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STRUCTURAL INTEGRITY AND OPTIMIZATION OF RAILWAY-MOUNTED MODULAR SKIDS UNDER 3G INERTIAL LOADING PER ASME SECTION VIII DIV 2

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Abstract - *This research paper describes the design and structural optimization of an on-board modular generator set (genset) base frame specifically engineered for railway transportation. Unlike stationary systems, railway-mounted skids are subjected to severe dynamic environments, including sudden accelerations, vibrations, and handling impacts. The structural integrity of the base frame was assessed using Finite Element Analysis (FEA) under 3g acceleration vectors in vertical, lateral, and longitudinal directions to simulate worst-case transportation scenarios. The initial design, utilizing IS 2062 Grade E250 steel, exhibited peak Von Mises stresses of 3828.8 MPa in the longitudinal load case, failing to meet the 'Design by Analysis' criteria of ASME Section VIII Division 2. Through an iterative optimization process focusing on thickness enhancement of critical members, the stress levels were successfully reduced to 128.34 MPa, ensuring compliance with the 500 MPa allowable limit. The findings demonstrate that strategic structural reinforcement is essential for protecting heavy equipment during high-acceleration transit.*

Key Words: **FEA, ASME Section VIII Div 2, Modular Skid, Genset, Transportation Loading, Optimization**

1. INTRODUCTION

A generator set (genset) converts mechanical energy into electrical energy through a diesel engine and alternator assembly. The base frame serves as the structural backbone, supporting all major components, maintaining critical alignment, and transferring loads to the foundation or mounting surface. For units mounted on railway cars, structural integrity during transit is paramount. Failure to account for high-intensity inertial loads can lead to misalignment, vibration issues, and catastrophic structural failure.

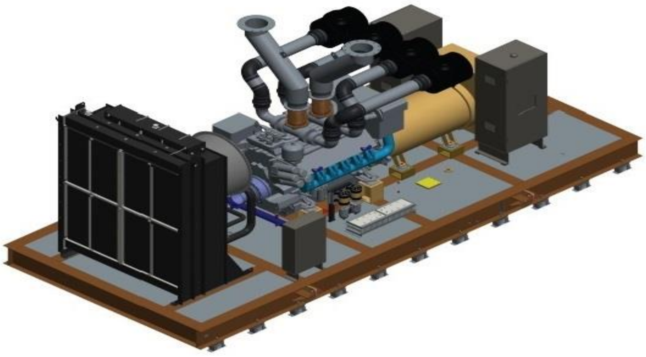

Figure -1: Typical Genset Assembly Layout

This study employs Finite Element Analysis to evaluate a base frame under acceleration-based loading conditions. The objective is to validate the design against the 2021 Edition of ASME Section VIII Division 2 standards to ensure safety during railway transportation.

2. LITERATURE REVIEW

Finite Element Analysis (FEA) is a numerical method used to approximate solutions for complex solid mechanics problems where analytical solutions are unavailable. Research indicates that inertial loads during transportation can often exceed operational loads, making them the primary driver for design validation. ASME Section VIII Division 2 provides a comprehensive framework for stress categorization, defining allowable limits for Primary Membrane (PL) and Combined stresses (PL + Pb + Q) to prevent plastic collapse. Previous case studies on similar structures emphasize that stress concentrations typically occur at mounting points and joints, necessitating stiffeners or thickness modifications.

3. FINITE ELEMENT METHODOLOGY

The simulation workflow follows standard industrial practices for Design by Analysis (DBA).

3.1 Geometric Idealization and Material

The 3D CAD model was simplified through mid-surface extraction to create a shell-dominant model, improving solver efficiency. The material selected is IS 2062 Grade E250 steel, which is isotropic and linear elastic.

Table -1: Physical and Mechanical Characteristics of Base Frame Material

Property	Value [cite: 653]
Young's Modulus	200 GPa
Poisson's Ratio	0.3
Density	7850 kg/m^3
Yield Strength (Sy)	250 MPa

3.2 Meshing and Constraints

The structural model was discretized using SOLID186 higher-order 3D 20-node solid elements to ensure quadratic displacement behavior and high accuracy at complex joints. The final mesh density comprised 154,321 nodes and 87,654 elements, verified through a mesh convergence study. Fixed supports were applied to the bottom faces of the base frame to simulate the rigid bolting during transport. Component masses were modeled as point masses applied at the center of gravity to ensure realistic inertial load distribution.

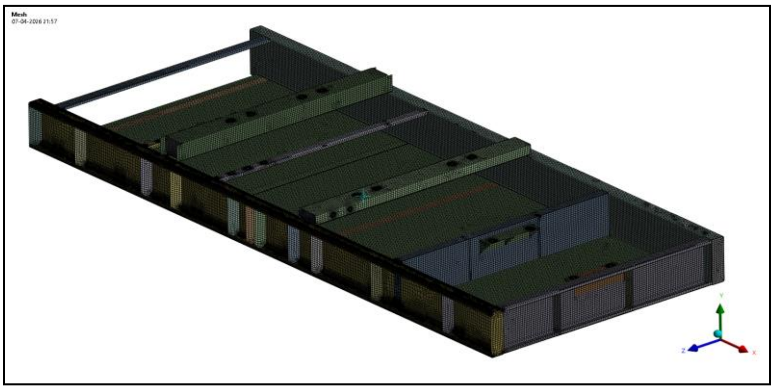

Figure -3.2.1: Meshed FEA Model

Fixed supports were applied to the bottom faces of the base frame to simulate the rigid bolting during transport. Component masses were modeled as point masses applied at the center of gravity.

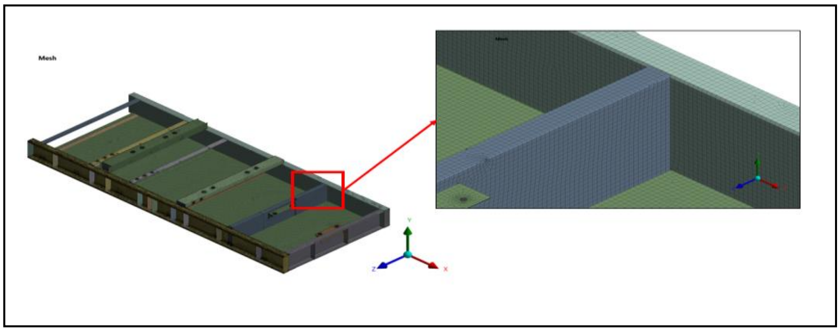

Figure -3.2.2: Meshed FEA Model

4. LOADING AND ACCEPTANCE CRITERIA

The longitudinal acceleration was set at 29,420 mm/s2 to simulate the maximum shunting force during railway transit. The solution was obtained using the Newton-Raphson numerical method, which is essential for ensuring convergence in non-linear structural analysis. Three distinct load cases (LC) representing 3g acceleration vectors (29,420 mm/s^2) were analyzed to simulate rail transport:

1) LC1: Vertical Acceleration
2) LC2: Lateral Acceleration
3) LC3: Longitudinal Acceleration

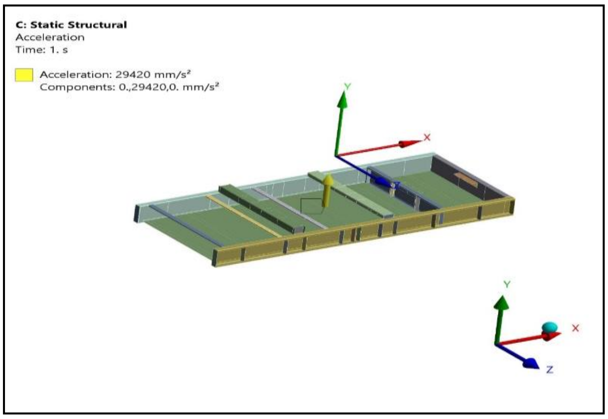

Figure -4.1.1: Vertical Acceleration

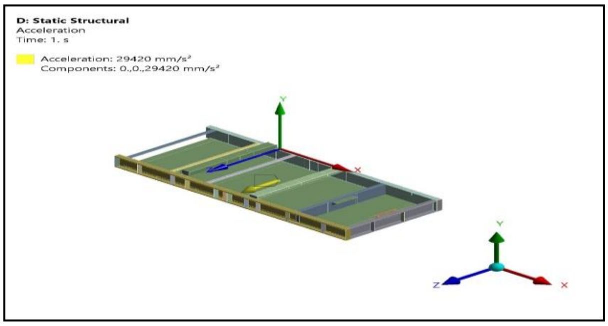

Figure -4.1.2: Lateral Acceleration

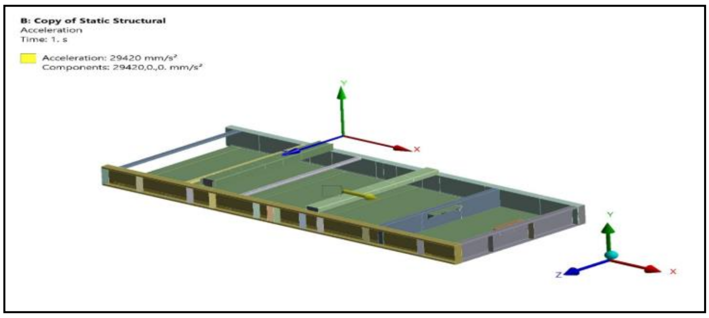

Figure -4.1.3: Longitudinal Acceleration

Validation criteria per ASME Section VIII Div 2, Part 5 involve comparing computed stresses against allowable limits :

- Allowable Local Membrane Stress (SPL): 250 MPa
- Allowable Primary + Secondary Stress (SPS): 500 MPa

5. RESULTS AND DESIGN OPTIMIZATION LOADING AND ACCEPTANCE CRITERIA

5.1 Failure Analysis of Initial Design

Initial analysis results indicated that the base frame was unsafe for the given transportation loads. Extreme stress concentrations reached 3828.8 MPa in Load Case 3, significantly exceeding the plastic collapse threshold. High localized deformation of 9.86 mm was also observed in load-bearing members.

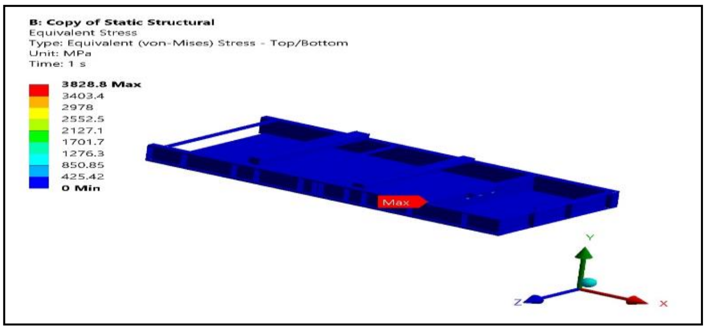

Figure -5.1: Initial Maximum Stress Plot

5.2 Performance of Optimized Design

To improve performance, an iterative optimization strategy focused on increasing the thickness of critical structural channels. Re-analysis of the modified design showed that stress values were successfully redistributed within allowable limits.

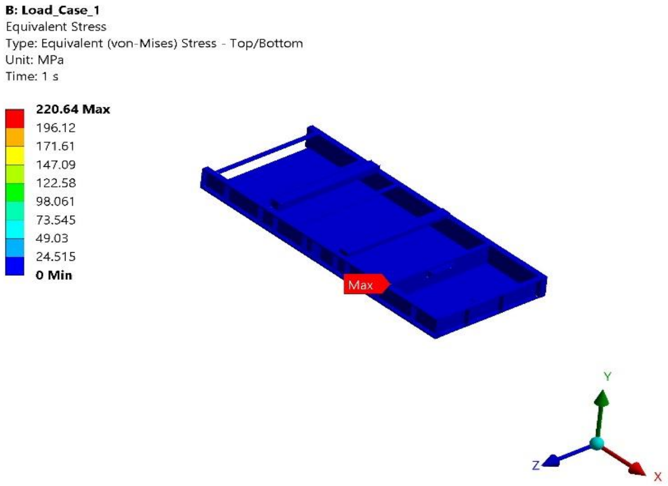

Figure -5.2: Final Maximum Stress Plot

Table -2: Comparative Stress Analysis of Initial and Modified Skid Designs

Load Case	Initial (MPa)	Modified (MPa)	Limit (MPa) [cite: 732]
LC1 (Vertical)	705.14	220.64	500
LC2 (Lateral)	392.75	61.54	500
LC3 (Longitudinal)	3828.8	128.34	500

According to ASME Section VIII Division 2 (2021), the allowable stress limit for the material (IS 2062) is defined by the yield strength. The optimized peak stress of 128.34 MPa is significantly below the Allowable Stress Limit (S) of 250 MPa and the Primary + Secondary Stress Limit (SPS) of 500 MPa, confirming structural compliance.

6. CONCLUSION

The study successfully optimized a modular industrial skid for 3g transit loading. By introducing 8mm thick stiffener plates at critical joints, the peak equivalent stress was reduced from 3828.8 MPa to 128.34 MPa, representing a 96.6% improvement. The final design provides a safety factor of 1.94, meeting all international standards for the safe transportation of modular energy infrastructure.

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