Design of Pre-Engineered Building (PEB) Structure

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Abstract - *Our project focuses on the designing of PEBs structure and the green building aspect of the structure. In India 67 million tons of food get wasted annually accounting for 92000 crores and being a developing country there will always be a need for an industrial structure for storing and other industrial activity. With the increasing demand for industrial sheds, the structures need to be designed fast and accurately. Any discrepancy and clash in the design of structure cause wastage and the use of BIM software can easily detect and solve such problems before the work even started. The PEB structure has 21,840 m3 and consists of non-prismatic members designed for bending moments at their respective nodes. The members are designed as per IS800 and connection as per AISC and IS. The project uses different software for designing such as ETABS, STAAD PRO, RAM CONNECTION and IDEASTAICA along with hand calculation following IS 875 parts 1, 2, and 3 for load calculation and IS 800*

Key Words: Structure, Designing, Steel, Green Building, Pollution, wastage, BIM, Technology, software.

1. INTRODUCTION

Advances in Technology make possible to design structure more accurately with least possible clashes with other aspects of the structure. This is now possible with the help of BIM and different software interoperability. With the growing demand of industry, housing sector, need of storage units etc. The PEBs structure is intelligently design to take forces and can be constructed rapidly. The PEBs planned and members are fabricated in factory and only need to be assembled at site, this help in reducing construction time considerably. . The advantage of PEB structure is that it can be constructed quickly with lesser amount of material in weight being used. As all the members are fabricated in factory and members need to be transported so it also cost lesser in transportation charges and easier to reach places that are harder to reach.

The greenhouse gases due to steel construction is lesser comparing to concrete construction and the need of framing for concreting, hydrating, and curing period is not required in steel construction. With the help of BIM and interoperability of different software to create and design structure we can reduce the wastage of material and time of construction.

1.1 OBJECTIVE & RESEARCH PROPOSAL

In the project we studied that extent of integration possible using different software's on one projects working on single point. We use ETABS to design members of structures and import the design file to STAAD Pro to design connection using RAM connection in STAAD pro. STAAD pro RAM connection only able to design generic connection inside STAAD PRO, so we used IDEASTATICA BIMLink to design connection from scratch using same design file

2. MATERIALS AND METHOD

There are various types of methods available according to the Indian Standard code –

- Limit State Method (LSM)
- Working State Method (WSM)
- Load Factor Method (LFM) or Ultimate Load Method (ULM)

Here LSM is used for member analysis.

In philosophy, LSM is such that the structure safely carries all the load over its entire life span without failing. The structure is unfit when its collapses or violates the serviceability requirement such as cracking and deflections. With the probabilistic approach design, load and design strength are determined. This philosophical method, design structure in such a way that it remains fit for its entire design life remaining within acceptable limits of safety and serviceability requirements. We use LSM methodology to design the PEB structure.

2.1 DESIGN PRINCIPLE OF LIMIT STATE METHOD

A well designed and well-planned structure has the least probability of its failure. The structure is designed based on the characteristic values of its material strengths and applied loads taking account of variation in materials property and load to be supported. Design value is obtained by applying partial safety factors. The reliability of the design is expressed as

Design Action (Qd) ≤ Design Strength (S_d)

The design action Qd is expressed as

$$Q_d = \sum_k \gamma_f Q_{ck}$$

And, the design strength Sd is obtained as

$$S_U = Su/\gamma_m$$

Where, Q_{ck} = characteristic load

S_U = ultimate strength

γ_f = partial safety factor for loads.

γ_m = partial safety factor for materials.

2.2 STRUCTURE SPECIFICATION –

Table 1 - Structure specification

01	The span of the PEB	40 m
02	Spacing of the PEB frame	7.66 m
03	Height of column	5 m
04	Length of building	91.1 m
05	Rise of the PEB	7 m
06	Slope of the roof (Θ)	10 degree
07	Length along the sloping roof	20.1 m
08	Length of each panel (c/c spacing of purlin)	7.66 m
09	Spacing of gable from PEB frame	7.42

2.3 WIND LOAD CALCULATION

Basic wind speed (Vb) = 33 m/s

Design Wind speed (V_Z) is given by

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

k1 = probability factor (risk coefficient)

k2 = terrain, height and structure size factor

k3 = topography factor

k4 = Cyclonic Factor

Vz = 33 m/s

Design wind pressure $(P_Z) = 0.6 \times V_Z^2$

Design Wind Pressure, $P_d = P_Z \times K_d \times K_a \times K_c$

Wind Directionality Factor, K_d= 0.9

Clause 7.2.1 of IS 875 - Part 3

Area Averaging Factor, K_a =0.80

Clause 7.2.2 of IS 875 - Part 3

Combination Factor, K_c = 0.90

Clause 7.3.3.13 of IS 875 - Part 3

$K_d \times K_a \times K_c$ = 0.648 > 0.7

Design Wind Pressure, P_d = 0.457 KN/m2

Pressure Coefficients:

Area of the face = 455m^2

Area of the opening = 44m^2

Percentage Area of the Opening = 9.65%

Encloser condition of the building = **Partially Enclosed**

Enclosed	0.2
Partially Enclosed	0.5
Open	0.7

$\frac{h}{w}$ = 0.125

$\frac{l}{w}$ = 2.28

$3/2 \le \frac{l}{w} < 4$

External Pressure Coefficient – Use table 4 from IS: 875 part 3 1987

2.4 MATERIAL REQUIRED

Table 2 -Material List by Section Property

Section	**Object Type**	**No of Pieces**	**Length**	**Weight**
			m	kN
member_ 700mm	Beam	34	154.098	166.0928
mem_1_prismatic_ 800mm_to_700mm	Beam	22	147.3982	173.1145
member_2_prismat_ 700mm_to_900mm	Beam	22	147.3981	227.7299
Column 400mm	Column	21	138.6	133.8249
Column middle	Column	26	130	124.8399
member_3_900_to_ 700	Beam	22	73.6992	113.8653
ISMC	Beam	104	791.54	273.43
ROD50	Beam	36	366.54	16.72
ROD50	Brace	12	109.83	5.08

3 RESULT

Following are the design result on PEB structure

3.1 SUPPORT REACTION

Table 3 - Support reaction

	Horizontal		Vertical	Moment KN-m		
	Fx kN	Fz kN	Fy kN	Mx	My	Mz
Max Fx	88.44	0.084	130.07	0	0	0
Min Fx	-88.43	0.083	130.10	0	0	0
Max Fy	0	0.001	313.436	0	0	0
Min Fy	-0.04	-4.61	-6.452	0	0	0
Max Fz	-0.015	14.723	21.973	0	0	0
Min Fz	-0.024	-14.73	36.62	0	0	0
Max Mx	20.784	0.056	48.817	0	0	0
Min Mx	20.784	0.056	48.817	0	0	0
Max My	20.784	0.056	48.817	0	0	0
Min My	20.784	0.056	48.817	0	0	0
Max Mz	20.784	0.056	48.817	0	0	0
Min Mz	20.784	0.056	48.817	0	0	0

3.2 BEAM END FORCES

Table 4 - Beam End Forces

	Fx kN	Fy kN	Fz kN	Mx kN-m	My kN-m	Mz kN-m
Max Fx	313.436	0	0.001	0	0	0
Min Fx	-14.427	-0.017	0.149	-1.2	1.498	-0.215
Max Fy	57.543	158.13	0	-0.001	-0.004	523.103
Min Fy	57.543	-158.13	0	0.001	-0.004	523.105
Max Fz	0.839	4.892	5.04	0.038	-7.611	3.625
Min Fz	2.139	8.111	-5.04	-0.038	9.273	9.017
Max Mx	0.697	6.392	2.116	1.923	8.024	3.288
Min Mx	0.957	-3.791	-2.116	-1.923	9.442	-0.124
Max My	0.418	3.837	-0.406	1.409	14.448	1.97
Min My	0.699	6.372	0.408	-1.409	-14.64	3.28
Max Mz	57.543	-158.13	0	0.001	-0.004	523.105
Min Mz	150.85	72.991	0	0	0	-364.957

3.3 DISPLACEMENT

Table 5 - Displacement

	X mm	Y mm	Z mm	Resultant mm	rX rad	rY rad	rZ rad
Max X	9.627	-14.42	-0.127	17.339	0	0	-0.001
Min X	-9.62	-14.42	-0.128	17.34	0	0	0.001
Max Y	-5.568	2.513	0.012	6.109	0	0	0
Min Y	2.65	-24.5	-0.03	24.657	0	0	-0.01
Max Z	0.003	-0.037	29.561	29.561	0.004	0.002	0
Min Z	0.004	-0.061	-29.836	29.836	-0	-0	0
Max rX	1.2	-10.487	5.231	11.781	0.046	0.005	-0.001
Min rX	1.202	-10.502	-5.268	11.81	-0.05	-0.01	-0.001
Max rY	0	0	0	0	0.001	0.051	-0.001
Min rY	0	0	0	0	0.001	-0.05	0.001
Max rZ	0.907	-9.266	-0.036	9.311	0	0	0.004
Min rZ	-0.91	-9.264	-0.036	9.309	0	0	-0.004
Max Rst	0.004	-0.061	-29.836	29.836	-0	-0	0

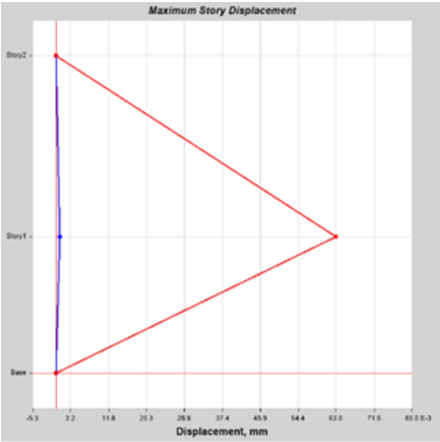

Chart 1 – Tabulated plot Coordinates of Displacement

3.4 CONNECTION DESIGN

Some of the connection are –

3.4.1 Apex Connection –

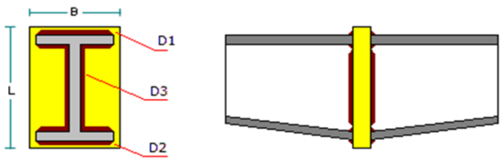

Fig 1 – Apex type connection detail diagram

Members
Configuration
Is apex : Yes
Vertical angle (deg) : 0
Right beam
Beams
Beam type : Tapered
member
Beam section : Taper_7
Beam initial height : 699.999 mm
Beam final height : 699.999 mm
Beam length : 3.35 m
Beam material :
STEEL_275_NMM2
Moment - Flange and web welded
Beam side
Top flange weld type : Fillet
Top beam flange weld : E70XX
D1: Weld size to top beam flange (1/16in) :
4
Bottom flange weld type : Fillet
Bottom beam flange weld : E70XX
D3: Weld size to bottom beam flange
(1/16in) : 4
Welding electrode to beam web: E70XX
D2: Weld size to beam web
(1/16in) : 3
Connecting plate
tp: Thickness : 25.4 mm
Material : A36

3.4.2 PURLIN CONNECTION

Material
Steel - E 165 (Fe 290)
Project item - Purlin Connection Design
Name - Purlin connection
Analysis - Stress, strain/loads in equilibrium

Table 6 – Load effects (forces in equilibrium)

Name	Mem	N	Vy	Vz	Mx	My	Mz
LE1	M1	-126.6	0.1	-121	0	106.6	0
	M2	0.1	0	0	0	0	0
LE2	M1	-141.8	0.1	-91	0	47.1	0
	M2	0.1	0	0	0	0	0

Table 7 - Summary of purlin connection result

Name	Value	Check status
Analysis	100.00%	OK
Plates	0.0 < 5.0%	OK
Welds	0.6 < 100%	OK
Buckling	Not calculated	

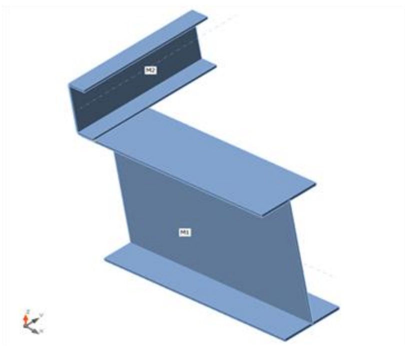

Fig 2 – Purlin connection

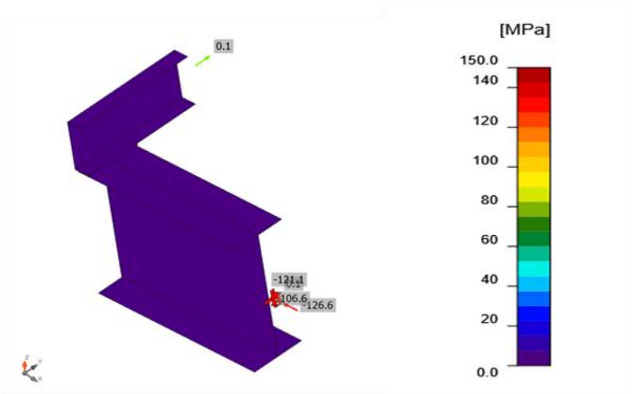

Fig 3 – Purlin connection equivalent stress check for load LE1

3.4.3 APEX CONNECTION

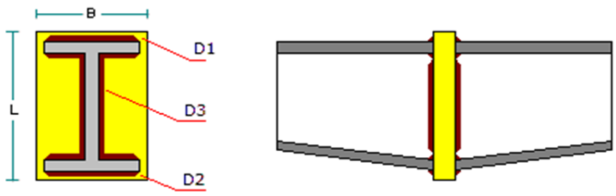

Fig 4 – Apex connection detail

Members
Configuration
Is apex : Yes
Vertical angle (deg) : 0
Right beam
Beams
Beam type : Tapered member
Beam section : Taper_7
Beam initial height : 699.999 mm
Beam final height : 699.999 mm
Beam length : 3.35 m
Beam material : STEEL_275_NMM2
Moment - Flange and web welded
Beam side
Top flange weld type : Fillet
Top beam flange weld: E70XX
D1: Weld size to top beam flange (1/16in): 4
Bottom flange weld type : Fillet
Bottom beam flange weld : E70XX
D3: Weld size to bottom beam flange (1/16in): 4
Welding electrode to beam web : E70XX
D2: Weld size to beam web (1/16in) : 3
Connecting plate
tp: Thickness : 25.4 mm
Material : A36

3.4.4 BEAM COLUMN FLANGE CONNECTION

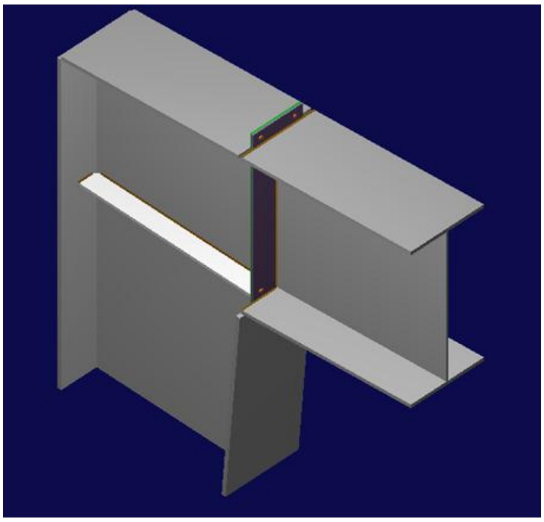

Fig 5 – Beam Column Flange (BCF) connection type

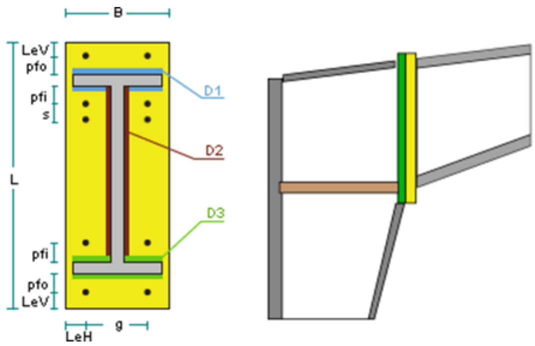

Fig 6 – Beam Column Flange (BCF) connection type detail

Members
Configuration
Is apex : Yes
Vertical angle (deg) : 0
Right beam
Beams
Beam type : Tapered member
Beam section : Taper_7
Beam initial height : 699.999 mm
Beam final height : 699.999 mm
Beam length : 3.35 m
Beam material : STEEL_275_NMM2
Moment - Flange and web welded
Beam side
Top flange weld type : Fillet
Top beam flange weld: E70XX
D1: Weld size to top beam flange (1/16in): 4
Bottom flange weld type : Fillet
Bottom beam flange weld : E70XX

D3: Weld size to bottom beam flange (1/16in): 4
Welding electrode to beam web: E70XX
D2: Weld size to beam web (1/16in): 3
Connecting plate
tp: Thickness : 25.4 mm
Material : A36
Members
Configuration
Exists opposite connection: No

Beam
General
Beam section : Taper_7
Beam material : STEEL_275_NMM2
Beam initial height : 699.999 mm
Beam final height : 699.999 mm
Beam length : 6.7 m
Vertical angle (deg) : 5.711
Include flange stiffener: No

Column
General
Support section : Taper_2
Support material : STEEL_275_NMM2
Support initial depth : 749.999 mm
Support final depth : 399.999 mm
Support length : 5 m

End plate
Connector
Plate extension: Extended external edge
Width : 203.2 mm
tp: Plate thickness : 6.35 mm
Plate material : A36
Fy : 0.248 kN/mm2
Fu : 0.4 kN/mm2
Hole type on plate : Standard (STD)
Flush extension length: 25.4 mm
Plate alignment : Vertical alignment

Weld
External flange weld type: Fillet
Weld to external flange: E70XX
D1: Weld size to external flange (1/16in): 3
Internal flange weld type : Fillet
Weld to internal flange : E70XX
D3: Weld size to internal flange (1/16in): 3
Web weld : E70XX
D2: Weld size to web (1/16in): 3
Bolts
tp: Connection plate thickness: 6.35 mm
Bolts: 1/2" A325 N
g: Gage - transverse c/c spacing: 139.7 mm
Hole type : Standard (STD)
Lev: Vertical edge distance : 31.75 mm
Leh: Horizontal edge distance : 31.75 mm
Bolt group (external extension)
pfo t: Distance from bolt rows to flange: 31.75 mm
Bolt group (external flange)
Bolts rows number : 1
pfi t: Distance from bolt rows to flange : 31.75 mm
Bolt group (internal flange)
Bolts rows number : 1
pfi b: Distance from bolt rows to flange: 31.75 mm

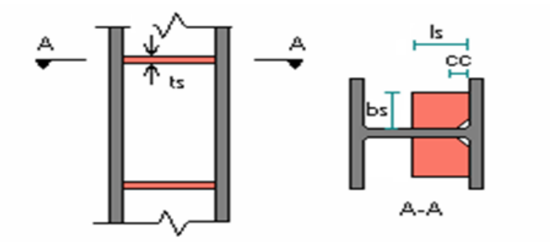

Fig 7 – Beam Column Flange (BCF) connection detail

Transverse stiffeners
Section : PL 12.7x76.2x727.65
Full depth : Yes
Length : 727.649 mm
bs: Transverse stiffeners width: 76.2 mm
cc: Corner clips : 19.05 mm
ts: Transverse stiffener thickness: 12.7 mm
Material : AS_Class 4.6
Weld type : Fillet
Welding electrode to support : AS E41XX
D: Weld size to support (1/16 in) : 3

3.4.5 BRACING CONNECTION

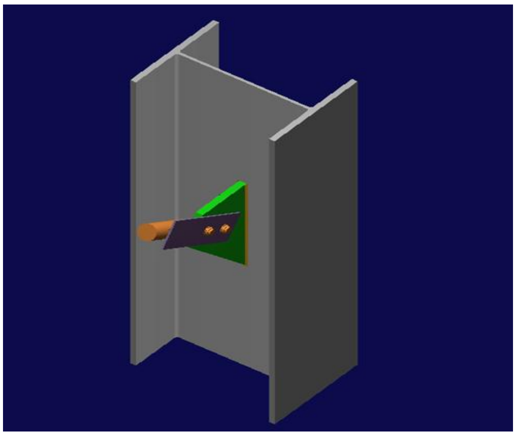

Fig 8 – Bracing connection

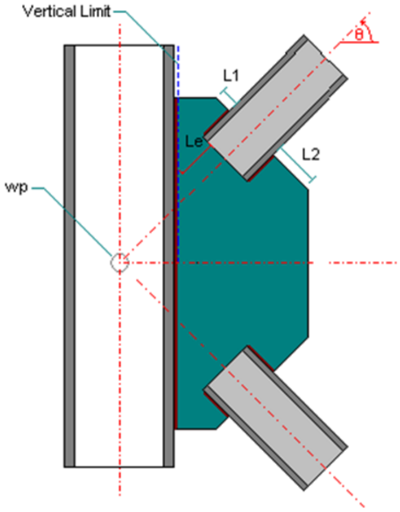

Fig 9 – Bracing connection detail

Members

Existing members

Right beam : No
Left beam : No
Upper right brace : Yes
Upper left brace : No
Lower left brace : No
Lower right brace : No
Align beams to top edge: No
Bracing cleat assembly: No

Column

General

Column section : Taper_2
Column material : STEEL_275_NMM2
Column orientation : Transversal
Is column end : No

Upper right brace

General

Section : Cir 0.05_0
Material : Q345
Slope angle (degrees) : 33.11
Additional vertical force: 0 kN

Additional geometric data

wpx: WP horizontal displacement: 0 mm
wpy: WP vertical displacement: 0 mm
Le: Minimum distance to other members: 25 mm
Le1: Left distance : 25 mm
Le2: Right distance : 25 mm

Interfaces

Upper right brace

Gusset

General

tg: Thickness: 20 mm
Material : E 250 A
LV: Length on column: 324.458 mm

Gusset-to-Brace connection

General

Connection type: Bolted
Bolts : M_20 G8_8
Hole type : STD
Hole type on gusset : STD
np: Number of rows of bolts longitudinally: 2
nc: Number of lines of bolts transversely: 1
sp: Longitudinal bolt spacing : 70 mm
ae1: Longitudinal distance to edge: 45 mm
ae3: Transverse distance to edge: 45 mm
Material : E 250 A
t: Thickness : 5 mm
Setback : 20 mm
Weld : E 49
Weld size : 5 mm
Weld length : 100 mm
Weld clearance: 5 mm

Gusset-to-Column connection

General

Connection type to column: Directly welded

Directly welded

Welding electrode : E 49
Weld size : 6 mm

3.4.6 BASE PLATE

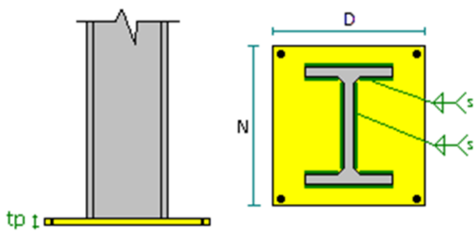

Fig 10 – Base plate connection detail

Members

Column

Section : Taper_2
Material : STEEL_275_NMM2

Longitudinal offset : 0 mm
Transversal offset : 0 mm

Connector

Base plate

Connection type : Unstiffened
Position on the support: Center
N: Depth : 460 mm
D: Gross width : 610 mm
tp: Thickness : 6 mm
Material : E 250 A
Column weld : E 41
s: Column weld size : 3 mm
Override A1/A2 ratio : No
Shear key type : None

Support

With pedestal : No
Longitudinal dimension : 2500 mm
Transversal dimension : 2500 mm
Thickness : 500 mm
Material : M40
Include grouting : No
Cover : 70 mm

Anchor

Anchor position : Transversal position
Rows number per side : 1
Anchors per row : 2
Longitudinal edge distance on the plate: 50 mm
Transverse edge distance on the plate : 50 mm
Head type : Hexagonal
Include lock nut : No
Anchor : M-8
Effective embedment depth : 150 mm
Total length : 166.56 mm
Material : Class 8.8
Fy : 640 N/mm2
Fu : 800 N/mm2
Splitting Failure : No
Cracked concrete : No
Non-ductile steel : No
Fasteners welded to base plate: No
Lever arm : No

Anchor supplementary reinforcement

Tension reinforcement: No
Shear reinforcement : No

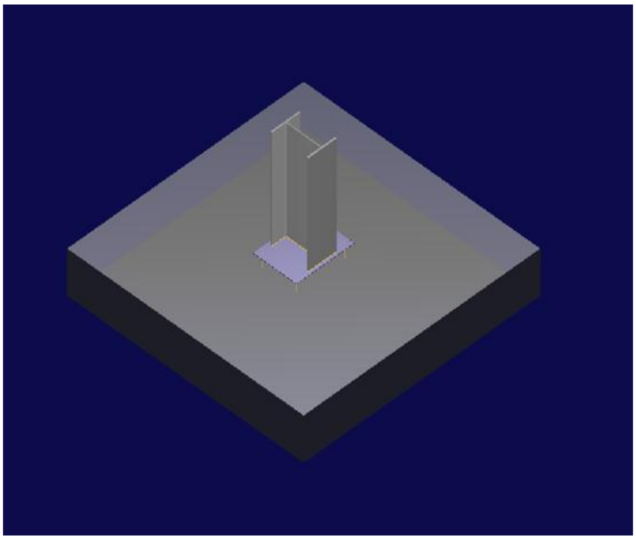

Fig 11 – Base plate connection

3.5 RENDER VIEW

Fig 12 – Render view of the PEB structure by STAAD pro

3.6 SHEAR DIAGRAM OF THE STRUCTURE

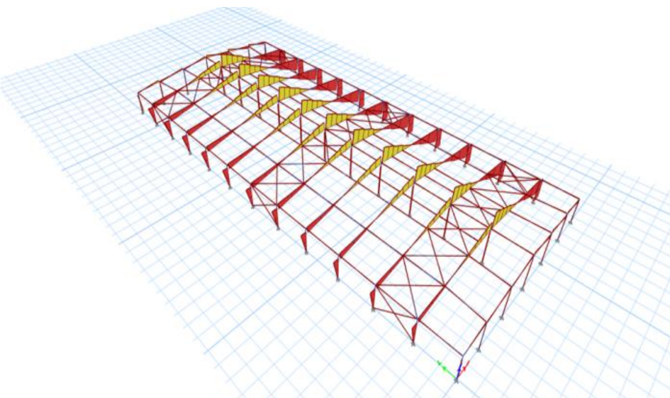

Fig 13 - Shear diagram of the structure

DISCUSSION –

We are able to design the structure and connection by codal provision and preliminary data. With the use of Etabs and Staad Pro we designed members of the structures and connection with the help of RAM connection and IdeaStatica. The data of model is transferred from one software to other with help of IFC file or plugins. Both the methods for transferring the data isn't completely successful in our case and some of the members need to redesign for further designing.

CONCLUSION –

The structure is prefabricated and it is only assembled on the site. The structure is pre planned according to the site conditions, wind conditions, earthquake forces, MEP loads and temperature stresses. Once the planning of structure is completed, the member is fabricated in the factory and assembled on the site requiring lesser time and fewer man power. Accuracy The member and connection are designed specifically for each node and use of Ram connection and Ideastatica connection can designed the connection to highest accuracy. The software designed file can be shared with various software using plugin. The file shared contain designed data from parent software which can now integrate with other data on other software like Revit to create highly accurate 3d Model. Low wastage the PEBs structure after designing is fabricated in a factory part by part and only requisite amount of material is cut from bigger sheet of rolls to form a fabricated member of a PEB and the scraps from the sheets can be collected for recycling.

- The structure is prefabricated and it is only assembled on the site.
- The structure is pre planned according to the site conditions, wind conditions, earthquake forces, MEP loads and temperature stresses.
- Once the planning of structure is completed, the member is fabricated in the factory and assembled on the site requiring lesser time and fewer man power.
- Accuracy The member and connection are designed specifically for each node and use of Ram connection and Ideastatica connection can designed the connection to highest accuracy.
- The software designed file can be shared with various software using plugin.
- The file shared contain designed data from parent software which can now integrate with other data on other software like Revit to create highly accurate 3d Model.

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BIOGRAPHIES

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