A Comparative Study of High-Rise Building with Floating Columns by Providing Different Types of Bracing Systems

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Abstract: In today's era, the concept of building with floating columns have become very popular. In floating columns, some columns are eliminated from main frame and load coming from upper columns is transmitted through beams to lower floors. Eliminating columns in frame of building gives us extra space for use which is today's requirement. Previous study shows that such structure cannot be constructed in highly seismic zone areas as they are unstable in nature. In present scenario we will study behavior of multi-story building with floating columns, without floating columns and floating columns with different bracings systems. Our study will mainly deal with increasing the seismic performance of building with floating columns by providing suitable type of bracing. The analysis will be carried out in Etabs software. In our study response spectrum analysis and wind load by using gust factor method will be carried out for evaluating performance of all the seven configurations of buildings. Results based on parameters such as time period, base shear, story drift and story displacement will be compared based on seismic excitation. The results obtained show increase in time period, story displacement, and drift in model with floating column as compared to model with bracings systems. After introduction of bracings in model, performance of the model with floating columns was observed to improve and better stability results were obtained.

Keywords: Steel Bracing, Floating Columns, High-rise Building, Response Spectrum Analysis, Wind Load Analysis, Moment Resisting Frame (MRF).

1.0 Introduction

A column is said to be a vertical member starting from foundation and transferring the load to the bottom level. When a vertical element ends at its lower level and rests on beam which is a horizontal member that is known as floating column. Therefore, the beams transfer the load to other columns below it. Theoretically these types of structures can be analyzed and designed. A lot of multi-story buildings in urban India nowadays have open first story as an unavoidable feature. This is basically being adopted to accommodate parking or reception lobbies in the first story. Though the seismic base shear acting on the building during an earthquake depends on its natural period, the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In Gujarat during the 2001 Bhuj earthquake so many multi-story buildings having an open ground story intended for parking collapsed or severely damaged.

In one of recent incident most of buildings that collapsed in Turkey earthquake had soft story at ground level for parking. This is very common in turkey and this is where design fails in earthquake. It was observed that such structure is very much at risk in earthquake or other natural disaster conditions. So, to avoid collapse buildings should be provided with lateral force resisting system like dampers, shear walls or bracing systems.

In a hotel or commercial building, where the lower floors contain banquet halls, conference rooms, lobbies, showrooms or parking areas, large uninterrupted space is required for the movement of people or vehicles. Some columns from the upper story are terminated at the first floor or higher level. These floating columns are supported on beams called transfer girders. They can also be supported on slabs called transfer slabs. A transfer girder transmits the load from a discontinuous column to the columns in the story beneath, which support the transfer girder.

Therefore, the structures previously made with these types of discontinuous members are endangered in seismic regions. However, those structures cannot be demolished, to a certain extent study can be done to strengthen the structure or some remedial features can be suggested. The columns of the first story can be made stronger, the stiffness of these columns can be increased by retrofitting or these may be provided with bracing to decrease the lateral deformation.

1.1 Features of Bracing system

Most of the multi-story buildings are made of RCC frame building so its great importance given to make the structure safe against lateral load produce due to wind, earthquake. There are various lateral resisting system and steel bracing is one of them. Due to their high strength, stiffness and lateral load capacity, steel bracing is an ideal choice for lateral load resisting system in a reinforced concrete structure.

Steel bracing is a highly efficient and economical method of resisting horizontal forces in a frame structure. Bracing is efficient because they act by reducing the bending moment and shear forces in the columns of the structure and lateral loads on the structure are transferred to the foundation by axial actions. Besides they also improve the stiffness and strength capacity of the structure. There are various techniques such as infilling walls, adding walls to existing columns, shear wall, encasing columns, and adding steel bracing to improve the strength and/or ductility of existing buildings.

A bracing system improves the seismic performance of the frame by increasing its lateral stiffness and capacity. Through the addition of the bracing system, load would be transferred out of the frame and into the braces, bypassing the weak columns while increasing strength. Steel braced frames are efficient structural systems for buildings subjected to seismic or wind lateral loadings. Therefore, the use of steel bracing systems for retrofitting reinforced concrete frames with inadequate lateral resistance is attractive.

2.0 Objectives of Present Study

1. To carry out comparison for building with floating column and different bracing systems based on different parameters like
    a) Storey displacement
    b) Storey drift
    c) Base shear
    d) Time period
2. To study effects of providing floating column in moment resisting frame.
3. To perform and understand response spectrum analysis and wind load analysis by gust factor method on high rise building models.
4. To suggest most suitable bracing system on basis of the performance of structure.
5. Modelling and analysing of G+35 multi-story building with floating column along with different bracing systems using Etabs 2018 software.

6. To understand the behaviour of multi-story building with and without floating column under earthquake and wind loads.
7. To analyse the building structure in seismic zone IV with medium soil condition to obtain the results.

3.0 Problem Statement

To study and compare the behavior of high-rise buildings (G+35) with floating column by providing different types of bracing systems. For this purpose, various cases are considered like moment resisting frame, framed structure with floating column, Framed structure with floating column and bracing system (X, V, inverted V, diagonal eccentric forward and diagonal eccentric backward). The dynamic analysis is done by response spectrum method for seismic zone IV for medium soil conditions and dynamic wind analysis is done by gust factor method.

Table 1. Configurations of models

Model number	Type of configuration	
Model-01	Moment resisting frame	For response spectrum analysis
		For dynamic wind load using gust factor
Model-02	Framed structure with floating column	For response spectrum analysis
		For dynamic wind load using gust factor
Model-03	Structure with floating column and X type bracing system	For response spectrum analysis
		For dynamic wind load using gust factor
Model-04	Structure with floating column and diagonal eccentric backward bracing system	For response spectrum analysis
		For dynamic wind load using gust factor
Model-05	Structure with floating column and V shape bracing system	For response spectrum analysis
		For dynamic wind load using gust factor
Model-06	Structure with floating column and inverted V shape bracing system	For response spectrum analysis
		For dynamic wind load using gust factor
Model-07	Structure with floating column and diagonal eccentric forward bracing system	For response spectrum analysis
		For dynamic wind load using gust factor

Table 2. Input data for modelling

Input Data		
Plan size	32m X32m	
Spacing between column c/c in both direction	4 m c/c	
Height of building	105 m	
Slab thickness	150 mm	
Bracing size	ISA110X110X10 mm	
Floor to floor height	3.0m	
Column size	From story base to 7^{th}	550 mm x 550 mm
	From story 7^{th} - 19^{th}	400 mm x 400 mm
	From story 19^{th} - 35^{th}	300 mm x 300 mm
Beam size	From story base to 7^{th}	300 mm x 550 mm
	From story 8^{th} - 19^{th}	300 mm x 400 mm
	From story 20^{th} - 35^{th}	230 mm x 300 mm

Table 3. Material properties of structure

Material properties	
Grade of concrete	M30
Grade of steel	HYSD550
Density of concrete	25 kN/m^3
Density of steel	78.5 kN/m^3
Density of light weight block	10 kN/m^3

Table 4. Loading on structure

Loading [as per IS 875 part 2 1987]	
Live load	Floors =3 kN/m^2 Terrace=1.5 kN/m^2
Dead load	1.2 kN/m^2
Wall load	Floors = 0.23*3.0*10=6.9 kN Terrace= 0.23*1.2 *10=2.76 kN

Table 5. Seismic data for structure

Seismic parameters [as per IS 1893 part-1 2016]	
Seismic zone (Z)	IV [0.24]
Soil category	II [medium soil]
Response reduction factor	5
Importance factor	1
Damping	5%

Table 6. Wind data for structure

Wind parameters [as per IS 875 part-3 2015]	
Wind speed	50 m/s
Terrain category	4
Class	C

4.0 Methodology

- 35 storied MRF (moment resisting frame) with floating column, X bracing system, diagonal eccentric backward bracing system, V shape bracing system, inverted V shape bracing system, diagonal eccentric forward bracing system having a plan size of 32 m X 32 m with structural height 105 m are taken for analysis.
- Response spectrum analysis is carried out for models in X and Y direction with seismic zone IV and medium soil condition.
- Basic wind load 50 m/s as per 875 part-2 2015 for Delhi with terrain category 4 and class C is taken for wind load calculation.

- As per IS 875-part 3 tall structure are wind sensitive and it should be design for dynamic wind load (as per cluse 9.1 of IS 875 part 3 2015).
- For dynamic wind load, wind load is calculated by Gust factor method using the formulae from IS 875-part 3 (2015) clause 10 with the help of excel spreadsheet in X and Y direction.

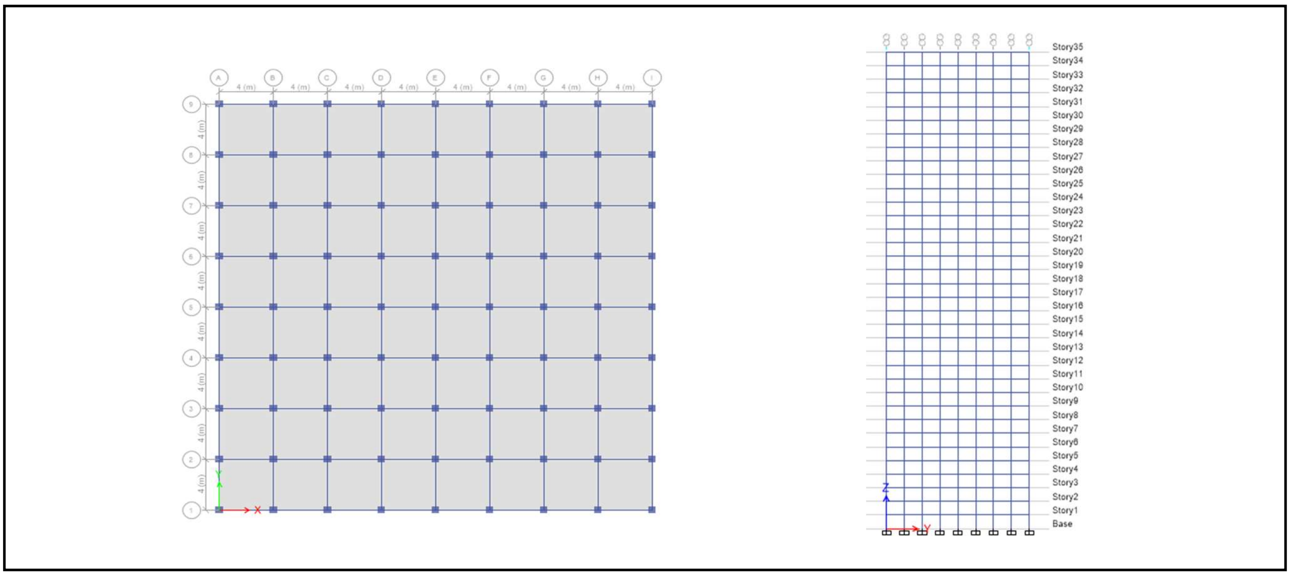

Fig. 1. Plan and elevation of Moment resisting frame

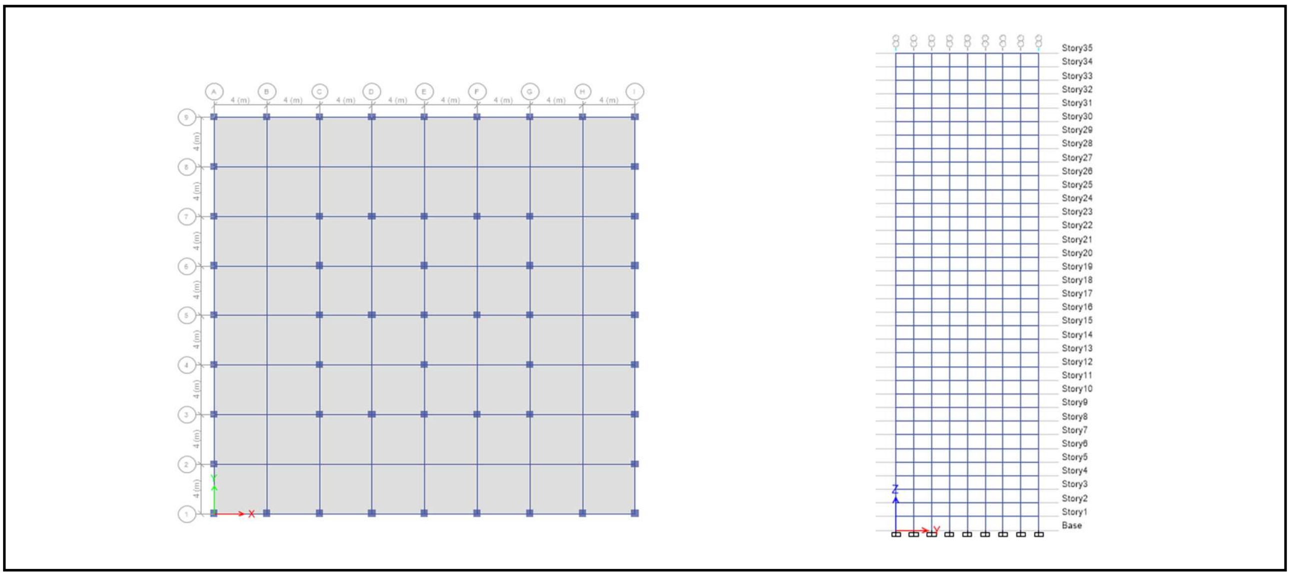

Fig. 2. Plan and elevation of Moment resisting frame with floating columns

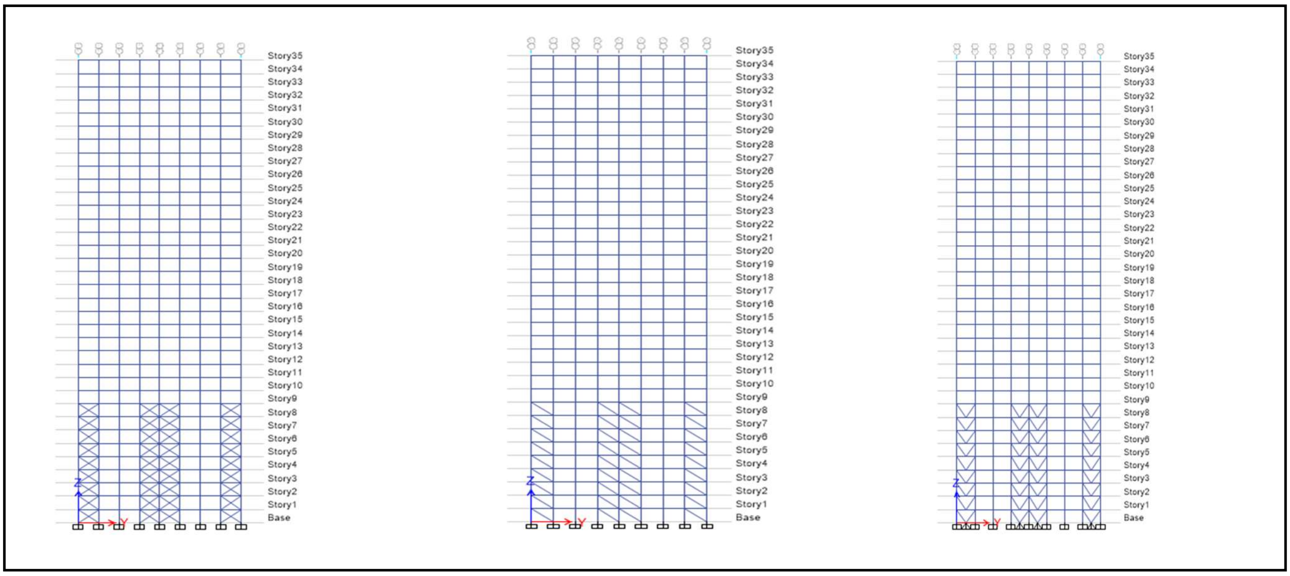

Fig. 3. Elevation of X type, Diagonal eccentric backward, V shape of bracing systems

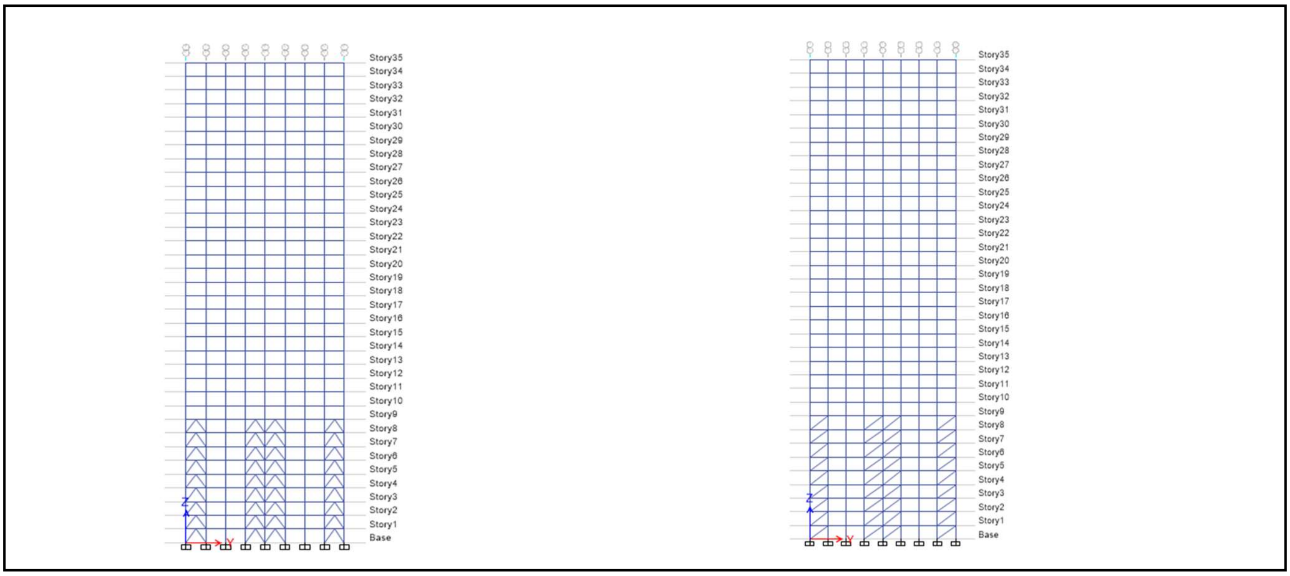

Fig. 4. Elevation of Inverted V shape & Diagonal eccentric forward bracing system

5.0 Results and Discussions

The responses of structure i.e., story displacement, story drift, base shear and time period for response spectrum method and wind load analysis by gust factor method for all models are compared and tabulated.

5.1 Story Displacement

Story Displacement is defined as relative lateral displacement between base of structure to top story under consideration. The maximum permissible displacement allowed for tall structure is hs/500, where hs is the height of structure. The maximum allowed displacement of model = 105/500 =0.21m i.e., 210 mm.

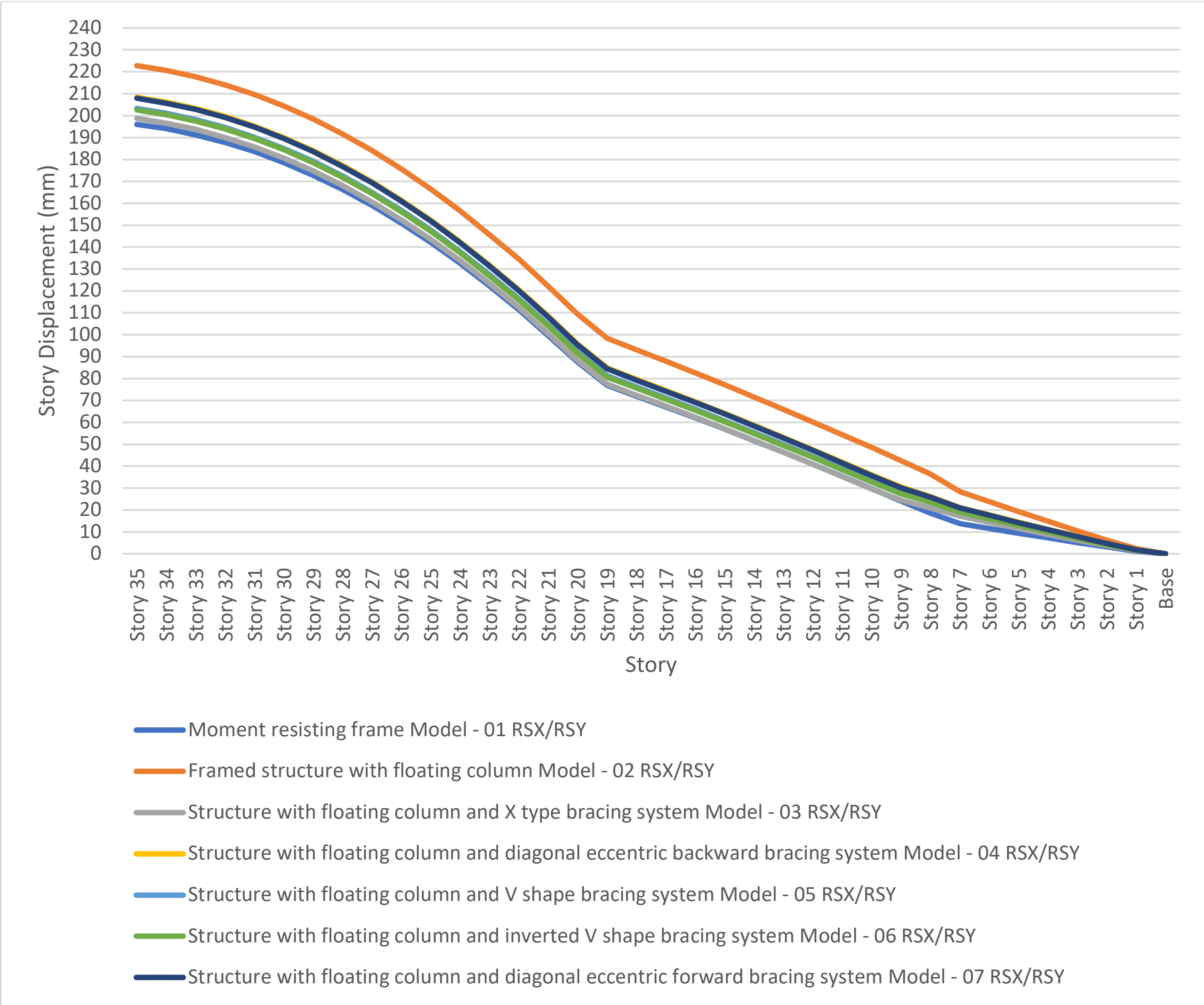

Fig. 5. Story displacement for response spectrum analysis in X & Y-direction

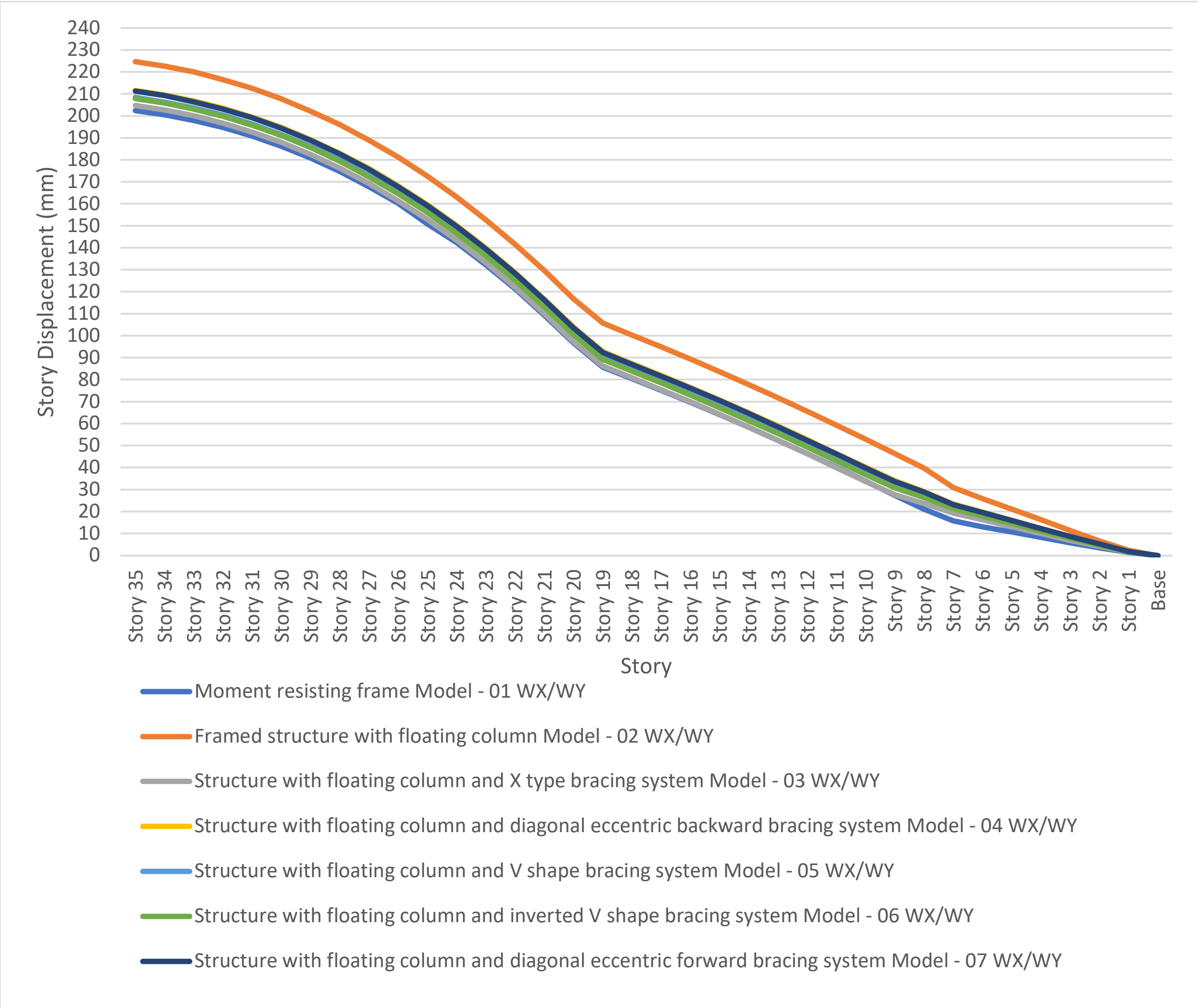

Fig. 6. Story displacement for wind load in X & Y direction

5.2 Story Drift

Story Drift is defined as per IS 1893 part 1 (2015), it is a relative Displacement between the floors above or below the story under consideration. For response spectrum analysis, according to IS16700 2017 clause 5.4.1, pg. 5 permissible story drift is hi/250, where hi is floor to floor height of structure, so for this analysis work permissible story drift is 3.0*/250=0.012 m =12 mm.

A. Story Drift Results for Response spectrum analysis

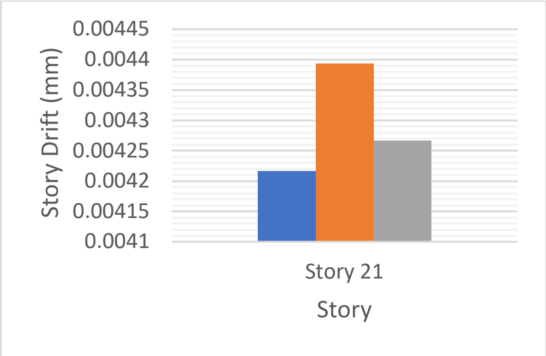

Fig.7. Result for Model 01,02 and 03

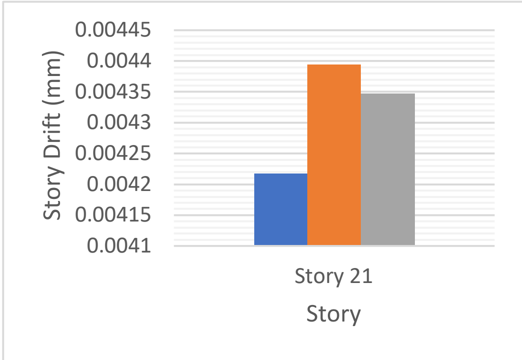

Fig.8.Result for Model 01,02 and 04

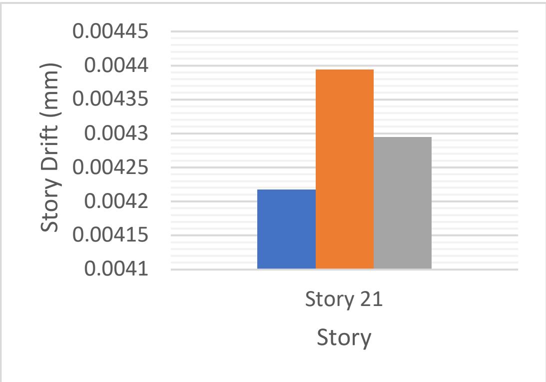

Fig.9. Results for Model 01,02 and 05

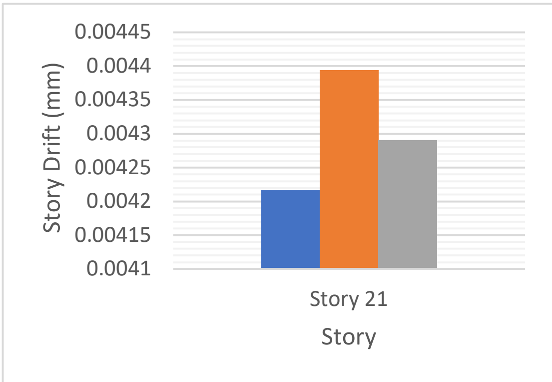

Fig.10.Results for Model 01,02 and 06

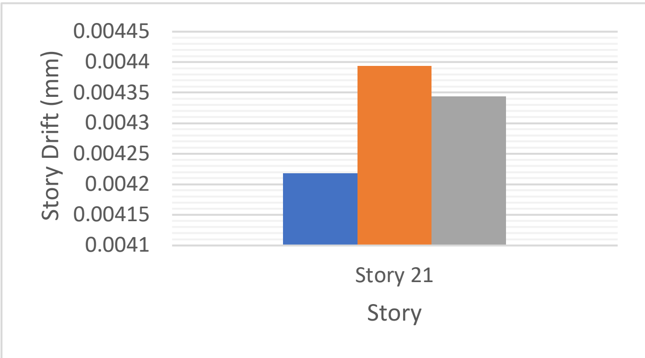

Fig.11.Results for Model 01,02 and 07

B. Story Drift for Wind load analysis

For wind load analysis, the permissible story drift according to IS16700 2017 clause 5.4.1, pg. 5 it is hi/400=3.0/400 =0.0075 m = 7.5 mm wind analysis models.

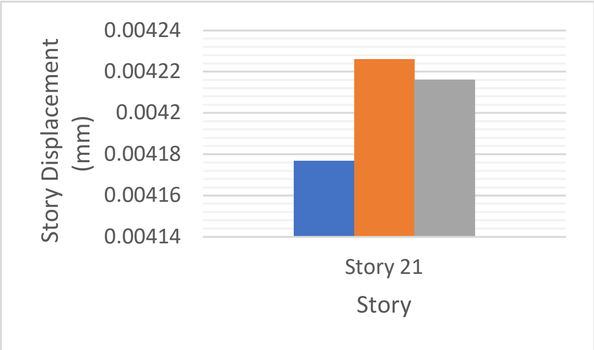

Fig.12.Results for Model 01,02 and 03

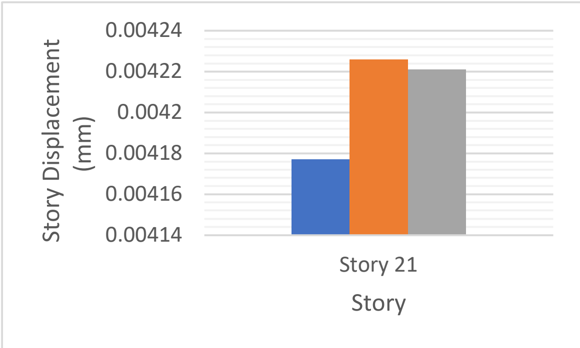

Fig.13.Results for Model 01,02 and 04

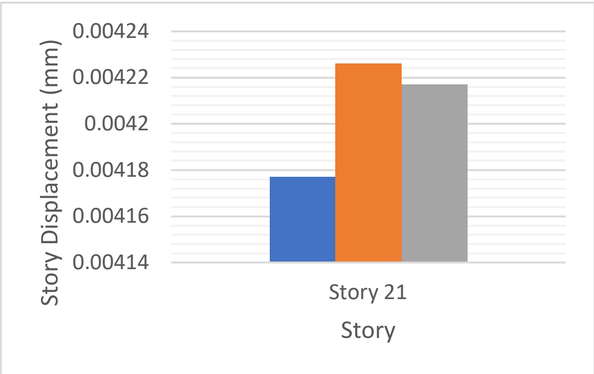

Fig.14.Results for Model 01,02 and 05

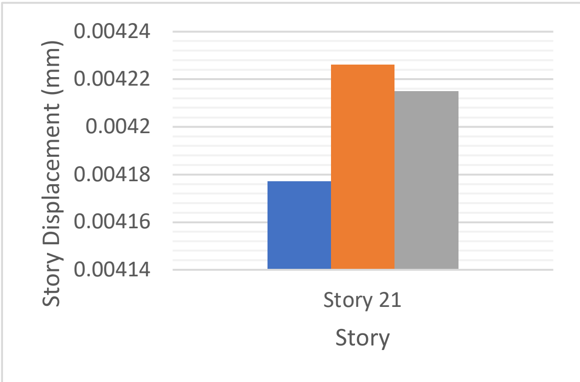

Fig.15.Results for Model 01,02 and 06

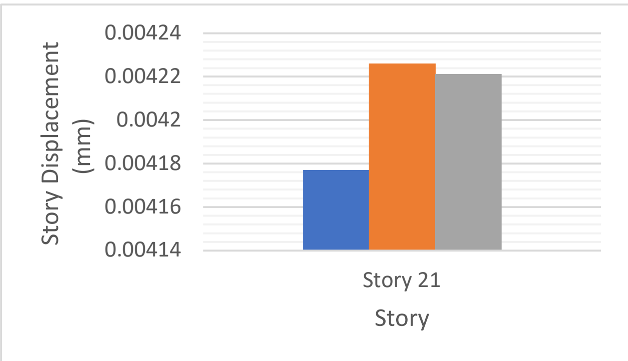

Fig.16.Results for Model 01,02 and 07

5.3 Base Shear

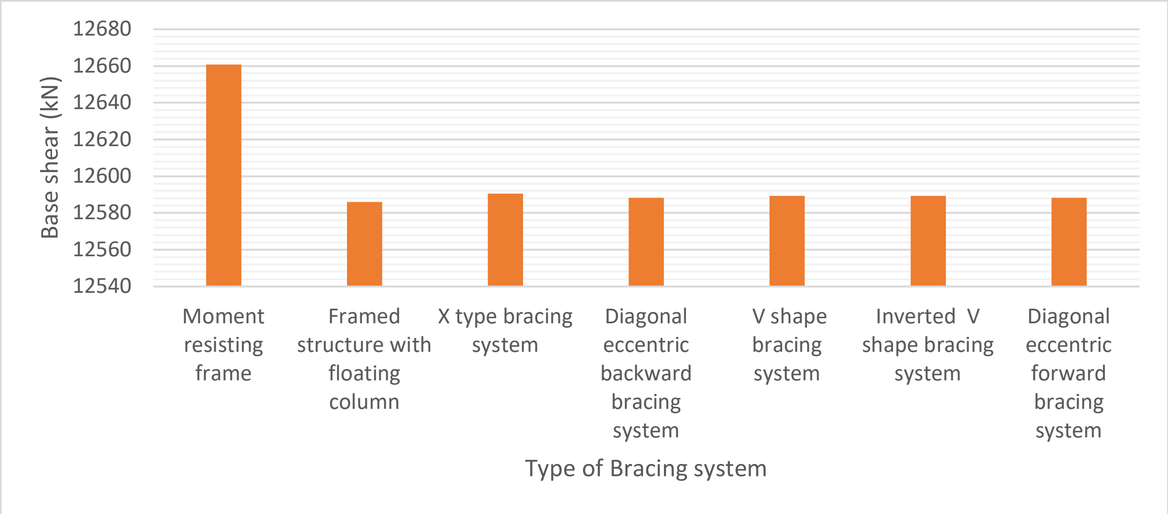

Fig.17.Base shear in X & Y direction

5.4 Time Period

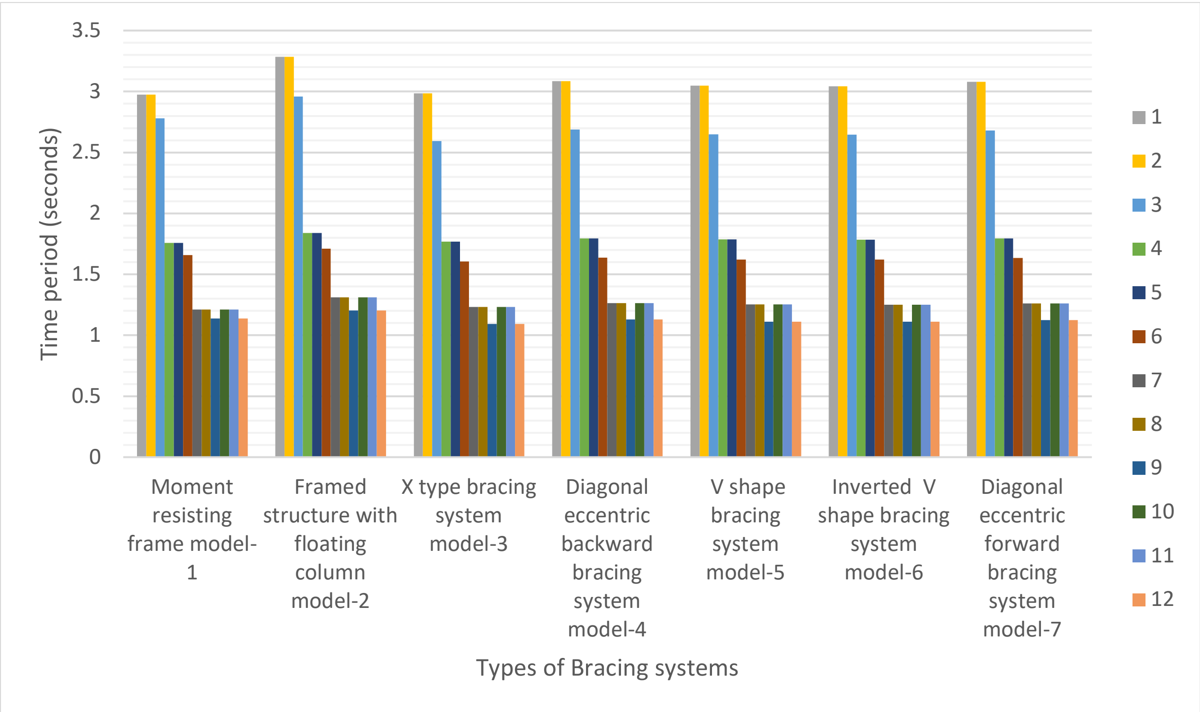

Fig.18. Time period for response spectrum analysis

6.0 Conclusions

Following conclusion have been drawn based on the result obtained from the analysis of all models.

1) **Story displacement for response spectrum analysis** of model, the maximum displacement for X-type bracing system, Diagonal eccentric backward bracing system, V shape bracing system, Inverted V shape bracing system, Diagonal eccentric forward bracing system is less about 10.82%, 6.5%, 8.79%, 9.1% and 6.7% in X & Y-direction respectively as compared to moment resisting frame with floating column.
2) **Story displacement for Wind analysis** of model, the maximum displacement for X-type bracing system, Diagonal eccentric backward bracing system, V shape bracing system, Inverted V shape bracing system, Diagonal eccentric forward bracing system is less about 8.87%, 5.83%, 7.25%, 7.52% and 6.0% in X & Y-direction respectively as compared to moment resisting frame with floating column.
3) **Maximum story drift for response spectrum analysis**, the maximum story drift for X-type bracing system, Diagonal eccentric backward bracing system, V shape bracing system, Inverted V shape bracing system, Diagonal eccentric forward bracing system are less about 2.9%, 1.07%, 2.25%, 2.36% ,1.13% respectively in X-direction and in Y-direction as compared to moment resisting frame with floating column drift.
4) **Maximum story drift for wind analysis**, the maximum story drift for X-type bracing system, Diagonal eccentric backward bracing system, V shape bracing system, Inverted V shape bracing system, Diagonal eccentric forward bracing system are less about 0.24%, 0.12%, 0.22%, 0.26% ,0.12% respectively in X-direction and in Y-direction as compared to moment resisting frame with floating column drift.
5) **The maximum base shear**, Moment resisting frame shows maximum base shear value of 12660.774 KN in both direction and framed structure with floating column shows minimum base shear of 12585.992 KN in both directions.
6) **The time period for response spectrum model**, X-type bracing system, Diagonal eccentric backward bracing system, V shape bracing system, Inverted V shape bracing system, Diagonal eccentric forward bracing system are less about 9.07%, 6.03%, 7.22%, 7.37%, 6.21% respectively as compared to moment resisting frame with floating columns.
7) Wind load analysis shows higher story displacement and story drift values than response spectrum analysis.
8) Framed structure with X type of bracing system shows less time period for response spectrum analysis out of all models with different bracing system when compared to moment resisting frame with floating columns.
9) All models of response spectrum analysis satisfy the criteria of IS 16700 (2017) clause 5.5.2., the translational lateral natural period in any of the two horizontal plan directions shall not exceed 8seconds.
10) Framed structure with X type of bracings shows less displacement, story drift and time period for both response spectrum analysis and wind load analysis.
11) Framed structure with floating column shows less base shear value than moment resisting frame due to elimination of columns.
12) By providing floating columns in framed structure there is increase in time period, therefore by providing bracings, time period of structure reduces.
13) After comparing all parameters, it was observed X type of bracing system provide better stability and perform better when floating columns are present in structure.

14) Therefore, it was observed by providing bracings, ill effects of providing floating columns can be overcome as it enhances its structural performance and make structure stable and safe against casualty.

7.0 Future Scope

This study can be extended by

i. Considering different geometrical shape of plan.
ii. By changing location of floating columns and analyzing.
iii. The same study can be analyzed with steel structure and results based on parameters can be compared.
iv. Present study can be analyzed by varying size of structural elements of buildings like beams and columns.
v. Present study can be analyzed and compared by varying height of structure.
vi. The same study can be analyzed by non-linear dynamic method for more realistic results.
vii. Study can be extended by considering different seismic zones and soil strata available

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