Analysis of multi storeyed rigid frame steel structure with box configuration

[1]Kartikkumar Prajapati, [2]Prof. Roshni John,

[1]Pursuing M.E Structural Engineering, [2]Professor ,
[1]Department of Civil Engineering,
[1]Saraswati College of engineering
Navi Mumbai, India,

Abstract- Multistoried high-rise buildings have become an essential part of cities which comprises of structural steel, concrete or composite construction. The use of structural steel in high-rise buildings has been quite popular from many decades due its many advantages. The most widely used and simplest form of structural system being rigid frame system, has certain drawbacks. With the increase in height of structure, the lateral deflection due to wind and seismic forces increases which concerns the strength and serviceability criteria. Many advanced techniques are developed to deal with this issue of lateral deflection in high-rise buildings but they often involve complex analysis and its construction is costly. In this thesis a structural system termed as 'Box configuration' is proposed to be used. Three models Ground plus 10, 15 and 20 respectively are designed for only vertical loads where rolled steel I-beam sections are used for primary and secondary beams. Box configuration means replacing the outer periphery beams of structure on selected storeys with a heavier beam than required such that it forms a box like formation in the elevation. The number of box configurations formed depends of numbers of storeys where outer periphery beams are replaced. Wind and seismic forces were then introduced on the models with and without box configuration and a comparison was made focusing on the maximum lateral deflection that each model undergo. With increase in number of box configuration by one each, an approximate 6 percent reduction in maximum lateral deflection was recorded. For all the three models of varying heights, above 20 percent reduction in lateral deflection was observed when maximum number of box configuration possible was adopted. Thus, adopting box configuration in rigid frame steel structures provides reasonably good amount of lateral stability without use of any complex structural system.

Keywords—Box configuration, lateral deflection, rigid frame, steel structure, Multistoreyed

INTRODUCTION

The fascination of achieving greater height in a structure began many decades ago and is still on with new heights being achieved in the form of multistoreyed buildings. However, with increase in height of a building, the number of structural challenges it has to face also increases. The most prime challenge is to control the lateral or horizontal deflection due to wind and seismic forces. It becomes very important to evaluate these forces accurately and analyze its effect on the proposed high-rise structure. Negligence in wind and seismic forces in high rise structures have resulted in hazard to structure and humans many times in the past. Hence many structural systems have been developed with time whose implementation has resulted in making the structure safe and serviceable. Selecting a structural system depends on many factors. A structural engineer needs to have a thorough knowledge of behavior of a structural system that are adopted in existing structures. Its advantages and disadvantages are also to be evaluated before adopting it for a proposed structure.

The availability of structural steel was a landmark in construction industry as it had many advantages over the conventional methods that were used before a century. Structural steel made it possible to build longer spans and taller structures with more efficiency and safety. Rigid frames steel structures are the most popular structures and are most widely used all around the globe. A new concept of box configuration is being proposed in rigid framed structures which tends to increase the lateral stability of multistoreyed high-rise structures.

BOX CONFIGURATION

A box configuration means replacing certain members of a rigid frame by heavier members such that it forms box like configuration in its elevation. The following illustrations explain how a box configuration is adopted in a typical rigid frame structure.

Rigid Frame with no box configuration

Fig.1

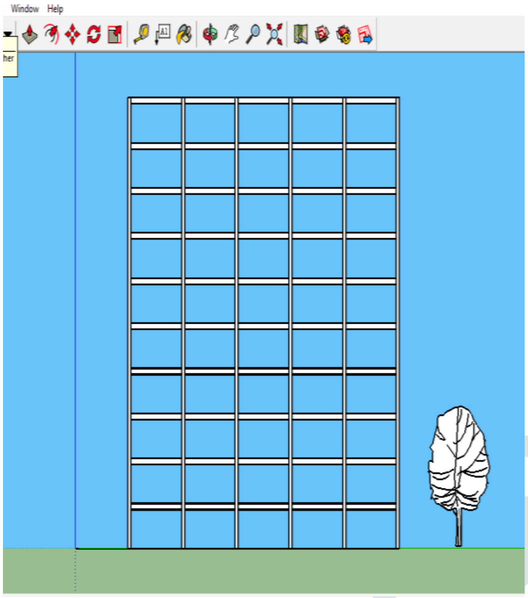
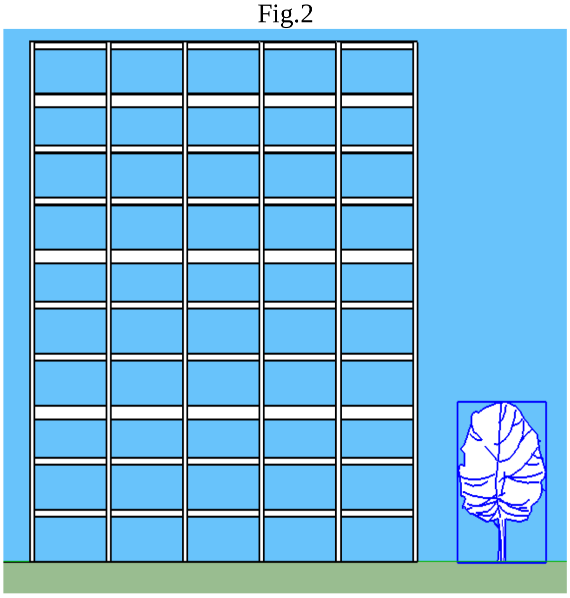


Fig.1 illustrates a typical rigid frame steel structure which is designed to sustain only vertical loads (i.e. Dead, superimposed dead and live loads). Since loads on all storeys are same, hence depth of beam on all storeys is same.

Rigid Frame with box configuration

In the above structure the beams in outer periphery on floor 3, 6, 9 are replaced by a heavy beam (heavier section from available rolled steel beam sections). It is to be assumed that column sections in a multistoreyed high-rise structure are generally heavier than beams. Thus, after replacing the selected beams, the structural system exhibits a box type configuration as shown in Fig.2

Fig.2



It can be observed in fig.2 that after replacing beams on floor 3,6 & 9 the structure gives a formation of 3 boxes.
Fig.3 below shows the box configuration formation by highlighting them. Since the number of boxes formed are three, this will be termed as a three-box configuration.

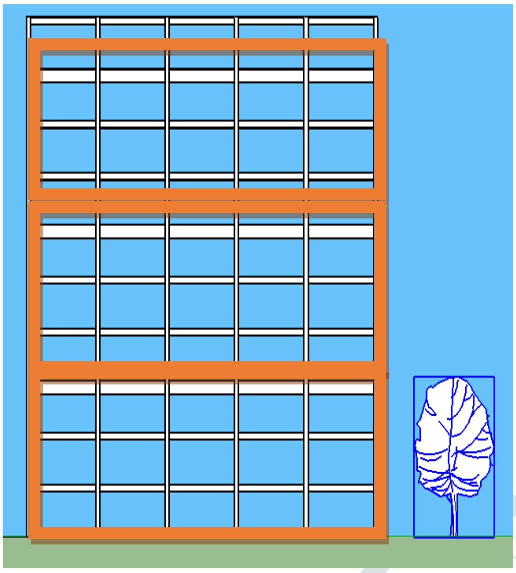


Fig-03

The number of box formed depend on the number of storeys on which outer beams are replaced

OBJECTIVES AND DETAILS OF THE STUDY

Box configuration is a newly proposed system that is being introduced to rigid framed steel structure to increase its lateral stability. Hence a comparative study will be carried out on models without box configurations versus the models with box configurations.

Following are the objectives of this study:

1. To study changes in maximum horizontal sway/deflection of building when box configuration system is adopted. This sway is to be compared with that of the structure without box configuration. This study will be performed on three models i.e. Ground+10, Ground+15 & Ground+20 storey structure.
2. To study effect of torsion on a G+10 storey structure with and without box configuration.

Details of models for first objective.

The structure to be analyzed is considered as an urban commercial office building hence all the loads assumed are for commercial buildings as per IS:875 part II (Reaffirmed 2003). The three models of varying height will have same plan. The plan is symmetric on both axes and has a floor to floor height of 4 meters.

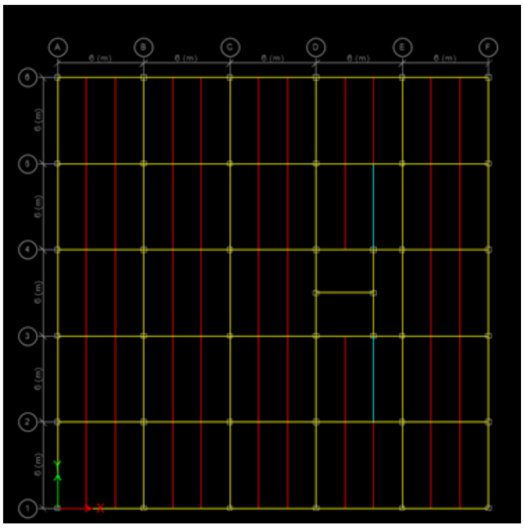


Fig. 4

There are 5 bays in both axis of 6 meters span each. The yellow colored beams are the primary beams and the red colored beams are secondary. Secondary beams are at a spacing of 2 meters. The beams are to be selected from the rolled steel beam sections as per IS:808 1989(reaffirmed 1999). The columns are hollow box sections with concrete infill of suitable grade. Slabs are deck type. Secondary beams are assumed to be simply supported. Other relevant data is provided in table.1 below.

Type of structure	Commercial (office building)
Typical floor height	4 meters
Ground floor height	4 meters
Grade of structural steel	Fe250
Grades of infill concrete used	M25 & M40
Live load	4kN/m2 (as per IS 875:part 2) Reaffirmed 2003
Floor finish	1kN/m2
Density of structural steel	7800kg/m3
Density of infill concrete	25kN/m3
Density of internal partition AAC blocks	6kN/m3
Density of outer glass cladding	25kN/m3
Zone factor	(Zone 3) – 0.24
Response Reduction factor	5
Importance factor	1
Damping	5%

Table. 1

Details of model for second objective (Torsional effect)

A new model is studied for torsional effect due to seismic forces. The plan is rectangular and the columns are placed in a manner such that torsion is induced in the structure when seismic load acts on it. Figure.5 illustrates the plan of model. It can be observed that columns on lower two grid are stiffer and on upper side are slender in X-direction. Due to this arrangement the structure will rotate clockwise when seismic forces are applied in positive X-direction.

METHODOLOGY

Methodology for first objective is as follows

1. Design a model of Ground +10 storeys for vertical static loads only.
2. Model to be subjected to Wind and Seismic load and maximum lateral deflection is recorded.

Introduce one box configuration in the model and the new value of maximum lateral deflection due to wind and seismic force is recorded

3. Introduce 2 box, 3 box configuration and so on and repeat above process of recording the values of maximum lateral deflection respectively. The number of box configuration is to be increased till it is practically possible.
4. This methodology is adopted for two other models of ground +15 and ground + 20 storey structure.

Load combinations considered for the two objectives are

1. Initial model is designed for only vertical loads of combination 1.5(DL + IL + LL).

2. The model is then tested & modified for lateral loads having following combination
    - 1.2 (DL+IL+LL+WindX)
    - 1.2 (DL+IL+LL+EQX)
    - 1.5 (DL+IL+WindX)
    - 1.5 (DL+IL+EQX)

The first model which is a ground +10 storey structure is designed for vertical static loads only. The primary and secondary beams are designed by ETABS software from available rolled beam sections. Columns are designed as hollow square sections having dimensions 350 x 350 mm and thickness 16mm. the hollow square sections are having concrete infill of grade M25 for G+10 structure. Figure 5 below displays the model designed for only vertical loads. This model will be termed as the no box configuration model.

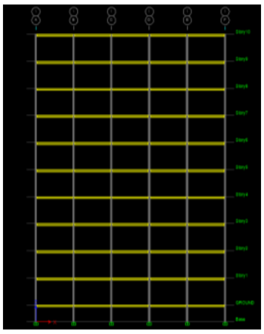
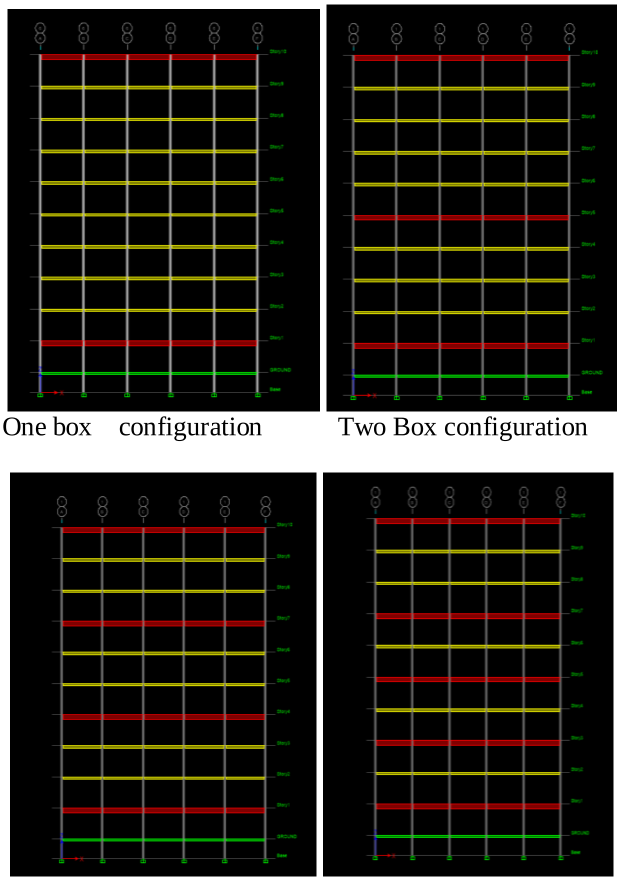


Fig. 5

and and seismic forces are applied in X direction on this model and values of maximum lateral deflection are recorded in table 2. The beams on outer periphery on storey 1 and storey 10 are replaced by ISMB 600 which is much stiffer than ISMB 300 which was assigned during ETABS design for vertical loads. This replacement forms one box configuration in the given structure. Our model with one box configuration is also subjected to same intensity and direction of wind and seismic forces and values of lateral deflection are recorded in table 2. Similarly, models with two, three and four box configurations are created and subjected to same lateral forces to note their respective values of lateral deflections. Fig. 6 displays the one, two, three and four box configurations. The beams highlighted by red color indicate the ISMB 600 beams in Fig 6. It can be observed that in Ground + 10 structure, a maximum of four box configuration can be adopted.



One box configuration Two Box configuration

Three Box configuration Four box configuration

Fig.6

The deflection of the structure after applying lateral forces is displayed in figure 7 below.

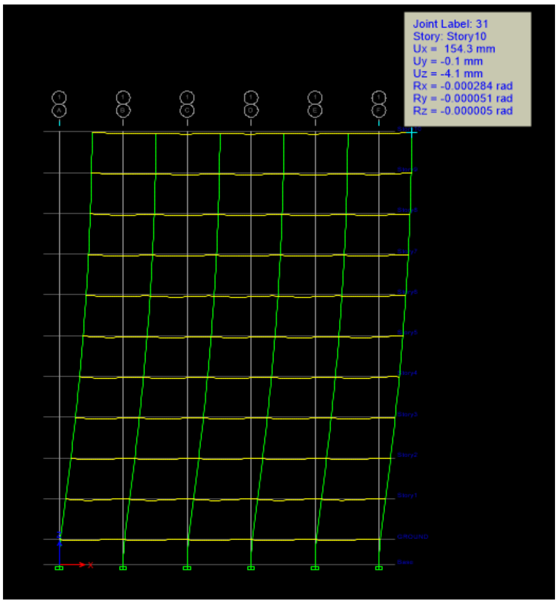


Fig.7
Lateral deflection in no box model for wind load.

Table 1

In a similar manner, the other two models of ground + 15 and ground + 20 storeys are designed for vertical loads and then tested for lateral deflections with and without box configurations. For the ground + 15 model, a maximum of five box configurations were adopted and for the ground + 20 model a maximum of 6 box configurations were adopted.

The results of maximum lateral deflection for wind and seismic forces for all the three models have been tabulated below.

Methodology for the second objective of torsional analysis

1. Design a Ground + 10 structure for static vertical load. The structure has a rectangular plan such that the dimension on structure is less in direction of earthquake force applied. Also, column placement is not even so that structure tends to twist upon application of seismic load. The columns on lower side of plan are much stiffer than other columns to produce torsional twist on purpose.

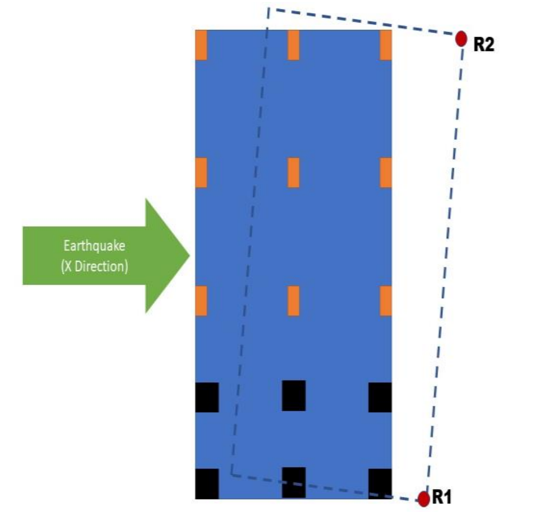


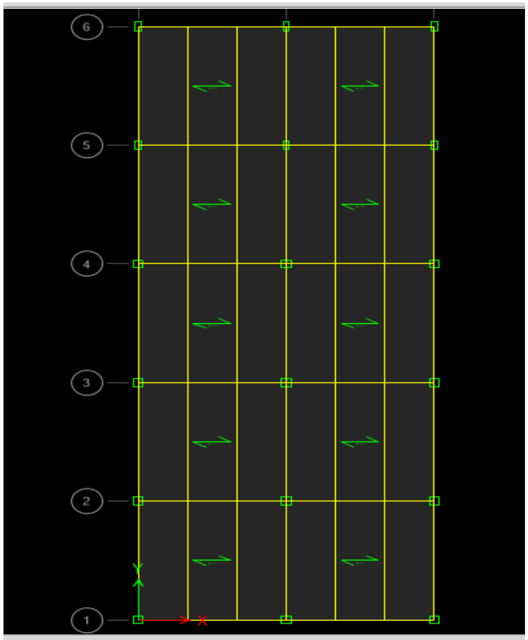
Fig. 8

The top storey lateral deflection on the two corners in plan-view is termed as 'R1 and 'R2'respectively as illustrated in Fig.8. It is obvious that when the structure undergoes torsion due to seismic force, the values of R1 and R2 will not be same. The part of structure having stiffer columns will deflect less. It is also understood that more the difference between values of R1 and R2 means more is the torsional twist the structure is undergoing.

1. The structure with no box configuration is subjected to seismic loads and the values of R1 and R2 are recorded.
2. The same structure is modelled with three box configuration and subjected to same seismic forces. The new values of R1 and R2 are recorded.
3. A comparison is made between difference of R1 and R2 values for both the cases.

Details of the model for second objective

The Ground + 10 storey model kept rectangular in plan on puropose such that its dimension in direction of earthquake (X direction) is less. It has 2 bays in X-direction of 6 meters each and 5 bays in Y-direction of 6 meters each.



Plan View
Fig. 9

It can be seen in Fig. 9 that the columns in lower four gridlines of the plan are stiffer as compared to above ones. This arrangement of column will ensure that the structure will twist when seismic force acts in X-direction. The columns on lower side are steel box sections having cross section dimensions 400x400x20 mm. The slender columns on upper side of plan have dimensions 400x250x20 mm. The columns are analyzed and found to be safe for vertical loads on this model. All other design data and loading pattern is same as in first objective This model with no box configuration is subjected to seismic load and the deflection pattern clearly shows that building has undergone torsion. It is illustrated in Fig.10 below

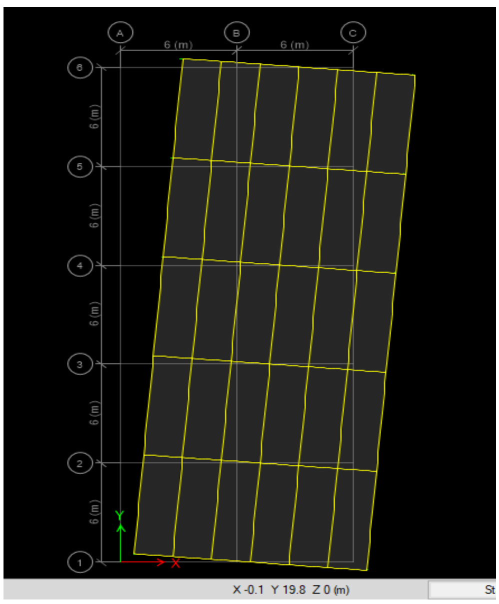


Fig. 10

The values of R1 and R2 are recorded in table 2 below. The same structure with a three box configuration where the outer periphery beams on storey 3, 6 and 10 are replaced with heavier ISMB600 beams. The R1, R2 values for three box configuration structure are also recorded and comparison is made.

Model (Configuration)	Maximum lateral displacement on top storey (mm)		Difference (mm)
	R2	R1	(R2 – R1)
No box	177.9	2.4	175.5
3 box	137.8	17.2	120.6

Table 2

RESULTS AND DISCUSSIONS

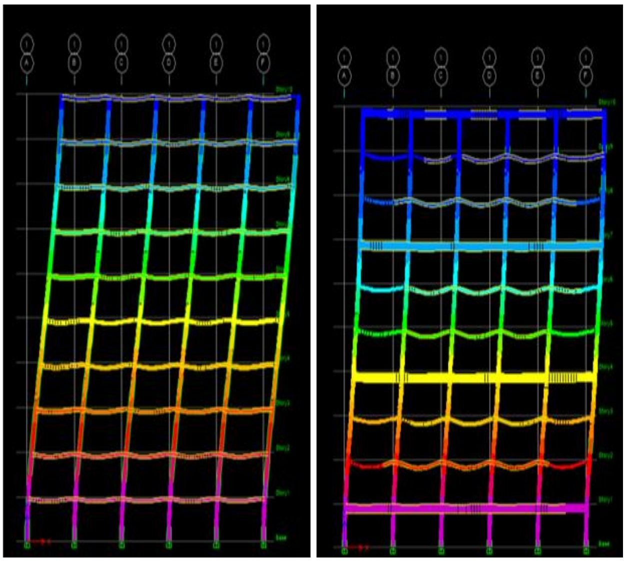
First objective

Table 1 shows the maximum lateral deflection values when wind and seismic loads are applied on a structure that is designed only to withstand vertical static loads (with and without box configurations). It is clearly reflected that there is a significant reduction in lateral deflection between same structure with and without box configuration.
The average percentage reduction in lateral deflections for three models are as follows

Model	Average % reduction in lateral deflection
G + 10	21.52
G + 15	23.00
G + 20	24.28

Table 3

Thus, adopting box configuration for rigid frame steel structure has decreased the lateral sway of all the three models of varying heights. From table 1 it can also be observed that by increasing number of box configuration by one unit, there is an approximate reduction of 5 percent in the lateral deflection. Fig.11 illustrates how the use of box configuration makes difference in the deflection pattern of a structure.



Deflection pattern without and with 3 box configuration
Fig.11

Second objective

If the two corner points in the structure would have deflected in the same direction by equal values upon application of seismic loads, then the difference between R1 and R2 would have been nil. But in our case, there is a significant difference in structure without box configuration which is initially designed to carry only vertical load. This difference in R1 and R2 values justifies that torsion has been generated due to our column arrangement and the building has undergone twist.
The difference between R1 and R2 values can be assumed to be directly proportional to the twist because the angle by which the structure will twist will be a function of R1 and R2. Hence it can be understood that higher the difference between R1 and R2, higher will be the torsion and vice versa.

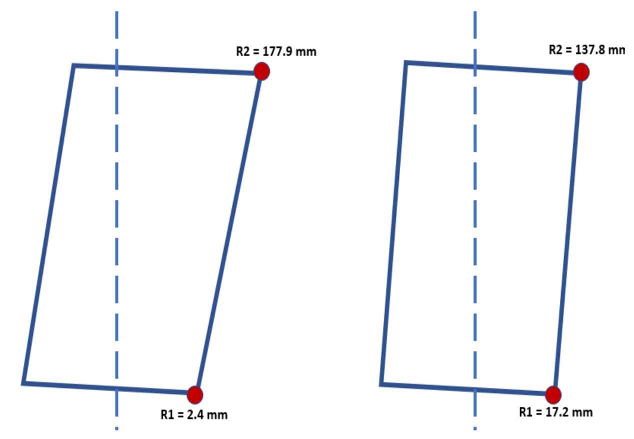


Fig 12

Figure 12 shows the sketch representing respective R1 and R2 values of no box configuration model on left and 3 box configuration model on right. There is a 31.2 percent reduction in torsional twist of structure after 3 box configurations was adopted on the rigid steel frame structure.

CONCLUSIONS

For the first objective, which was to check the performance of structure under wind and seismic load with and without box configuration, it was found that all the three models with varying heights became more stable against lateral sway when box configuration was adopted. Hence it can be concluded that adopting box configuration provides more lateral stability to rigid frame structures.

For the second objective which was to test the structure for torsional twist due to seismic load, again adopting box configuration resulted in more stability against torsion. Hence it can be concluded that adopting box configuration provides an added benefit of torsional stability in case of earthquake.

A prime issue to be noticed is that many complex structural systems like dampers, base isolation techniques etc. are available to increase the stability of structure but they involve complexity in terms of analysis and on-site construction too. In comparison to the complex techniques, the concept of box configuration is quite simple in terms of analysis and implementation too.

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