

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Seismic Analysis & Design of Multistorey Steel Building

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Abstract— Steel is one of the most widely used material for building construction in the world. The inherent strength, toughness and high ductility of steel are characteristics that are ideal for seismic design. To utilize these advantages for seismic applications, the design engineer has to be familiar with the relevant steel design provisions and their intent given in codes. The paper work describes the seismic analysis and design of industrial shed subjected to dead load, live load, wind load and earthquake load. For paper work the equivalent static analysis is carried out for multistorey steel building with pitched roof is done. The industrial structures shall be mainly designed and constructed to resist the wind effects in accordance with the requirements and provisions of IS:875 (Part 3):1987. This standard describes the procedure for wind resistant of such structures. The seismic analysis & design of multistorey steel building is carried out using Software Computer Aided Design i.e., (STAAD PRO). The main parameters consider for comparing wind performance of buildings are bending moment, shear force, deflection and axial force. This paper work is focused on industrial shed truss and supporting columns. The seismic design of building frame presented in this project is based on IS:1893:2002, IS:1893:2005 and IS:800:2007. The building consists of two storey. The selection of arbitrary sections has been done following a standard procedure.

In the process of design the section has undergone numerous iterations till all the criteria mentioned in the IS 800 have been satisfied. The designed frame was again analyzed and results were compared in terms of sections used. Relevant calculations have been shown and the figures have been drawn. The software used for analysis and design is STAAD PRO. Both during design and analysis sufficient manual calculations have been made.

Keywords— Seismic Force, Steel, Multi-Storey Building, Strength, Ductility

I. INTRODUCTION

This Steel is a material which has high strength per unit mass. Steel is a common building material used throughout the construction industry. Industrial buildings are generally designed as enclosures that provide space for internal activities, which may involve use of overhead cranes or suspended equipments as well as provision of office space or mezzanine floors. Its primary purpose is to form a skeleton for the building or the structure essentially the part of the structure that holds everything up and together. Steel has many advantages when compared to other building materials such as concrete, timber, plastics and the newer composite materials. Steel is one of the friendliest environmental building materials. Steel is 100% recyclable material. Of all the structural building material in use today steel is perhaps the most universally acceptable as versatile material for engineering construction. Function of all the structure is to withstand stresses due to loads i.e., wind, earthquake etc. without failure or undue distress such as excessive deflections, dangerous vibrations etc. Steel as a building material has been studied and tested for many years.

In this paper the study is done for the seismic analysis and design of multistorey steel building. Trusses are triangular frame works, consisting of essentially axially loaded members which are more efficient in resisting external loads since the cross section is nearly uniformly stressed. They are extensively used, especially to span large gaps. Trusses are used in roofs of single storey industrial buildings, long span floors and roofs of multistorey buildings, to resist gravity loads.

The whole analysis and design of steel building is done as per IS : 875 (Part 1) : 1987, IS : 875(Part 2) : 1987, IS : 875 (Part 3) : 1987 and IS : 800 : 2007 with the help of Staad Pro. The whole analysis and design done as per static method.

II. SCOPE

Over here the study is done for stability analysis of industrial shed subjected to wind load. The analysis is done for stresses, bending moments, deflections and axial forces as per grid formation methodology.

III. DESIGN PHILOSOPHY

Before we proceed with the actual analysis and design of structure following points are considered -

- A. The structural system and type
- B. The choice of an open or covered structure
- C. The selection of the construction material
- D. The location, ground conditions i.e., geography of the area
- E. The method which is used

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- F. The design concept
- G. IS codes used

With the use of proper method, IS code and also all analysis and design done by STAAD PRO.

IV. EXPERIMENTAL WORK

Manual Calculations

Design is done for a fink type roof truss for an industrial building for the following data:

Overall length of the building = 40 m

Overall width of the building = 16 m

Spacing of the trusses = 8 m

Rise of truss = $\frac{1}{4}$ of span

Self-weight of purline = 318 N/m

Height of column = 12 m

Roofing and side covering = Asbestos cement sheets
= 171 N/m²

The building is located in industrial area MIDC, Akola. Both the ends of the trusses are hinge.

Use steel of grade Fe₄₁₅.

Step 1 :- Given data.

Type of truss=Fink type truss

L = 40 m

Span = 16 m

Spacing of truss = 8 m

Rise of truss = $\frac{1}{4}$ of span

Self weight of purline = 318 N/m

Height of column = 12 m

Roofing and side covering = Asbestos cement sheets = 171 N/m²

Industrial area = MIDC, Akola

Steel grade = Fe₄₁₅.

Both the ends are hinge.

Step 2 :- To find .

Design roof truss.

Step 3 :-Diagram.

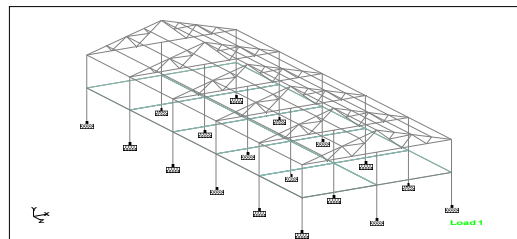


Fig. 1. Steel building.

Step 4 :- Calculation of θ .

$$\tan \theta = 4/8$$

$$\theta = 26.56^\circ$$

Step 5:- Calculation of length of rafter.

$$\begin{aligned} \text{Length of principal rafter} &= \sqrt{4^2 + 8^2} \\ &= 8.94 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Length of each panel} &= 8.94/4 \\ &= 2.235 \text{ m} \end{aligned}$$

Step 6 :- Calculation of loads .

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1) Dead load:

1) Assume weight of bracing = 12 N/m²

2) Dead load of AC sheet = 171 N/m²

3) Self weight of roof truss = $(\text{span}/3 + 5) \times 10$
 $= (16/3 + 5) \times 10$
 $= 103.33 \text{ N/m}^2$
 $\approx 110 \text{ N/m}^2$

4) Self weight of purlin = 318 N/m

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=for inner frame

=318 × spacing of truss

=318 × 8

=2544 N

=for outer frame

=318 × 4

=1272 N

5) DL on inner frame intermediate panel = $(12 + 171 + 110) \times (8 \times 2.235) + 2544$
 $= 7.8 \text{ KN}$

6) DL on inner end panel = $7.8/2 = 3.9 \text{ KN}$

7) DL on outer frame intermediate panel = $(12 + 171 + 110) \times (4 \times 2.235) + 1272$
 $= 3.9 \text{ KN}$

8) DL on outer frame end panel = $3.9/2 = 1.95 \text{ KN}$

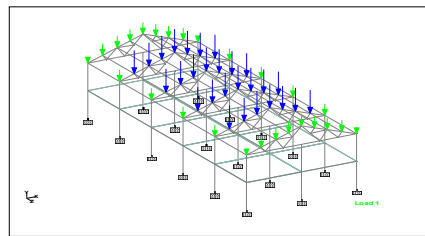


Fig.2. Dead load .

2) Live load :-

1) $\theta = 26.56^\circ$

2) Live load = $750 - 20(26.56 - 10)$
 $= 418.68 \text{ N/m}^2$

3) Live load on inner frame each intermediate panel = Live load × spacing of truss on both side
 $= 418.68 \times 8 \times 2.235 = 7485.99 \text{ N} = 7.5 \text{ KN}$

4) Live load on inner frame each end panel = $7.5/2 = 3.75 \text{ KN}$

5) Live load on outer frame each intermediate panel = Live load × spacing of truss on both side
 $= 418.68 \times 4 \times 2.235 = 3750 \text{ N} = 3.75 \text{ KN}$

6) Live load on outer frame each end panel = $3.75/2 = 1.875 \text{ KN}$

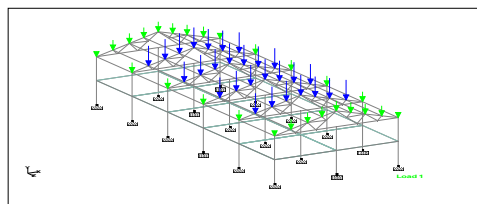


Fig. 3. Live load.

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3) Wind load:-

1) Basic wind velocity = $V_b = 44$ m/sec (Appendix A, clause 5.2, page no. 53)

2) Class of structure = All general building & structure

3) Mean probable design life of structure in years = 50 years

4) Risk coefficient (k_1) :-

TABLE I
RISK COEFFICIENT (k_1)

Year	city	k_1
50 years	Akola	1

$k_1 = 1$ (from IS :875:Part 3:1987 , table no.1, page no. 11)

5) Terrain factor (k_2) :-

From table no. 2 , page no. 12, IS:875:Part 3:1987

For open structure = Category 2

Class A = Upto 20 m

From table no. 2 ,category 2 , class A

TABLE II
TERRAIN FACTOR (k_2)

Height	k_2
10	1
12	X
15	1.05

$$x = 1.05 - ((1.05 - 1) / (15 - 10)) \times (15 - 12)$$

Therefore, $k_2 = x = 1.02$ for 12 m building height.

6) Topography factor (k_3) :-

$k_3 = 1$ when θ is greater than 3° i.e., $\theta > 3^\circ$ (as per IS:875:Part 3:1987)

7) Calculation of wind speed (V_z) :-

$$\begin{aligned} V_z &= k_1 \times k_2 \times k_3 \times V_b \\ &= 1 \times 1.02 \times 1 \times 44 \\ &= 44.88 \text{ m/s} \end{aligned}$$

8) Calculation of design wind pressure (p_d) :-

$$\begin{aligned} p_d &= 0.6 \times (V_z)^2 \\ &= 0.6 \times (44.88)^2 \\ &= 1208.59 \text{ N/m}^2 \\ &= 1.21 \text{ KN/m}^2 \end{aligned}$$

9) Calculation of external & internal air pressure coefficients:-

i) External air pressure coefficient :-

C_{pe} for the condition $1/2 < h/w < 3/2$ and

For $\theta = 26.56$, from IS: 875: Part 3:1987, table no. 5

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TABLE III
EXTERNAL AIR PRESSURE COEFFICIENT

θ	wind EF	lee EG
20	-0.7	-0.8
26.56	x1	x2
30	-0.2	-0.8

Therefore,

$$x1 = -0.2 - [(-0.2 + 0.7)/(30 - 20)] \times (30 - 26.56) \\ = -0.3717$$

$$x1 \approx -0.37 \text{ (windward side)}$$

$$x2 = -0.8 - [(-0.8 + 0.8)/(30 - 20)] \times (30 - 26.56)$$

$$x2 = -0.8 \text{ (leeward side)}$$

Therefore,

$$C_{pe} \text{ (windward side)} = -0.37$$

$$C_{pe} \text{ (leeward side)} = -0.8$$

ii) Internal air pressure coefficients:-

The internal air pressure coefficients (C_{pi}) = ± 0.5 when the opening in the building upto (5 % to 20 %)

10) Calculation of wind load:-

$$1) \text{ Wind load} = [C_{pe} - C_{pi}] \times p_d \times A$$

Where,

A = area, p_d = design wind pressure

$$\text{Wind load} = [C_{pe} - C_{pi}] \times p_d \times A \\ = [-0.8 - 0.5] \times 1.21 \times 8 \times 2.235 \\ = -28.12 \text{ KN} \\ \approx 28.12 \text{ KN (Uplift)}$$

$$2) \text{ Wind load per unit length of purline} = 28.12/8 = 3.315 \text{ KN/m}$$

3) Wind load on the panel points :-

Windward side,

$$F = [C_{pe} - C_{pi}] \times p_d \times A \\ = [-0.37 - 0.5] \times 1.21 \times 8 \times 2.235 \\ = -18.82 \text{ KN}$$

Therefore, wind load on each intermediate panel point = - 18.82 KN

$$\text{And wind load on end panel} = (-18.82)/2 \\ = -9.41 \text{ KN}$$

Leeward side,

$$F = [C_{pe} - C_{pi}] \times p_d \times A \\ = [-0.8 - 0.5] \times 1.21 \times 8 \times 2.235 \\ = -28.12 \text{ KN}$$

Therefore, wind load on each intermediate panel point = - 28.12 KN

$$\text{And wind load on each end panel} = -28.12/2 \\ = -14.06 \text{ KN.}$$

Calculations using Staad Pro Software:

Seismic analysis & design totally carried out only by Staad Pro Software.

Total no. of Nodes = 132

Total no. of Beams = 276

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Total no. of Plates = 10

TABLE IV
SECTION PROPERTIES

Pro p	Section	Area (cm ²)	I _{yy} (cm ⁴)	I _{zz} (cm ⁴)	J (cm ⁴)
2	ISA75X75X5 SD	14.540	141.378	79.656	1.229
3	I80012B50012	387.000	42.4E 3	494E 3	104.371
4	ISA35X35X3 SD	4.060	8.671	4.726	0.123
5	ISA50X50X3 SD	5.900	25.233	14.299	0.177
6	ISA40X40X3 SD	4.680	12.941	7.164	0.141
7	ISA25X25X3 SD	2.820	3.165	1.641	0.087
8	ISA75X75X6 SD	17.320	169.919	93.765	2.117
9	ISA50X50X6 SD	11.360	50.807	26.252	1.397
10	ISA45X45X3 SD	5.280	18.392	10.323	0.159
11	ISA55X55X5 SD	10.540	55.972	30.338	0.896
12	ISA70X70X5 SD	13.540	115.025	64.318	1.146
13	ISA30X30X3 SD	3.460	5.478	2.916	0.105
14	ISA50X50X4 SD	7.760	33.686	18.522	0.418
15	ISA90X90X8 SD	27.580	391.988	213.302	6.007
16	ISA65X65X6 SD	14.880	110.700	59.972	1.829
17	ISA90X90X6 SD	20.940	293.176	165.174	2.549
18	ISA50X50X5 SD	9.580	42.206	22.501	0.812
19	ISA45X45X5 SD	8.560	30.811	16.148	0.729
20	ISA150X150X 10 SD	58.060	2.26E 3	1.27E 3	19.667
21	ISA65X65X5 SD	12.50	92.042	51.09	1.062

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TABLE V- PLATE THICKNESS

Prop	Node A (cm)	Node B (cm)	Node C (cm)	Node D (cm)	Material
1	2.800	2.800	2.800	2.800	STEEL

TABLE VI- MATERIALS

Mat	Name	E (kN/mm ²)	n	Density (kg/m ³)	a (1/°K)
3	STEEL	205.000	0.30 0	7.83E 3	12E -6
4	ALUMIN UM	68.948	0.33 0	2.71E 3	23E -6
5	CONCRE TE	21.718	0.17 0	2.4E 3	10E -6

V. RESULT AND OBSERVATION

Example was taken under consideration with dimensions and material grade as follows – Design a fink type roof truss for an industrial building for the following data:

Overall length of the building = 40 m

Overall width of the building = 16 m

Spacing of the trusses = 8 m

Rise of truss = ¼ of span

Self weight of purline = 318 N/m

Height of column = 12 m

Roofing and side covering = Asbestos cement sheet = 171 N/m²

The building is located in industrial area MIDC, Akola. Both the ends of the trusses are hinge.

Use steel of grade Fe₄₁₅.

- A. All the values of constant are calculated using IS:875(Part 1):1987, IS:875(Part 2):1987, IS:875(Part 3):1987, IS:1893:2002, 2005 and IS:800:2007
- B. Whole design is done in STAAD PRO Software using IS:800:2007(LSD).
- C. For analysis and design static method is adopted.
- D. In this paper the above example solved and all analysis & design is done.
- E. Table shows the results from solving above example.
- F. All the results of analysis and design are obtained using basic load cases and their load combinations with the help of Staad Pro Software only.

TABLE VII- BASIC LOAD CASES

Number	Name
1	ELX
2	ELZ
3	DL
4	LL
5	WLX
6	WLZ

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TABLE VIII- COMBINATION LOAD CASES:

Comb.	Combination L/C Name	Primary	Primary L/C Name
5	1.7(DL+LL)	3	DL
		4	LL
6	1.2(DL+LL+W LX)	3	DL
		4	LL
		5	W LX
7	1.2(DL+LL+W LZ)	3	DL
		4	LL
		6	W LZ
8	1.5(DL+W LX)	3	DL
		5	W LX
9	1.5(DL+W LZ)	3	DL
		6	W LZ
10	1.3(DL+LL+ELX)	3	DL
		4	LL
		1	ELX
11	1.3(DL+LL-ELX)	3	DL
		4	LL
		1	ELX
12	1.3(DL+LL+ELZ)	3	DL
		4	LL
		2	ELZ
13	1.3(DL+LL-ELZ)	3	DL
		4	LL
		2	ELZ

TABLE IX- FINAL RESULTS:

Beam	L/C		Dist m	Fx kN
73	5 1.7(DL+LL)	Max +ve	N/A	N/A
		Max -ve	0	-128.104
1	5 1.7(DL+LL)	Max +ve	N/A	N/A
		Max -ve	0	-58.059
1	7 1.7(DL+LL)	Max +ve	N/A	N/A

VI. CONCLUSION

Industrial shed analysis consist of five trusses which is two storey two bay steel structure. Complete analysis of structure is done considering Dead Load, Live Load, Wind Load and Seismic load in various combinations a per IS:800:2007, IS:1893:2002, IS:875:1987 etc. Since the structure is symmetrical in nature, some of important analysis remark are highlighted for various load

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case consideration for outer and inner frame. While, analysis, each inner and outer frame consisting of 36 members in total, various key observations are made.

When structure is subjected to Dead Load, Live Load & Wind Load, the results of beam end forces or axial forces reflects that even though wind force is considered maximum design force values for combination of Dead Load & Live Load with specified factor. Further it is marked from Table No.6.1., that Horizontal members i.e., tie are subjected to Tensile forces where as members of rafters are subjected to compressive forces. Struts are also under compression. When the values of forces are compared with the effects of wind force i.e., the values of combination of Dead Load+ Live Load with Dead Load + Live Load and Wind Load, it is clear that the magnitude decreases when wind is considered. However, nature of forces are not getting changed drastically.

Even the values while considering wind force in X-direction is less as compared to wind load in Z-direction. However, it is very clear that the design is done for maximum values and thus, effective combination for structure subjected to dead load, live load and wind load is found to be combination of dead load and live load. While designing structure, ISA were used for truss members and I- sections are used for beams and columns. With the parameter of optimizing section ,the size of truss members vary such that structure resists dead load, live load and wind load successfully.

As the magnitude of forces on inner frame are almost twice to that of outer frame, corresponding changes in analysis results were obtained, such that for member 1, maximum $F_x = -58.059$ KN. However on the same location in inner frame maximum $F_x = 128.104$ KN and similarly, for other members too. Which reflect that inner frame needs to be more stronger than outer frame.

Same structure when subjected seismic forces for various seismic zones, following conclusion can be drawn. In case of such seismic analysis it is marked that maximum beam end forces or axial forces are developed for combination of dead load and live load. On the contrary, with introduction of seismic forces the magnitude of horizontal forces in X-direction and Z-direction decreases, which make it clear that design forces were again for structure subjected to combination of dead load+ live load.

With change in seismic zones for structure, the analysis results reflects that the magnitude of beam end forces are getting increased with increase in seismic severity of zones. Still they are less as compared with forces developed due to dead load and live load.

Such as for member 1 forces induced due to dead load+ live load is $-60.454(T)$, whereas for Zone II (DL+LL+EL) = -46.4 KN, Zone III (DL+LL+EL) = -46.382 KN, Zone IV (DL+LL+EL) = -46.883 KN and Zone V (DL+LL+EL) = -47.578 KN. These all values are taken from above tables .

This highlights that with change in earthquake severity the horizontal or lateral forces within member increases. As again design is done for maximum force within member, the multistorey steel building i.e., multistorey steel industrial shed is design for combination for DL+LL, which lead to conclusion that as steel being ductile material is good enough in absorbing seismic or lateral forces. Further, if such structure is design by considering dead load, live load and wind load will be safe against earthquake forces also magnitude is less for combinations which include earthquake forces too. Thus, in design results, the same structure seems stable against seismic forces.

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