Size Optimization of Steel Using Diaphragm Actions in Vertical and Horizontal Plane

S. N. K. Vinod and S. Praveenkumar

Abstract In construction industry, the usage of structural steel in the building has increased and it can also be recycled in the future. The structural members in tall industrial steel buildings like column occupies more space due to larger section size which causes obstruction. In order to achieve economical section size for tall industrial steel building, spacing of columns is ideal, to be chosen with trial and error method for assessing the distance of center to center of column. The bracings system is provided in vertical plane, which will be tied to the major axis of column above certain height in nonusable space and also bracings system in horizontal plane, where both the planes act as a diaphragm. Due to connection in the major axis of column, section reduction will be possible by distribution of forces equally. The members used in bracing system will be of higher section due to distribution of more forces. For this the members of different shapes are used, to find the optimum section for the bracing members. This helps in optimizing the section size of the tall steel building.

Keywords Diaphragm actions · Shape of structural member · Bracing techniques

1 Introduction

The diaphragms act as slab arrangement and help in distributing the lateral forces to the columns in each story of the building. Here, the diaphragm is made as slab arrangement using bracing system but there will be no additional gravity load acting above the diaphragms. With this arrangement, diaphragm is used in the tall industrial building to get the stress distribution to take place in both the sides of the column, which helps in reducing the section size.

In this paper, the application of diaphragms in tall industrial building is tried in two planes. One is along the vertical plane connecting the columns in major axis

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for certain height more like a lattice arrangement. Second one is in the horizontal plane, the diaphragms arrangement will be of bracing system thickness. Connecting the major axis of the column with these two arrangements, the optimum results are gathered. Using this, diaphragms are added in the model and then analyzed. The analyzed results are compared with normal building model arrangement without diaphragms.

2 Methodology

The tall building is model size of 20 m wide and 25 m height and 50 m in length, based on this the modeling is done. The modeling is done with spacing of 6.25 m c/c of column along the length and at the gable end side the spacing is 4 m c/c and purlin spacing is 1.6 m c/c. which can be referred in Fig. 1 for model A, it is simple and a regular model without diaphragm which consists of tie member, wind bracing, column bracing, the model A, B and C is made with fixed supports.

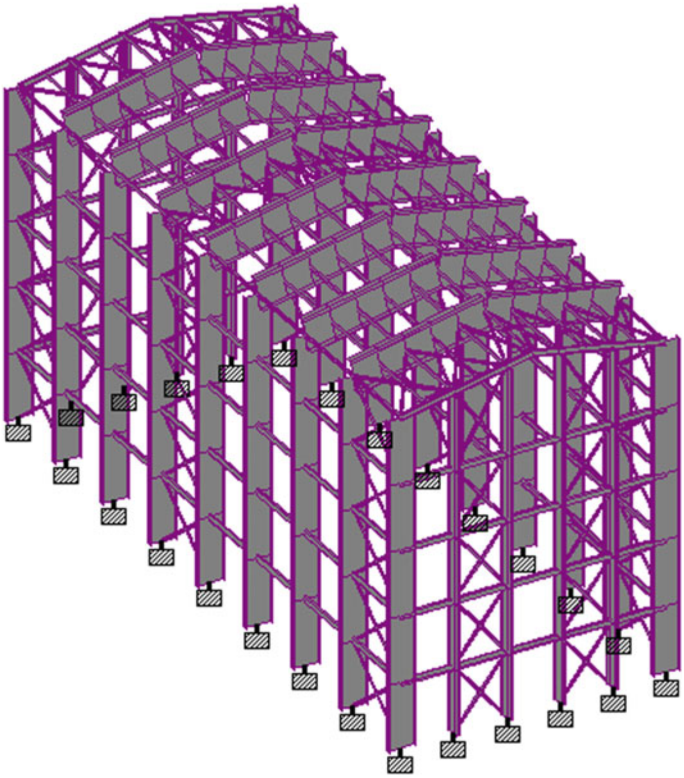

Fig. 1 Model A without diaphragm

Wind bracing on the rafter members at three locations as shown in Fig. 1 along the length of building for three bays, column bracing is located in three places as shown in Fig. 1 along the length at end side and one at mid portion of length and column bracing along the width in two bays at gable end side. Similarly, for the model B the diaphragms placed at 10 m height in vertical plane with bracing connecting the steel columns, and model C is prepared with diaphragms actions in horizontal plane above 10 m height. The overall for model B and model C is shown in Figs. 2 and 3, respectively.

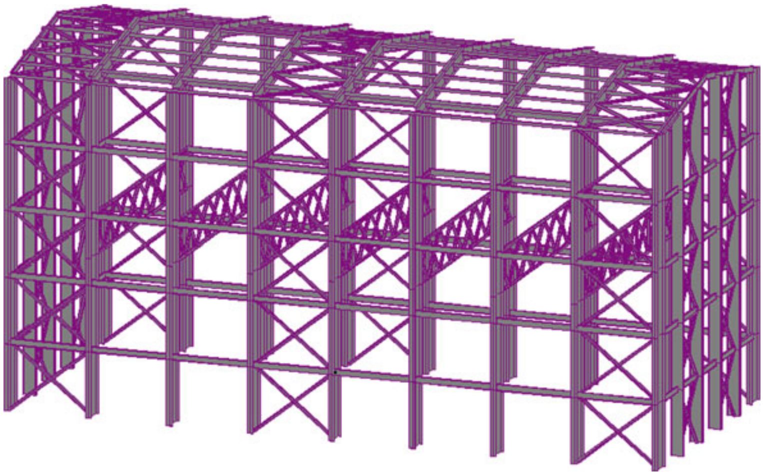

Fig. 2 Model B with vertical diaphragms

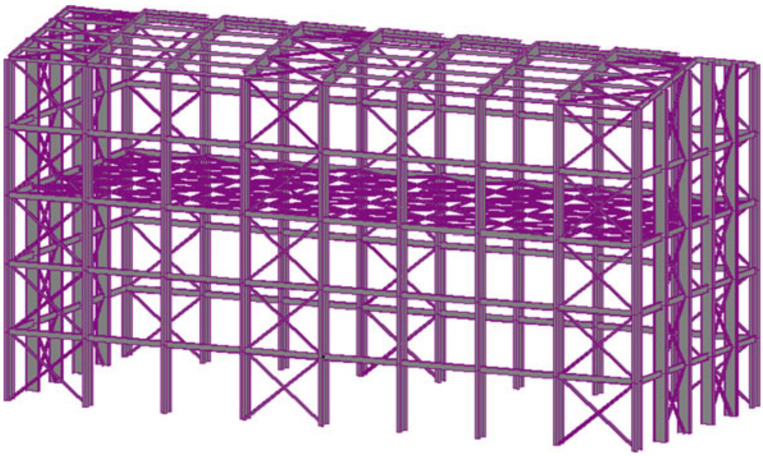

Fig. 3 Model C with horizontal diaphragms

The model B and model C from Figs. 2 and 3 shows that the diaphragms arrangement is compared with the regular arrangements of model A.

2.1 Diaphragms Arrangements

The model B and C has the diaphragms connected to steel column in the major axis of the member and in the minor axis the regular tie members are connected. The diaphragm bracing arrangement for model B in vertical is shown in Fig. 4 and similarly for the horizontal diaphragms is shown in Fig. 5.

3 Structural Configurations Details

The structure is configured as shown in figures above and the details of the building and dimensions are given in Table 1.

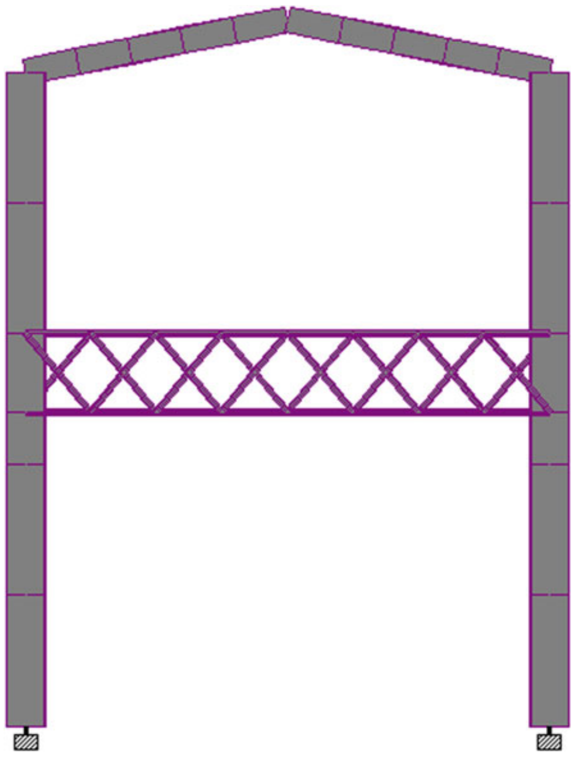

Fig. 4 Model B diaphragm in vertical plane in elevation

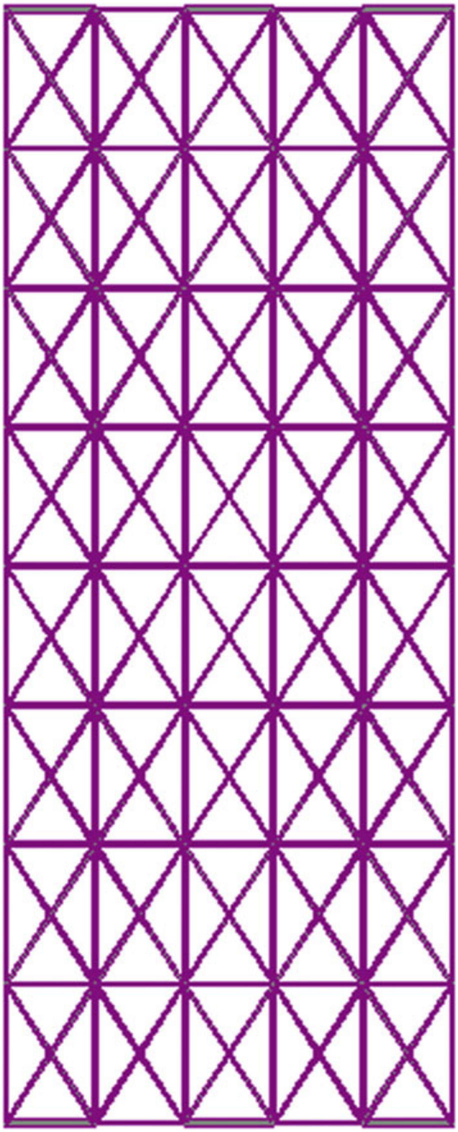

Fig. 5 Model C diaphragm in horizontal plane in plan

Table 1 Structure configuration

S. No	Type of building	Industrial building
1	Type of structure	Single-story building
2	Location	Ludhiana
3	Total length of building	50 m
4	Width of building	20 m
5	Eves height of building	25 m
6	Bay spacing of column	6.25 m
7	Slope of roof	6°
8	Diaphgrams at	10 m height
9	Shape of structural column used	I section
10	Shape of structural beam used	I section
11	Shape of bracing member used	Circular section
12	Shape of purlin used	Channel section
13	Grade of steel used	Fe250 grade

4 Load Calculations

4.1 Dead Load (DL)

The dead load of the structure is taken for all the members used in the model, the loads assumed other than self-weight for model analysis are given below. The sheet weight of 0.06 KN/sqm is taken here.

- Dead load = 0.80 KN/m.

4.2 Live Load (LL)

The live load of the structure is taken as per IS 875 part 3, normally the live load reduction takes place when the slope exceeds 10° then the reduction live load is to be carried out, but here the slope of roof is 6 ° then as per code the live load shall be kept as such, which is 0.75 KN/sqm. And live load is not going to act on all of the roof at all times, hence the 2/3rd of live load can be used for designing purpose which is 0.5 KN/sqm.

- Live load = 2.85 KN/m.

Table 2 Wind load parameter

S. No	Description	Data
1	Wind speed	47 m/s
2	Basic wind speed coefficient, k_1	1
3	Terrain category, k_2	1
4	Ground level undulations	1
5	Design wind pressure	1.325 KN/Sqm

4.3 Wind Load (WL)

The wind loads shall be as per IS 875 part 3, with factors for k_1, k_2, k_3 is taken as 1 and with wind speed is 47 m/s.

From Table 2, data is used for analysis for model A, B, C, the values from table are used in the Staad pro to compute the loads on the members.

4.4 Earth Quake Load (EQ)

The earthquake loads shall be as per IS 1893(2005) part 4, the parameters for the seismic definition for computing the seismic load in Staad pro is given in Table 3.

The values are entered in seismic definition in the Staad pro for computing the loads and analyzing the models.

Table 3 Seismic load parameter

S. No	Description	Data
1	Seismic zone	III
2	Response reduction factor	5
3	Importance factor	1
4	Rock/soil type	2 (medium soil)
5	Structure type	2 (steel building)
6	Damping ratio	5%
7	Period in X direction	0.02 s
8	Period in Y direction	0.0127 s
9	Foundation depth	1.5 m

4.5 Load Combinations

The load combinations used as per IS 800-2007 are as follows:

1. 1.5DL + 1.5LL
2. 1.5DL + 1.5WL 0
3. 1.5DL + 1.5WL 90
4. 1.5DL + 1.5WL PARALLEL
5. 1.2DL + 1.2LL + 1.2WL 0
6. 1.2DL + 1.2LL + 1.2WL 90
7. 1.2DL + 1.2LL + 1.2WL PARALLEL
8. 1.2DL + 1.2LL + 1.2EQ X
9. 1.2DL + 1.2LL + 1.2EQ -X
10. 1.2DL + 1.2LL + 1.2EQ Z
11. 1.2DL + 1.2LL + 1.2EQ -Z
12. 1.5DL + 1.5EQ X
13. 1.5DL + 1.5EQ -X
14. 1.5DL + 1.5EQ Z
15. 1.5DL + 1.5EQ -Z
16. 0.9DL + 1.5WL 0
17. 0.9DL + 1.5WL 90
18. 0.9DL + 1.5WL PARALLEL

The model is analyzed and the moments in the columns are higher for the load case 16, 17, 18 and 2, 3, 4 which are critical load cases, since the building height is more than the width of building it behaves as slender member as a whole.

5 Staad.Pro Procedure

The Staad.Pro software package is a structural analysis and design software which helps in modeling, analyzing and designing the structure. The software supports standards of several countries, including Indian standard. The procedure includes modeling the structure, applying properties, specifications, loads and load combinations, analyzing and designing the structure. This software is an effective and user-friendly tool for three-dimensional model generation, analysis and multi-material designs.

In STAAD Pro, utilization ratio is the critical value that indicates the suitability of the member as per codes. Normally, a value higher than 1.0 indicates the extent to which the member is overstressed, and a value below 1.0 tells us there is serve capacity available. 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.

6 Results and Discussion

The design parameter used for designing the section for different models are given below.

The design parameter is varying for each model, which is the length factor in the major axis is varying due to the addition of diaphragms, with this the member is designed as per the inputs given. It is the critical factor for designing the steel member here. The design parameter used for designing the section for model A, B and C is shown in Figs. 6, 7 and 8.

6.1 Dimension Size Comparison

The section size assumed initially are I section for steel column and raft beam. Based on the moment and shear forces, the section is designed and the weight of structure seems to comparatively less for diaphragms models B and C compared with model A, similarly the section sizes are higher for the model A.

Now taking the portal frames in 2D arrangement to compare the section sizes and other results, which are given in Table 4.

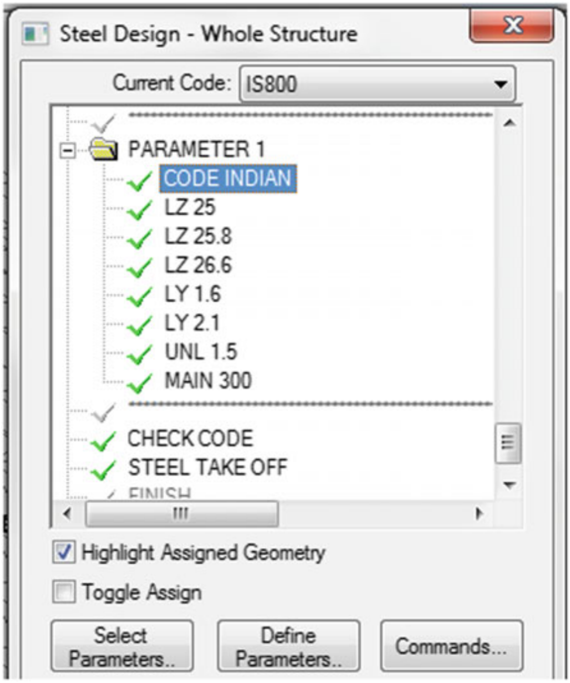

Fig. 6 Design parameters for model A

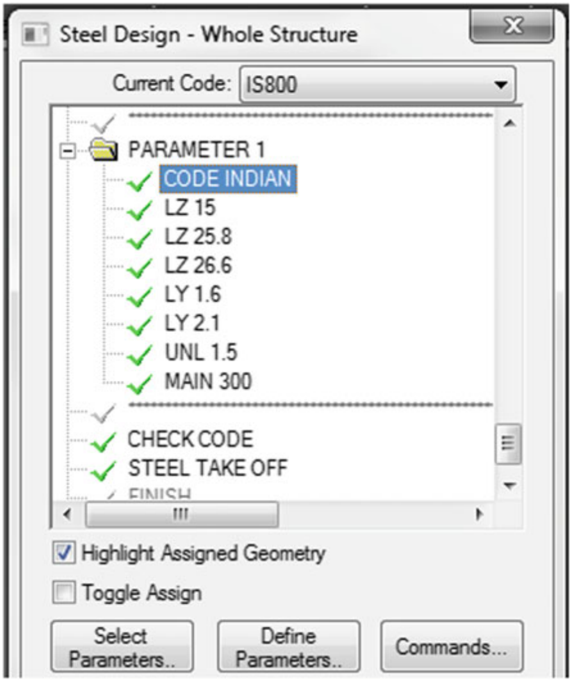

Fig. 7 Design parameters for model B

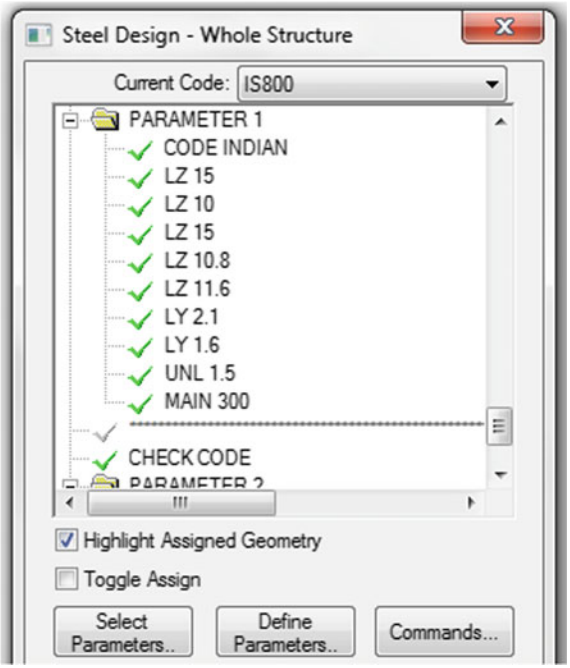

Fig. 8 Design parameters for model C

Table 4 Section sizes, moment, shear

S. No	Description	I—section sizes in MM	Moment	Shear
1	Model A	1950 × 550 × W10TK × F10Tk	2762 KN-M	183 KN
2	Model B	1500 × 450 × W10TK × F12Tk	1940 KN-M	167 KN
3	Model C	950 × 325 × W10TK × F12Tk	776 KN-M	216 KN

Table 5 Deflection of column

S. No	Description	Deflection in MM	Permissible deflection in MM
1	Model A	69	100
2	Model B	62	100
3	Model C	86	100

Table 4 results the steel column sizes that are given, where the model A is higher in section size which is due to high stresses induced due to the unsupported length in the major axis has greater length. The model B is comparatively low in section size due to the connectivity of diaphragms in the major axis of the column and model C is even lesser in section size compared with model A and B.

The deflection results from Table 5 represents the column at the ridge level where the raft beam and column connection takes place, deflection value varies for each model due to variations in the section size and the deflection values are within the permissible limit and deflection seems to be less in the model B.

6.2 Section Steel Weight Comparisons

The section size weight is taken for comparisons in 2D frame and as well as 3D frame, the comparison results are given in the table below.

Table 6 and 7 shows the steel weight is gradually decreasing from the model A to B to C, it is noticed that the model C has low section weight in 3D frame analysis and design. The results are same in the 2D frame weight comparison.

The steel weight for 3D frame includes members like purlin, bracing, portal frame member and tie members. The 2D frame steel weight includes only the portal frame member. The chart for the same is shown in Figs. 9 and 10.

Table 6 Steel weight comparison in 3D

S. No	Description	Weight in KN
1	Model A	2875
2	Model B	2600
3	Model C	2454

Table 7 Steel weight comparison in 2D

S. No	Description	Weight in KN
1	Model A	200
2	Model B	167
3	Model C	106

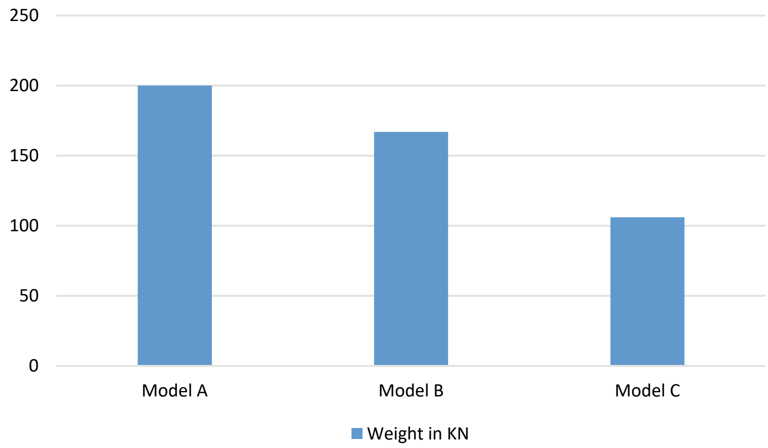

Fig. 9 Weight comparison for 2D frame model

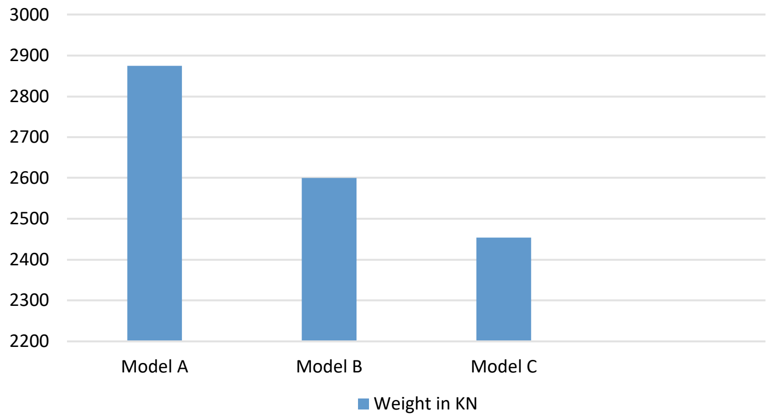

Fig. 10 Weight comparison for 3D frame models

7 Conclusion

- The model analysis of different arrangement of diaphragms gives some additional stiffness in the structure, thus helps in reducing the section size of members. This also provides some resistance against the lateral forces due to the diaphragms action, especially in the horizontal plane the effect of diaphragm is effective in reducing the section sizes.
- The deflection limit from the results shows that section above the diaphragm action is susceptible to more deflection in the horizontal plane of model B diaphragm, but in the vertical plane diaphragm the deflection value is less compared with the regular model A arrangement.
- The section size variation in all the models is compared and the result of model C the section size is less compared with others, hence the model C arrangement can help in increasing the usage space of the building.
- The structural section size reduction will also reflect in the steel weight, thus from the results of comparison of steel weight the model C has the least weight over other models A and B. Hence, this helps in reduction cost compared with other models.
- The diaphragms arrangement model is useful only when the building above certain height has nonusable space, then only the diaphragm arrangement will become possible and should be free from obstructions of amenities of building usage.

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