INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 12-10-2022

Accepted: 24-12-2022

Published: 25-01-2023

Citation: Sukumar B, Abirami G, Priya H, Hamid M (2023) A Comparative Study on the Design of Pre-Engineered Building with Indian and American Codes. Indian Journal of Science and Technology 16(4): 239-248. https://doi.org/10.17485/IJST/v16i4.1980

* **Corresponding author**.

hod.civil@rmkec.ac.in

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

A Comparative Study on the Design of Pre-Engineered Building with Indian and American Codes

Binu Sukumar[1]*, G Abirami[2], Hari Priya[2], Mozafar Hamid[3]

1 Professor and Head of the Department, Dept. of Civil Engineering, RMK Engineering College, Chennai, Tamil Nadu, India
2 Under-Graduate Student, Department of Civil Engineering, RMK Engineering College, Chennai, Tamil Nadu, India
3 Engineering Services Manager, Blue Scope Steel India Private Limited, Chennai, Tamil Nadu, India

Abstract

Objective: To compare the Industrial Gable Building using both Indian and American Codes. The Study is focused on arriving the tonnage differences and variations in the design parameters. **Methods:** A detailed study on Indian and American codes is done for the Gable Building. The Industrial Building is designed using various codes i.e., ASCE 7-16, MBMA-2012, IS 875 (part 1-5), IS 1893-2007, IS 800. The study project is then analyzed using the StaadPro Software for both the codes. **Findings:** Under similar environmental conditions and exposures, the American code is seemed to be more effective when compared to the Indian code having a weight difference of 38%. The revision of IS code will make it compatible with other international standards. Separate code book for Pre-Engineered buildings is important which helps to optimize the steel consumption and in overall cost reduction. The recent researches in PEB Technology includes the advantage of PEB with the Conventional Steel Building (CSB) in terms of tonnage, cost, ease of construction and design of various components of PEB structures. Being an emerging technology in India, codal standards available are for a conventional steel structure which is practiced for the PEB also. **Novelty:** In the PEB industry, we have observed that American code is widely used despite other codal provision. To find the extent of variation in sway and deflection limits of Indian code to American code, this study is made which we found not done earlier. And to suggest for the revision of codal data, to make Indian code compatible with other codes.

Keywords: Pre-Engineered Building (PEB); Structural Analysis and Design; Steel Structures; Comparison; Crane

1 Introduction

Pre-Engineered Buildings (PEB) is an emerging technology which is found more advantageous than the Conventional Steel building[(1)]. The main concept of the PEB is the reduction in the sectional depth in the location of lesser moment. Though every country follows their own codal provision, as far as PEB American code is found to be used in Western and Asian countries. The limits for sway and deflections of the member in American code is higher than the other codal standards which make it more effective in terms of tonnage and cost.

In India, the steel structures are designed as PEB using the codal standards of conventional steel building. Also, the limits fixed to control sway and deflection is lesser. As a result, PEB is not completely effective despite its idea of sectional reduction. This study focuses on the design of an Industrial Gable building with crane using Indian and American code and to derive a comparison in the weight and effect of each load case on the building in terms of a quantitative data.

1.1 Pre-Engineered Building

Pre-Engineered Buildings are pre-determined assemble of structural members that has proven over time to meet a wide range of structural requirements. PEB's are factory made and are erected to the site. Complete shop fabrication results in superior quality and significant saving of construction time. PEB is designed to customer's specification that varies from one to another.

Connection pattern and support arrangements are standardized and hundreds of pre-Engineered details are developed. These Pre-Engineered details are directly used in the buildings depending upon the exact requirements. This concept speeds up the design and detailing of the building thereby greatly reducing the cycle time [2]. These structures are not highly affected by environment and will not require regular maintenance. Recent studies prove that Pre-Engineered buildings can save up to 30% in overall construction cost due to tapered section. The reason behind the tapered section is wherever the Bending Moment is minimum the section can be tapered thereby reducing the depth of the section. Moreover, they offer a larger clear span.

1.2 Components of PEB

The Pre-Engineered Building comprises of three components they are [3],

- Primary Component (Main Frame, Columns, Rafters, Bracings)
- Secondary Component (Purlins & Girls, Eave Struts, Tie rods & Angle Bracings and Washers)
- Roof and Wall Panels (Gable trim, Eave trim, Ridge trim and Panels/Sheeting)

The Pre-Engineered Building comprises of three components they are

2 Methodology

2.1 Modeling

The model of the Pre-Engineered Building is analyzed and designed using the StaadPro Software. The details of the Industrial Gable Building taken for the project are shown in Table 1 .

Table 1. Data adopted for PEB Model

Parameter	Type/Value
Location	Chennai, Tamil Nadu
Building Length	37.5 m
Building Width	30.0 m
Eave Height	8.50 m
Bay Spacing	7.50 m
Roof Slope	1 in 10
Material Yield Stress	379.2 Mpa
Concrete Grade	M20
Max. spacing for Purlins & Girts	1.525m (5'0")
Max. spacing for Flange Brace	3.050m (10'-0")

The typical plan of the Pre-Engineered Building is presented below from Figure 1 .

The Interior Main frames are rigid and tapered built up I section. The End Wall frames are continuous beam with turned interior columns. The Secondary Framing is of Cold Formed Z shaped section for Purlins and Girts and the Covering is a trapezoidal profile sheets for walls and roofs.

a. Structural Design and Drawing:

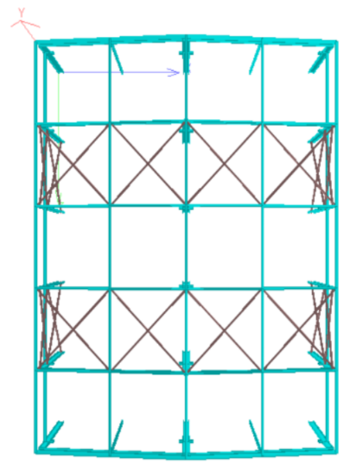

Fig 1. Plan

Wind Co-efficient, Design Parameters and Serviceability condition are considered as per the respective codes. Loads are calculated for the Interior & End frames; wall girts and roof purlins as per the codes.

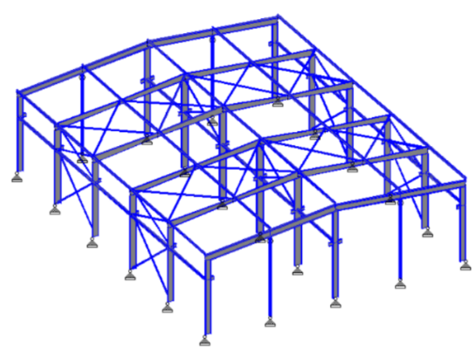

Fig 2. StaadPro Model

2.2 Frame Load Calculations

The loads considered for the design are

- Dead Load
- Live Load
- Collateral Load
- Wind Load
- Seismic Load
- Brace Load
- Crane Load

2.3 Load Calculation for American Code

Total Dead load comprises of Weight of Sheeting in addition to Purlin or Girt Weight. Collateral load includes Miscellaneous Support loading such as Lights, Sprinklers, Suspended Ceiling, Ducts/ Piping etc., Minimum Roof Live Load is taken from the ASCE 7-16 Table 4-1 Page no.186.

Reduced Roof Live load is calculated for end Frame as well as for Interior frames separately.
Reduced Live Load $L_r = L_o R_1 R_2$
Where R_1 is calculated as follows
1.0 for $A_t < 18.58$sq.m
And R_2 is calculated as follows
1.0 for $F < 4$ sq.m
$R_2 = 1.2 - 0.05F$ for 4 sq.m $< F < 12$ sq.m
0.6 for $F > 12$ sq.m
For a pitched roof, F = 0.12 x slope with slope expressed in percentage point.
$F = 0.12 \times 1/10 \times 100$
$F = 1.2\%$
$R_2 = 1$ since $F < 4$
Reduced Roof Live Load $L_r = L_o R_1 R_2$
The longitudinal and lateral loads such as Wind load and Seismic loads are resisted by the roof and wall bracing systems.
Wind load is calculated as per section 6.0 of ASCE7-16
The Wind Pressure is calculated by the formula,
Wind pressure,
$(q_z) = 0.613 K_z K_{zt} K_d K_e V_b^2 I$
Where 0.613 is constant, K_z is Velocity pressure exposure coefficient, K_{zt} is the Topographic factor, K_d is the Directionality factor, K_e is the Ground elevation factor, V_b is the basic wind speed and I is the Importance factor. Net Pressure Coefficient for the Wind load is calculated by the formula $GC_{pe} \pm GC_{pi}$ where G is the Gust effect factor as per the section 26.9.1 of ASCE 7-2016. Wind Load is finally calculated by multiplying the wind pressure with the Wind coefficient and Tributary width. The tributary width for the corner columns is taken as half of the End post spacing and for the end post columns as end post spacing. Seismic Zone is calculated based on UBC 1997. Structure Period (T)
$T = 0.0853 \times h^{0.75}$
where h is the Eave height of the building
Total Base shear shall not exceed
$V = [C_v \times I / R \times T] \times W$
where C_v is the seismic coefficient, I is the importance factor, R is the response reduction factor, T is the structure period and W is the seismic load. When the Total base shear calculated exceeds the maximum value it is limited to the maximum value, hence Design Total Base Shear Cis the Base Shear $V = C_s \times W$ where $C_s$seismic coefficient.

2.4 Load Calculation for Indian Code

Dead load is calculated as per IS 875-2015 Part 1 Table 1, it comprises of Weight of Sheeting in addition to Purlin or Girt Weight. Collateral load includes Miscellaneous Support loading such as Lights, Sprinklers, Suspended Ceiling, Ducts/ Piping etc., Roof Live Load is taken from IS 875-2015 Part 2 Table 2.

The longitudinal and lateral loads such as Wind load and Seismic loads are resisted by the roof and wall bracing systems. Wind load is calculated from IS 875-2015 Part 3, the Wind Pressure is calculated by the formula,
Design Wind speed,
$(v_z) = k_1 \times k_2 \times k_3 \times k_4 \times V_b$
where k_1 is the Risk coefficient From Table 1 of IS 875: 2015 Part-3 Page 11, k_2 indicates the wind speed variation with height in different Terrains, k_3 is the Topographic factor and k_4 is stipulated according to the importance of the structure. The Wind Pressure at any height above the mean ground level shall be obtained by the following relationship between the Wind Pressure and the Wind Speed as, $P_z = 0.6V_z^2$ where P_{zz} where $P_z$is the Wind Pressure at height z and $V_z$is the design Wind speed at height z.

The Design Wind Pressure P_d can be obtained as
$P_d = K_d K_a K_c P_z$
where K_d is the Wind Directionality factor, K_a is the Area Averaging factor and K_c is the Combination factor. The value of P_d however shall not be taken as less than 0.7 P_z .Net Pressure Coefficient for the Wind load is calculated by the formula $C_{pe} \pm C_{pi}$. Wind Load is finally calculated by multiplying the wind pressure with the Wind coefficient and Tributary width.

Design Horizontal Seismic Pressure = $[ZI/2R] \times S_a/g$ where Z is the Zone factor, I is the Importance factor, R is the Response Reduction factor and S_a/g is the constant. The Seismic load is calculated by multiplying the dead load with A_h, where A_h is the seismic coefficient.

Wind Pressure Coefficient for various load cases are
Wind Perpendicular to Ridge W1 Right i.e., W1>
(Wind Right + Internal Pressure)
Wind Perpendicular to Ridge W1 Left i.e., W1<
(Wind Right + Internal Pressure)
Wind Perpendicular to Ridge W1 Right i.e., W2>
(Wind Right + Internal Suction)
Wind Perpendicular to Ridge W1 Left i.e., W2<
(Wind Right + Internal Suction)
Wind Parallel to Ridge WP

2.5 Crane Details

Table 2. Crane Specification as per Vendor

Type of Crane	Top Running
Service Classification	Heavy Service (Ware house)
Crane Capacity	100 kN
Crane Weight	38.55 kN
Crab/Trolley Weight	6.10 kN
Wheel Base	2.50 m
Bridge Span	13 m
Number of wheels	4 nos
Number of wheels/sides	2 nos

The height of the gantry rail from the floor is of 6.3 meters. The site clearance for the runway beam of the crane is given as 300 mm on both the sides. A total of 2 cranes units are provided on both the axle. The distance of the roof bottom to the center of the hook is taken as 1.69 meters. The nearest hook approach on either side is around 1.1 meters. The minimum head room required as per Industrial standard for 10-ton single girder is 1.2 meters.

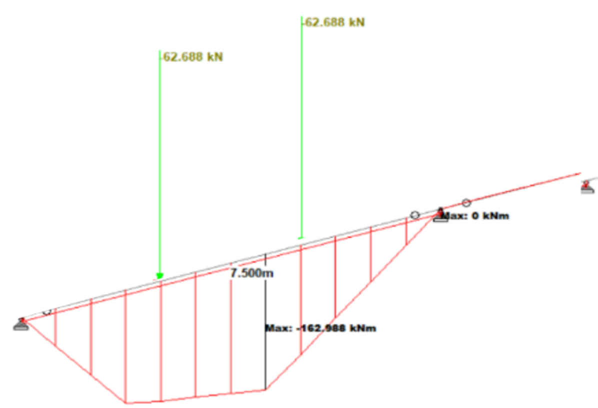

Fig 3. Wheel Load

Wheel load is calculated by the formula, Wheel load WH = [(Rated Capacity of the crane + (Weight of the Hoist) + (0.5 x Weight of crane)]/ (Number of wheels at one side). Vertical Impact of a pendent operator crane is 10% of the wheel load.

The lateral force is calculated by the formula Lat_F = 20% [rated crane capacity + weight of the hoist] / 4. And the longitudinal force is calculated by Lon_F = 10% of the maximum wheel load x number of wheels per side. For runway beam that carries the crane, built-up section is used as per IS808-1989. Beam is of ISMB450 and then channel over it is ISMC300. The crane unit is fixed to the rail which is supported on the runway beam, thus the load from the runway beam is taken to the column through the brackets attached. To make the connection easier straight columns are provided.

Table 3. Total applied Load (KN)

	American Code			Indian Code		
Load Case	**Σ x (lateral)**	**Σ y (vertical)**	**Σ z (longitudinal)**	**Σ x (lateral)**	**Σ y (vertical)**	**Σ z (longitudinal)**
DL	0	-791.22	0	0	-942.96	0
LL	0	-661.78	0	0	-861.74	0
W1>	426.83	598.23	0	419.68	783.90	0
W1<	-426.83	598.23	0	-419.68	783.90	0
W2>	426.79	1117.23	0	419.65	1449.24	0
W2<	-426.79	1117.23	0	-419.65	1449.24	0
WP	0	1362.36	0	0	1663.38	0
WB1>	0	0	193.28	0	0	199.07
WB1<	0	0	-193.28	0	0	-199.07
WB2>	0	0	-18.38	0	0	22.13
WB2<	0	0	18.38	0	0	-22.13
E>	48.32	0	0	36.08	0	0
E<	-43.56	0	-4.76	-32.55	0	3.54
EB>	0	0	38.95	0	0	49.55
EB<	0	0	-38.95	0	0	-49.55
CG	0	-172.34	0	0	-172.34	0
CR	-44.60	-1443.00	-26.78	-44.60	-1443.00	-26.78

2.6 Load Combinations

A load combination results when more than one load type acts on the building. These combinations with the load factors for each load type is used to ensure the safety of the structure under maximum expected loading scenarios.

The basic load combination as per Indian code is as follows,

- DL + LL
- DL + CG + LL
- DL + CG + LL + WL
- DL + WL
- DL + CG + LL + E
- DL + CG + LL + CR
- DL + CG + LL + WL + CR
- DL + CG + LL + E + CR
- DL + E

Whereas for American code the basic load combinations are,

- DL + CG + LL
- DL + CG + WL
- DL + WL
- DL + CG + CR
- DL + CG + LL + WL
- DL + CG + WL + CR
- DL + CG + E
- DL + E

The load cases take different coefficients based on the combinations. Also, the load combinations multiply considering the direction, location and the position of the application of the load.

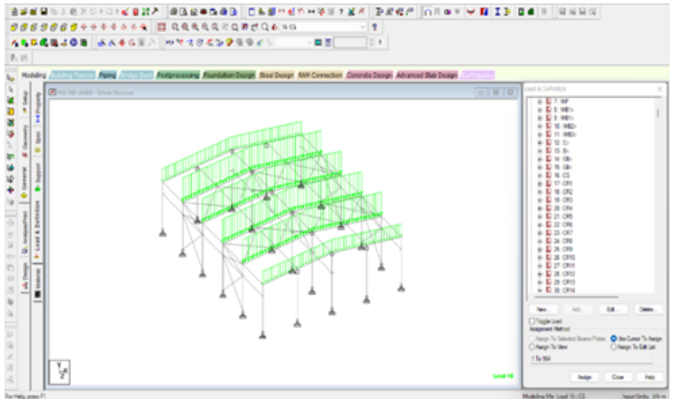

Fig 4. PEB subjected to Dead load

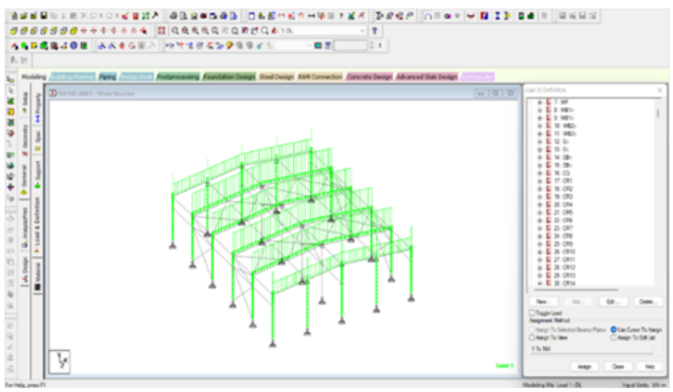

Fig 5. PEB subjected to Live load

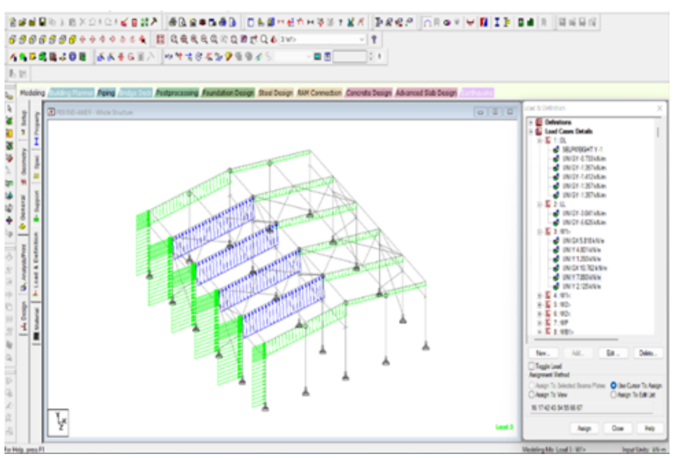

Fig 6. PEB subjected to Wind load

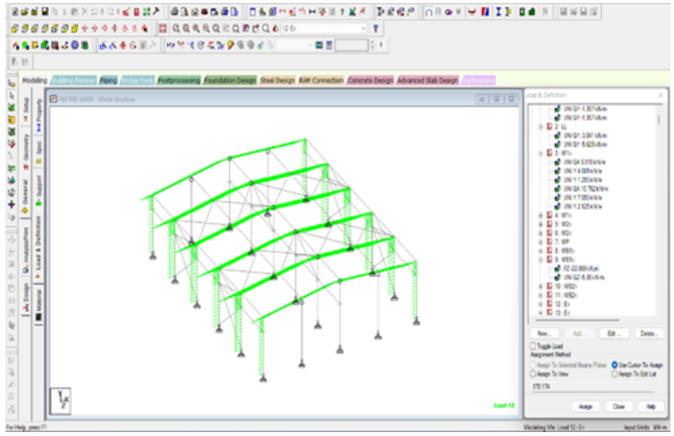

Fig 7. PEB subjected to Seismic load

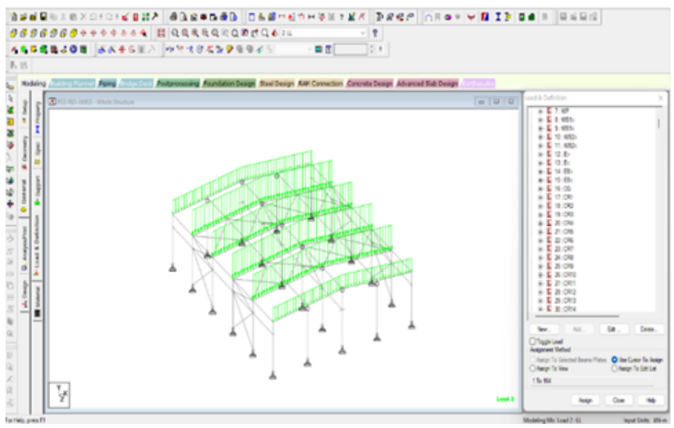

Fig 8. PEB subjected to Collateral load

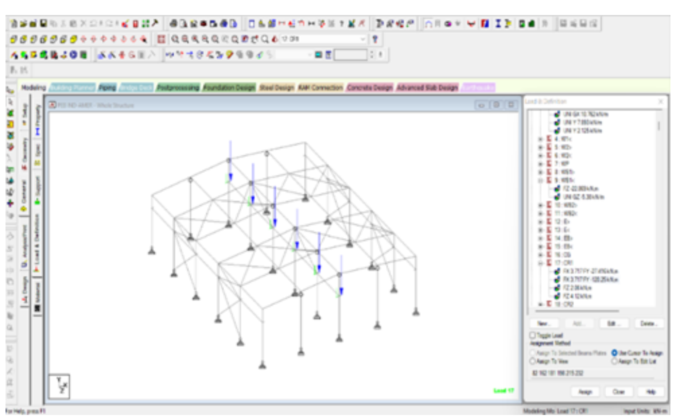

Fig 9. PEB subjected to Crane load

3 Result and Discussion

Table 4. Comparison on the result of American and Indian Design

	AMERICAN DESIGN ASCE 7 -2016 ASD		INDIAN DESIGN IS 800 – 2007 LSD	
Yield Stress N/mm^2	379.2		379.2	
Section	3 Plate Section		3 Plate Section	
Stress Increase	1.0		1.0	
Type of Loads	Working load		Factored load	
Allowable Lateral Deflection	Eave Height / 100 = 85 mm		Eave Height / 200 = 42.5 mm	
Allowable Vertical Deflection	Span / 180 = 83.33 mm		Span / 180 = 83.33 mm	
Weight in Tons	26.7101		37.0446	
Ratio (Weight)	1.00		1.38	
	End Frame	Interior Frame	End Frame	Interior Frame
Wind load				
W1 Wall (kN)	37.37	69.13	49.45	91.477
W1 Roof (kN)	45.089	83.39	72.42	118.98
W2 Wall (kN)	26.29	48.629	27.47	50.813
W2 Roof (kN)	72.84	134.12	111.35	183.07
Seismic load				
Wall	0.323	0.595	0.238	0.442
Roof	2.246	4.16	1.688	3.105
Vertical Clearance (m)	7.634	7.750	7.684	7.434
Horizontal Clearance	13.859	13.729	13.784	13.609
Maximum Vertical Deflection (mm)	1.957	18.993	2.613	14.709
Maximum Lateral Deflection (mm)	13.212	55.402	32.791	41.395
Coefficients (Min)	Design	Deflection	Design	Deflection
Dead load	0.6	-	1.2	1.0
Live load	0.75	1.0	1.05	0.8
Wind load	0.225	0.42	0.6	0.8
Seismic load	0.7	0.6	0.6	1.0
Crane load	0.75	0.1	0.53	0.8

Based on the study the following conclusions are drawn,

- The Steel consumption of this structure as per ASCE 7-2016 and IS 800 is in the ratio of 1: 1.38.
- The Wind coefficient as per ASCE 7 -2016 code is least when compared to the Indian code. This results in a lesser wind load in American Design.
- The Seismic load is slightly high in American code when compared to the IS code as the base shear seismic coefficient considered in the American Code is higher than the Indian Code.
- The live load reduction is applicable based on the area of roof in American code, which is not taken in Indian Code when the slope is less than 10^0.
- Serviceability condition (i.e., deflection) are very stringent in IS code and the advantage of wall covering is not explicitly mentioned.
- In American code the allowable vertical deflection is span / 180 and for lateral deflection it is height / 100, whereas in Indian code the allowable vertical deflection is span / 180 and for lateral deflection it is height / 200.
- The member design is governed by the strength criteria as per the American code and the serviceability is the main criteria as per the Indian Code.
- Vertical and horizontal clearance are less as per Indian design due to the higher member depths.
- The load combinations for the deflection as per the Indian code is the summation of two or more load cases where as in American code it is a single load case.

4 Conclusion

The study exhibits a tonnage difference of 38% higher in Indian code to American code. The revision of IS code will make it compatible with other international standards. In IS 800-2007 the serviceability limit is somewhat bought down but it has to be looked in detail with respect to American code. The sway and deflection limits are higher in American code which directly affects the section sizes. So, these limits can be revised based on Indian conditions. Separate codal provisions for Pre-Engineered buildings is important which helps to optimize the steel consumption and in overall cost reduction. As per Indian code when Higher grade steel is used, the member becomes brittle which is not the case as per American code. This restricts the usage of certain section sizes and to provide an alternate stabilizing member, thereby increasing the tonnage.

The limitation of the study is that it is caried out for a location in India and the design is done based on the prevailing Indian conditions using American code. Several considerations in American code are taken with respect to Indian topographical condition. The study is further aimed in a comparison of single slope building with other structures like multi gable, mono gable including various building components like mezzanine, monorail, pipe rack in both the codes.

Acknowledgment

We wish to express our sincere thanks to BlueScope Steel India Private Limited for providing the facilities to carry out this work. We are proudly obliged to render our immense gratitude to R.M.K. Engineering College for providing an excellent platform to connect with the industry.

References

1) Pantheeradi SS, Abraham. Comparative Study of Pre-Engineered Building and Conventional Steel Building. *International Journal of Engineering Research and Technology* . 2022. Available from: https://doi.org/10.17577/IJERTV11IS010131.
2) Pratik R, Atwal V, Tomar. Analysis and Design of Pre-Engineered Building Using IS 800:2007 and International Standards. *International Advanced Research Journal in Science, Engineering and Technology*. 2013;4(11). Available from: https://doi.org/10.17148/IARJSET.2017.41119.
3) Gawade MD, Waghe UP. Study of Pre-Engineered Building Concept. *Journal of Research in Engineering and Applied Sciences*. 2018;03(03):88–91. Available from: https://doi.org/10.46565/jreas.2018.v03i03.003.