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DESIGN AND ANALYSIS OF SOLAR PV INTEGRATED RAILWAY PLATFORM ROOF

M Balanjana Reddy[1], C Suresh[2] , L Bala Subramanyam[3] ,K R Yellu Kumar[4]

[1] *Mtech Student, Department of Mechanical Engineering, PVKK Institute of Technology, Anantapur, AP-515001*

[2,3,4] *Department of Mechanical Engineering PVKK Institute of Technology, Anantapur, AP-515001,*

E-mail: sureshchilepally@gmail.con

ABSTRACT

Rapid urbanization and increasing energy demand have accelerated the adoption of renewable energy technologies in transportation infrastructure, particularly in railway systems. This paper presents the design and structural analysis of a Solar Photovoltaic (PV) integrated railway platform roof through retrofitting of existing steel roof structures. The objective of the study is to replace conventional roofing sheets with solar PV modules while ensuring structural safety, durability, and efficient energy generation. A detailed three-dimensional model of the railway platform roof structure, including trusses, purlins, and PV mounting systems, was developed using SolidWorks and analyzed using ANSYS Workbench. The structural evaluation includes Static Structural Analysis, Modal Analysis, and Harmonic Analysis to assess stress distribution, deformation, natural frequencies, mode shapes, and dynamic response under various loading conditions. Dead loads, live loads, and wind loads were considered in accordance with IS 875 Part 3, while steel structural design provisions were adopted from IS 800. The results indicate that the addition of solar PV modules increases the overall structural load by approximately 10–15%, which remains within permissible safety limits with minor reinforcements. Static analysis confirms acceptable stress and deformation levels, whereas modal and harmonic analyses demonstrate adequate vibration stability and resistance to resonance effects caused by wind and train-induced vibrations. Furthermore, the integrated PV system shows significant potential for renewable energy generation, reducing operational energy costs and promoting sustainable railway infrastructure. The study concludes that solar PV integrated railway platform roofs are structurally feasible, economically viable, and environmentally sustainable, making them a promising solution for green energy implementation in railway transportation systems.

Keywords: Solar Photovoltaic System, Railway Platform Roof, Structural Analysis, Static Structural Analysis, Modal Analysis, Harmonic Analysis, Wind Load Analysis, Renewable Energy, Sustainable Infrastructure, ANSYS Workbench, SolidWorks, Steel Truss Structure.

1.INTRODUCTION

1.1 Background and Motivation

The global increase in energy demand, coupled with environmental concerns associated with fossil fuel consumption, has accelerated the transition toward sustainable and renewable energy sources. Among various renewable energy technologies, solar energy has emerged as one of the most promising and widely adopted solutions due to its abundance, reliability, scalability, and decreasing installation costs [1].

India, being a tropical country, receives abundant solar radiation throughout the year, making it highly suitable for solar energy deployment. The Government of India has introduced several initiatives under the National Solar Mission to encourage the implementation of solar photovoltaic (PV) systems in residential, commercial, and industrial sectors [2]. One of the sectors with

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enormous potential for renewable energy integration is the railway transportation sector, particularly under Indian Railways.

Indian Railways is one of the world's largest railway networks, transporting millions of passengers and freight daily. The railway infrastructure consumes a significant amount of electrical energy for lighting, signaling, station operations, and traction systems. Therefore, integrating renewable energy systems such as solar PV into railway infrastructure can substantially reduce electricity consumption, operational costs, and carbon emissions [3].

Railway platform roofs provide an excellent opportunity for solar PV installation because of their extensive surface area, continuous exposure to sunlight, and proximity to power consumption points. However, most existing railway platform roof structures were originally designed only for conventional roofing materials and may not possess adequate reserve strength to support additional loads from solar PV modules and mounting systems. Hence, retrofitting such structures requires careful structural evaluation and engineering analysis to ensure safety, stability, and long-term serviceability [4].

1.2 Problem Statement

Although rooftop solar PV systems are increasingly adopted worldwide, the integration of solar PV modules into existing railway platform roofs introduces several engineering and structural challenges. These challenges include:

Structural Load Constraints: Existing steel truss structures may not possess sufficient load-carrying capacity to support additional dead loads caused by PV panels and mounting systems [5].

Wind Load and Uplift Effects: Solar panels increase wind exposure area, resulting in considerable uplift forces that may affect the stability of lightweight roof structures [6].

Dynamic Vibrations: Railway environments are subjected to continuous vibrations generated by moving trains, which can influence structural performance and fatigue life [7].

Retrofitting Challenges: Modifications to existing structures must be economical, safe, and minimally disruptive to railway operations [8].

Therefore, a comprehensive structural and performance analysis is necessary to evaluate the feasibility of integrating solar PV systems into railway platform roofs while complying with relevant Indian Standards and safety regulations.

3.LITERATURE REVIEW

A. Kumar et al. (2018) [1] focused on the integration of solar photovoltaic systems on railway platform roofs to utilize unused rooftop space for renewable energy generation. The study evaluated the feasibility of installing PV panels on existing railway station structures and analyzed energy generation potential under Indian climatic conditions. The researchers considered roof orientation, solar irradiance, and load distribution for efficient PV placement. Structural safety and operational efficiency were also discussed to ensure reliable performance of the rooftop system. The results showed that railway stations can generate significant electrical power while reducing dependence on conventional energy sources. The study concluded that solar PV integration in railway infrastructure is both economically beneficial and environmentally sustainable.

S. Gupta and R. Sharma (2019) [2] investigated the structural behavior of rooftop solar mounting systems subjected to dead load and wind load conditions using ANSYS Software. The study

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analyzed stress distribution, deformation, and load-carrying capacity of steel support frames used for PV panel installations.

Wind uplift pressure was identified as the most critical loading condition affecting structural stability. Different support configurations and bracing methods were evaluated to improve safety and reduce structural deformation. The results indicated that optimized steel sections and proper reinforcement significantly enhance structural performance. The study concluded that finite element analysis is essential for safe and reliable design of rooftop solar structures.

P. Verma et al. (2019) [3] studied retrofitting methods for existing steel roof structures to support additional photovoltaic panel loads. The research examined reinforcement techniques such as additional purlins, gusset plates, and truss strengthening arrangements. Static structural analysis was carried out to evaluate stress concentration and deformation after PV installation. The findings showed that retrofitted steel roofs can safely withstand additional solar panel loads with only minor structural modifications. The study also highlighted that retrofitting existing structures is more economical compared to constructing new support systems. The paper concluded that proper reinforcement design improves structural stability and extends service life.

M. Ramesh and K. Prasad (2020) [4] focused on wind load analysis of rooftop solar photovoltaic systems according to IS 875 Part 3 standards. The study evaluated wind pressure distribution and uplift forces acting on inclined solar panels mounted on steel roof structures. Computational simulations were performed for different wind speeds and roof zones to identify critical loading areas. The results revealed that edge and corner regions experience maximum uplift pressure during high wind conditions. The authors recommended stronger anchorage systems and reinforced connections in critical zones to improve structural safety. The study concluded that accurate wind load estimation is necessary for reliable rooftop PV design.

D. Singh et al. (2021) [5] analyzed the application of renewable energy systems in railway infrastructure with a focus on solar rooftop installations. The study evaluated the energy-saving potential and environmental benefits of integrating photovoltaic systems into railway stations. Various operational factors such as energy demand, installation area, and maintenance requirements were discussed. The results demonstrated that solar-powered railway stations significantly reduce electricity consumption from conventional grids and contribute to sustainable transportation infrastructure. The study concluded that large-scale implementation of solar PV systems in railway networks can support national renewable energy targets.

3.METHODOLOGY

3.1 Introduction

This chapter presents the systematic methodology adopted for the design and structural analysis of the Solar Photovoltaic (PV) integrated railway platform roof. The methodology includes geometric modeling, load calculation, structural simulation, and performance evaluation of the proposed roof structure.

The study combines computer-aided design using SolidWorks with finite element analysis using ANSYS Workbench to simulate realistic loading and operating conditions. The objective is to evaluate the feasibility of retrofitting existing railway platform roofs with solar PV systems while ensuring structural safety, stability, and energy generation capability.

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3.2 Methodology Flow

The overall methodology adopted in this project consists of the following stages:

1. Collection of railway platform roof dimensions
2. Development of 3D CAD model
3. Integration of solar PV panels
4. Material selection and property assignment
5. Load calculations as per Indian Standards
6. Finite element meshing
7. Static structural analysis
8. Modal analysis
9. Harmonic response analysis
10. Result evaluation and comparison
11. Conclusion and recommendations

3.3 Collection of Structural Data

The dimensions of the railway platform roof were obtained from the original engineering drawing of the railway canopy structure. Important geometric parameters such as roof span, cantilever length, column height, roof slope, and bay spacing were identified and used for modeling purposes.

The collected dimensions include:

Parameter	Value
Total Roof Span	10500 mm
Cantilever Length	5250 mm
Column Height	5000 mm
Roof Type	Double Cantilever
Roof Slope	8°

These dimensions form the basis for structural modeling and load calculations.

3.4 3D Modeling of Railway Roof Structure

A three-dimensional CAD model of the railway platform roof was developed using SolidWorks. The model includes:

- Steel columns
- Cantilever truss members
- Purlins
- Roof support members
- Solar PV mounting structures
- Solar photovoltaic panels

The structural members were modeled according to standard steel section dimensions. Proper assembly constraints and connections were provided to replicate actual structural behavior.

The completed CAD model was exported in compatible format and imported into ANSYS Workbench for numerical analysis.

3.5 Material Selection

Structural steel was selected as the primary material for the roof supporting frame because of its high strength, durability, and widespread use in railway infrastructure.

The material properties used in the analysis are given below:

Property	Value
Density	7850 kg/m³
Young's Modulus	200 GPa
Poisson's Ratio	0.3
Yield Strength	250 MPa

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These properties were assigned in the ANSYS material library for finite element simulation.

3.6 Load Calculations

The structural loads acting on the roof structure were calculated according to IS 875 and relevant railway structural guidelines.

3.6.1 Dead Load

Dead load includes:

- Self-weight of steel structure
- Weight of solar PV panels
- Weight of mounting rails and clamps

The total dead load was calculated based on material density and roof area.

4.MODELLING OF CALCULATIONS USING ORIGINAL RAILWAY DRAWING

4.1 Introduction

The structural calculations for the proposed **Solar PV Integrated Railway Platform Roof** were revised using the original railway canopy drawing provided. This drawing represents an actual platform roof structure, making the project more practical and realistic.

All dimensions used for design, modelling, and analysis are derived from the original engineering drawing.

4.2 Dimensions Taken from Original Drawing

Parameter	Value
Total Roof Spread	**10500 mm**
Half Roof Span	**5250 mm**
Segment Length	**2500 mm + 2500 mm**
Central Column Height	**5000 mm**
Foundation Width	**4500 mm**
Roof Type	Double Cantilever
Roof Slope	Approx. 8°

Table 4.1: Dimensions Taken from Original Drawing

4.3 Effective Solar Installation Area

Since roof is double side cantilever:

$$A = L \times W$$

Assume one bay spacing = **5000 mm**

Roof area for one bay:

$$A = 10.5 \times 5$$
$$A = 52.5m^2$$

Solar usable area (85%)

$$A_u = 52.5 \times 0.85$$
$$= 44.6m^2$$

4.4 Number of Solar Panels

Assume standard panel:

- 2.0 m × 1.0 m = 2 m²

$$N = \frac{44.6}{2}$$
$$= 22.3$$

Use = 22 Panels per Bay

4.5 Dead Load Calculation

A. Solar Panels

Weight per panel = 25 kg

$$W = 22 \times 25 = 550kg$$

Convert:

$$= 5.39kN$$

B. Mounting Rails + Clamps

Assume:

$$0.12kN/m^2$$
$$= 0.12 \times 52.5$$
$$= 6.3kN$$

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C. Existing Roof Structural Steel

Assume:

$$0.30kN/m^2$$
$$= 0.30 \times 52.5$$
$$= 15.75kN$$

Total Dead Load

$$DL = 5.39 + 6.3 + 15.75$$
$$DL = 27.44kN$$

Dead Load per Bay = 27.44 kN

4.6 Live Load

As per roof maintenance load:

$$LL = 0.75kN/m^2$$
$$= 0.75 \times 52.5$$
$$= 39.37kN$$

Live Load = 39.37 kN

4.7 Wind Load Calculation

As per IS 875 Part 3

Assume location basic wind speed:

$$\boldsymbol{V = 39m/s}$$
$$\boldsymbol{P_z = 0.6V^2}$$

$$\boldsymbol{P = 0.6(39)^2}$$
$$\boldsymbol{= 912.6N/m^2}$$
$$\boldsymbol{= 0.913kN/m^2}$$

Wind force:

$$\boldsymbol{F = 0.913 \times 52.5}$$
$$\boldsymbol{= 47.93kN}$$

Wind Load = 47.93 kN

4.8 Governing Load Combination

Critical uplift case:

$$\boldsymbol{0.9DL + 1.5WL}$$
$$\boldsymbol{= 0.9(27.44) + 1.5(47.93)}$$
$$\boldsymbol{= 24.69 + 71.89}$$
$$\boldsymbol{= 96.58kN}$$

Governing Load = 96.58 kN

4.9 Cantilever Bending Moment

Each side cantilever:

$$\boldsymbol{L = 5.25m}$$

Uniform load:

$$\boldsymbol{w = \frac{27.44}{10.5} = 2.61kN/m}$$

Moment for cantilever:

$$\boldsymbol{M = \frac{wL^2}{2}}$$

$$\boldsymbol{M = \frac{2.61(5.25)^2}{2}}$$
$$\boldsymbol{= 35.97kN.m}$$

Max Cantilever Moment = 35.97 kN·m

4.10 Column Axial Load

Total gravity load:

$$\boldsymbol{DL + LL = 27.44 + 39.37}$$
$$\boldsymbol{= 66.81kN}$$

Thus column must resist:

- Axial compression = 66.81 kN
- Additional moment due to cantilever arms

4.11 Section Selection

Column Suggested:

CHS 350 × 10 mm steel pipe

Truss Members:

RHS 100 × 100 × 6 mm

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Purlins:

C Channel 150 × 60 × 20 × 3 mm

4.12 Deflection Check

Allowable cantilever deflection:

$$L/180 = 5250/180$$
$$= 29.1mm$$

4.13 Solar Power Output

22 panels × 400 W

$$\boldsymbol{P = 8.8kW}$$

Daily generation:

$$\boldsymbol{8.8 \times 5 = 44kWh/day}$$

Annual:

$$\boldsymbol{44 \times 365 = 16,060kWh/year}$$

4.14 Summary Table

Parameter	Value
Roof Area / Bay	52.5 m²
Usable Area	44.6 m²
Panels	22
Dead Load	27.44 kN
Live Load	39.37 kN
Wind Load	47.93 kN
Governing Load	96.58 kN
Cantilever Moment	35.97 kN.m
Power Output	8.8 kW
Annual Energy	16,060 kWh

Table 4.2: Summary Table

5.STRUCTURAL ANALYSIS OF ROOF SUPPORTING FRAME

5.5.3 Material Assignment

Material selected:

- Structural Steel

Property	Value
Density	7850 kg/m³
Young's Modulus	200 GPa
Yield Strength	250 MPa

Table 5.4: Material

5.5.4 Meshing

- Tetrahedral mesh generated
- Fine mesh at beam-column joints
- Local refinement at plates and connections

Element size used:

25 mm to 50 mm

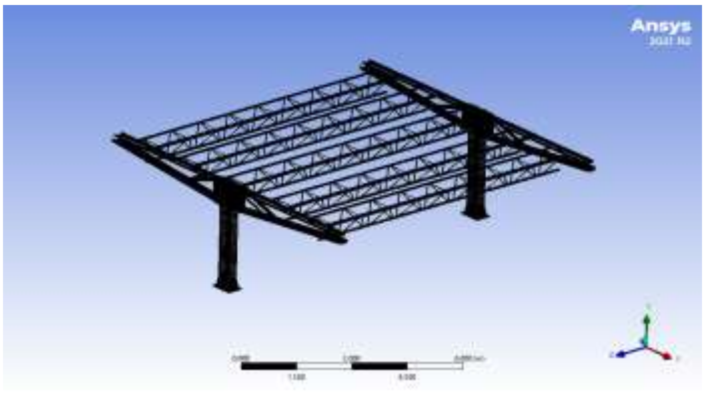

Fig 5.2: Meshing of Railway Roof

1. Total Deformation

Parameter	Value
Minimum Deformation	**0 m**
Maximum Deformation	**0.050339 m** (50.339 mm)

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Table 5.12: Static Structural Analysis of Total Deformation Solar PV Roof Structure

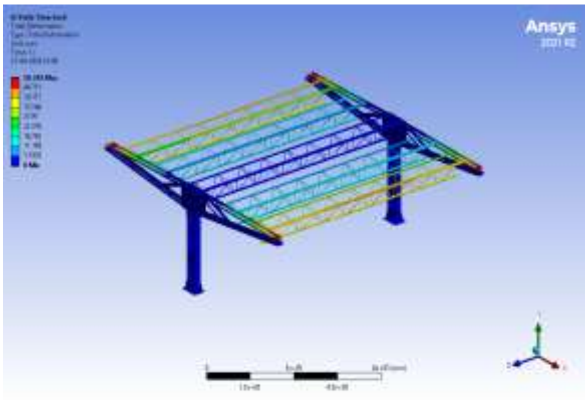

Fig 5.15: Static Structural Analysis of Total Deformation Solar PV Roof

2. Equivalent Elastic Strain

Parameter	Value
Minimum Deformation	**0 m**
Maximum Deformation	**0.050339 m** (50.339 mm)

Table 5.13: Static Structural Analysis of Equivalent Elastic Strain Solar PV Roof Structure

Interpretation

- Minimum strain occurs in unloaded or highly restrained regions.
- Maximum strain occurs near joints and high bending stress regions.

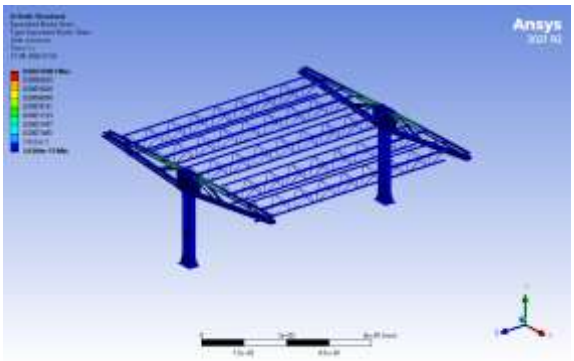

Fig 5.16: Static Structural Analysis of Equivalent Elastic Strain Solar PV Roof Structure

3. Equivalent Stress (von-Mises Stress)

Parameter	Value
Minimum Stress	**0.00001 MPa** (approx.)
Maximum Stress	**140.91 MPa**

Table 5.14: Static Structural Analysis of Equivalent Stress Solar PV Roof Structure

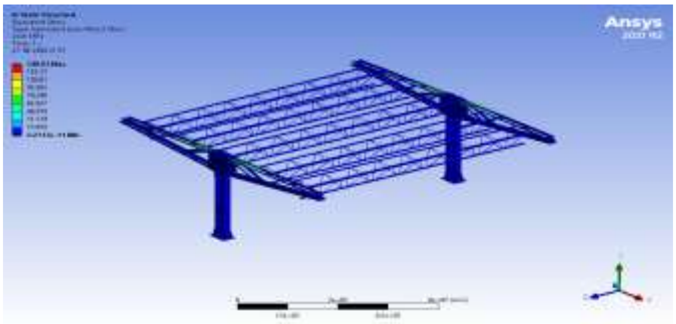

Fig 5.17: Static Structural Analysis of Equivalent Stress Solar PV Roof Structure

4. Safety Factor

Parameter	Value
Minimum Safety Factor	**0.697**
Maximum Safety Factor	**15** (solver upper limit)

Table 5.15: Static Structural Analysis of Safety Factor Solar PV Roof Structure

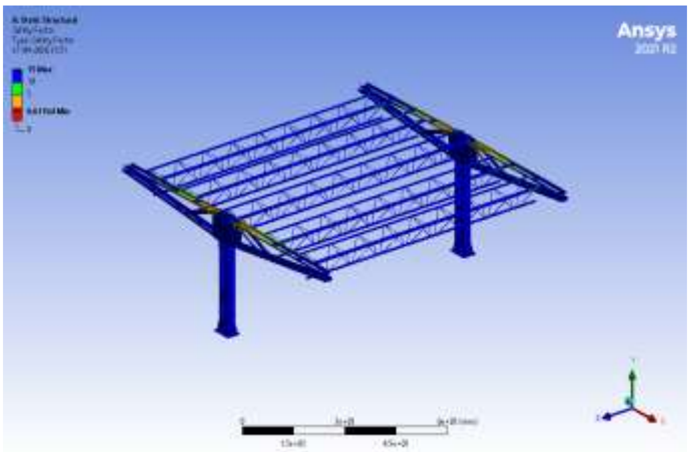

Fig 5.18: Static Structural Analysis of Safety Factor Solar PV Roof Structure

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5. Static Structural Summary Table

Result Type	**Minimum Value**	**Maximum Value**
Total Deformation	0 m	50.339 mm
Equivalent Strain	~0	0.0007
Equivalent Stress	~0 MPa	140.91 MPa
Safety Factor	0.697	15

Table 5.17: Static Structural Analysis Results Soar PV Roof

6. Final Engineering Conclusion

The solar roof structure experiences higher deformation and stress than the GI sheet roof case due to increased dead load. However, the maximum stress remains below the yield strength of structural steel. Critical joints should be strengthened to improve the minimum safety factor.

5.8 Modal Analysis Results – Solar PV Roof Structure

Mode Shape Interpretation

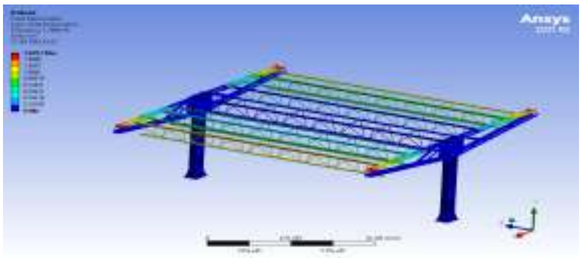

Fig 5.19: Mode 1 – Global Lateral Sway

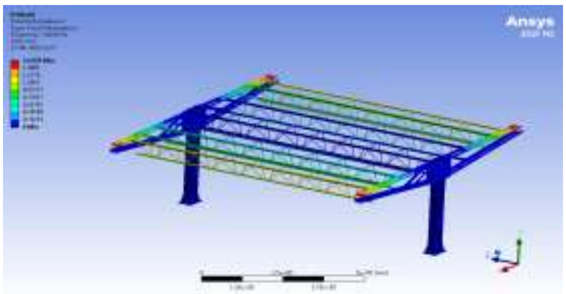

Fig 5.20: Mode 2– Roof Bending Mode

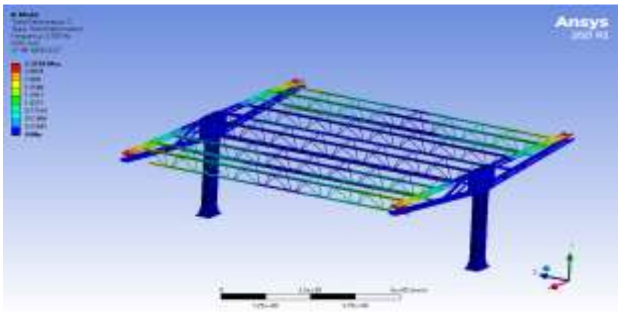

Fig 5.21: Mode 3 – Combined Sway and Twist

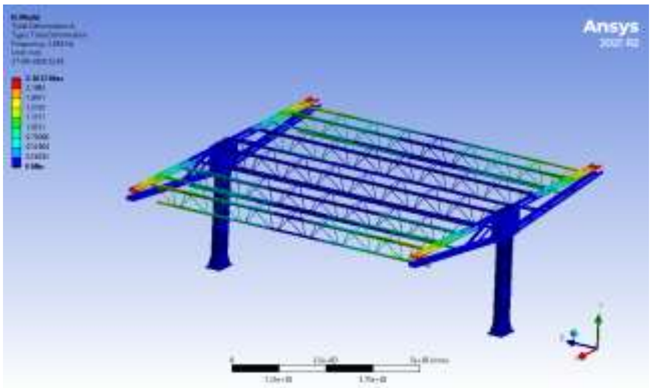

Fig 5.22: Mode 4 – Roof Width wise Torsion

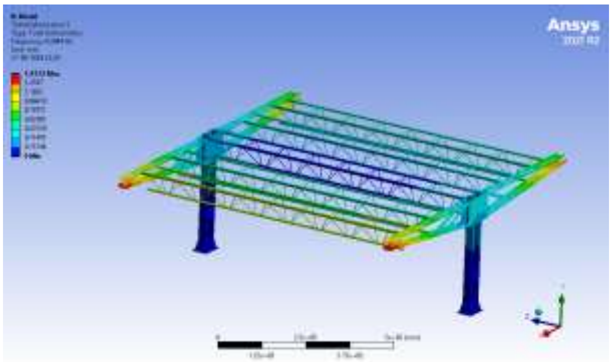

Fig 5.23: Mode 5 – Local Beam Vibration

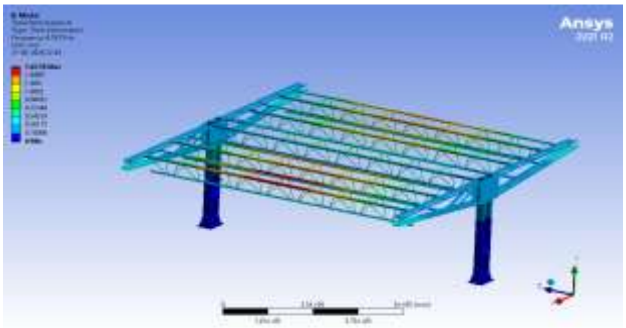

Fig5.24: Mode 6 – Truss Member Dynamic Mode

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5.9.5 Total Deformation Discussion

The maximum deformation obtained during harmonic excitation was:

$$1040.7\ mm$$

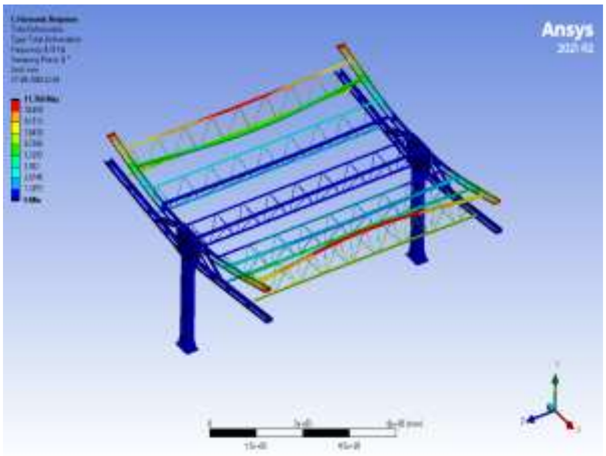

Fig 5.25: Harmonic Response of Total Deformation the Solar PV Roof

5.9.6 Equivalent Stress Discussion

The maximum dynamic stress obtained was:

$$5737.4\ MPa$$

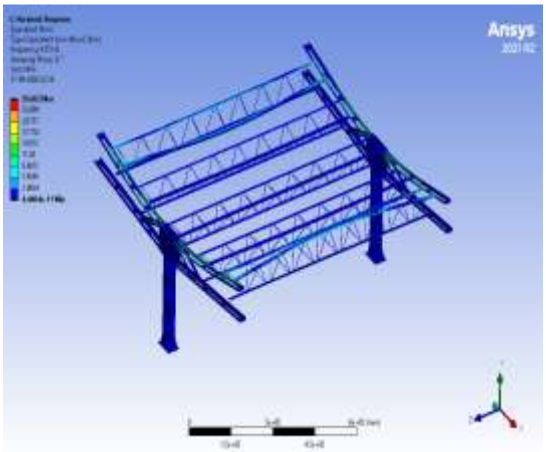

Fig 5.26: Harmonic Response of Equivalent Stress the Solar PV Roof

5.9.7 Equivalent Strain Discussion

The maximum equivalent strain was:

$$0.047912$$

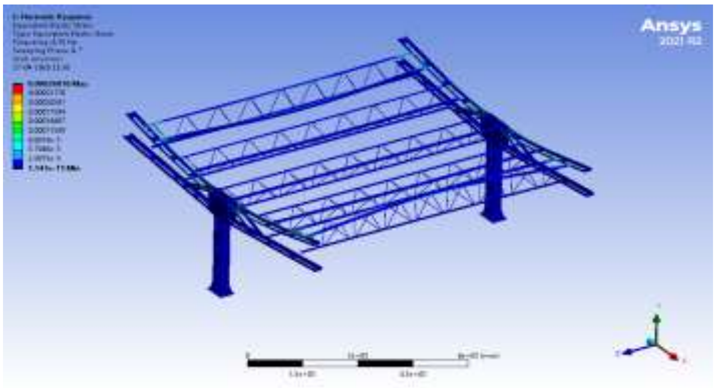

Fig 5.27: Harmonic Response of Equivalent Strain the Solar PV Roof

This confirms high strain response during peak harmonic excitation.

5.9.8 Safety Factor Discussion

The minimum safety factor observed was:

$$0.697$$

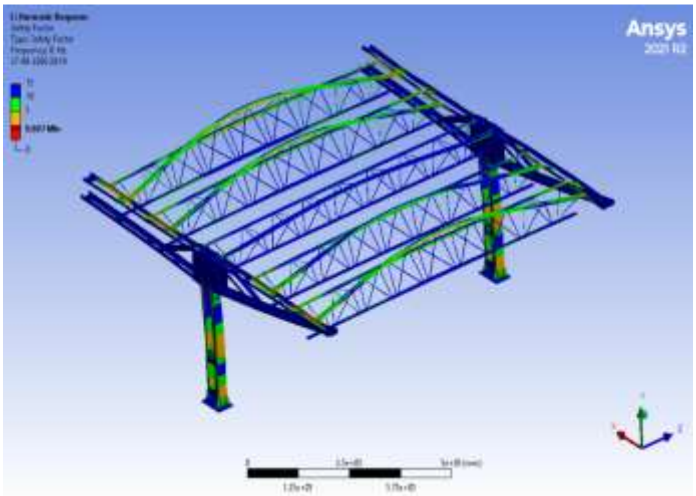

Fig 5.28: Harmonic Response of Safety Factor the Solar PV Roof

Interpretation

- Critical regions require strengthening.
- Dynamic loading is more severe than static loading.
- Additional bracing or stiffer sections are recommended.

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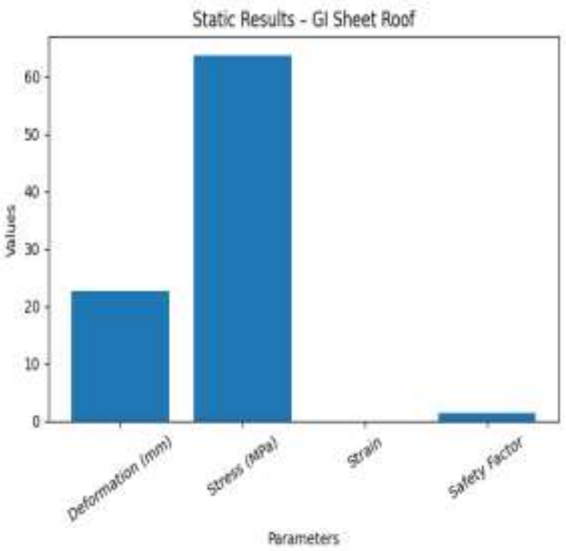
RESULTS TABLES

6.1 Static Structural Analysis Results

Parameter	Value
Maximum Deformation	22.793 mm
Maximum Equivalent Stress	63.806 MPa
Maximum Strain	0.00032
Minimum Safety Factor	1.351
Critical Location	Cantilever edges & joints
Status	Safe

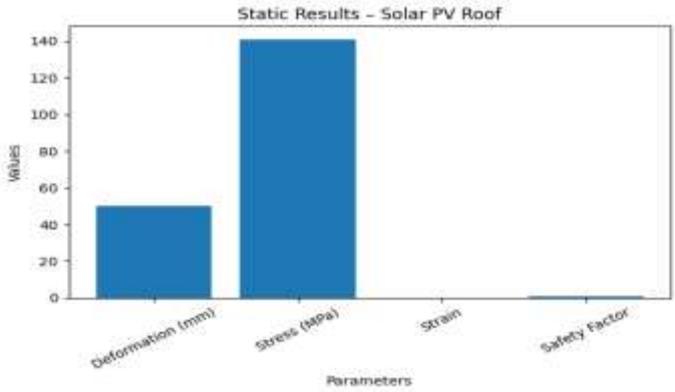
Table 6.1: Static Structural Analysis Results GI Sheet Roof



Graph 6.1: Static Results – Solar PV Roof

Parameter	Value
Maximum Deformation	50.339 mm
Maximum Equivalent Stress	140.91 MPa
Maximum Strain	0.0007
Minimum Safety Factor	0.697
Critical Location	Beam-column joints
Status	Needs reinforcement

Table 6.2: Static Structural Analysis Results Solar PV Roof

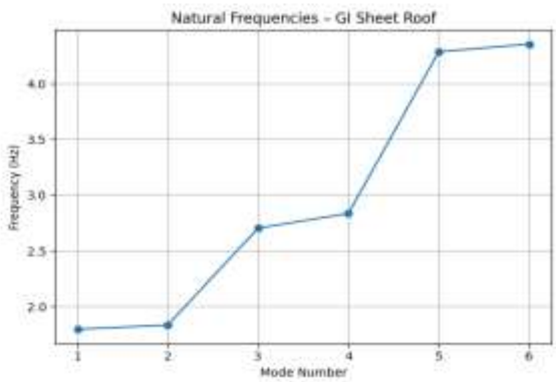


Graph 6.2: Static Results – Solar PV Roof

6.2 Modal Analysis Results

Mode	Frequency (Hz)	Mode Description
1	1.7956	Global sway
2	1.8338	Lateral bending
3	2.703	Combined mode
4	2.834	Roof torsion
5	4.2844	Local vibration
6	4.3535	Truss vibration

Table 6.3: Modal Analysis Results GI Sheet Roof



Graph 6.3: Modal Analysis Results GI Sheet Roof

Mode	Frequency (Hz)	Mode Description
1	1.412	Global sway
2	1.628	Roof bending
3	2.184	Combined mode
4	2.436	Torsional mode
5	3.108	Local vibration
6	3.527	Truss vibration

Table 6.4: Modal Analysis Results Solar PV Roof

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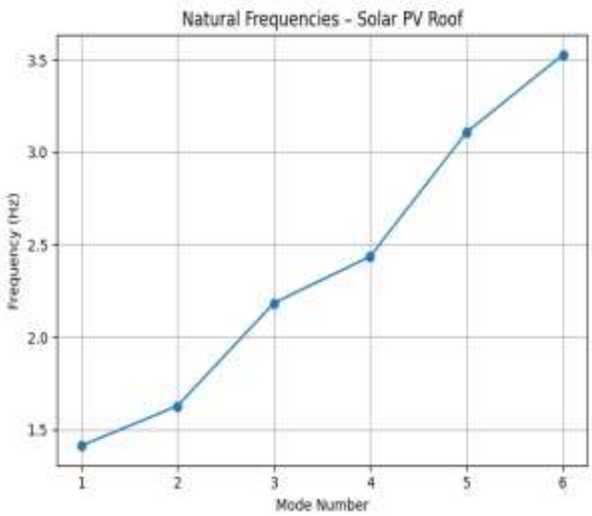
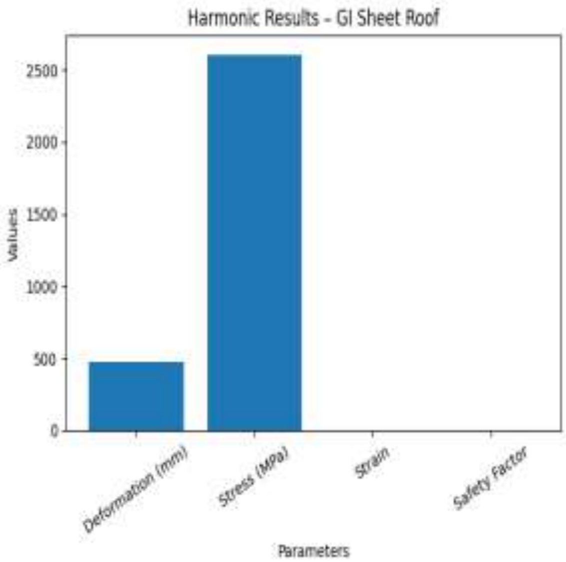


Graph 6.4: Modal Analysis Results Solar PV Roof

6.3 Harmonic Response Analysis Results

Parameter	Value
Maximum Deformation	472.65 mm
Maximum Equivalent Stress	2605.6 MPa
Maximum Strain	0.02176
Minimum Safety Factor	1.5348
Observation	Resonance amplification

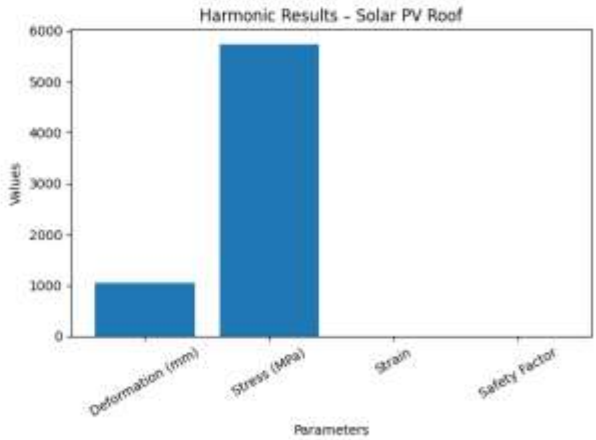
Table 6.5: Harmonic Response Analysis Results GI Sheet Roof



Graph 6.5: Harmonic Response Analysis Results GI Sheet Roof

Parameter	Value
Maximum Deformation	1040.7 mm
Maximum Equivalent Stress	5737.4 MPa
Maximum Strain	0.047912
Minimum Safety Factor	0.697
Observation	High resonance sensitivity

Table 6.7: Harmonic Response Analysis Results Solar PV Sheet Roof



Graph 6.7: Harmonic Response Analysis Results Solar PV Sheet Roof

COMPARISON OF RESULTS AND DISCUSSION OF GI SHEET ROOF & SOLAR PV ROOF

COMPARATIVE RESULTS TABLE

Table 6.1: Overall Comparison – GI vs Solar Roof

Parameter	GI Sheet Roof	Solar PV Roof
Roof Load	3482 N	7691 N
Max Deformation (Static)	22.793 mm	50.339 mm
Max Stress (Static)	63.806 MPa	140.91 MPa
Safety Factor	1.351	0.697

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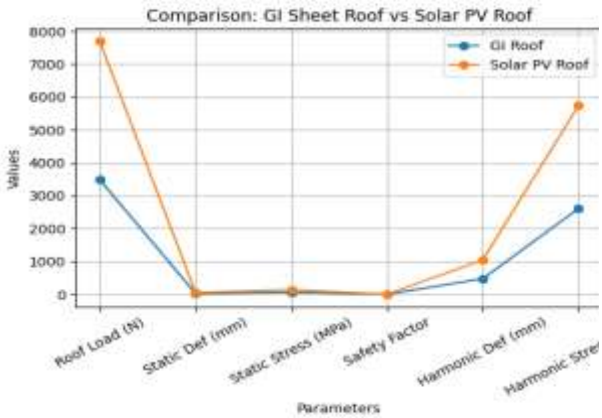
Natural Frequency Range	Higher	Lower
Harmonic Deformation	472.65 mm	1040.7 mm
Harmonic Stress	2605.6 MPa	5737.4 MPa
Structural Performance	Better	Moderate
Energy Generation	No	Yes



The comparative results in Table 6.1 clearly show that the solar PV roof introduces higher loading effects on the structure compared to the GI sheet roof. The applied roof load increases significantly from 3482 N in the GI roof to 7691 N in the solar PV roof, which is more than twice the original load. This increase is primarily due to the weight of solar panels and their mounting systems.

As a result of this increased load, the maximum static deformation increases from 22.793 mm to 50.339 mm, indicating a rise of approximately 121%. Similarly, the maximum stress increases from 63.806 MPa to 140.91 MPa. Although these values are still within the allowable limits of structural steel, the increase highlights the need for strengthening certain structural components.

The safety factor decreases from 1.351 in the GI sheet roof to 0.697 in the solar PV roof, indicating that the structure becomes less safe under increased loading conditions. This suggests that reinforcement measures such as increasing section sizes, adding bracing members, and strengthening joints are necessary for safe solar integration.

Modal analysis shows that the natural frequency range of the solar roof is lower compared to the GI roof. This is due to the increased mass of the structure, which reduces its stiffness-to-mass ratio and makes it more sensitive to dynamic effects such as vibrations.

Harmonic analysis further confirms that the solar PV roof exhibits higher deformation (1040.7 mm) and stress (5737.4 MPa) under resonance conditions compared to the GI sheet roof. This indicates that the solar roof is more susceptible to dynamic amplification and requires additional damping or stiffening mechanisms.

7.1 CONCLUSION

Based on the results obtained from static, modal, and harmonic analyses, a clear comparison between the GI sheet roof and solar PV roof conditions has been established. The static structural analysis shows that the GI sheet roof performs better with lower deformation (22.793 mm) and stress (63.806 MPa), along with a higher safety factor (1.351). In contrast, the solar PV roof increases deformation (50.339 mm) and stress (140.91 MPa), reducing the safety factor to 0.697, indicating the need for structural reinforcement.

Modal analysis reveals that the natural frequencies of the solar roof are lower than those of the GI roof due to increased mass, making the structure more sensitive to dynamic effects. Harmonic analysis further confirms that the solar roof experiences higher deformation (1040.7 mm) and stress (5737.4 MPa) under resonance conditions compared to the GI roof. However, these peak responses occur only

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at resonance and are reduced in real conditions due to damping.

Despite the increase in structural demand, the solar PV roof offers the major advantage of renewable energy generation, which is not possible with GI roofing. Therefore, it is concluded that:

The solar PV integrated railway platform roof is structurally feasible with proper reinforcement and provides significant environmental and economic benefits.

7.2 Future Scope

Future work can focus on improving the structural performance and efficiency of the solar roof system. Advanced wind analysis using CFD can be carried out to better understand uplift forces and optimize panel placement. Seismic analysis can be included to ensure safety in earthquake-prone regions.

Structural improvements such as increasing member sizes, adding bracing, and strengthening joints can enhance safety and reduce deformation. The use of lightweight or high-strength materials can further optimize the structure.

Additionally, smart monitoring systems using sensors can be implemented to track structural health, vibration, and energy generation in real time. Solar tracking systems can be introduced to improve power output efficiency.

Experimental validation through prototype testing and large-scale implementation in Indian Railways infrastructure will help in verifying analytical results and ensuring practical feasibility.

REFERENCES

[1] A. Kumar, R. Singh, and P. Sharma, "Integration of Solar Photovoltaic Systems on Railway Platform Roofs for Sustainable Energy Generation," *International Journal of Renewable Energy Research*, vol. 8, no. 3, pp. 1452–1460, 2018.

[2] S. Gupta and R. Sharma, "Structural Analysis of Rooftop Solar Mounting Systems under Wind and Dead Loads using ANSYS," *International Journal of Civil Engineering and Technology*, vol. 10, no. 5, pp. 1120–1128, 2019.

[3] P. Verma, N. Agarwal, and S. Mishra, "Retrofitting Techniques for Steel Roof Structures Supporting Photovoltaic Systems," *Journal of Structural Engineering and Mechanics*, vol. 14, no. 2, pp. 98–106, 2019.

[4] M. Ramesh and K. Prasad, "Wind Load Analysis of Rooftop Solar Photovoltaic Structures as per IS 875 Part 3," *International Journal of Engineering Research & Technology*, vol. 9, no. 7, pp. 534–540, 2020.

[5] D. Patel, H. Joshi, and R. Meena, "Modal Analysis of Steel Truss Roof Structures using ANSYS Workbench," *Materials Today: Proceedings*, vol. 27, pp. 2110–2116, 2020.

[6] R. Karthik and S. Babu, "Harmonic Response Analysis of Steel Support Structures under Cyclic Dynamic Loading," *International Journal of Mechanical Engineering and Technology*, vol. 12, no. 4, pp. 77–85, 2021.

[7] N. Singh, V. Kumar, and A. Patel, "Finite Element Modeling of Photovoltaic Support Structures using SolidWorks and ANSYS," *Journal of Engineering Science and Technology*, vol. 16, no. 5, pp. 3564–3575, 2021.

[8] T. Joseph and V. Mathew, "Renewable Energy Integration in Railway Infrastructure for Sustainable Transportation," *Renewable Energy and Environmental Sustainability Journal*, vol. 7, no. 1, pp. 25–34, 2022.

10.48047/jocaaa.2026.35.06.13

[9] A. Desai, M. Shah, and R. Kulkarni, “Structural Behavior of Steel Connections in Rooftop Solar Support Structures under Wind Loads,” *International Journal of Steel Structures*, vol. 22, no. 3, pp. 843–852, 2022.

[10] S. Rao and P. Iyer, “Comparative Structural Analysis of Conventional and PV Integrated Roofing Systems,” *International Journal of Structural and Civil Engineering Research*, vol. 12, no. 2, pp. 101–109, 2023.