

# Analysis & Design of Pre-Engineered Building using Jack Beam & its use in steel industry

Dhanaraj S. Aundhkar<sup>1</sup>, Dr. Ashok Kasnale<sup>2</sup>, Prof. Vishwajeet A. Kadlag<sup>3</sup>

PG student, Department of Civil Engineering, Dr. D. Y. Patil School of Engineering & Technology, Lohgaon, Pune, Maharashtra, India<sup>1</sup>

Principle and Project Guide, Department of Civil Engineering, Dr. D. Y. Patil School of Engineering & Technology, Lohgaon, Pune, Maharashtra, India<sup>2</sup>

Associate Professor, Project Co-Guide and PG Co-Ordinator, Department of Civil Engineering, Dr. D. Y. Patil School of Engineering & Technology, Lohgaon, Pune, Maharashtra, India<sup>3</sup>

**ABSTRACT:** Now a day's concept of Pre-Engineered building is growing stage in steel industry in world. Use of PEB buildings as industry, warehouse, cold storage & factory. Every building has a different use in its application. Proper utilization of space is mandatory & advantageous for its application. From initial stage, architect, consultants, structural engineer has a agenda & challenge for space management. Many consultants has a special requirement for column less structure. Some user of PEB buildings has a special requirement of open space used for movement of tailors, machines, hoppers, special arrangement openings. In that case, any obstruction of column is not allowed. This space management concept can be achieved from initial stage of designing structure. Jack beam can be considered from respected side wall columns. By considering a jack beam, spans up to 15 m to 30m can be considered as column less structure. While considering jack beam, there is a reduction in total number of columns.. While designing PEB building, bay spacing, orientation of column, shall be decided at initial stage.

**KEYWORDS:** Pre-Engineered Building, Staad-Pro, Jack Beam, Tapered column, Loading, Deflection, Utilisation Ratio.

## I. INTRODUCTION

The scientific-sounding term pre-engineered buildings came into being in the 1960s. Typically, a pre-engineered building is a metal building that consists of light gauge metal standing seam roof panels on steel purlins spanning between rigid frames with light gauge metal wall cladding. In other words, it has a much greater vertical and horizontal deflection. Pre-engineered buildings are generally low rise buildings which are ideal for offices, houses, showrooms, shop fronts etc. One may think about its possibility, but it's a fact many people are not aware about Pre Engineered Buildings. If we go for regular steel structures, time frame will be more, and also cost will be more, and both together i.e. time and cost, makes it uneconomical. Thus in pre-engineered buildings, the total design is done in the factory, and as per the design, members are pre-fabricated and then transported to the site where they are erected in a time less than 6 to 8 weeks.

Also a special concept of Jack Beam is employed to support another beam or rafter, thus eliminating a column support at that location. Jack beams are commonly used in multi-span buildings where the client may need additional clear space for equipment or for material handling purpose. Jack beams may also be required in sidewalls where an oversized framed opening (i.e. larger than the bay spacing) is required, thus eliminating a sidewall column. Jack beams are designed to support dead plus live loads i.e. gravity loads, and dead plus wind uplift loads in their major axis. When sidewall jack beams are required, they are generally not designed to withstand any lateral or horizontal wind loads in their minor axis. To eliminate this minor axis bending in the jack beam, the intermediate rigid frame rafter resting on the jack beam should always be braced in the roof back to the adjacent main rigid frames. Therefore the horizontal load from the wind transmitted to the rafter is then distributed through the bracing to the adjacent main rigid frames. These adjacent rigid frames should be designed for additional vertical and horizontal loads from the jack beam. Pre-engineered building creates and maintains in real time multidimensional, data rich views through a project support is currently being implemented by Staad-pro software packages for design and engineering. Choosing steel to design a Pre-engineered steel structures building is to choose a material which offers low cost, strength, durability, design

flexibility, adaptability and recyclability. Steel is the basic material that is used in the Materials that are used for Pre-engineered steel building. It negates from regional sources. Plan & 3d view for above reference is as follows :

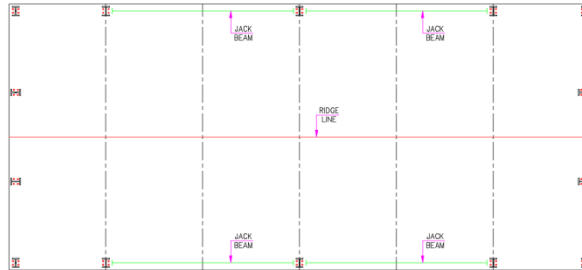


Fig 1 Plan for PEB building

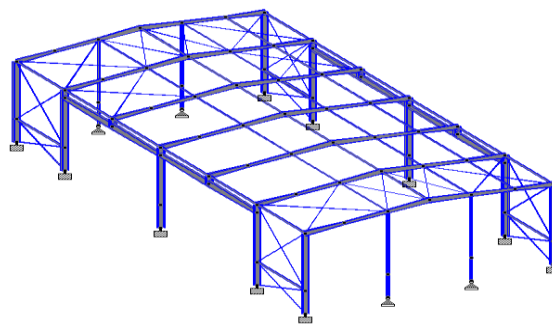


Fig 2 Staad-3D model

It is a combination of precast & prefabricated structures. Pre-engineered buildings are generally low rise buildings which are ideal for offices, than half the normal time. Although PEB systems are extensively used in industrial and many other non-residential constructions worldwide, it is relatively a new concept in India. Houses, showrooms, shop fronts etc. The application of pre-engineered buildings concept to low rise buildings is very economical and speedy. Buildings can be constructed in less.

## II. LITERATURE REVIEW

Syed Firoz, Sarath, Chandra Kumar et.al (2012)

Observed that, The pre-engineered steel building system construction has great advantages to the single storey buildings, practical and efficient alternative to conventional buildings, the System representing one central model within multiple disciplines. Pre-engineered building creates and maintains in real time multidimensional, data rich views through a project support is currently being implemented by Staad-pro software packages for design and engineering. Choosing steel to design a Pre-engineered steel structures building is to choose a material which offers low cost, strength, durability, design flexibility, adaptability and recyclability. Steel is the basic material that is used in the Materials that are used for Pre-engineered steel building. It negates from regional sources. It also means choosing reliable industrial products which come in a huge range of shapes and colours; it means rapid site installation and less energy consumption. It means choosing to commit to the principles of sustainability. Infinitely recyclable, steel is the material that reflects the imperatives of sustainable development.

Aijaz Ahmad Zende 1, Prof. A. V. Kulkarni , et.al (Jan. - Feb. 2013)

Observes that even though PEB structures provides clear span, it weighs lesser than that of Conventional Buildings. Infinitely recyclable, steel is the material that reflects the imperatives of sustainable development. For longer span structures, Conventional buildings are not suitable with clear spans. Pre-engineered building are the best solution for longer span structures without any interior column in between as seen in this present work, an industrial structure has been designed for 88m. With the advent of computerization, the design possibilities became almost limitless. Saving of



material on low stress area of the primary framing members makes Pre- engineered buildings more economical than Conventional steel buildings especially for low rise buildings spanning up to 90.0 meters with eave heights up to 30.0 meters. PEB structures are found to be costly as compared to Conventional structures in case of smaller span structures. To Conclude Pre-Engineered Building Construction gives the end users a much more economical and better solution for long span structures where large column free areas are needed.

Jatin D. Thaka r, 2 Prof. P.G. Patel

observes that Pre-engineered building are steel building wherein the framing members and other components are fully fabricated in the factory after designing and brought to the site for assembly, mainly by nut-bolts, thereby resulting into a steel structure of high quality and precision. In conventional steel construction, we have site welding involved, which is not the case in P.E.B using nut-bolt mechanism. These structures use hot rolled tapered sections for primary framing and cold rolled sections (generally Z and C sections) for secondary framing as per the internal stress requirements, thus reducing wastage of steel and the self- weight of the structure and hence lighter foundations. International codes are referred in their design as per the MBMA (Metal Building Manufacturers Association) standards which are more flexible allowing the use of built - up sections of minimum 3.5 mm thickness against 6 mm as minimum criteria in conventional steel sections .There is use of steel of high strength (345MPa) which prominently speaks about greater strength with judicious use of steel as a result of tapered profile. The tapered section concept was first adopted in U.S.A keeping in mind the bending moment diagram. At locations of high bending moment values, greater depth is used while less moment encouraged the use of lesser depths. Further unlike the conventional steel sections, where Moment of inertia (I) remains constant, it is not so in case of P.E.B due to varying depths.

G. SaiKiran , A. KailasaRao, R . Pradeep Kumar (Aug 2014)

observes that, In recent years, the introduction of Pre Engineered Building (PEB) concept in the design of structures has helped in optimizing design. The adoptability of PEB in the place of Conventional Steel Building (CSB) design concept resulted in many advantages, including economy and easier fabrication. In this study, an industrial structure (Ware House) is analyzed and designed according to the Indian standards, IS 800-1984, IS 800-2007 and also by referring MBMA-96 and AISC-89. In this study, a structure with length 187m,width 40m,with clear height 8m and having R-Slope 1:10,isconsidered to carry out analysis& design for 2D frames (End frame, frame without crane and frame with 3 module cranes). The economy of the structure is discussed in terms of its weight comparison, between Indian codes (IS800-1984, IS800-2007) & American code (MBMA-96), & between Indian codes (IS800-1984, IS800-2007).

### III. STRUCTURAL CONFIGURATION

Sr. No	Parameter	Detail
1	Location	Pune, Maharashtra
2	Length of building	45.0m C/C
3	Width of building	22.27m C/C
4	Height of building	10.5m (clear)
5	Seismic zone for Pune	III
6	Wind speed for Pune	39 m/sec
7	Wind terrain category	2
8	Wind Class	C
9	Slope of roof for PEB	5.71 Degree
10	Soil type	Medium
11	Importance factor	1
12	Response reduction factor	5
13	Bay spacing	7.5 m C/C

Above building is designed as per parameters given in above table. Wind calculation is done as per IS 875 Part III 1987. Seismic design calculation is done as per IS 1893 2002. Base shear of building is calculated as per self-weight of building. In staad pro parameters apply to the respected member is as per American code. Built up section design as per American code AISC code. Codes & standards used for above building is as per below table



Sr. No	Codes & Standards	Detail
1	MBMA 2010	Metal Building Manufactures Association
2	AISC	American Institute of Steel Construction
3	IS 875-Part-III 1987	Code of practice for design loads
4	IS 1893 Part-I 2002	Seismic Design Code
5	AISI	American Iron and Steel Institute

Steel structural is designed with moment connection in transverse direction & shear connection along longitudinal direction with fixed base condition. The steel frame is adequately tied up with plan bracing. Steel structure modeled in STAAD Pro. The design of beams & columns has been designed using STAAD Pro software. Also forces coming from longitudinal direction are resisted by wind bent or bracing in lateral direction. This wind forces at gable shall be 50% transfer to roof & 50% transfer to foundation.

#### IV. LOADING CALCULATION

##### Seismic load calculation

Earthquake loads affect the design of structures in areas of great seismic activity. The proposed structures in this project shall be analyzed for seismic forces. The seismic zone shall be considered as per IS: 1893-2002 (Part1). For analysis and design, Zone III shall be considered as Pune region falls under this zone as per IS: 1893- 2002.

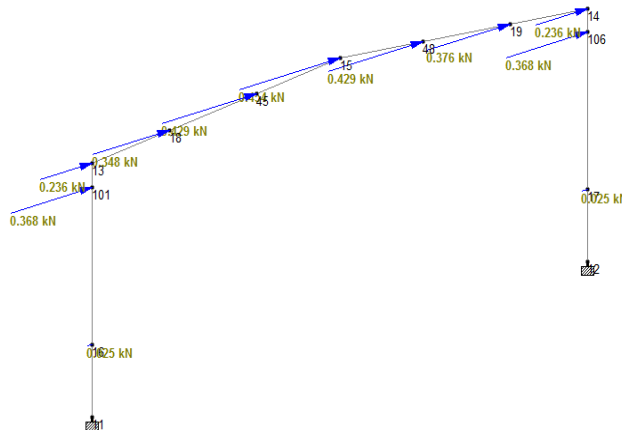


Fig 3 Seismic load in +X direction

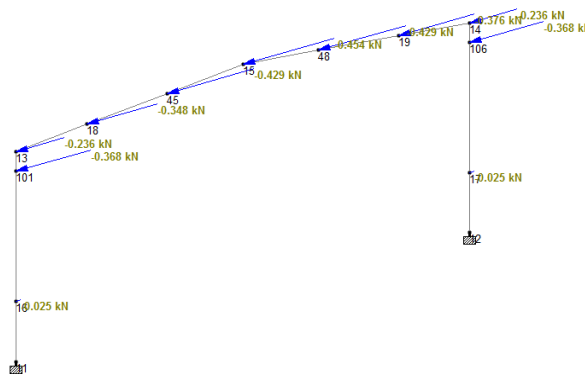


Fig 4 Seismic load in -X direction

Dead load calculation

Dead load calculation includes Purlins, sheeting, sag rod and insulation material. The total load transferring from these components is 0.10 KN/m<sup>2</sup>.

Total Dead load = 0.1\*7.5(Bay Spacing) = -0.75 KN/m

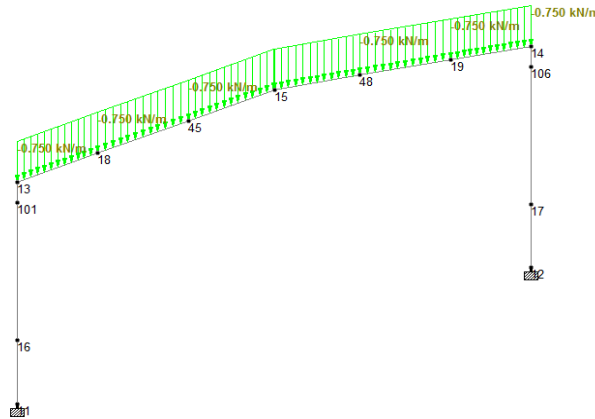


Fig 5 Dead load in -Y direction

Live load calculation

Live Load is considered as 0.57 KN/m<sup>2</sup> according to American code of practice for roof where access is not provided except for maintenance and for a roof where slope is greater than 10 degree then there is reduction of 0.02 KN/m<sup>2</sup> for every degree in increase above 10 degree.

Total Live load = 0.57\*7.5(Bay Spacing) = -4.275 KN/m

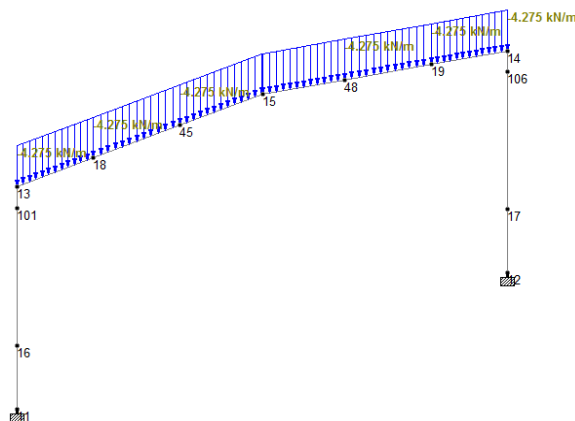


Fig 6 Live load in -Y direction

Wind Load calculation

Basic wind speed = 39 m/sec

Risk coefficient (K1) = 1

Terrain height & size factor = 0.98

Topography factor = 1

Design wind speed (Vz) = Vb x K1 x K2 x K3

= 39x1x0.98x1

= 38.22 m/s

Design wind pressure (Pz) = 0.6x (Vz)<sup>2</sup>



$(P_z) = 0.876 \text{ KN/m}^2$

Design Wind Pressure  $(P_z) = 0.876 \text{ kn/m}^2$

Wind load is calculated as per IS873 (PartII). The wind load over the roof can be provided as uniformly distributed load acting outward over the roof and which is calculated as per table 16 given in IS-875 part III . For side walls, the wind load is applied as uniformly distributed load acting inward or outward to the walls according to the wind cases. Wind forces can be calculated from Longitudinal & transverse direction. Below are the different cases for wind application for above building as follows.

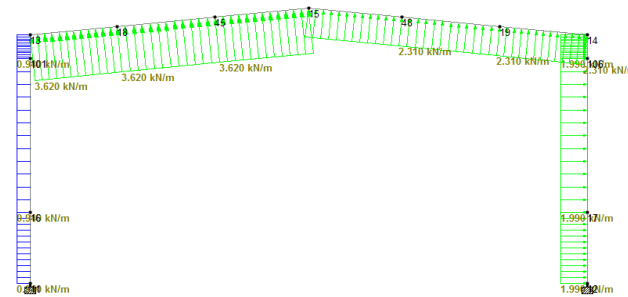


Fig 7 Wind load in +X direction (Pressure)

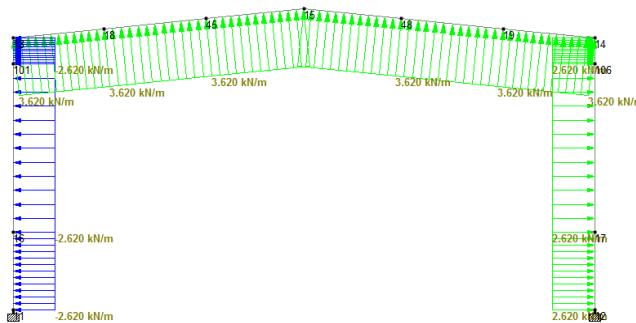


Fig 8 Wind load in -X direction (Suction)

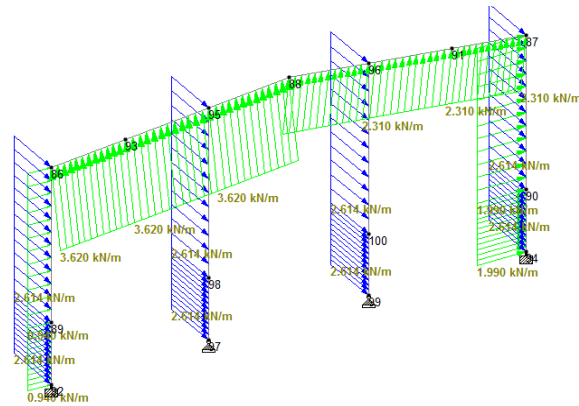


Fig 8 Wind load in + Z direction (Suction)



The Staad- Pro used in structural analysis and design structure. The procedure for design of structure is modelling the structure, specs to structure, support, loading and load combination, of analysing and design of the structure. In StaadPro utilization ratio indicates the suitability of the member as per codes. Normally a value higher than 1 indicates the given member is no suitable for a given loading & load combination, and value below 1.0 indicates the reserve capacity available. The critical conditions used as criteria to determine Pass/Fail status are Slenderness limits, axial compression and bending, axial tension and bending, Maximum w/t ratios and Shear. Rigid steel frames of the building are mainly considered as the Main Frames of PEB. PEB rigid frame comprises of tapered columns and tapered rafters (the fabricated tapered sections are referred to as built-up members). The tapered sections are fabricated using the state of art technology wherein the flanges are welded to the web. Splice plates are welded to the ends of the tapered sections. The frame is erected by bolting the splice plates of connecting sections together.

V. ANALYSIS & RESULTS

In Staad- Pro utilization ratio indicates the suitability of the member as per codes. Normally a value higher than 1 indicates the given member is no suitable for a given loading & load combination, and value below 1.0 indicates the reserve capacity available. The critical conditions used as criteria to determine Pass/Fail status are Slenderness limits, axial compression and bending, axial tension and bending, Maximum w/t ratios and Shear. While optimizing the above building using jack beam, building can be checked for horizontal & vertical deflection. As per (AISC) American Institute of Steel Construction, different criterion for deflection has been given as follows. Below is deflection criterion as per Staad-Pro Results & manual results as follows.

Column Deflection Summary (Horizontal)

Allowable deflection = 10500 / 100  
= 105 mm

Node No	Actual deflection (mm)	Allowable Deflection (mm)	Governing Case
104	21.383	105	Wind

Rafter Deflection Summary (Vertical)

Allowable deflection = 22270 / 180  
= 123.7 mm

Node No	Actual deflection (mm)	Allowable Deflection (mm)	Governing Case
24	90.289	123.7	Live Load

As per Staad Pro Deflection Summary is as follows.

	Node	L/C	Horizontal		Vertical	Resultant	Rotational		
			X mm	Y mm	Z mm		mm	rX rad	rY rad
Max X	102	9 WIND2	20.549	7.148	-0.015	21.757	-0.000	-0.000	-0.000
Min X	104	10 WIND3	-21.383	13.125	-0.038	25.090	-0.000	0.000	-0.000
Max Y	24	12 WIND5	-4.724	75.562	-31.664	82.064	-0.002	-0.000	-0.000
Min Y	24	6 LL	-0.001	-90.289	0.010	90.289	-0.000	-0.000	0.000
Max Z	53	15 WIND8	4.381	0.000	50.830	51.019	0.013	-0.000	-0.001
Min Z	98	13 WIND6	4.381	0.000	-50.830	51.019	-0.013	0.000	-0.001
Max rX	52	15 WIND8	0.000	0.000	0.000	0.000	0.019	-0.000	-0.002
Min rX	97	13 WIND6	0.000	0.000	0.000	0.000	-0.019	0.000	-0.002
Max rY	110	14 WIND7	-8.502	0.299	24.779	26.199	0.001	0.002	-0.001
Min rY	106	12 WIND5	-8.502	0.299	-24.779	26.199	-0.001	-0.002	-0.001
Max rZ	23	6 LL	7.461	-17.190	0.004	18.740	0.000	-0.000	0.010
Min rZ	22	6 LL	-7.462	-17.190	0.005	18.740	0.000	-0.000	-0.010
Max Rs	24	6 LL	-0.001	-90.289	0.010	90.289	-0.000	-0.000	0.000

For achieving an optimization of building, a structural engineer has to break a rafter as per bending moment diagram as follows. For breaking of rafter points, he has to check 1st bending & shear of the frame. After applying all the loads to the building, analysis has been done.

Jack Beam summary (Vertical)



In this building jack beam can be designed for 15m span center to center. In Staad-pro software, jack beam is designed as a simply supported beam with a point load of corresponding rafter. As per AISC code, jack beam is checked for vertical deflection of span/240.

$$\begin{aligned} \text{Allowable deflection} &= 15000 / 240 \\ &= 62.5 \text{ mm} \end{aligned}$$

Node No	Actual deflection (mm)	Allowable Deflection (mm)	Governing Case
104	17.166	62.5	Live load

Below image shows jack beam is connected to corresponding side wall column. That jack beam is designed as a simply supported beam. Also jack beam to column connection is a shear connection. Transfer of moment to column is not possible due to shear connection.

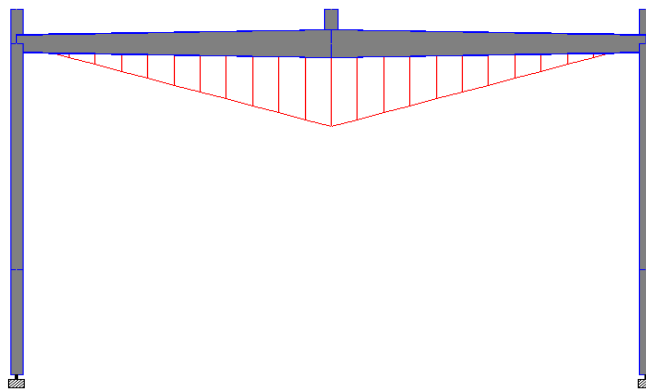


Fig 9 Jack Beam Deflection

Utilization Ratio

In Staad- Pro utilization ratio indicates the suitability of the member as per codes. Normally a value higher than 1 indicates the given member is no suitable for a given loading & load combination, and value below 1.0 indicates the reserve capacity available. The critical conditions used as criteria to determine Pass/Fail status are Slenderness limits, axial compression and bending, axial tension and bending, Maximum w/t ratios and Shear. For achieving an optimization of building, a structural engineer has to break a rafter as per bending moment diagram as follows. For breaking of rafter points, he has to check 1st bending & shear of the frame. After applying all the loads to the building, analysis has been done.

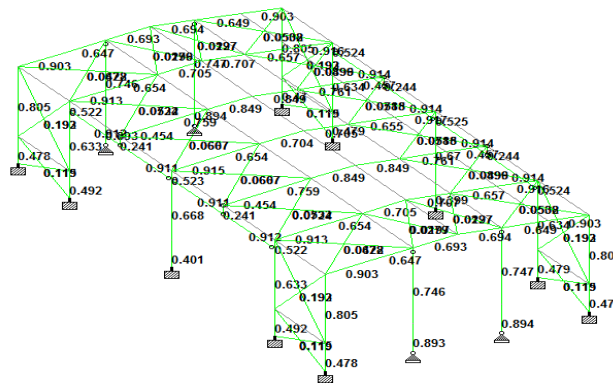


Fig 10 Staad Pro Result



## VI. SUMMARY

While designing PEB building, main concept is optimizing the bay spacing. The above calculation of PEB building states that extra column needed for PEB frame is not required for built up frame. Client, architect, consultants has special requirement about space management. While achieving this requirement to structural steel design engineer, he has to use a Jack beam structure. Jack beam is designed as a simply supported beam in actual case. Both end connection for jack beam is pinned shear connection. It did not transfer any moment to corresponding column. Only shear produced due to supporting frame is transferred to side wall columns. Single point load of frame weight is considered for jack beam design. Jack beam is also designed for horizontal forces from wind in longitudinal direction.

## VII. CONCLUSION

Less number of columns in building, proper use of space is possible only when jack beam is considered instead of taking columns. By considering jack beam instead of column, it will reduce the weight of building drastically. As the PEB industry as a vast scope in international market. The main agenda of consultant, architect & structural engineer is achieved by considering jack beam concept instead of taking column. Also the density of building is reduces by considering jack beam, as the weight of building drastically reduces. The space management concept can be achieved very accurately by installing Jack Beam in building instead of taking columns. It reduces clear span of building. Designer can be able to take clear span of building from 15m to 25m column less structure. Space required for machineries, loading unloading platform, truck vehicle movement can be get in clear by considering jack beam instead of taking columns.

## REFERENCES

- [1] IS: 800-2007: Code of practice for general construction in steel.
- [2] IS: 1893 (Part 1) – 2002. Criteria for Earthquake Resistant Design structure. New Delhi BIS 2002.
- [3] IS: 875 (Part 1) - 1987: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures Dead Loads
- [4] IS: 875 (Part 2) - 1987: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures- Live Loads
- [5] IS: 875 (Part 3) - 1987:- Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures Wind Loads
- [6] AISC- American institute of steel construction -1989, Manual of Steel Construction, Allowable Stress Design
- [7] Zamil Steel Building Design Manual 2007
- [8] Impact of three dimensional parametric modelling on building on productivity in structural engineering practice. Technion Israel Institute of Technology, Israel, August, 2007, 381-24348-8
- [9] Second edition of Limit State Design In Structural Steel By M.R. Shiyekar
- [10] Basic concepts of Pre Engineered Buildings by S. Khalid Hashmi , Kirby Building system ltd.
- [11] Pre-Engineered for success :Tracking growth of PEB Steel Buildings in India
- [12] Tata BlueScope building products – Purlin and girt
- [13] International Alliance for Interoperability. <http://www.buildingsmart.com/>