

ANALYSIS, DESIGN AND OPTIMIZATION OF PRE ENGINEERED BUILDING SUBJECTED TO DIFFERENT WIND SPEEDS

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Abstract- *Pre Engineered Building type of structures are extensively used as industrial structures which consists of channel steel purlins spanned between the rigid frames and also with the wall cladding at sides. Pre Engineered Buildings structures which are less height structures are useful for houses, offices, showrooms etc. As conventional structures need longer time for constructing and also costly for larger length spans and also require heavier foundations. In the present work to find the wind effects on pre-engineered buildings, Pre Engineered Buildings structures, with x bracings at the ends are considered in analysis of structure having material grade properties Fe250 steel and structure sizes along height is 10m from the foundation or footing top, length of shed is 184m and width of shed is 40m, column to column distance in shed is 8m. Base conditions as pinned base and structures are analyzed using STAAD Pro with wind velocities 33, 39, 44, 47, 50 and 55m/s as per IS 875-3. It is observed that the structures subjected to higher wind velocities are more affected, and also observed that the sections are optimized for bracings and purlins, bracings optimized section is PIP1937L and purlins optimized section ISMC150.*

Keywords: *Pre Engineered Buildings, Optimization, Wind Loads, Staad.Pro Software, IS 875 Part 3.*

I. INTRODUCTION

Lots of studies had been conducted on Overview and analysis of Pre Engineered Buildings, comparative study of conventional buildings and Pre Engineered Buildings.

Pre engineered structures are steel structures fabricated and designed in manufacturing plant. All components transported to project area then lifted using cranes and placed in positions and then joined using welds, bolts and nuts. Tapered I section members are connected with bolts. Vertical structure elements are pillars and members those are connected with columns are called rafters. PEB members are rigid, flexible and light gauge members produced in different forms and sizes, shapes they are called as primary frame systems. The primary framed system is basic units of all Pre-Engineered Buildings. Spacing between the column and rafters are decided in the designing sections based on the lateral loads and the dimensions of the structure to

II. LITERATURE REVIEW

Aijaz Ahmad Zende, Prof. A. V. Kulkarni, Aslam Hutagia (2013) prepared Comparative Study of Analysis and Design of Pre-Engineered - Buildings and Conventional Frames and found that for larger spans conventional structures are not possible. PEB structures are suitable for longer spans and weight of steel can be reduced 27% and also found that PEB structures are costly for smaller spans and they are economical for spans 90m with eave heights 30m and the self weights are reduced by 10-15% in PEB structures.

Pradeep V, Papa Rao G (2014) prepared Comparative Study of Pre Engineered and Conventional Industrial Building and concluded that PEB structures are 26% lighter than conventional steel building, light weight Z purlins are used in the PEB structures and rolled steel sections are used in conventional structures and the costs are reduced by 30% lesser than the cost of conventional structures.

J.Jayavelmurugan, J.R.Thirumal, Padmanabhan haridas (2015) made a Study of Pre Engineered metal Structures and concluded that steel is high speed construction for buildings of various categories, steel strength and large clear spans means the design is not constrained for intermediate walls.

Shrunkhal V Bhagatkar, Farman Iqbal Shaikh, Bhanu Prakash Gupta and Deepak Kharta (2015) made A Study On Pre-Engineered Building – A Construction Technique and concluded that PEB structures can be easily designed by design standards and construction sequences and also its energy efficient, speedy in construction, important and its reliable as compared to regular conventional buildings.

Jinsha M S, Linda Ann Mathew (2015) made Analysis of Pre –Engineered Buildings and concluded that the weight of the PEB depends on the bay spacing and the increase the bay spacing up to certain spacing weight reduces and further makes weight heavier and PEB structures with 8m spacing is found to be more economical.

Mr. Aditya P. Mehendale, Prof. Dr. A. K. Gupta & Prof. D. B. Desai (2016) proposed Overview of PEB and conveyed

be considered. PEB elements are more efficient in resisting the and pressures acting on them when compared to truss and arch type sheds, time of completion is around 30 40% lesser when compared to other industrial shed configuration.

III MODELLING

In the present study to find the wind effects on Pre Engineered Buildings (PEB) structures, with x bracings at the ends are considered in modeling of structures having material properties Fe250 steel and structure dimensions height is 10m from the foundation or footing top, length of shed is 184m and width of shed is 40m, column to column distance in shed is 8m. Support conditions are considered as pinned base and structures are modeled using Staad.Pro with wind velocities 33,39,44,47,50 and 55m/s as per IS 875-3.

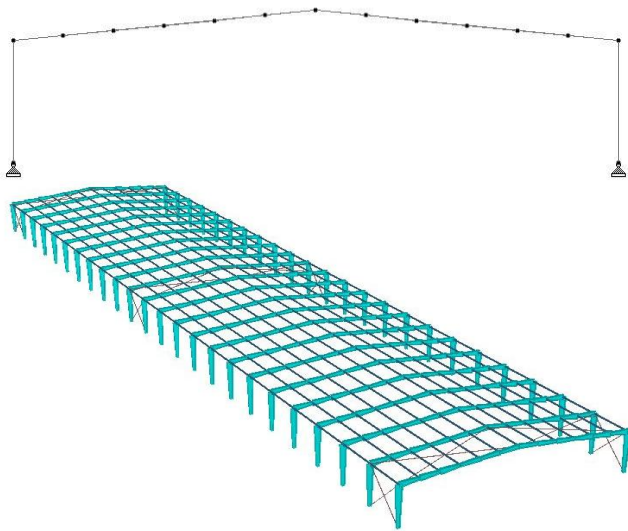


Fig. 1: Modeling of PEB structures

IV METHODOLOGY

A study is undertaken which involves analysis, design and optimization of Pre Engineered Buildings with different Wind loads. The design parameters are considered and the analysis is done using Staad.Pro software.

Following data is used in the analysis of Pre Engineered Buildings

- Type of frame: Pre Engineered Building with pinned base.
- Material: Fe250
- Loadings: Dead, Live and Wind speeds
- Height of building: 10m
- Length: 184m
- Width: 40m
- Height of Column: 8m
- Ridge Angle: 1:10
- Wind Speeds: 33,39,44,47,50,55m/sec
- Software: Staad.Pro
- Type of soil: Hard
- Geometry of building: Symmetric
- End Bracing: X

that PEB structures are easily designed, speed in construction and erecting the members. PEB structures are faster than truss type structures and 25% less time and consuming 30% lighter than conventional buildings.

- Bay Spacing: 8m centre to centre
- Spacing of purlins: 3.35m
- Dead load on roof: 0.256 KN/m²
- Total dead weight on purlin: 0.86 KN/m
- Live load on roof: 0.75 KN/m²
- Total live load on purlin: 2.52KN/m

Section Properties:

- Columns: Tapered I section
Base = 0.4m, Top = 1m
- Column and roof bracings: Pipe 100mm diameter
- Purlins: Channel ISMC 100
- Rafter: Tapered I section
Base = 1m, Top = 0.5m

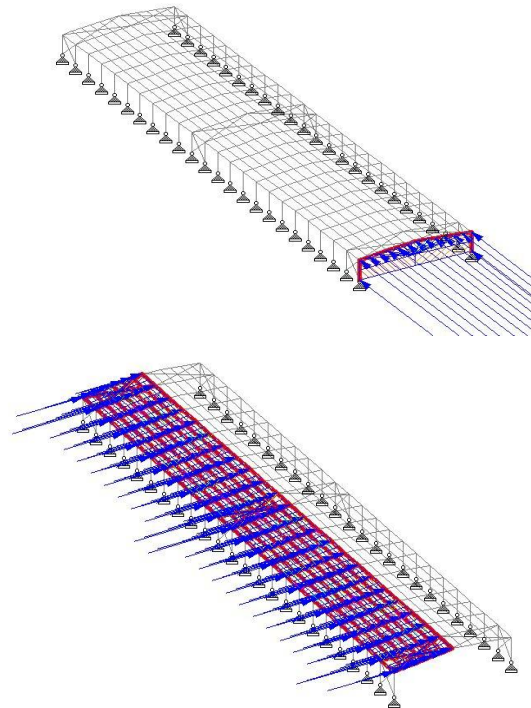


Fig 2: Wind load applications

Wind load calculations

As per IS: 875 (Part-3) - 2015

Design Data:

Type of Structure : PEB Structures with Terrain Category – 2

Basic Wind Speed : 33 m/sec

K₁ – Risk Coefficient for important buildings/ towers = 1

K₂ – Variation with Height in Different Terrains = 1

K₃ – Topography Factor (Upwind slope <3°)
= 1

K₄ – Importance Factor for Cyclonic Region
= 1.15

Design Wind Speed - $V_Z = V_B K_1 K_2 K_3 K_4$

Design Wind Pressure - $P_z = 0.6 V_Z^2$

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	33	1	1	1	1.15	37.95	0.86
2	10	33	1	1	1	1.15	37.95	0.86

Basic Wind Speed : **39 m/sec**

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	39	1	1	1	1.15	44.85	1.21
2	10	39	1	1	1	1.15	44.85	1.21

Basic Wind Speed : **44 m/sec**

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	44	1	1	1	1.15	50.6	1.54
2	10	44	1	1	1	1.15	50.6	1.54

Basic Wind Speed : **47 m/sec**

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	47	1	1	1	1.15	54.05	1.75
2	10	47	1	1	1	1.15	54.05	1.75

Basic Wind Speed : **50 m/sec**

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	50	1	1	1	1.15	57.5	1.98
2	10	50	1	1	1	1.15	57.5	1.98

Basic Wind Speed : **55 m/sec**

S.No	Height	V_B	K_1	K_2	K_3	K_4	V_z	P_z
	(m)	(m/sec)					(m/sec)	(k.N/m ²)
1	8	55	1	1	1	1.15	63.25	2.40
2	10	55	1	1	1	1.15	63.25	2.40

V RESULT AND DISCUSSION

The results obtained by wind effects on Pre Engineered Buildings (PEB) structures, with x bracings at the ends are considered in modeling of structures having material properties Fe250 steel and structure dimensions height is 10m from the foundation or footing top, length of shed is 184m and width of shed is 40m, column to column distance in shed is 8m. Support conditions are considered as pinned base and structures are modeled using Staad.Pro with wind velocities 33, 39, 44, 47, 50 and 55m/s as per IS 875-3.

Structure-1: PEB structure with wind speed 33m/s

Structure-2: PEB structure with wind speed 39m/s

Structure-3: PEB structure with wind speed 44m/s

Structure-4: PEB structure with wind speed 47m/s

Structure-5: PEB structure with wind speed 50m/s

Structure-6: PEB structure with wind speed 55m/s

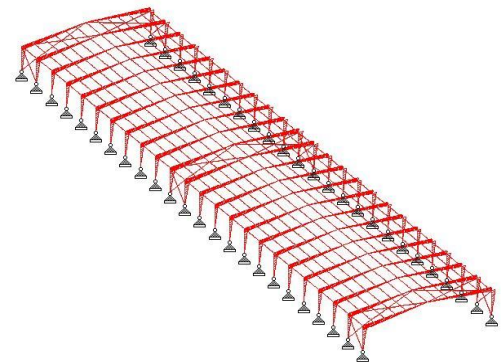


Fig 4.1: Variation of Bending Moment in PEB structure

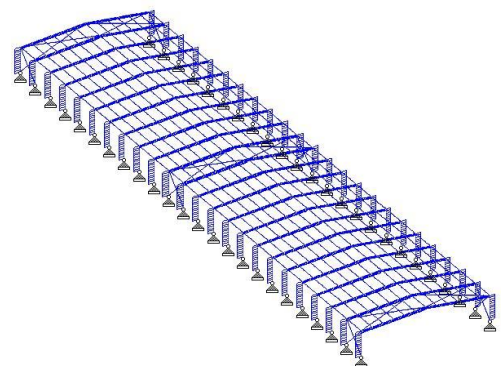


Fig 4.2: Variation of Shear Force in PEB structure

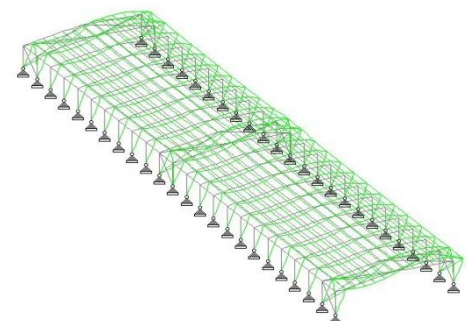
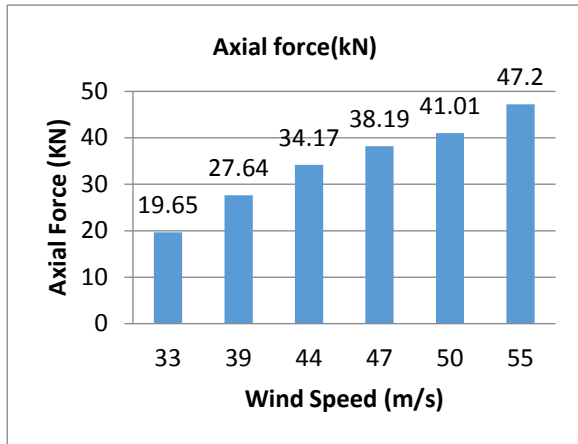


Fig 3: Variation of Deflection in PEB structure

Table 4.1: Axial force in column PEB structure

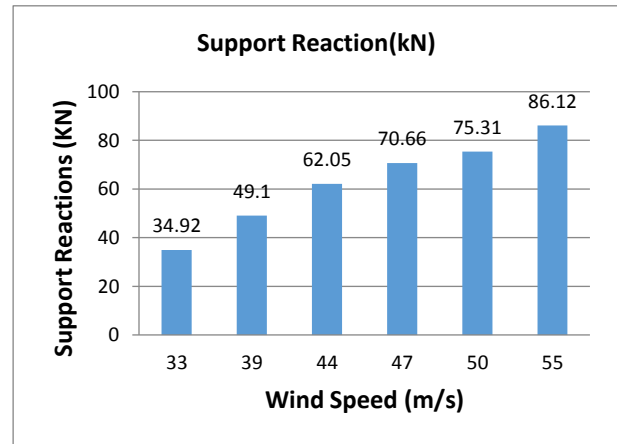
Wind speed(m/s)	Axial force(kN)
33	19.65
39	27.64
44	34.17
47	38.19
50	41.01
55	47.20



Graph 4.1: Axial Force in column PEB structure

Table 4.3: Support Reaction in column PEB structure

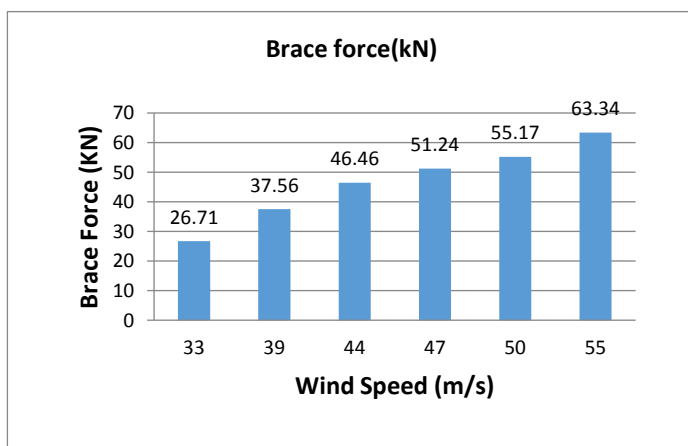
Wind speed(m/s)	Support Reactions (kN)
33	26.71
39	37.56
44	46.46
47	51.24
50	55.17
55	63.34



Graph 4.3: Support Reaction in column PEB structure

Table 4.2: Force in x bracings of PEB structure

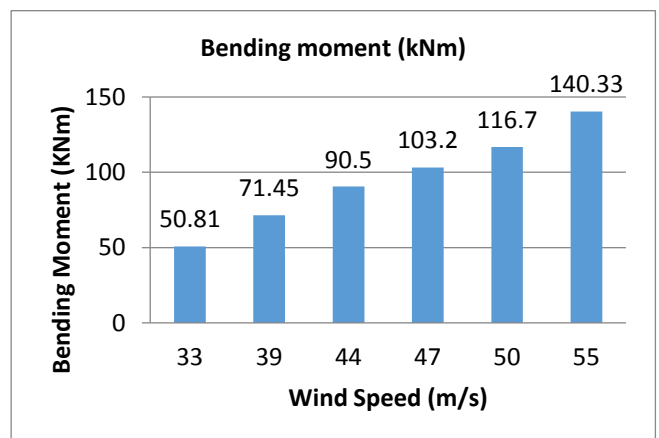
Wind speed(m/s)	Brace force(kN)
33	26.71
39	37.56
44	46.46
47	51.24
50	55.17
55	63.34



Graph 4.2: Force in x bracings of PEB structure

Table 4.4: Bending Moment in the Rafter

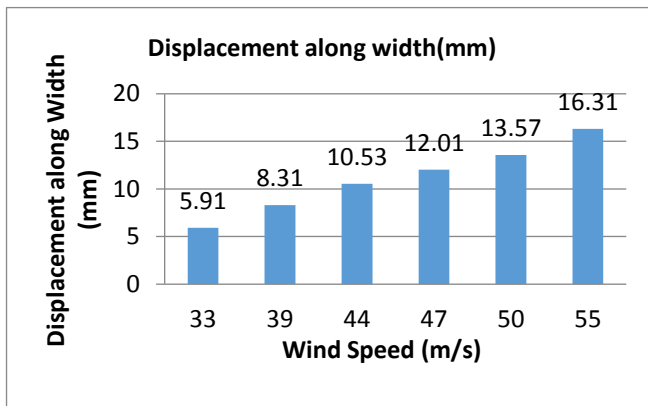
Wind speed(m/s)	Bending Moment (kNm)
33	50.81
39	71.45
44	90.50
47	103.20
50	116.70
55	140.33



Graph 4.4: Bending Moment in the Rafter

Table 4.5: Lateral Displacement along Width

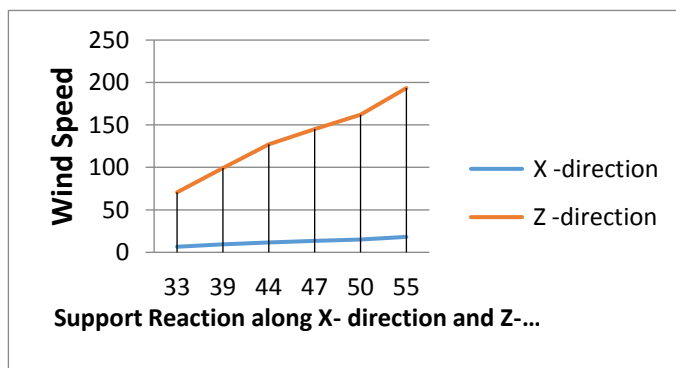
Wind speed(m/s)	Displacement along Width (mm)
33	5.91
39	8.31
44	10.53
47	12.01
50	13.57
55	16.31



Graph 4.5: Lateral Displacement along width

Table 4.9: Horizontal support reaction along x and z direction

Wind speed (m/s)	Support reaction along X-direction	Support reaction along Z -direction
33	6.57	70.61
39	9.24	99.30
44	11.70	127.25
47	13.34	145.06
50	15.09	161.93
55	18.15	193.41



Graph 4.9: Horizontal support reaction along x and z direction

Table 4.10: Optimization of sections of PEB structures

Member type	Chosen section	Optimized section
Bracings	PIP213L	PIP1937L
Purlins	ISMC175	ISMC150

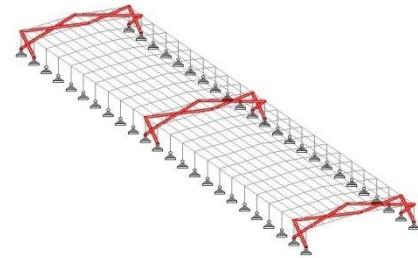


Fig 4.4: Optimization of bracing in PEB structure

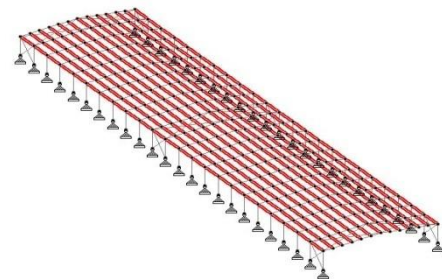


Fig 4.5: Optimization of purlins in PEB structure

Base Plate Design:

Load on base plate = 459.15kN

Height = 400mm,

Breadth = 400mm

Thickness of Flange = 25mm

Thickness of Web = 16mm

Bearing strength of concrete = $0.45f_{ck}$

= 0.45×25

= 11.25N/mm²

Required area of base plate = $459.15 \times 10^3 / 11.25$

= 40813.33mm²

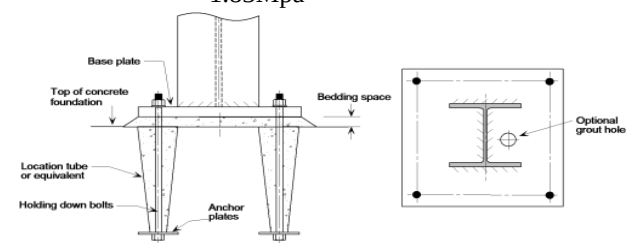
Use a base plate of size = 500mmx500mm

Area = 250000mm²

Projection will be 50mm on each side

$W = 459.15 \times 10^3 / (500 \times 500)$

= 1.83Mpa



$$\begin{aligned}ts &= \text{Thickness of slab} \\ts &= \sqrt{2.5w(a^2-0.3b^2)}\gamma_{mo}/f_y \\ts &= \sqrt{(2.5 \times 1.83(50^2-0.3 \times 50^2))1.10/250} \\ts &= 5.93 < 25\text{mm}\end{aligned}$$

Hence provide 500x500x25mm plate

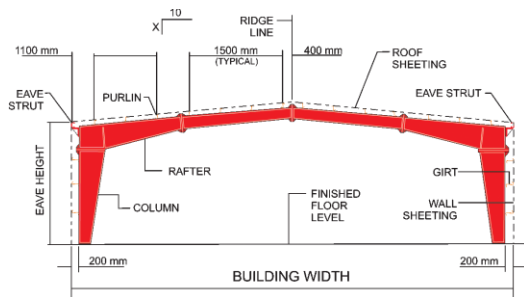
Provide 4 no's 20mm Φ and 300mm long anchor bolts to connect base plate to the foundation concrete
 6mm filled weld around the column section to held the base plate in place

$$\text{Length of the weld along the I section} = 2(400+400-16+400-25) = 2318\text{mm}$$

$$\begin{aligned}\text{Effective length} &= 2318-2(4+2)2a \\&= 2174\text{mm}\end{aligned}$$

Connection Design for Column and Rafter

$$\begin{aligned}\text{Reaction force} &= 150 \text{ KN} \\ \text{Bending moment} &= 80 \text{ KNm} \\ \text{Providing 22mm bolts} \\ \text{Gross diameter} &= 22+1.5 \\ &= 23.5\text{mm}\end{aligned}$$



$$\begin{aligned}\text{Value of bolt in single shear} &= (3.14/4) \times 23.5^2 \times 100 \\ &= 43373.6\text{N}\end{aligned}$$

$$\begin{aligned}\text{Value of bolt in double shear} &= 2 \times (3.14/4) \times 23.5^2 \times 100 \\ &= 86747.2\text{N}\end{aligned}$$

$$\begin{aligned}\text{Value of bolt in tension} &= (3.14/4) \times 23.5^2 \times 100 \\ &= 43373.6\text{N}\end{aligned}$$

$$\begin{aligned}\text{Value of bolt in bearing for 10mm web angles} &= 23.5 \times 10 \times 300 = 70,500\text{N}\end{aligned}$$

Bolts are subjected to a pull acting through the centroid of bolts

$$p = M/(D+t) = 131147.54\text{N}$$

$$\begin{aligned}\text{Number of bolts to resist pull} &= 131147.54/43373.6 = 3.023 = 4\end{aligned}$$

Bolts connecting the pnb members sections will be in single shear and bearing

$$R_v = 43373.6\text{N}$$

$$V = M/D = 80 \times 103 \times 103/600 = 133333.33\text{N}$$

$$\text{Number of bolts, } n' = 133333.33/43373.6 = 3.07 = 4$$

Connection Design for Purlin to Rafter

Design of Purlins:

$$\text{Span of purlin} = 8\text{m}$$

$$\text{Spacing of purlin} = 3.35\text{m}$$

$$\text{Slope} = 5.71^\circ$$

Calculation for Dead load:

$$\text{GI sheeting} = 0.085 \text{ kN/m}^2$$

$$\text{Fixings} = 0.025 \text{ kN/m}^2$$

$$\text{Services} = 0.100 \text{ kN/m}^2$$

$$\text{Total load} = 0.210 \text{ kN/m}^2$$

$$\text{Live load on purlin} = 0.4 \text{ kN/m}^2$$

$$\text{Dead load} = 0.21 \text{ kN/m}^2$$

$$\text{Wind pressure} = 2.4 \text{ kN/m}^2$$

Load combinations

$$\text{DL+LL} = 0.21+0.4 = 0.61 \text{ kN/m}^2$$

DL+WL

$$\begin{aligned}\text{Normal to slope} &= -2.4+0.21\cos 5.71 = -2.19 \\ &\text{ kN/m}^2\end{aligned}$$

$$\begin{aligned}\text{Parallel to slope} &= 0.21\sin 5.71 = 0.021 \\ &\text{ kN/m}^2\end{aligned}$$

Load on Purlin

$$W_z = 0.61\cos 5.71 \times 3.35 = 2.03 \text{ kN/m}$$

$$W_y = 0.61\sin 5.71 \times 3.35 = 0.2 \text{ kN/m}$$

$$M_z = 1.5 \times 2.03 \times 8^2/10 = 19.5 \text{ kNm}$$

$$M_y = 1.5 \times 0.2 \times 8^2/10 = 1.92 \text{ kNm}$$

$$SF_z = 1.5 \times 2.03 \times 8/2 = 12.18 \text{ kN}$$

ISM 100 for which the properties are as follows:

$$D = 100 \text{ mm}; b_y = 50 \text{ mm}; t = 5 \text{ mm}; t_f = 7.7$$

mm

$$I = 192 \times 10^4 \text{ mm}^4$$

$$Z = 37.3 \times 10^3 \text{ mm}^3, \quad Z = 7.71 \times 10^3$$

mm³

$$Z_p = z \ 43.83 \times 10^3 \text{ mm}^3, \quad Z_p = y \ 16.238 \times 10^3$$

mm³

$$b/t_f = 50/7.7 = 6.49 < 9.4$$

Section classification:

$$d/t = (100 - 2 \times 7.7)/5.0 = 16.92 < 42$$

Hence the section is plastic.

Check for shear capacity

As per clause 8.4 of IS 800,

$$A_v = (100 \times 5.0) = 500 \text{ mm}^2$$

$$\frac{A_v f_{yw}}{\sqrt{3} \gamma_{mo}} = \frac{500 \times 250}{\sqrt{3} \times 1.1 \times 10^3} = 65.6 \text{ kN} > 12.18 \text{ kN}$$

Hence shear capacity is very large compared to the shear force.

Check for Moment capacity

$$\begin{aligned}M_{dz} &= \frac{b Z_p z f_y}{\gamma_{mo}} = \frac{1 \times 43.83 \times 250 \times 10^3}{1.1 \times 10^3} = 9.96 \text{ kNm}\end{aligned}$$

The above value should be less than

$$\frac{1.2 \times 37.3 \times 250 \times 10^3}{1.1 \times 10^3} = 10.17 \text{ kNm} > 9.96 \text{ kNm}$$

Check for biaxial bending

$$\frac{M_z}{M_{dz}} + \frac{M_y}{M_{dy}} < 1$$

$$0.68 < 1$$

Hence safe

Check for Deflection

Calculation for deflection is based on the serviceability condition, i.e., with

Unfactored imposed loads.

$$W = 1.168 \times 5 = 5.84 \text{ kN}$$

$$\delta = \frac{5WL^3}{384EI_z}$$

$$= \frac{5 \times 5.84 \times 1000 \times 5000^3}{384 \times 2 \times 10^5 \times 192 \times 10^4} = 24.75 \text{ mm}$$

As per IS 800, Table 6, deflection limit is $L/150 = 33.33 \text{ mm} > 24.75 \text{ mm}$

VI CONCLUSIONS

The following are the conclusions drawn from the analysis results of pre-engineered buildings (PEB) structures, having material properties Fe250 steel and structure dimensions height is 10m from the foundation or footing top, length of shed is 184m and width of shed is 40m, modeled using STAAD Pro subjected to wind velocities 33, 39, 44, 47, 50 and 55m/s as per IS 875-3.

1. With the increase in the wind speed and structure results displacements, support reactions bending moments and axial forces are increased.
2. Axial forces in the columns are 19.65kN, 27.64kN, 34.17kN, 38.19kN, 41kN & 47.20kN in structure-1, structure-2, structure-3, structure-4, structure-5 & structure-6.
3. Brace force in x bracing are 26.71kN, 37.56kN, 46.46kN, 51.24kN, 55.17kN & 63.34kN in structure-1, structure-2, structure-3, structure-4, structure-5 & structure-6.
4. Support reaction at base are 34.92kN, 49.10kN, 62.05kN, 70.66kN, 75.31kN & 86.12kN in structure-1, structure-2, structure-3, structure-4, structure-5 & structure-6.
5. Bending moment at the rafters are 50.81kNm, 71.45kNm, 90.50kNm, 103.20kNm, 116.70kNm and 140.33kNm in structure-1, structure-2, structure-3, structure-4, structure-5 and structure-6.
6. Displacement along width direction is 5.91mm, 8.31mm, 10.53mm, 12mm, 13.57mm and 16.31mm in structure-1, structure-2, structure-3, structure-4, structure-5 and structure-6.
7. Displacement along length direction is 1.53mm, 2.15mm, 2.71mm, 3.09mm, 3.34mm

structure-3, structure-4, structure-5 and structure-6.

13. Support reactions along length direction 70.61kN, 99.30kN, 127.25kN, 145.06kN, 161.93kN & 193.41kN in structure-1, structure-2, structure-3, structure-4, structure-5 and structure-6.
 14. Structure results in columns for structure-2, structure-3, structure-4, structure-5 and structure-6 increased by 40.66%, 73.89%, 94.35% 108.65% and 140.20% when compared with structure1.
 15. Horizontal support reactions are increased by 10.75 times along length direction when compared to width direction.
- With the increase in the wind speed higher sections are required to resist the lateral forces.

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and 3.99mm in structure-1, structure-2, structure-3, structure-4, structure-5 and structure-6.

8. Support reactions along width direction 6.57kN, 9.24kN, 11.70kN, 13.34kN, 15.09kN & 18.15kN in structure-1, structure-2,
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