e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:11/November-2024 Impact Factor- 8.187 www.irjmets.com

RESPONSE SPECTRUM ANALYSIS OF PRE-ENGINEERED BUILDINGS IN COMPLIANCE WITH IS CODES

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ABSTRACT

In recent times, the field of structural engineering has witnessed remarkable advances in science and technology, leading to a significant rise in the use of pre-engineered buildings in both industrial and residential sectors. Pre-engineered buildings are particularly well-suited for important structures as they offer heightened safety & expedited construction when compared to traditional RCC structures. This paper aims to conduct a thorough analysis of a pre-engineered steel structure, considering various loads such as seismic loads, wind loads, dead loads, live loads, as well as different load combinations including strength and serviceability load combinations. The focus will also be on the use of high-quality construction systems and efficient pre-engineering concepts, ultimately resulting in cost and time savings compared to RCC structures.

Keywords: Pre-Engineered Buildings, Staad-Pro CONNECT EDITION V22 Software, RCC Structures.

I. INTRODUCTION

Pre-engineered buildings, also known as pre-fabricated buildings, have gained immense popularity in India in recent years due to their numerous advantages. In the country's quest for rapid urbanization and infrastructure development, pre-engineered buildings have emerged as a viable solution for constructing structures quickly and efficiently.

Pre-engineered buildings are designed and manufactured off site, mainly in factories, and then transported to the construction site for installation. This approach offers several advantages, including reduced construction time, increased accuracy and lower labor costs. The pre-fabricated components are designed to fit together easily, allowing for rapid assembly and minimizing the need for on-site welding, cutting, or shaping. This streamlined process enables builders to complete projects faster, which is particularly essential in India where urbanization is proceeding at a breakneck pace.

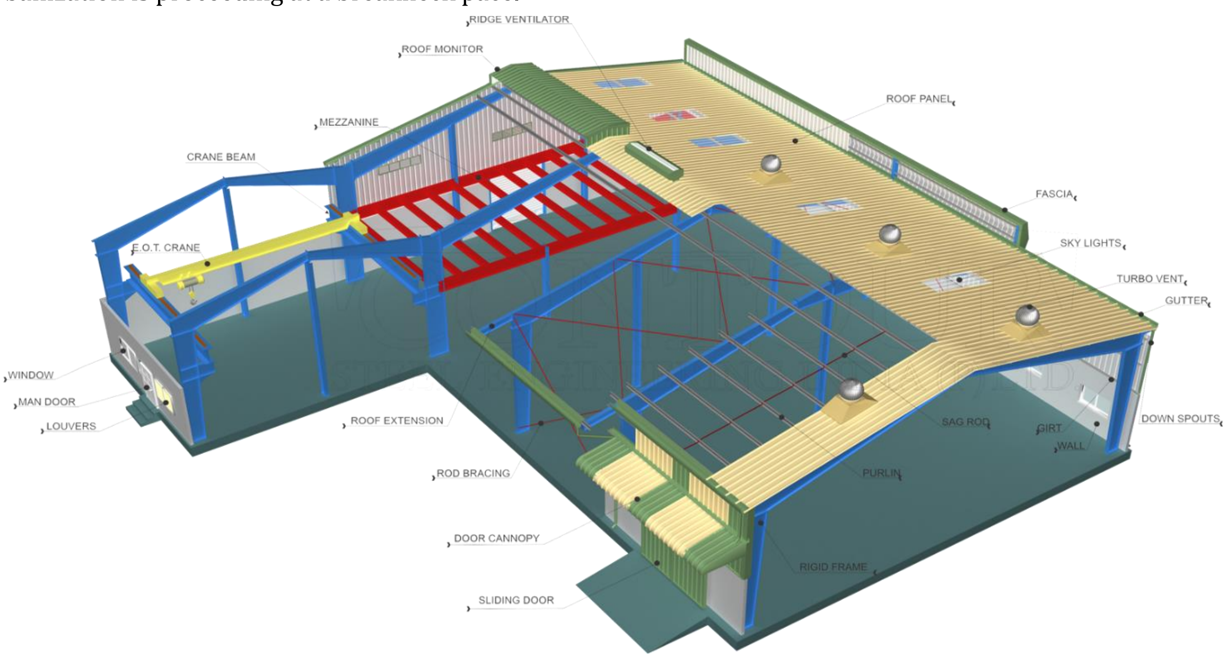

Fig 1: Pre Engineered Building

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Components of PEBs

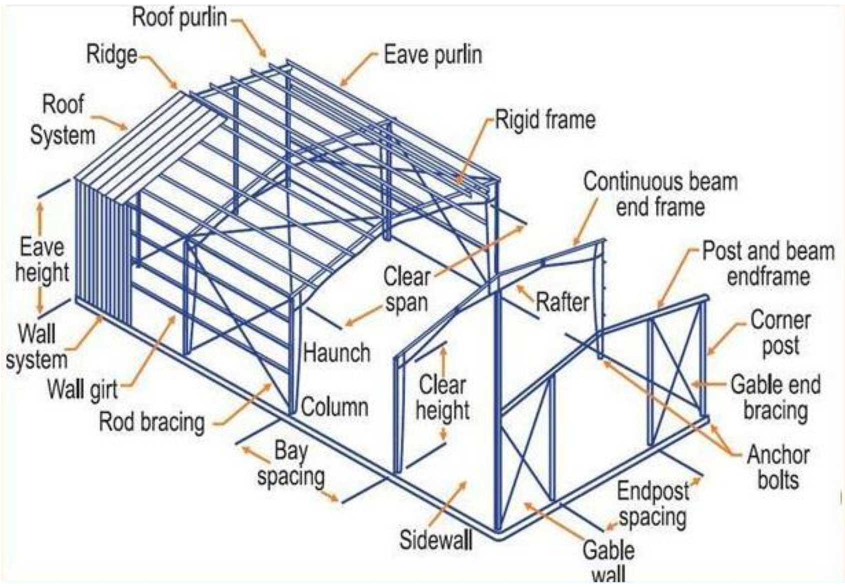

Fig 2: Components of PEBs

The components of a pre-engineered building typically include

- Main Frames
- Secondary Framing
- Roofing System
- Wall Systems
- Mezzanine Systems
- Fastener
- Accessories

Loads Considered

- Dead Loads: Dead Loads are considered as per IS 875 - I
- Live Loads: Live Loads are considered as per IS 875 – II
- Wind Loads: Wind loads are a critical consideration in design of pre-engineered buildings (PEBs) due to their large exposed surfaces. IS 875 (Part III) provides guidelines for determining wind loads on structures.
- Seismic Loads: Response Spectrum Analysis - RSA is a computational technique employed to predict a structure's maximum response when subjected to sudden, intense forces, such as earthquakes or explosive blasts. Fundamentally, it's a statistical method within linear dynamics that quantifies the contribution of each inherent vibrational mode to determine the potential maximum seismic reaction of an essentially elastic structure.

STAAD.Pro CONNECT Edition

STAAD.Pro Connect Edition is a comprehensive structural analysis & design software widely used by civil and structural engineers for designing and analyzing various type of structures such as building, bridge, tower, industrial structures, and more. It is developed by Bentley Systems and is known for its advanced analysis capabilities and user-friendly interface.

STAAD.Pro Connect Edition provides a wide range of analysis option including linear static analysis, dynamic response analysis, and nonlinear analysis. Engineers can simulate and evaluate the behavior of structure under various load conditions, ensuring their safety and performance. It also offers advanced modules for specialized analyses such as seismic analysis, wind load analysis, and foundation design.

II. OBJECTIVES

a. To evaluate the structural response of the pre-engineered building under the influence of different loads such as Dead Load, Live Load, Seismic load (Response Spectrum) and Wind Load.

b. To quantify the amount of steel utilized in the construction of a pre-engineered building.

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c. To explore the advanced analysis features of STAAD Pro CONNECT Edition.

III. METHODOLOGY

The methodology steps for analyzing a pre-engineered building using STAAD.Pro can be outlined as follows:

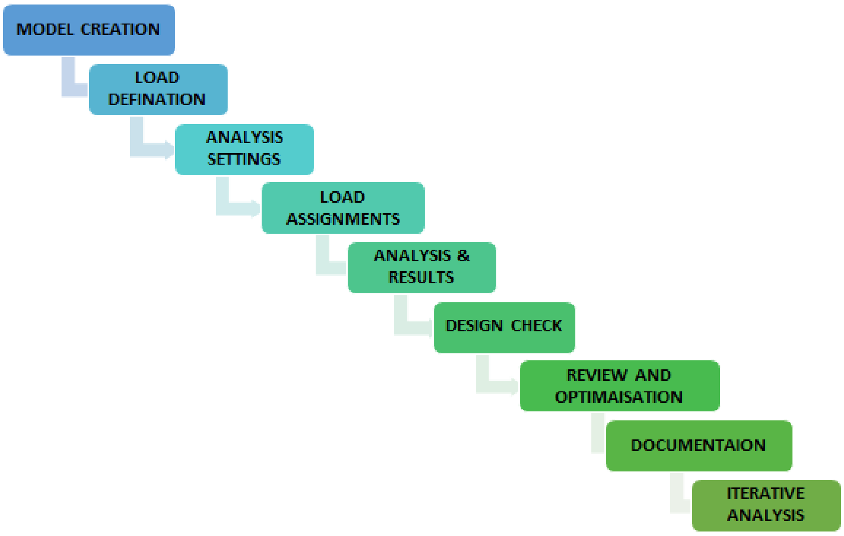

Fig 3: Methodology Flowchart

PROBLEM STATEMENT

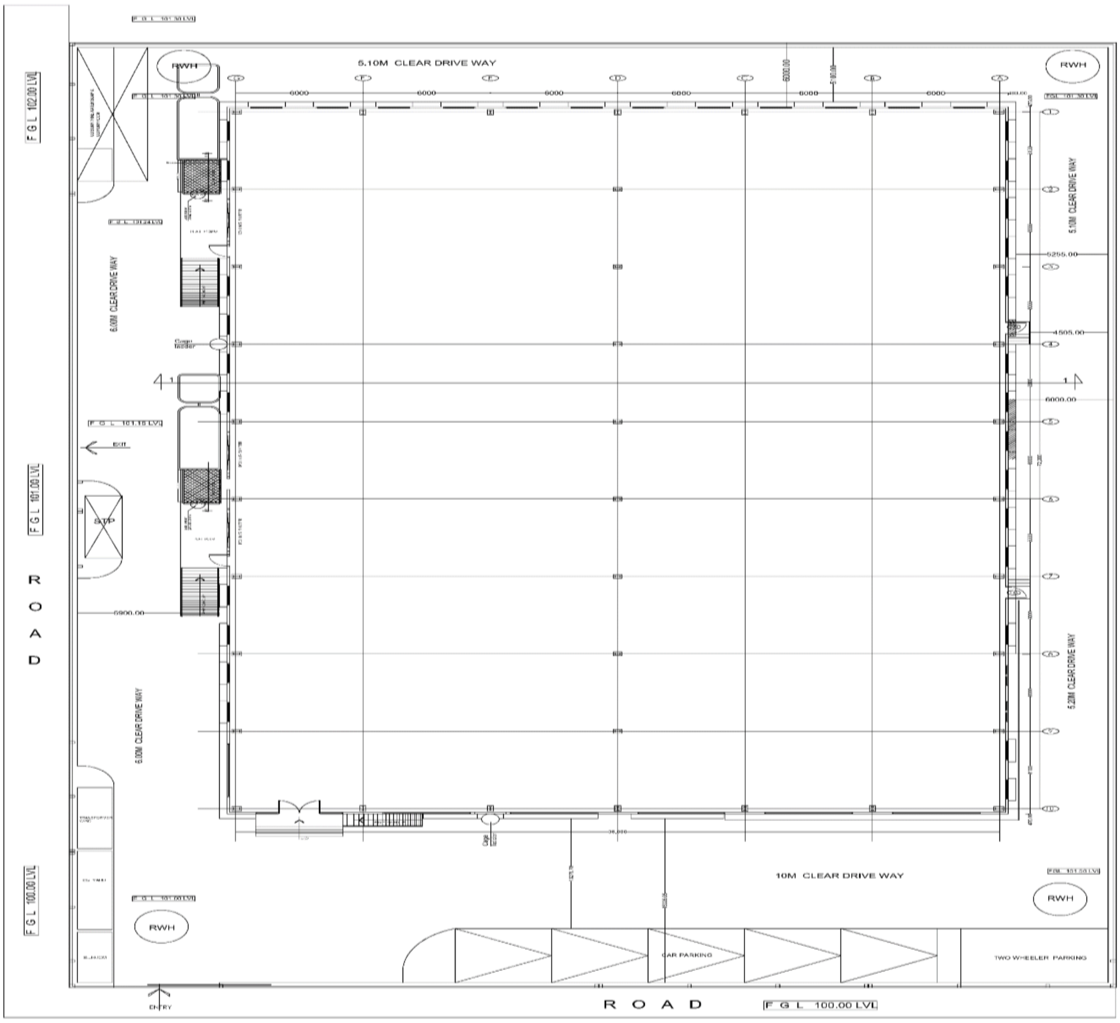

Fig. 4: Architectural Plan

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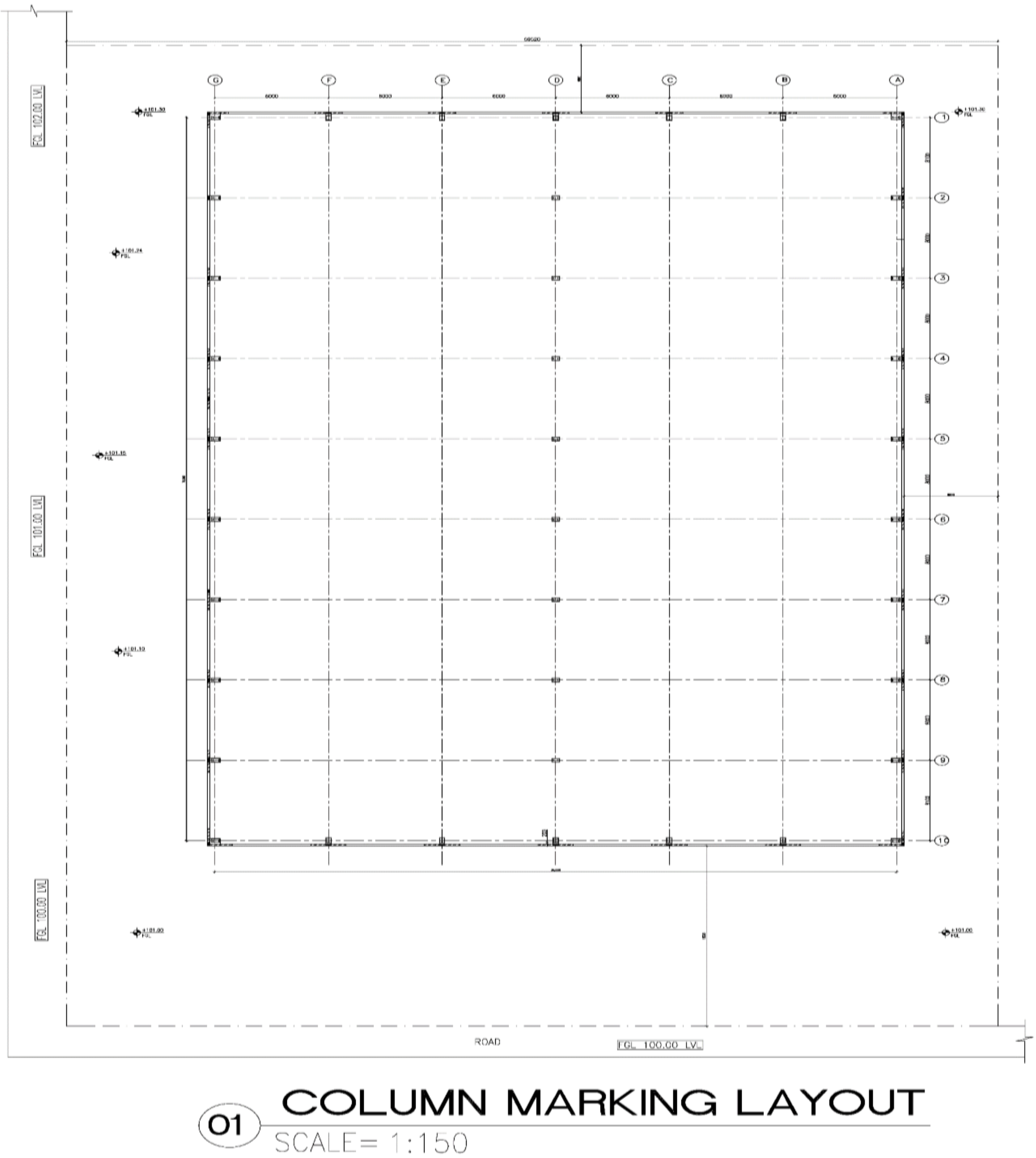

Fig. 5: Column Layout

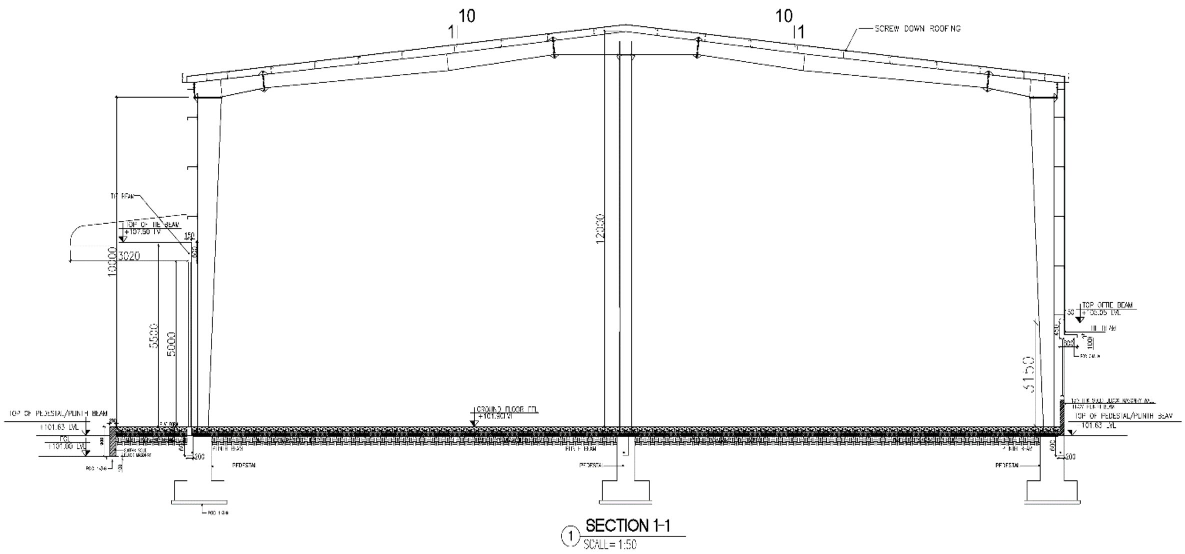

Fig. 6: Section 1-1 (Main Frame)

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Table 1: Structural Properties

GEOMETRIC DETAILS	
Structure	Industrial warehouse
Plan Area	2600 m^2
Height of structure	12m
Area [L x W]	72.2m x 36m
Bay Spacing (Length Wise)	8.1m
Bay Spacing (Width wise)	6m
No of Story	Ground floor only
Roof Slope	1:10
Length of canopy	8.6m
Brick Wall height	Up to 3m
Purlin Spacing	1.5m
Location of structure	Chennai

Table 2: Section Properties

Size of Rafter	Start	900mm / 600mm x 6mm / 250mm x 12mm
	Middle	600mm / 600mm x6mm / 250mm x 12mm
	End	600mm / 900mm x6mm / 250mm x 12mm
Gable Rafter	400mm / 400mm x 5mm / 150mm x 8mm	
Size of Column	Higher End	900mm / 750mm x 6mm / 250mm x 12mm
	Middle	750mm / 650mm x 6mm / 250mm x 12mm
	Lower End	650mm / 500mm x 6mm / 250mm x 12mm
Wind Columns	400mm / 400mm x 6mm / 200mm x 10mm	
Middle Columns	500mm / 900 mm x 6mm / 250mm x 12mm	
Size of canopy	300mm / 300mm x 5mm /150mm x 8mm	
Tie Beams	150X150X4.0 SHS [TATA Structure Steel – Square Hallow steel]	
Bracings	25mm Steel Rod sections	

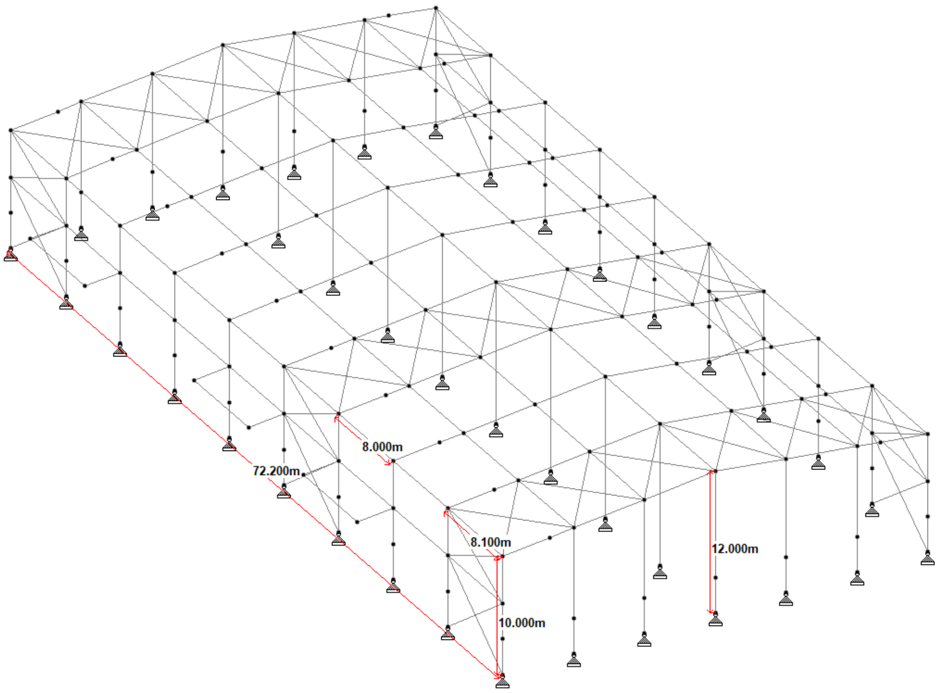

Fig 7: 3D view of the building

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DIFFERENT LOADS CONSIDERED

➢ **Dead Load**

1. **Self-Weight Factor = 1.15** (15% of Self weight is for connections)

- Weight of roofing sheet (0.47mm thick sheeting) = 5.00kg/m^2
- Weight of sag rods, flange braces, etc. = 5.00kg/m^2
- Collateral load = 10.00 kg/m^2

2. UDL Load on main rafter = Total load x Bay spacing = 0.20x8.1 = **1.620kN/m**

- Assumed weight of purlins [270x75x20x2.55] = 8.771kg/m
- UDL load due to purlin over the main rafter = (no of purlin x purlin length x weight of purlin per m) / Rafter length
- No of purlin = Round off (Rafter length/ Purlin spacing) +1 = Round off (18.060/1.5) +1 = 14.00

3. UDL load due to purlin on the main rafter = (14x8.1x8.77)/18.062 =55.06Kg/m = **0.551kN/m**
4. **Total UDL on roof on main rafter = 1.52+0.551 = 2.1710kN/m**
5. **Total UDL on roof on gable rafter = 2.171/2 = 1.0860kN/m**

- Weight of side wall sheet = 5.00kg/m^2
- Weight of sag rods, flange braces, etc. = 5.00kg/m^2
- Total sheet + Sag rods, flange braces etc. = 0.1x8.1 = 0.810kN/m
- Girts (270x75x20x2.55 for bay spacing 8.1m) = 8.770 kg/m
- Girts (230x75x20x2. for bay spacing 6m) = 6.320 kg/m
- Girts (8.1m spacing) = (6x8.77x8.1)/7 = 0.6080 kN/m

6. **Total load on main column at 8.1m spacing = 0.81+0.608 = 1.41kN/m**
7. **Total load on gable column = 1.41/2 = 0.705kN/m**

- Total Sheet + sag rods, flange braces, etc. =0.1x6 = 0.6kN/m
- Girts (6m spacing) = (7x6.32x6)/7 = 0.3792 = 0.38kN/m

8. **Total load on main column at 6m spacing = 0.6+0.38 = 0.980kN/m**
9. **Total load on gable column at 6m spacing = 0.98/2 = 0.490kN/m**

- Assumed weight of eave strut (CS270x75x20x3.15) = 10.7kg/m
- Weight of Eave Gutter (Assumed size = 0.25x0.25x0.001) = [(0.25+0.25+0.25) x0.001x7850] = 5.89 kg/m
- Load Due to Eave Gutter and Eave Strut = 10.7+5.89 = 16.59 kg/m

10. **Point Load due to Eave Gutter and Eave Strut = 16.59 x 8.1 = 134.37 kg = 1.344 kN**
11. **Point load on gable column = 0.672 kN**

➢ **Live Load**

1. **Roof Live load is considered as per IS875 Part II = 0.75kN/m^2**
2. **UDL Load on Rafter = 0.75 x 8.1 = 6.075 kN/m**
3. **UDL Load on Gabble End Rafter = 0.5 x 6.075 = 3.0375 kN/m**

Assuming Eave Gutter size as = 250X250X1mm

4. **LL due to water in Gutter on main Columns**

= (0.25x0.25x10x8.1)

= 5.063 kN

5. **LL due to water in Gutter on Gable end columns**

= 0.5(0.25 x 0.25 x 10 x 8.1)

= 2.532 kN

➢ **Seismic Load**

To determine the response spectrum for Zone 3 as per IS code, the seismic zone factor (Z) was initially set to 0.16. Considering the building's occupancy and function, an importance factor (I) of 1.0 was assigned. The soil type was classified as medium according to IS code provisions. A response reduction factor of 5.0, typical for steel buildings, and a damping ratio of 5% were adopted. These parameters were used to calculate the design horizontal seismic-coefficient (Ah), which was then used to generate the response spectrum based on the IS code-defined shape.

➢ **Wind Load**

Wind load assigning as per IS875 – Part III code.

- Location: Chennai
- Basic Wind Speed: V_b = 50m/s
- Probability Factor: K_1 = 1.0 [Table-1]
- Terrain Roughness & Height factor = K_2 = 1.0 [Table-2] [Category -2]
- Topography factor = K_3 = 1.0 [Clause – 6.3.3.1]
- Importance Factor for cyclonic regions = K_4 = 1.15 [For Industrial Buildings]

Design Wind Speed

$V_L = V_b \times K_1 \times K_2 \times K_3 \times K_4$

$= 50.0 \times 1.0 \times 1.0 \times 1.0 \times 1.15$

$\mathbf{V_L = 57.51\ m/s}$

Wind Pressure

$P_z = 0.60 \times [V_z]^2\ N/m^2$

$= 0.6 \times [57.51]^2$

$\mathbf{P_z = 1.985\ kN/m^2}$

- Wind Directionality Factor: K_d = 1 [Clause- 7.2.1]
- Area Averaging Factor: K_a = 0.83 [Table-4]
- Tributary area = 10 x 8.1 = 81m^2
- Combination Factor = Kc = 0.9 [Clause- 7.3.3.13]

Design Wind Pressure:

$P_d = K_d \times K_a \times K_c \times P_z$

$= 1 \times 0.83 \times 0.9 \times 1.985$

$\mathbf{P_d = 1.483\ kN/m^2}$

Wind Load on Individual Members: [Clause: 7.3.1]

$\mathbf{F = (C_{pe} - C_{pi})\ A\ P_d}$

Where

C_{pe} = External pressure coefficient

C_{pi} = Internal pressure coefficient

P_d = Design Wind Speed

A = Surface area of structural

LOAD COMBINATIONS:

IS Codes:

- IS800 2007
- IS875 PART-I (DL)
- IS875 PART-II (LL)
- IS875 PART-III (WL)
- IS1893 PART-I 2017 (EL)
- IS811-COLD FORMED SECTIONS

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Strength Load Combinations

- 101 : 1.5 DL + 1.5 LL
- 102 : 1.2 DL + 1.2 LL + 1.2 WL (0+CPI)
- 103 : 1.2 DL + 1.2 LL + 1.2 WL (0-CPI)
- 104 : 1.2 DL + 1.2 LL +1.2 WL (90+CPI)
- 105 : 1.2 DL + 1.2 LL + 1.2 WL (90-CPI)
- 106 : 1.2 DL + 1.2 LL + EQ X +VE
- 107 : 1.2 DL + 1.2 LL + EQ Z +VE
- 108 : 1.5 DL + 1.5 WL (0+CPI)
- 109 : 1.5 DL + 1.5 WL (0-CPI)
- 110 : 1.5 DL + 1.5 WL (90+CPI)
- 111 : 1.5 DL + 1.5 WL (90-CPI)
- 112 : 0.9 DL + 1.5 EQ X
- 113 : 0.9 DL + 1.5 EQ Z
- 114 : 0.9 DL + 1.5 WL (0+CPI)
- 115 : 0.9 DL + 1.5 WL (0-CPI)
- 116 : 0.9 DL + 1.5 WL (90+CPI)
- 117 : 0.9 DL + 1.5 WL (90-CPI)
- 118 : 1.5 DL + 1.5 EQ X
- 119 : 1.5 DL + 1.5 EQ Z

Serviceability Load Combinations

- 301 : SERVICE COMBO 1.0 DL + 1.0 LL
- 302 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 EQ X
- 303 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 EQ Z
- 304 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 WL (0+CPI)
- 305 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 WL (0-CPI)
- 306 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 WL (90+C...
- 307 : SERVICE COMBO 1.0 DL + 0.8 LL + 0.8 WL (90-C...
- 308 : SERVICE COMBO 1.0 DL + 1.0 EQ X
- 309 : SERVICE COMBO 1.0 DL + 1.0 EQ Z
- 310 : SERVICE COMBO 1.0 DL + 1.0 WL (0+CPI)
- 311 : SERVICE COMBO 1.0 DL + 1.0 WL (0-CPI)
- 312 : SERVICE COMBO 1.0 DL + 1.0 WL (90+CPI)
- 313 : SERVICE COMBO 1.0 DL + 1.0 WL (90-CPI)

IV. RESULTS AND DISCUSSION

a. Utilization Ratio

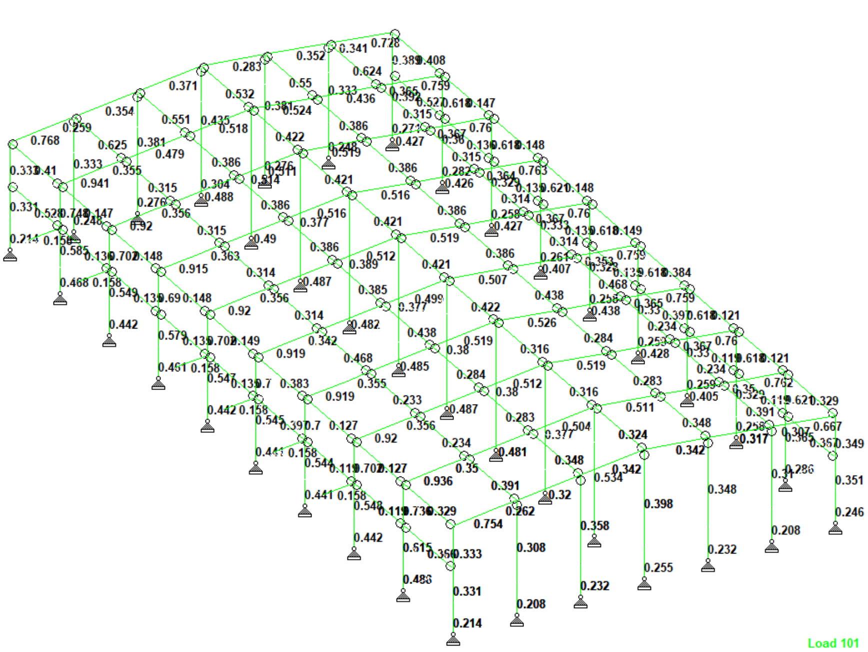

Fig 8: Utilization Ratio

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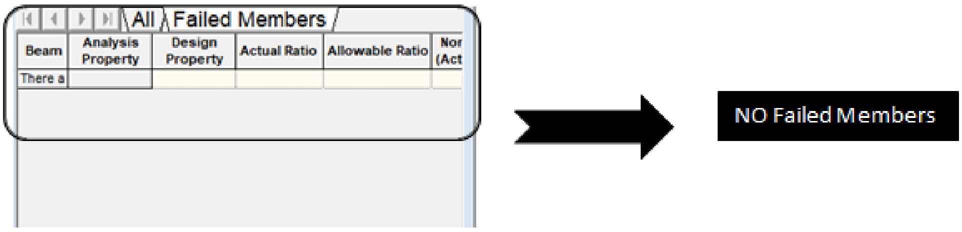

- A comprehensive unity check was performed on the structural model using STAAD.Pro. The results indicate that all structural members comply with the specified design codes & load combinations. The maximum unity ratio obtained for any member is 0.92 (which should be under 1).
- Hence in our model the max unity value is 0.919, this confirms the structural adequacy of the design.

b. Displacement

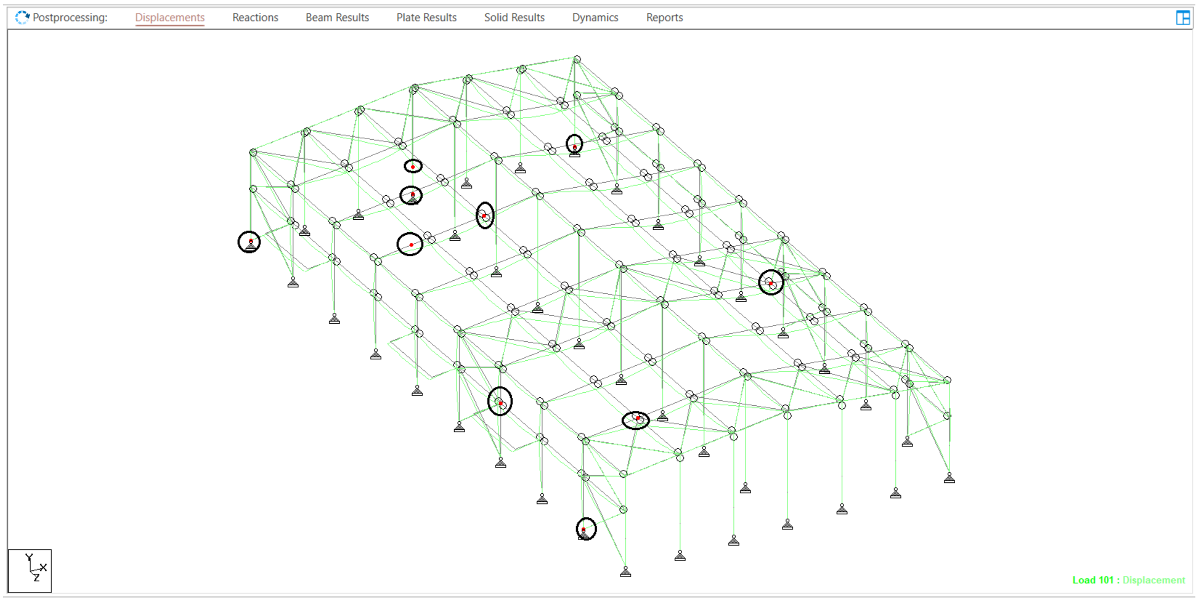

Fig 9: Nodal Displacements

Displacement Limits as per Indian standards:

Table 3: Displacement limits

Description	**IS 800**	
	Vertical	Lateral
Main Frames	L/180	H/150

A. Vertical displacement:

Height of the building = 12,000 mm

Allowable displacement = 12000/180

= 66.66 mm

- Max displacement obtained in y direction = 23.009mm

B. Lateral Displacements:

Width of the building = 36,000 mm

Allowable displacement = 36,000/150

= 240mm

- Max displacement obtained in x direction = 78.564 mm
- allowable displacement is > Obtained max displacement
- Hence both vertical and lateral displacements are within limits.

C. Bending Moment

Table 4: Bending Moment summary

	Beam	L/C	Mz kN-m
Max Fy	111	114 0.9 DL + 1.5 WL (0+CPI)	-626.64
Min Fy	43	114 0.9 DL + 1.5 WL (0+CPI)	-679.709
Min My	3	114 0.9 DL + 1.5 WL (0+CPI)	-85.985
Max Mz	216	101 1.5 DL + 1.5 LL	545.572
Min Mz	152	116 0.9 DL + 1.5 WL (90+CPI)	-741.609

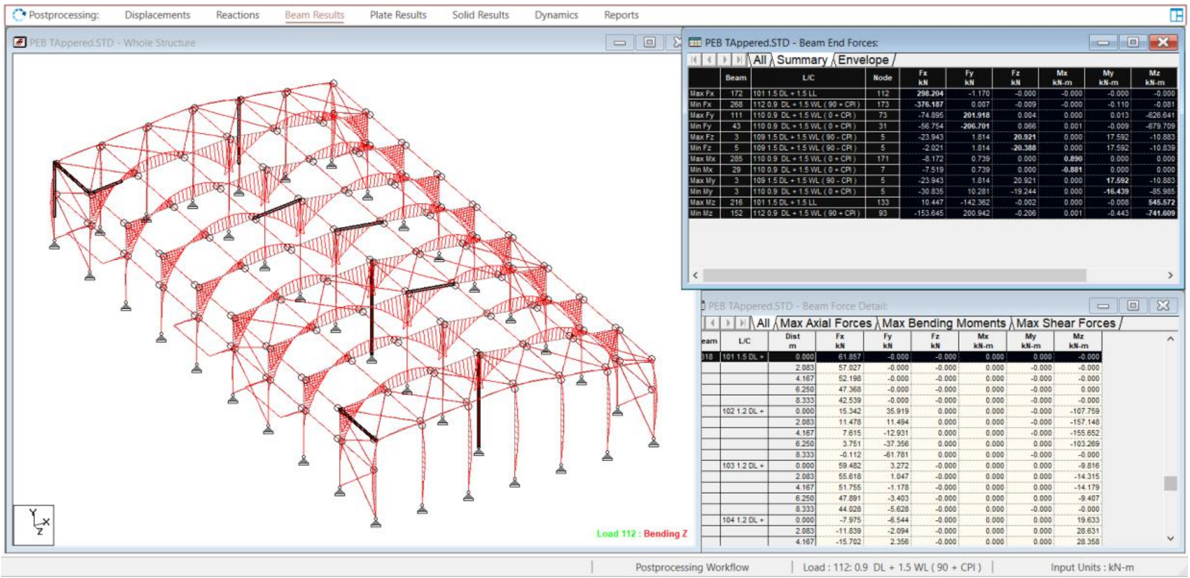

Fig 10: Bending Moment

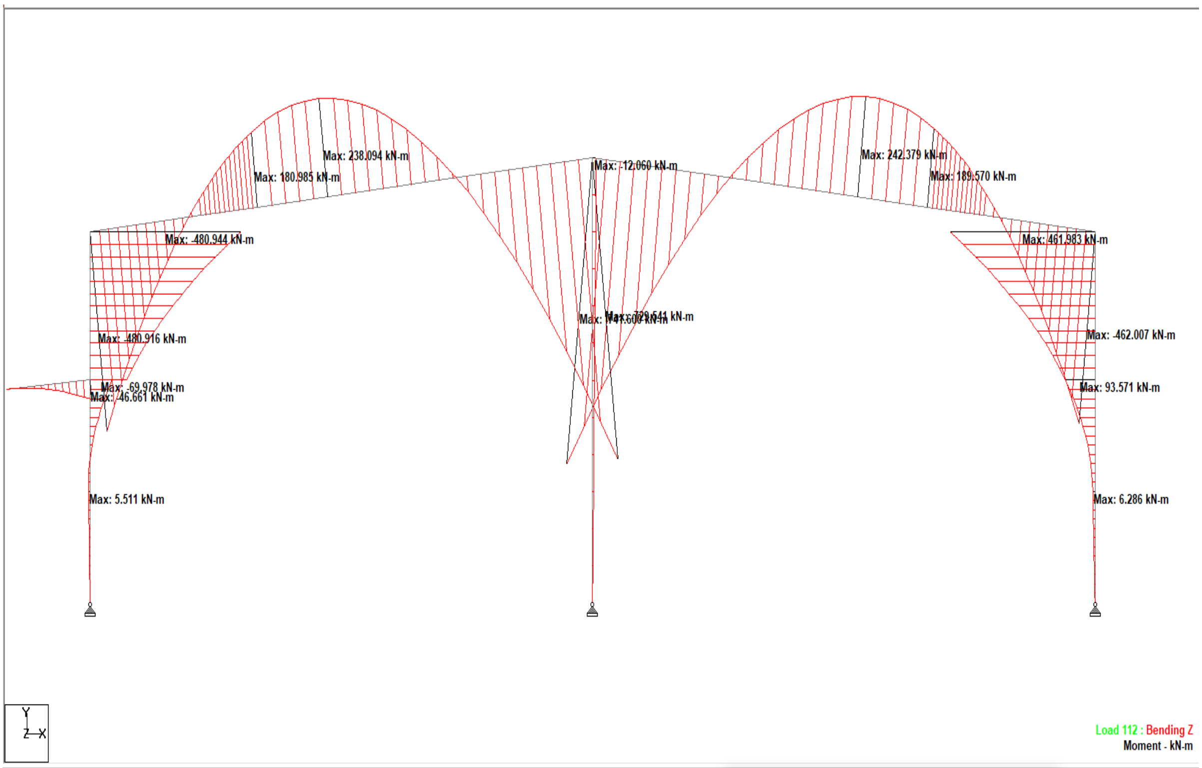

Fig 11: Bending Moment of Main Frame

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D. Shear Force

Table 5: Shear Forces summary

	Beam	L/C	Fy kN
Max Fx	172	101 1.5 DL + 1.5 LL	298.204
Min Fx	268	116 0.9 DL + 1.5 WL (90+CPI)	-376.187
Max Fy	111	114 0.9 DL + 1.5 WL (0+CPI)	201.918
Min Fy	43	114 0.9 DL + 1.5 WL (0+CPI)	-206.7
Max Mz	216	101 1.5 DL + 1.5 LL	-142.362
Min Mz	152	116 0.9 DL + 1.5 WL (90+CPI)	200.942

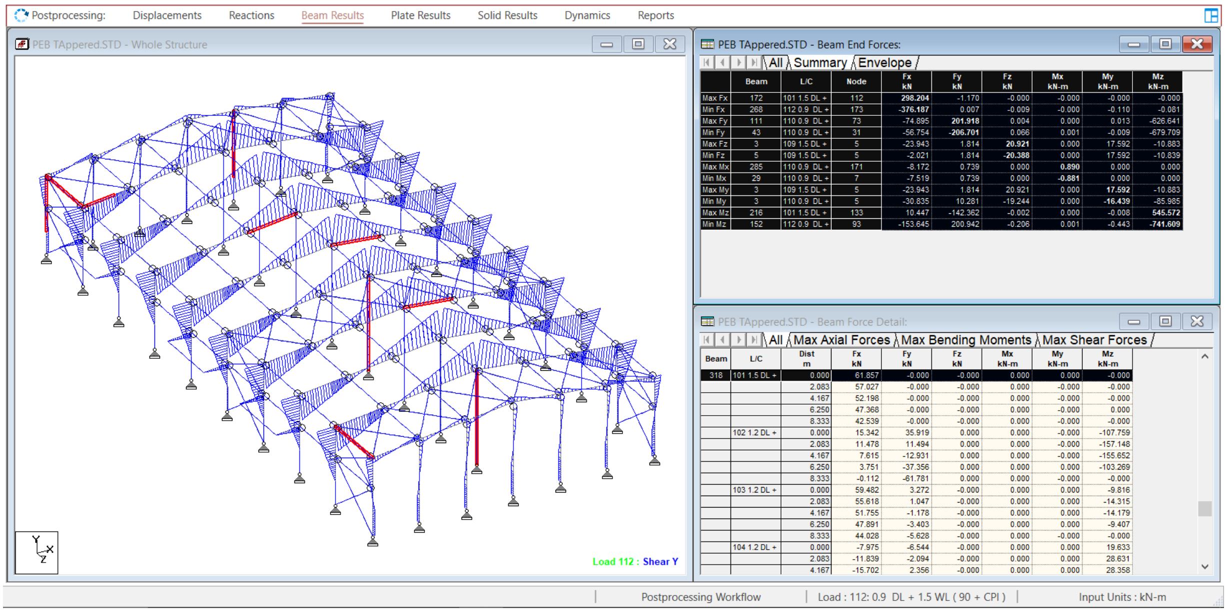

Fig 12: Shear Force

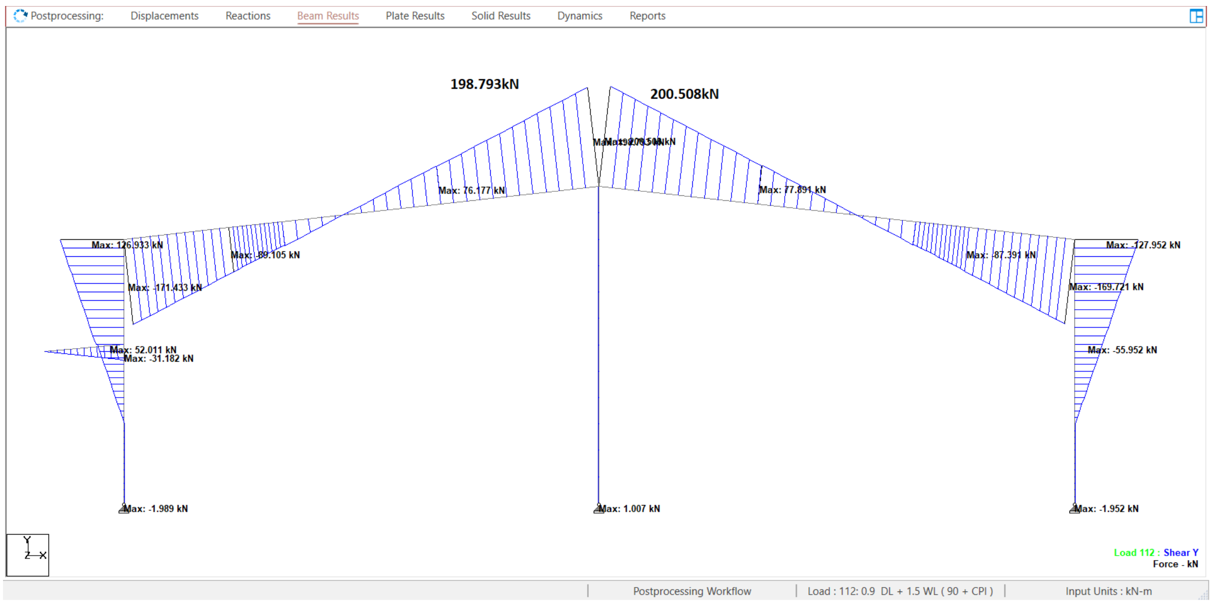

Fig 13: Shear-Force of Main Frame

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E. Axial Force

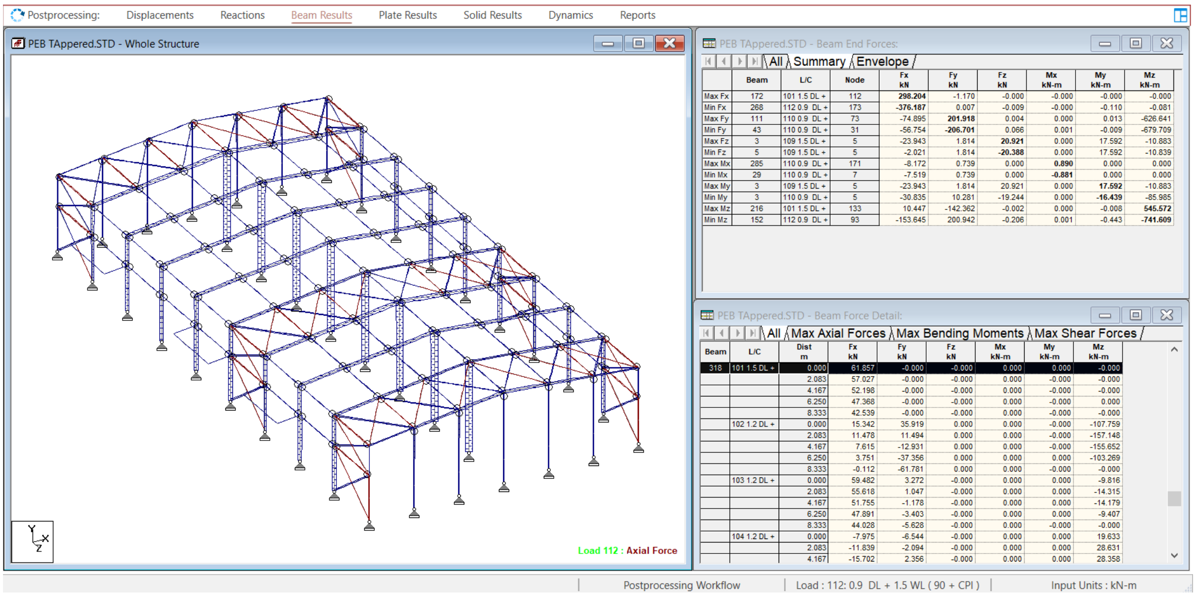

Fig 14: Axial Force

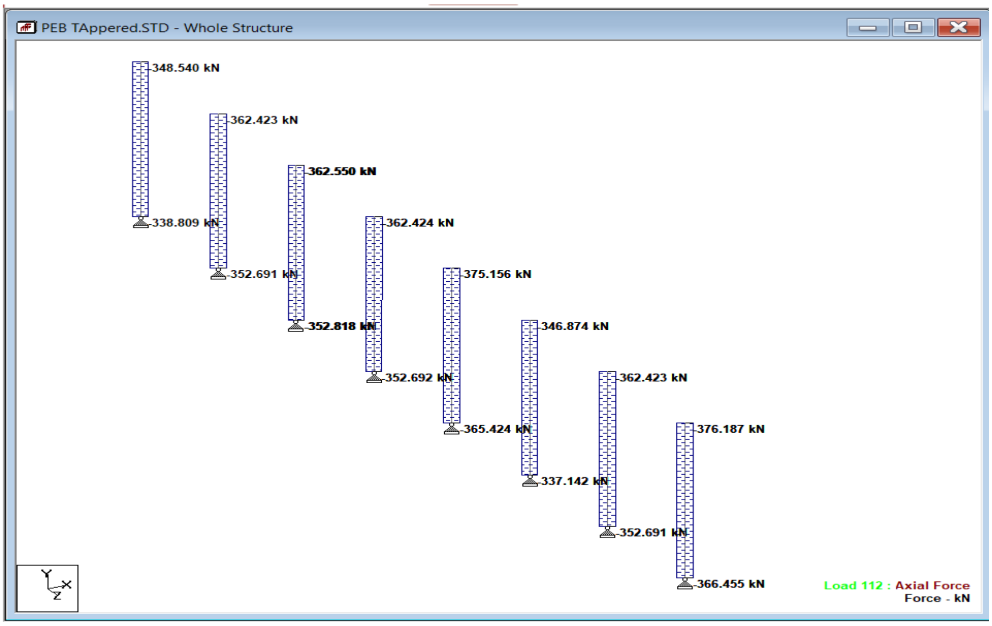

Fig 15: Axial Force of Middle Columns

F. Base Reactions

Table 6: Base reactions summary

	Node	L/C	Fx kN	Fy kN	Fz kN	M kN-m
Max Fx	168	101 1.5 DL + 1.5 LL	26.989	159.88	-0.001	0
Min Fx	168	115 0.9 DL + 1.5 WL (0-CPI)	-77.449	-25.456	-1.222	0
Max Fy	112	101 1.5 DL + 1.5 LL	1.17	298.204	0	0
Min Fy	172	116 0.9 DL + 1.5 WL (90+CPI)	-0.007	-366.455	-0.009	0
Max Fz	9	108 1.5 DL + 1.5 WL (0+CPI)	0	-11.997	49.461	0
Min Fz	1	117 0.9 DL + 1.5 WL (90-CPI)	-2.094	-78.809	-74.726	0
Max Mx	1	101 1.5 DL + 1.5 LL	2.107	56.222	0.012	0

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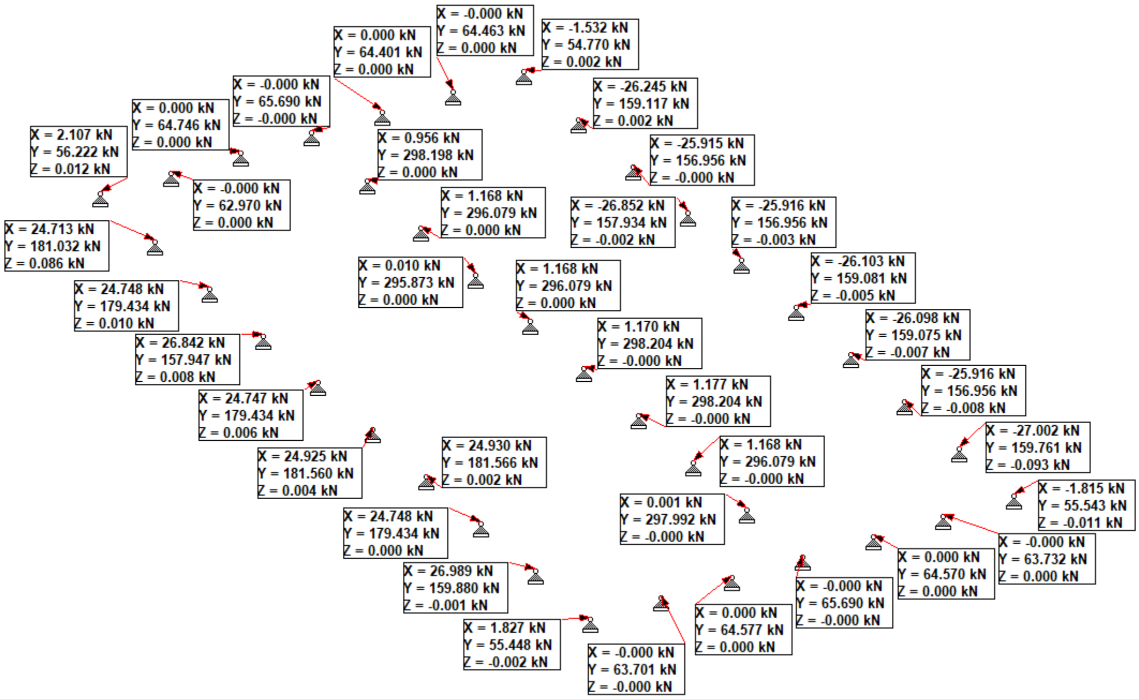

Fig 16: Base Reactions

V. CONCLUSION

a. The analysis revealed that the pre-engineered building effectively withstands the combined effects of Dead Load, Live Load, Seismic load (Response Spectrum) and Wind Load. The structural response, including deflections and stresses, was found to be within acceptable limits as per the relevant Indian standards, indicating that the design is both safe and efficient.

b. The project successfully quantified the amount of steel used in the pre-engineered building. The optimization of steel usage was achieved through careful consideration of load combinations and structural efficiency, leading to a cost-effective and material-efficient design.

c. The advanced analysis capabilities of STAAD Pro CONNECT Edition provided comprehensive insights into the behavior of the pre-engineered building under various loading conditions. The software's tools and features allowed for a detailed and accurate simulation, which contributed to the precision of the design and analysis.

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