	12176.13	N
2)	1.5 [DL ± ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$)]	15220.16	N
3)	0.9 DL ± 1.5 ($EL_X \pm 0.3\ EL_Y \pm 0.3\ EL_Z$)	11585.49	N

Now using maximum values of loads calculated, the analysis can be carried out in Ansys static structural analysis system.

4.3. Simulation in Ansys

The geometry model used for analysis is shown in **Figure 3**. It shows the canopy of the Genset.

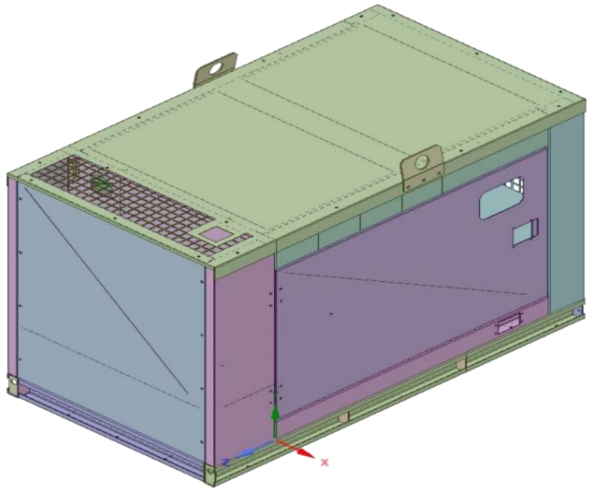

Figure 3: Input model of Genset

All components of the Genset are shown in **Figure 4**. The FEA modelling operations carried out using various tools in the Ansys. The operations like extraction of mid-surfaces, cleaning up geometry by removing extra edges, chamfers, fillets, etc., are carried out. Body to body connectivity and shared topology are the major things to consider in the FEA modelling of the Genset. Meshing of model is done as shown in **Figure 5**.

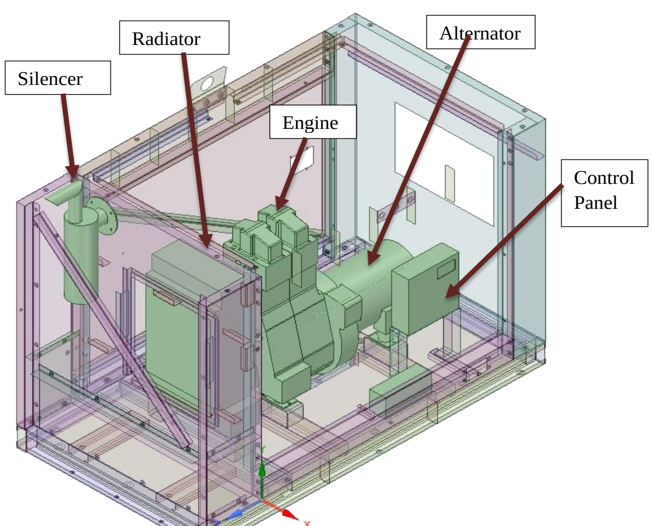

Figure 4: Genset Components

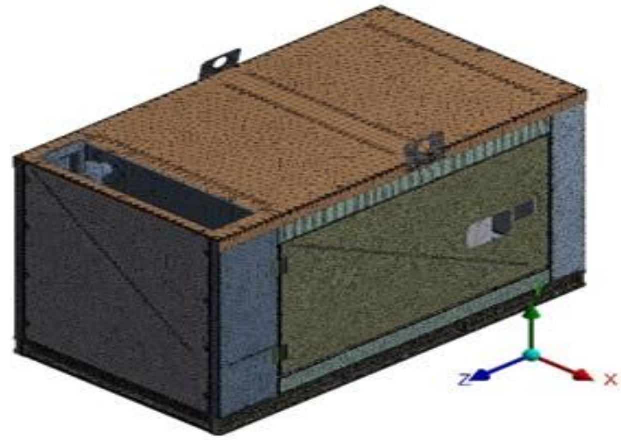

Figure 5: Meshed Model

Various elements like SHELL181, BEAM188, MASS 21, SOLID186, etc. are used for the meshing of the Model.

The loading and boundary conditions used for the analysis is as shown in **Figure 6, 7 and 8**.

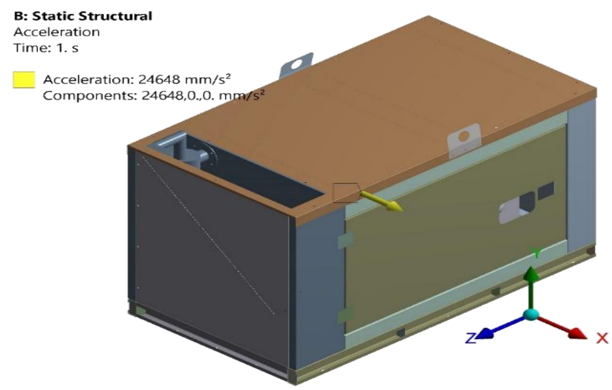

Figure 6: Load in X-direction

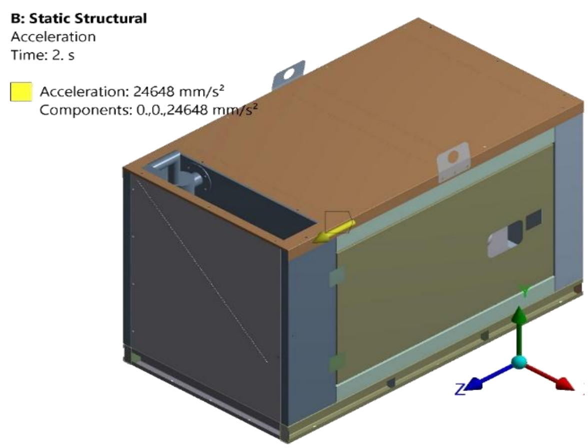

Figure 7: Load in Z-direction

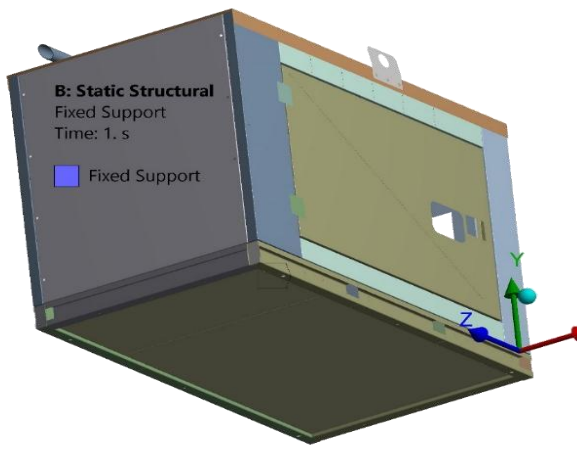

Figure 8: Fixed Supports at the bottom

Figure 6 and 7, shows the load applied in X-direction and Z-direction respectively. The loads are applied in terms of acceleration loads, which are calculated with reference to IS-1893 Part 1: 2016.

Boundary conditions are applied as fixed supports at the bottom of Genset structure, as shown in **Figure 8**.

4.4. Result Discussion

After carrying out the analysis in Ansys Static Structural analysis system, the following result plots are obtained. The result plots are shown with description below. The description contains the values of displacements and stresses obtained.

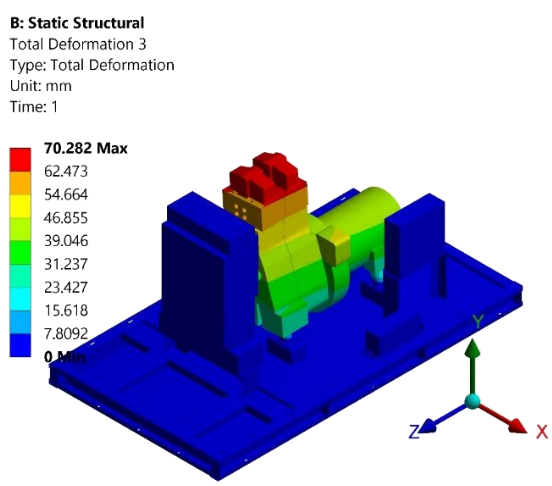

Figure 9: Total Deformation X-direction

Figure 9 shows the Total deformation plot in X-direction of the system. The maximum Total deformation value is 70.28 mm on the engine block.

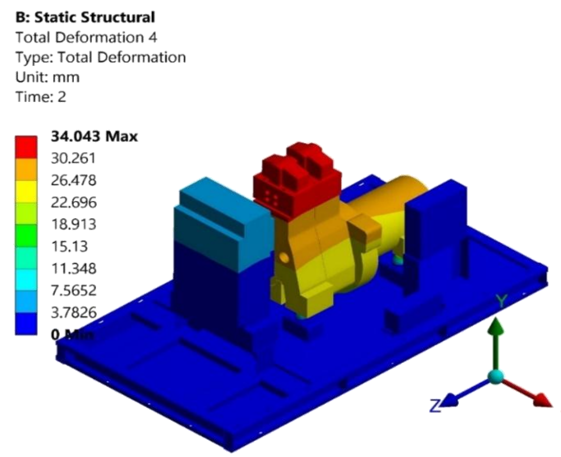

Figure 10: Total Deformation Z-direction

Figure 10 shows the Total deformation plot in Z-direction of the system. The maximum Total deformation value is 34.043 mm on the engine block.

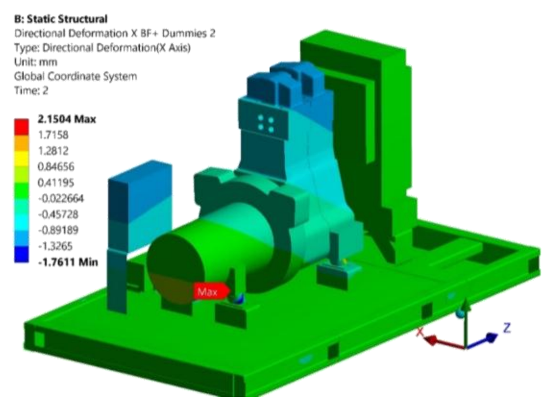

Figure 11: Directional Deformation X-direction

Figure 11 shows the Directional deformation plot in X-direction of the system. The maximum Directional deformation (X-Direction) value is 2.15 mm on the AVM.

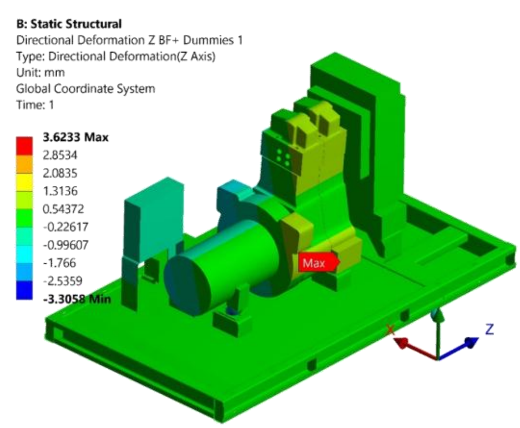

Figure 12: Directional Deformation Z-direction

Figure 12 shows the Directional deformation plot in Z-direction of the system. The maximum Directional deformation (Z-Direction) value is 3.62 mm on the AVM.

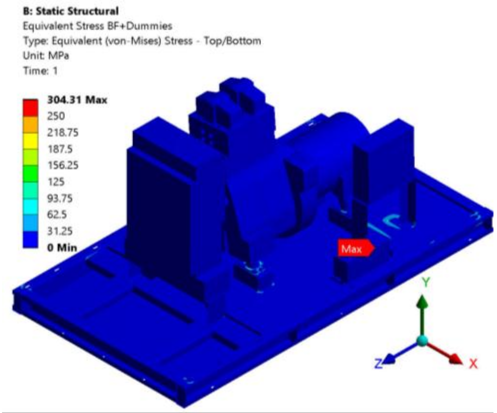

Figure 13: Equivalent Stress in X-direction

von-Mises Stress (SEQV) are within permissible limit at all the regions except in the region of the Control Panel mounting, where stresses exceeds the material permissible limit due to localised stress singularity, under the action of EQ load (2.51G).

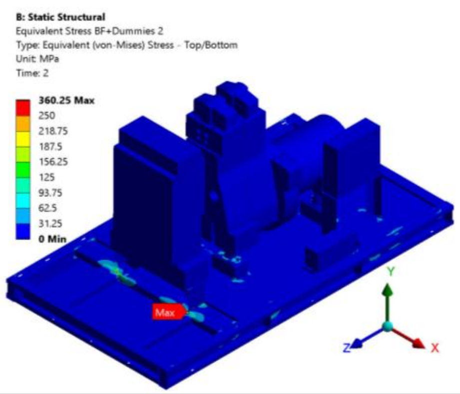

Figure 14: Equivalent Stress in Z-direction

von-Mises Stress (SEQV) are within permissible limit at all the regions except in the region of the Radiator mounting, where stresses exceeds the material permissible limit due to localised stress singularity, under the action of EQ load (2.51G).

V. Conclusion

The paper demonstrates the process of calculation of earthquake loads and various load combinations.
It also illustrates the procedure of analysis in Ansys static structural analysis system.

As per the results of the analysis, stresses in the genset model are found within permissible material limit but Some areas show higher value of stresses due to localised stress singularity and can be neglected.

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