Design Optimisation of an Aircraft Hangar with Various Parameters

Danush. J[1], J. Ajith[2], N. Kalaivanan[3]
[1]*PG Student, Department of Civil Engineering, Easwari Engineering College, Chennai*
[2]*Assistant Professor, Department of Civil Engineering, Easwari Engineering College, Chennai*
[3]*Structural Engineer, Metal Scope (INDIA) Private Limited, Pondicherry*

Abstract- **Steel structures are the most common and smart choice for industrial construction they are basically because of its ability to create large span space at low cost. Along with the existence of Conventional Steel Building (CSB), the Pre-Engineered Building (PEB) came into being from 1960s. The methodology tracked followed in PEB is highly multifaceted not just because of the quality in pre-designing and pre-fabrication but also due to the light weight outcome and economically sound factor. In this study, using STAAD.Pro an Aircraft Hangar is designed for a clear span of 60m and is compared with PEB structure. Therefore, the most optimised structured is found by comparing different sections, support conditions, ridge angles and bay spacings for the same structure.**

Index Terms- **Aircraft Hangar, Bay spacings/ Ridge angles(B/□), Conventional Steel Building (CSB), Pre-Engineered Building(PEB), Hollow Pre-Engineered Building(H-PEB).**

I. INTRODUCTION

Steel industry is one of the super growing industries in almost every part of the world. Being the second fastest growing economy in the world India has a huge percentage of it is attributed to the construction industries. They are not just economical but also highly eco-friendly when it comes to a treat of global warming, steel is 100% recyclable and the most recycled material. Thus, each ton of recycled steel saves 2,500 pounds of iron ore and approximately 1,000 pounds of coal. Steel members also have the advantages of high tensile strength and ductility. Steel is mostly used in the construction of industrial building with larger span when the concrete is not under the feasible state or the construction time is critical.

In CSB, the sections used for columns and beams are the mill produced hot rolled sections. The hot rolled sections manufactured are of constant depth therefore on the area of low internal stress it leads to excess design of the member. The basis of the PEB concept lies in providing the required section at the location. The sections can be varying throughout the length according to the bending moment diagram by utilization of non-prismatic rigid frames with slender elements thus optimizing material usage and reducing the total weight of the structure. Tapered I section made with built-up thin plates, Standard hot-rolled sections, cold-formed sections, profiled roofing sheets, etc. are used for constructing PEB.

A hangar is a closed structure to hold aircraft in protective storage. Hangars are used for protection from weather, direct sunlight, maintenance, repair, manufacture, assembly and storage of aircraft on airfields, aircraft carriers and ships. Hangars need special structures to be built. The width of the doors is too large and spans from 30 meters to 120 meters and so on for the aircraft entrance. The bigger the aircraft, the more complex a structure is. Hence these structures are specially designed and engineered to fit together to satisfy the unique requirements of specific end-uses.

A literature review is carried out on various studies of conventional steel building and pre-engineered buildings. The study on various design procedures, codal provisions, structural problems, different kinds of sections and various type of analysis carried is studied thoroughly before starting this thesis.

A. Objective of study

The main objective of this project is to optimise steel usage for an Aircraft Hangar which is designed using STAAD.Pro. The objective of this project is also to compare and study the difference in Bending moment, reactions and steel takeoff between Conventional and PEB; Fixed and Pinned support;

hot rolled, hollow and combination of both sections; different bay spacings and ridge angles.

II. STRUCTURE DESCRIPTION

The complete structure configuration details are given below:

Type of Structure : Aircraft Hangar
Location : Arakkonam, Tamil Nadu
Area : Primary Building - 3780m^2
Secondary Building - 360m^2
Total Building - 4176m^2
Length : 63m
Width : Primary Building - 60m (Clear span)
Secondary Building - 6m
Total Building - 72m
Eave height : 23.15m
Ridge angle : CSB - 1in4
PEB - 1in10
Comparative study - 1in5, 1in6, 1in7.5, 1in10, 1in15, 1in20
Bay spacing : CSB/PEB – 6m
Comparative study - 6m, 6.667m, 7.5m, 8.57m
Crane Capacity : 5t
Purlin spacing : 1.2m
Grade of steel : 350 Mpa

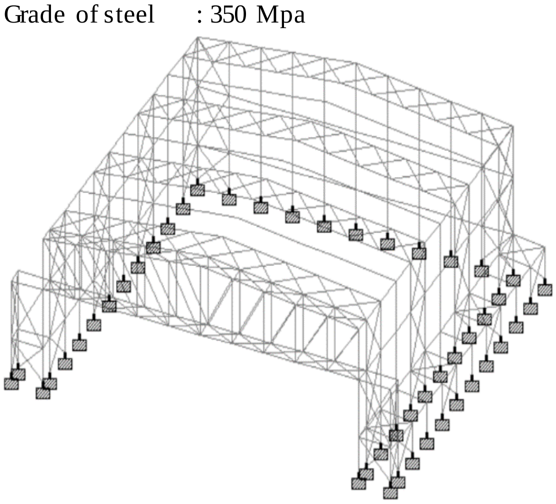

Figure 1 – Geometric view of PEB

A. Material

The yield strength of material used for PEB structure is 350Mpa whose density is 7850kg/m^3 and Young's modulus (E) is 2.0 x1011 N/m^2.

B. Modelling

Analysis is performed using STAAD PRO V8i. A total of 152 load combinations as per IS 875 consisting of dead, live, collateral, wind, earthquake and crane loads are considered. The structure is designed for parameters as mentioned earlier; the ridge angle (θ), bay spacing (B) are varied i.e at a time one is varied keeping the remaining constant. The combination of parameters which gives the low quantity of steel are noted.

III. LOAD CALCULATION

A. Dead Load

Dead load comprises of self-weight of the structure, weights of roofing, steel sheets, purlins, sag rods, bracings and other accessories.

Roof Sheet – GI Sheet with unit weight of 5.6 kg/m^2
Purlin - Assuming purlin unit weight of 6.4 kg/m^2
Total Dead load on plan area = 5.6 + 6.4 = 12 kg/m2
Dead load on Rigid frame = Total dead load on plan area * Bay Spacing = 0.12 kN/m^2 * 6m
= 0.72 kN/m

Side Cladding load same as dead load w.r.t different effective width.

B. Live Load

For single-story metal building systems, roof live load, essentially an allowance for the roof loading during its construction and maintenance. According to IS: 875 (Part 2) – 1987, for roof with no access provided, the live load can be taken as 0.75 kN/m^2

Total Live load on plan area = 0.75 kN/m^2
Live load on Rigid frame = Total Live load on plan area * Bay Spacing = 0.75 kN/m^2 * 6m
= 4.5 kN/m

C. Collateral Load

Collateral or superimposed dead load is a specific type of dead load that includes the weight of any materials other than the permanent construction.

Total Collateral load on plan area = 0.05kN/m^2
Collateral load on Rigid frame = Total collateral load on plan area * Bay spacing = 0.05 kN/m^2 * 6m
= 0.3 kN/m

D. Earthquake Load

Zone = III
Zone factor (Z) = 0.16
Important Factor (I) = 1
Response Reduction Factor (R) = 5

E. Crane Load

A Double girder EOT crane with a capacity of 5t and self weight of 92t is used in Hangar for aircraft maintenance, lifting heavy materials from one point to another. The cranes are supported by crane bridge end trucks bearing on rails that are supported on the top of the crane beams.

Table I - Crane load combinations

F. Wind Load

Wind load is calculated as per IS: 875 (Part 3) – 2015. For side walls, the wind load is applied as uniformly distributed loads acting inward or outward to the walls according to the wind case. The wind load over the roof can be provided as uniformly distributed load acting outward over the PEB rafter.

Basic Wind speed (V_b) = 50 m/sec

Risk coefficient (k_1) = 1

Terrain & Height factor for category 2 (k_2) = 1.08

Topography factor (k_3) = 1

Importance factor for cyclonic region (k_4) = 1

Design wind speed, $V_z = V_b * k_1 * k_2 * k_3 * k_4$

= 50 * 1 * 1.08 * 1 * 1 = 54 m/s

Wind pressure, $p_z = 0.6 * Vz^2 = 0.6 * 54^2$

= 1.75 kN/m^2

Design wind pressure, $p_d = K_d * K_a * K_c * p_z$

Wind directionality factor (K_d) =0.9

Area averaging factor (K_a) = 0.8

Combination factor (K_c) = 0.9

Design wind pressure, p_d = 0.9 * 0.8 * 0.9 * 1.75

= 1.13 kN/m^2 or 1.225 kN/m^2 (p_d should not be less than $0.7p_z$)

IV. ANALYSIS RESULTS

A comparative study is carried out from the analysis results. Each structure is compared and discussed considering certain parameters such as reaction and bending moment at support, bending moment at beam rafter junction, bending moment at ridge of rafter, steel takeoff and deflection. Detailed description of each structure is given below.

A. CSB VS PEB

The CSB has a constant frame depth of 2m. The PEB in other hand has a frame depth varying from 0.75m to 2m depending on the BM. Both the structures have been braced on 4 bays out of 10.

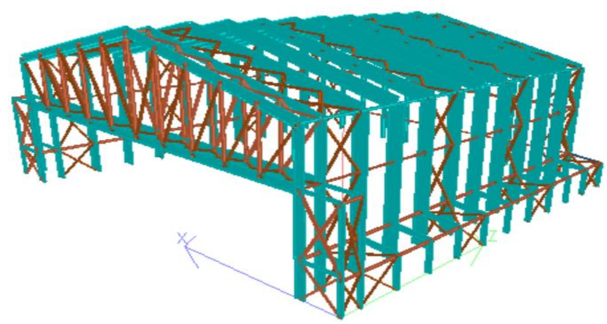

Figure 2 –Rendered view of CSB

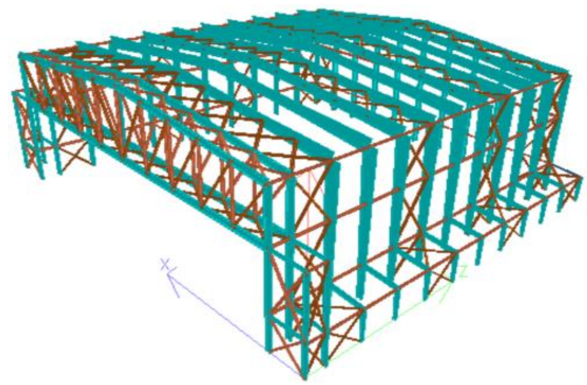

Figure 3 –Rendered view of PEB

Table II – Output Comparison CSB vs PEB

	CSB	PEB
Maximum Value of Reaction at Support (kN)	1485	1311
Maximum Value of Moment at Support (kNm)	2291	1776
Maximum Value of Moment at Beam Rafter Junction (kNm)	2871	3700
Maximum Value of Moment at Ridge of Rafter (kNm)	840	1636
Steel Consumption (t)	510	427

Deflection in CSB is less due to the frame depth of 2m and the 1in4 slope of ridge. The deflection limit for vertical and lateral deflection as per IS 800:2007

Case	Vertical Crane Live Load (kN)		Horizontal Crane Live Load (kN)
	Left corbel	Right corbel	
CL1	418.5	346.5	15
CL2	346.5	418.5	15
CL3	418.5	346.5	-15
CL4	346.5	418.5	-15

is as given below:

Allowable Lateral deflection limit =

Eave Height/150 = 23150/150 = 154.3 mm

Allowable Vertical deflection limit = Span/ 180

= 60000/180 = 333.3 mm

Table III – Deflection Comparison CSB vs PEB

Deflection Check	Allowable Deflection (mm)	Deflection values from STAAD (mm)	
		CSB	PEB
Lateral Deflection	154.3	36.8	83.3
Vertical Deflection	333.3	104	210

B. PEB WITH FIXED SUPPORT VS PEB WITH PINNED SUPPORT

For a height of 23.15m to control deflection fixed support is adopted. The structure is designed with pinned support and studied for comparative purpose. Both these structures have the same frame depth. PEB with fixed support is braced on 4 bays out of 10. While the pinned base is braced on 6 bays out of 10 to control deflection. Rendered view of PEB is same as Figure 3(Fixed).

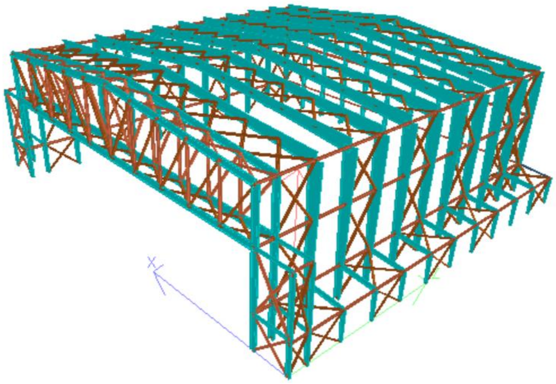

Figure 4 –Rendered view of PEB(Pinned)

Table IV – Output Comparison PEB (Fixed) VS PEB (Pinned)

	PEB (Fixed)	PEB (Pinned)
Maximum Value of Reaction at Support (kN)	1311	1395
Maximum Value of Moment at Support (kNm)	1776	0
Maximum Value of Moment at Beam Rafter Junction (kNm)	3700	3452
Maximum Value of Moment at Ridge of Rafter (kNm)	1636	1713
Steel Consumption (t)	427	478.9

Table V – Deflection Comparison PEB (Fixed) VS PEB (Pinned)

Deflection Check	Allowable Deflection (mm)	Deflection values from STAAD (mm)	
		PEB (pinned)	PEB (fixed)
Lateral Deflection	154.3	139.2	83.3
Vertical Deflection	333.3	236	210

C. PEB VS C-PEB VS H-PEB

The PEB consists of tapered I sections as frame and angle and channel sections as bracing and tie members. C-PEB consists of tapered I sections as frame and square hollow sections as bracing and rectangle hollow sections as tie members. The H-PEB is a single laced type built up section with the same frame depth as PEB made with square hollow sections and rectangle hollow sections. All these structures are braced on 4 out of 10 bays. Rendered view of PEB is same as Figure 3

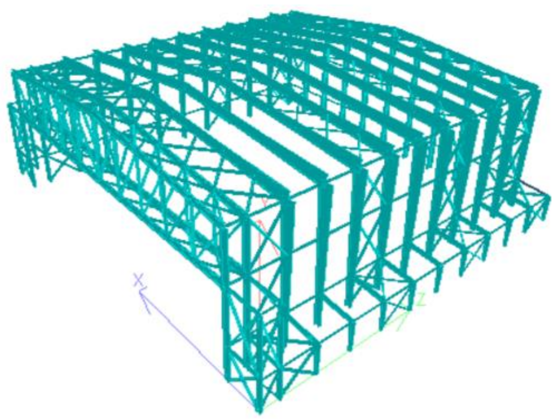

Figure 5 –Rendered view of C-PEB

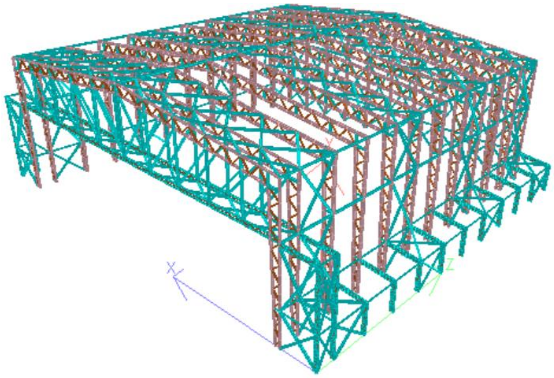

Figure 6 –Rendered view of H-PEB

Table VI – Output Comparison PEB VS C-PEB VS H-PEB

	PEB	C-PEB	H-PEB
Maximum Value of Reaction at Support (kN)	1311	1248	1954
Maximum Value of Moment at Support (kNm)	1776	1818	162
Maximum Value of Moment at Beam Rafter Junction (kNm)	3700	3791	522
Maximum Value of Moment at Ridge of Rafter (kNm)	1636	1558	65
Steel Consumption (t)	427	340.3	326.5

Table VII – Deflection Comparison PEB VS C-PEB VS H-PEB

Deflection Check	Allowable Deflection (mm)	Deflection values from STAAD (mm)		
		PEB	C-PEB	H-PEB
Lateral Deflection	154.3	83.3	85.4	103.1
Vertical Deflection	333.3	210	205.1	248.6

D. BAY SPACINGS AND RIDGE ANGLES

C-PEB is further analysed by changing bay spacings (B) and ridge angles (θ). Bay spacing from 6m to 8.57m reduces the number of bays from 10 to 7, hence reducing the number of columns. The structure with bay spacing of 6m, 6,667m and 7.5m are braced on 4 bays, the structure with bay spacing of 8.57m is braced on 3 bays. For each bay spacing (B) the ridge slope of the structure is changed to 1in5, 1in6, 1in7.5, 1in10, 1in15 & 1in20 (11.3^{θ}, 9.46^{θ}, 7.59^{θ}, 5.71^{θ}, 3.81^{θ} & 2.86^{θ}).

Table VIII – Output Comparison - Support reactions (B/θ)

Maximum Value of Reaction at Support (kN)						
B/θ	1 in 5	1 in 6	1 in 7.5	1 in 10	1 in 15	1 in 20
6m	1284	1316	1243	1248	1258	1245
6.667 m	1283	1304	1295	1304	1313	1270
7.5m	1308	1349	1325	1329	1334	1287
8.57m	1415	1436	1449	1438	1424	1392

Table IX – Output Comparison - Moment at support (B/θ)

Maximum Value of Moment at Support (kNm)						
B/θ	1 in 5	1 in 6	1 in 7.5	1 in 10	1 in 15	1 in 20
6m	1976	2057	1950	1818	1723	1704
6.667m	2223	2318	2195	1994	1940	1915
7.5m	2444	2524	2426	2219	2161	2153
8.57m	2938	3069	2890	2629	2572	2528

Table X – Output Comparison - Moment at Beam Rafter Junction (B/θ)

Maximum Value of Moment at Beam Rafter Junction(kNm)						
B/θ	1 in 5	1 in 6	1 in 7.5	1 in 10	1 in 15	1 in 20
6m	3923	4221	4035	3791	3638	3638
6.667m	4424	4765	4555	4134	4109	4101
7.5m	4904	5241	5084	4659	4660	4690
8.57m	5868	6335	6018	5480	5486	5449

Table XI – Output Comparison - Moment at Ridge of Rafter (B/θ)

Maximum Value of Moment at Ridge of Rafter (kNm)						
B/θ	1 in 5	1 in 6	1 in 7.5	1 in 10	1 in 15	1 in 20
6m	1414	1596	1591	1558	1676	1700
6.667m	1593	1801	1794	1687	1816	1844
7.5m	1737	1946	1997	1905	2022	2125
8.57m	2118	2404	2371	2229	2339	2389

Table XII – Output Comparison – Steel Consumption (B/θ)

Steel Consumption (t)						
B/θ	1 in 5	1 in 6	1 in 7.5	1 in 10	1 in 15	1 in 20
6m	355.4	352.1	347.9	340.3	339.5	336.6
6.667 m	337.8	334	331	321.8	320.9	318
7.5m	321.7	319.4	315.8	306.6	305.8	302.9
8.57m	295.	293.	291.	281.	279.	277.

	7	1	8	1	8	5

Table XIII – Deflection Comparison Bay spacings and ridge angles

B/□	1 in 5		1 in 6	
	Lateral	Vertical	Lateral	Vertical
6m	104	188.2	102.2	213.1
6.667m	116.9	212.2	115.1	240
7.5m	126.2	234.7	122.3	263.3
8.57m	153.7	282.6	151.5	321.5
B/□	1 in 7.5		1 in 10	
	Lateral	Vertical	Lateral	Vertical
6m	94.3	211.3	85.4	205.1
6.667m	105.9	238.5	94.6	222.4
7.5m	114.5	268.3	102.3	254.7
8.57m	138.6	315.9	123.6	295.8
B/□	1 in 15		1 in 20	
	Lateral	Vertical	Lateral	Vertical
6m	77.7	214.6	75.4	218
6.667m	87.2	232.5	84.7	236.4
7.5m	95	265.1	93.8	273
8.57m	114.5	308.4	111.3	312.3

Table XIV – Average increase in lateral deflection (B/θ)

B/□	% increase in Bay spacing	1 in 5	1 in 6	1 in 7.5
6m to 6.667m	11.12%	12.40%	12.62%	12.30%
6m to 7.5m	25.00%	21.35%	19.67%	21.42%
6m to 8.57m	42.83%	47.79%	48.24%	46.98%

1 in 10	1 in 15	1 in 20	Average increase in Lateral Deflection
10.77%	12.23%	12.33%	12.11%
19.79%	22.27%	24.40%	21.48%
44.73%	47.36%	47.61%	47.12%

Table XV – Average increase in vertical deflection (B/θ)

B/□	% increase in Bay spacing	1 in 5	1 in 6	1 in 7.5
6m to 6.667m	11.12%	12.75%	12.62%	12.87%
6m to 7.5m	25.00%	24.71%	23.56%	26.98%
6m to 8.57m	42.83%	50.16%	50.87%	49.50%

1 in 10	1 in 15	1 in 20	Average increase in Vertical Deflection
8.43%	8.34%	8.44%	10.58%
24.18%	23.53%	25.23%	24.70%
44.22%	43.71%	43.26%	46.95%

V. CONCLUSION

Structural modelling of Conventional Steel Aircraft Hangar Building, Pre Engineered Aircraft Hangar building and Hollow Pre Engineered Aircraft Hangar building is done using STAAD Pro. Analysis and Design are carried out for CSB, PEB and H-PEB as per the codal provisions and the following conclusions are arrived.

- For a clear span of 60m PEB weighed 16.3% less than CSB, hence PEB is better in economical and functional point of view.
- The PEB with fixed support weighed 10.8% less than pinned support for this clear span structure. Hence depending on client needs and soil condition suitable support condition can be chosen to optimise steel take off.
- Hollow sections are used in PEB replacing bracings, tie members made of angle and channel sections saved 20.3% of steel used.
- PEB constructed only with hollow sections (H-PEB) weighed 23.5% lesser than PEB with I section.
- The steel consumption decreases with increase in bay spacing and decrease in ridge angle.
- For a clear span of 60m with bay spacing of 8.57m, ridge angle of 1 in 20 showed lesser usage of steel.
- The ridge angle of 1in10 was a very effective and efficient in terms of BM, reactions and steel usage.

- For a constant frame depth if there is 11.1%, 25% and 42.83% increase in bay spacing there was about 12.1%, 21.48% and 47.12% increase in lateral deflection.
- For a constant frame depth if there is 11.1%, 25% and 42.83% increase in bay spacing there was about 10.58%, 24.7% and 46.95% increase in vertical deflection.

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