Seismic Performance Comparison of Different Mid-Rise Building Models by Using Linear Static Analysis

Mohammad Rafiqul Islam[1], Rakib Ahmed Chowdhury[2], Prithvi Dutta[2], Dr. Mohammod Aktarul Islam Chowdhury[3]

***Abstract*—** Structural stability and aesthetics views as well as optimum use of space and cost are generally the greatest concerns for the modern civil engineers and architects. So engineers have to look for different types and models of buildings. Moreover, Bangladesh is one of the most earthquake prone areas in South-Asia. Especially, Sylhet is the most vulnerable region in Bangladesh. Hence, it is important to check the seismic performance of different types of buildings. There are many static and dynamic procedures to assess the seismic performance of buildings. In this study, linear static analysis was used to check and compare the seismic performances of six models of mid-rise buildings having same surface area considering four different slab conditions. This study was done in accordance with the ACI 318-08, BNBC 2006 and UBC 1994. ETABS version 9.6 was used for the analysis. From the result of the linear static analysis, it was revealed that, case 1 model 3(irregular plan 1 with shear wall having conventional beam-column slab system) has the best performance for earthquake loads towards X-direction. On the other hand, case 1 model 5(irregular plan 2 with shear wall having conventional beam-column slab system) has shown better resistance against earthquake loads from Y-direction. Buildings of irregular plan showed more variable performances than that of regular square plan. At the same time, the study also found that, among the flat plate slab systems, flat plate with edge beam and without cantilever portion has the best resistance and stiffness against the earthquake loads.

Keywords— Linear static analysis, irregular plan, beam column slab, flat plate, inplane moment, displacement, drift.

1. INTRODUCTION

THE demand for multi storied mid-rise building models is increasing day by day on account of using the limited land space more efficiently and effectively. In general, when the building increases in height, the stiffness of the structure becomes more important. In tall buildings, lateral loads are the premier one which are quite variable and increase rapidly with height. Lateral force develops large overturning moment and vary in proportion to the square of the height, produce considerably higher force in top storey rather than bottom storey due to which building acts as a cantilever and cause sway movement or vibration [1]. Therefore, it is important for tall structures to have sufficient strength against vertical loads together with adequate stiffness to resist lateral forces.

Moreover, flat plate slab system is also becoming more popular than conventional beam-column slab system due to its aesthetics views, simple formwork and also as an economical alternative. But, flat plate slab system lacks resistance to lateral loads and has relatively low lateral stiffness. Therefore, this type of slab system gives rise to excessive lateral deformations.

Furthermore, Irregular plan building is used widely due to mainly asymmetric and non-uniform arrangement of masonry walls. This is also used due to shape of available spaces. But, irregularity in plan may cause large eccentricity between the building mass and stiffness centers, giving rise to damaging coupled lateral/torsional response [2]. Irregularity may also be caused local deformation due to torsional effect at its re-entrant corner during earthquake.

Shear wall is especially designed wall constructed with reinforced concrete and can absorb a lot of shear force created by earthquake load and hence increases the performance of the structures against the load.

In this study, a comparison of seismic performance among different types of mid-rise buildings with and without shear wall, of both conventional beam-column and flat plate slab system, both regular and irregular plan of same surface area has been done.

1. Assistant Professor, Shahjalal University of Science & Technology, Sylhet-3114, Bangladesh.
2. Graduate Student, Shahjalal University of Science & Technology, Sylhet-3114, Bangladesh.
3. Professor, Shahjalal University of Science & Technology, Sylhet-3114, Bangladesh.

There are many static and dynamic procedure to assess the seismic performance of a building. They are as below [3]:

Linear		Non-linear	
Static	Dynamic	Static	Dynamic
Seismic coefficient method	Response spectrum analysis	Pushover analysis	Time history analysis

Linear analysis gives the results only for primary stage that is within elastic region. On the contrary, Non-linear analysis gives the results beyond elastic region up to ultimate stage. Non-linear static analysis that can evaluate a building's performance beyond elastic range but it is unable to fully capture the dynamic response especially at higher mode [4]. In general, the results of non-linear analysis of a structure depends on its final displacement [5]. However, non-linear dynamic analysis is the most complete form of analysis. However, it is sensitive to modelling and ground motion assumption [4]. In this study, linear static procedure is used to evaluate the seismic performance of all the considered buildings.

2. OBJECTIVES

- To do linear static analysis of different mid-rise building models both with and without shear wall, conventional beam-column and flat plate slab system, having regular and irregular plan.
- To compare the results obtained from the analysis.
- To find which building model has better performance under the earthquake load.

3. METHOD

The method that has been used for the study is described below:

3.1 Choose different plans of mid-rise buildings:

Three plans of ten storied mid-rise building were selected for the analysis. One was regular square and other two were irregular plan. The surface area of each plan was same (60 ft × 60 ft). The analysis was done considering the Sylhet city which is an earthquake prone zone of Bangladesh (zone 3) according to the BNBC 2006 [6].

3.2 Consider slab condition:

One conventional beam column and three types of flat plate slab systems were considered (flat plate with edge beam without cantilever portion; flat plate with cantilever portion without edge beam; flat plate without edge beam and without cantilever portion).

3.3 Selection of position of shear wall:

Shear wall was located at the core of the buildings.

3.4 Determine building model:

For the analysis, six different types of models were taken. (Model 1- Plan 1 with shear wall, Model 2- Plan 1 without shear wall, Model 3- Plan 2 with shear wall, Model 4- Plan 2 without shear wall, Model 5-Plan 3 with shear wall, Model 6- Plan 3 without shear wall).

3.5 Choose an analysis software:

ETABS Version 9.6 was used for the analysis.

3.6 Analyse the building models by linear static method and collect data:

Then the linear static analysis of all the studied models were run. The required data which was used for the analysis is given at the "Building Models Data" section. After the analysis, results of inplane moment, base shear and displacement of all the considered models were collected.

3.7 Compare the results and make conclusion:

Results were compared among the considered different types of buildings and conclusion was made as which type of the buildings have better structural stability and performance under the seismic load on the basis of inplane moment and top floor displacement.

4. BUILDING MODELS DATA

In this study, three plans of building were chosen. For the convenient of the calculation, four columns were selected (C1, C2, C3, C4 as shown in below). Among the four selected columns, two were exterior, one was interior and another one was corner column.

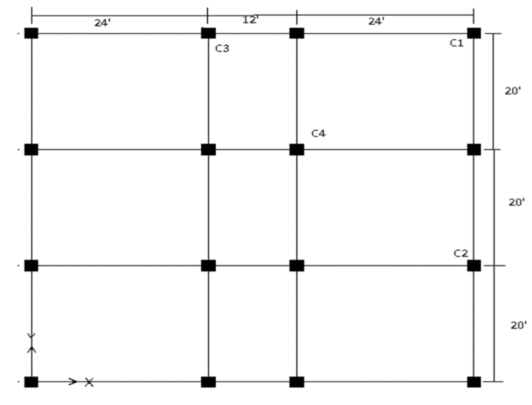

Fig. 1 Plan 1 (Square plan)

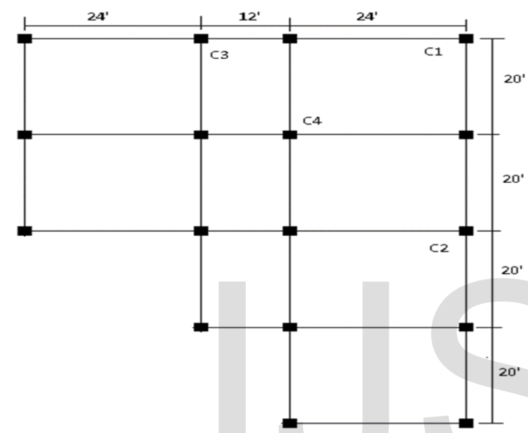

Fig. 2 Plan 2 (Irregular plan 1)

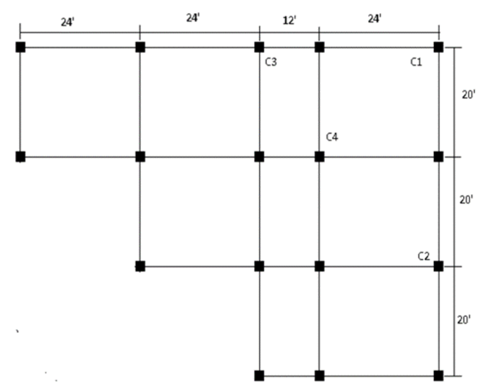

Fig. 3 Plan 3 (Irregular plan 2)

Six models were chosen for the analysis:

Model 1: Plan 1 with shear wall

Model 2: Plan 1 without shear wall

Model 3: Plan 2 with shear wall

Model 4: Plan 2 without shear wall
Model 5: Plan 3 with shear wall

Model 6: Plan 3 without shear wall

Four cases were considered for the study:

Case 1: Conventional beam-column slab system.

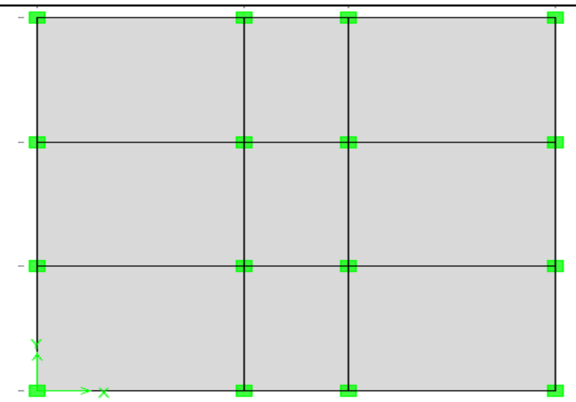

Fig. 4 Conventional beam-column slab

Case 2: Flat plate with edge beam and without cantilever portion.

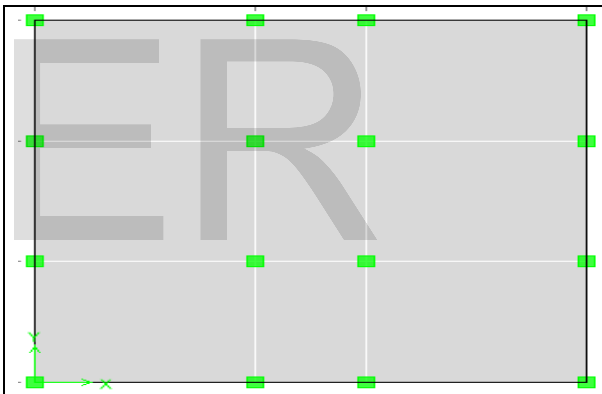

Fig. 5 Flat plate with edge beam and without cantilever portion

Case 3: Flat plate with cantilever portion and without edge beam.

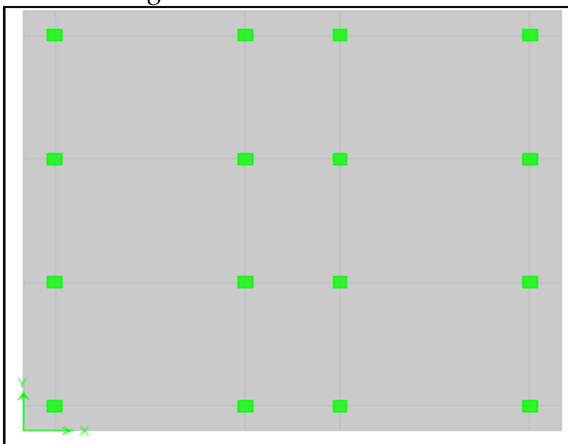

Fig. 6 Flat plate with cantilever portion and without edge beam

Case 4: Flat plate without edge beam and without cantilever portion.

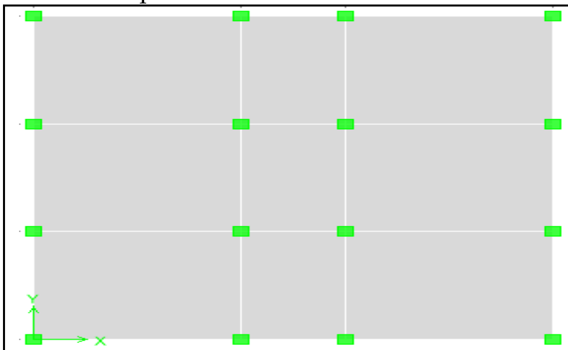

Fig 7 Flat plate without edge beam and without cantilever portion

TABLE 1: DETAILS MODELS DATA

No of storey	10
Storey height	10 ft
Type of frame	Special RC moment resisting frame fixed at the base.
Plan area	60 ft × 60 ft
Thickness of conventional beam-column slab	6 inch
Thickness of flat plate	9 inch
Size of columns	21 in × 21 in
Size of beams	12 in× 18 in
Shear wall thickness	12 inch
Extended length of cantilever portion	4 ft

Shear wall was located at the core of the building.

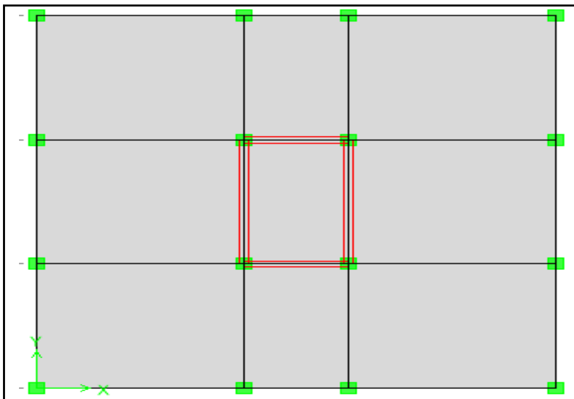

Fig. 8 Model 1

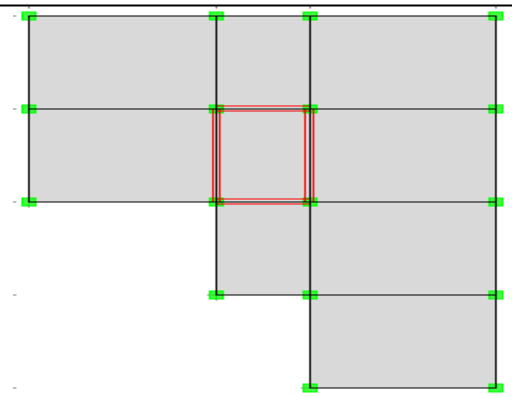

Fig. 9 Model 3

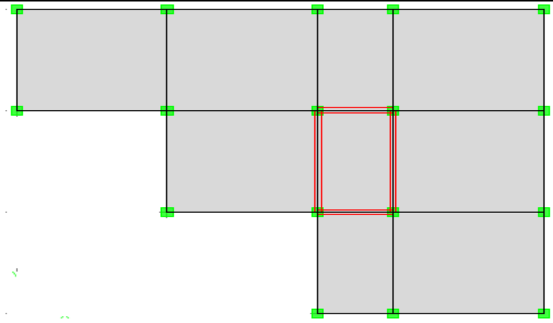

Fig. 10 Model 5

Applied loads in all the studied structures are given below:

TABLE 2: APPLIED LOADS ON BUILDINGS

Live Load	40 psf
Partition Wall load	50 psf
Floor Finish	25 psf
Earthquake loads were calculated directly by the ETABS 9.6 in accordance with the UBC – 94	

The coefficients of earthquake load are similar in UBC 1994 and BNBC 2006. The used coefficient for earthquake load calculation are given below:

TABLE 3: USED COEFFICIENT FOR EQ LOAD CALCULATION

Zone coefficient, Z	0.25 (Zone 3)
Site coefficient, S	1.5
Ct	0.075
Response modification coefficient, R	12

Structural importance coefficient, I	1

Material properties considered are given below:

TABLE 4: USED MATERIAL PROPERTIES

Compressive strength of concrete, f_c'	3500 psi
Yield strength of the steel, f_y	60000 psi
Modulus of elasticity of concrete, E	3372 ksi

5. RESULTS AND DISCUSSIONS

A comparison based on the summation of inplane moment on the four selected columns (C1, C2, C3, C4) has been given below:

TABLE 5: SUMMATION OF INPLANE MOMENT ON FOUR SELECTED COLUMNS OF CASE 1

Model	Moment for EQ-X (kip-ft)	Comment	Moment for EQ-Y(kip-ft)	Comment
1	68.9	22.69% greater than model 3	46.31	35.69% greater than model 5
2	293.56	422.72% greater than model 3	(295.92	767% greater than model 5
3	56.16	Minimum	48.67	42.6% greater than model 5
4	287.22	411.43% greater than model 3	288.18	, 744.36% greater than model 5
5	68.52	22% greater than model 3	34.13	Minimum
6	288.12	413.03% greater than model 3	290.38	750.81% greater than model 5

TABLE 6: SUMMATION OF INPLANE MOMENT ON FOUR SELECTED COLUMNS OF CASE 2

Model	Moment for EQ-X (kip-ft)	Comment	Moment for EQ-Y (kip-ft)	Comment
1	68.07	9.12% greater than model 3	57.22	46.57% greater than model 5
2	337.05	440.32% greater than model 3	338.65	767.44% greater than model 5
3	62.38	Minimum	57.22	46.57% greater than model 5
4	329.44	428.12% greater than model 3	322.95	727.23% greater than model 5
5	77.29	23.90% greater than model 3	39.04	Minimum
6	325.04	421.06% greater than model 3	331.2	748.36% greater than model 5

TABLE 7: SUMMATION OF INPALNE MOMENT ON FOUR SELECTED COLUMNS OF CASE 3

Model	Moment for EQ-X (kip-ft)	Comment	Moment for EQ-Y (kip-ft)	Comment
1	66.47	9.47% greater than model 3	47.67	20.47% greater than model 5
2	383.63	531.8% greater than model 3	383.93	870.26% greater than model 5
3	60.72	Minimum	60.58	53.1% greater than model 5

4	378.77	523.8% greater than model 3	376.84	852.34% greater than model 5
5	76.65	26.24% greater than model 1	39.57	Minimum
6	381.56	528.4% greater than model 1	380.2	860.83% greater than model 5

TABLE 8: SUMMATION OF INPLANE MOMENT ON FOUR SELECTED COLUMNS OF CASE 4

Model	Moment for EQ-X (kip-ft)	Comment	Moment for EQ-Y (kip-ft)	Comment
1	60.01	8.85% greater than model 3	41.18	18.78% greater than model 5
2	351.4	537.4% greater than model 3	352.94	918% greater than model 5
3	55.13	Minimum	50.07	44.42% greater than model 5
4	345.33	526.39% greater than model 3	345.33	896.05% greater than model 5
5	67.6	22.62% greater than model 3	34.67	Minimum
6	348.4	531.96% greater than model 3	346.31	898.88% greater than model 5

From table 5 to table 8, it can be seen that models without shear wall (model 2, model 4, model 6) are subjected to huge amount of inplane moment compared to that of the models with shear wall. This is due to the fact that, shear wall can absorb a lot of shear force. Hence, in the absence of shear wall, buildings are subjected to larger base shear resulted in 378.77-537.4% increased inplane moment for EQ-X and 727.23-918% for EQ-Y.
Among the models with shear wall, model 3 has shown the minimum inplane moment for EQ-X, 8.85-26.24% lesser than other two models with shear wall, but observed to be subjected to the highest inplane moment for EQ-Y. Inversely, model 5 has been subjected to the least inplane moment for EQ-Y, 18.78-53.1% better but has shown to be maximum for EQ-X. Model 1 has given medium and almost similar performance for both EQ-X and EQ-Y.

A comparison based on the top floor displacement are given below:

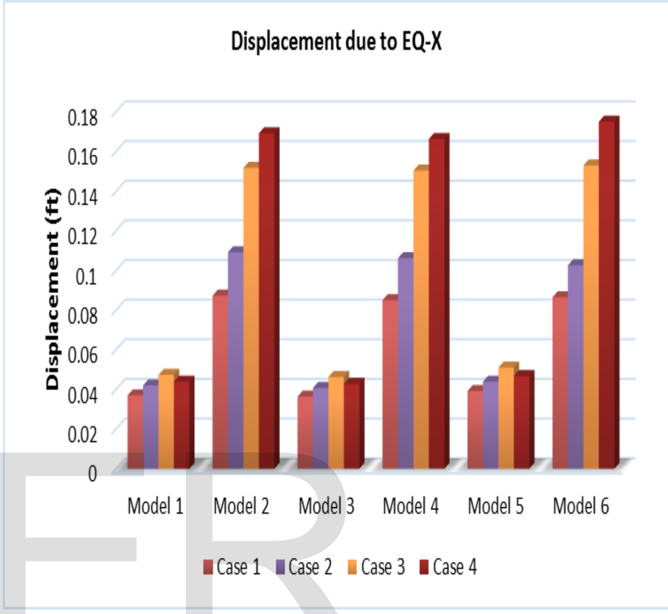

Fig. 11 Top floor displacement due to EQ-X for all the types of buildings considered.

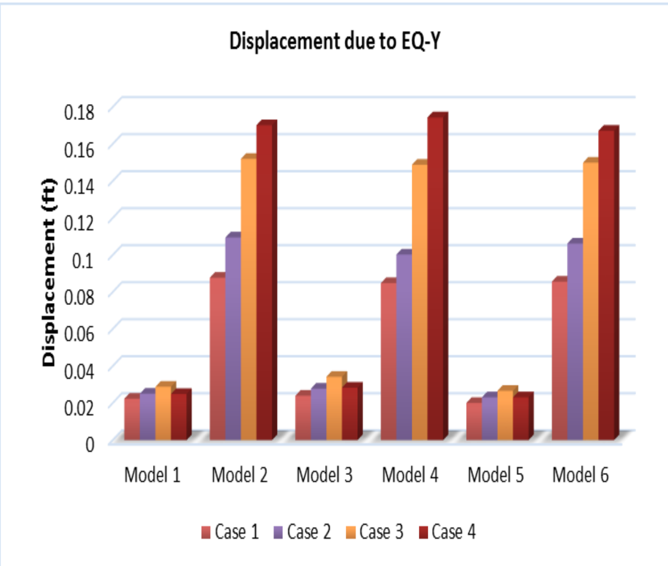

Fig. 12 Top floor displacement due to EQ-Y for all the types of buildings considered.

From the figure 11 and 12, it is observed that case 1 which is conventional beam-column slab system has the minimum displacement both for EQ-X and EQ-Y. Buildings with Conventional beam-column slab always have better rigidity and stiffness. Hence, it shows the least flexibility. Among the flat plate slab systems, case 2 shows the minimum displacement. Since, it contains edge beam, it has relatively higher stiffness and stability than the other types of flat plate slabs considered. Among the studied models, models with shear wall shows 133.46-308.44% better stability for EQ-X and 322.63-653.15% for EQ-Y than the models without shear wall. Model 3 shows better stiffness for EQ-X where it has poor performance for EQ-Y. Model 5 has the minimum displacement for EQ-Y but the maximum for EQ-X among the models with shear wall. In both the cases, model 1 which is conventional beam-column slab shows medium performance.

It is important to mention that linear static method is for the analysis which gives the buildings' response within its elastic region. Hence, from the above discussions, it can be said that, case 1 model 3 has the best seismic performance for EQ-X load where it is case 1 model 5 for EQ-Y when studied the structures are to be designed considering the elastic response only.

Maximum allowable drift which was calculated in according to the BNBC 2006 for each of the four cases considered are given in table 9.

TABLE 9: MAXIMUM DRIFT VALUE ACCORDING TO THE BNBC 2006

Case	Lateral load	Storey drift from ETABS	Maximum drift value according to BNBC 2006	Comment
1	EQ-X	0.000436	0.0762	Storey drift are within allowable limit according to BNBC 2006 [6]
	EQ-Y	0.000376	0.0762	
2	EQ-X	0.000503	0.0762	
	EQ-Y	0.000493	0.0762	
3	EQ-X	0.000757	0.0762	
	EQ-Y	0.000749	0.0762	
4	EQ-X	0.000982	0.0762	
	EQ-Y	0.000964	0.0762	

From the table 9, it has been seen that, in according to the BNBC 2006 [6], storey drift of all the studied four cases are well within the safe limit.

6. CONCLUSION

- Presence of shear wall increases the stability and stiffness of the buildings 133.46-308.44% for EQ-X and 322.63-653.15% for EQ-Y.

- Inplane moment of the buildings have been reduced 378.77-537.4% for EQ-X and 727.23-918% for EQ-Y due to presence of shear wall.

- Seismic performance of an irregular plan building depends on the direction of earthquake. A building with irregular plan may be the best for earthquake from a certain direction but it can be altered completely with the change of course.

- Buildings with regular square plan has shown almost similar performance under earthquake load for either direction.

- Case 1 model 3 (Irregular plan-1 with shear wall of conventional beam-column slab system) gives the best performance and stability under EQ-X load.

- Case 1 model 5 (Irregular plan-2 with shear wall of conventional beam-column slab system) has shown better stiffness and rigidity than any other models under EQ-Y load.

- Case 2 (Flat plate with edge beam without cantilever portion) are observed to be having better stiffness and stability among the flat plate slab systems.

- Models without shear wall (model 2, model 4, model 6) of case 4 (flat plate without edge beam and without cantilever portion) has shown to be the most vulnerable for both EQ-X and EQ-Y load.

- In accordance with the BNBC 2006, all the four cases are safe as the drift of them are well within the guideline of safe value.

REFERENCES

[1] K. Navyashree and T. S. Sahana, “Use of flat slab in multi-storey commercial building suited in high seismic zone.” *International Journal of Research in Engineering and Technology*. vol. 3, Aug. 2014.

[2] A. Giordano, M. Guadagnuolo and G. Faella, “Pushover analysis of plan irregular masonry buildings.” *14th World Conference on Earthquake Engineering, Beijing, China*, 2008.

[3] R. G. Khan and M. R. Vyawahare, “Push over analysis of tall building with soft stories at different levels.” *International Journal of Engineering Research and Applications*, vol. 3, pp. 176-185, Jul-Aug. 2013.

[4] D. B. Karwar and R. S. Londhe, “Performance of RC framed structure by using pushover analysis.” *International Journal of Emerging Trend and Advanced Engineering*. vol. 4, pp 488-491, June 2014.

[5] A. Srinivasu and B. P. Rao, “Non-linear static analysis of multi-storied buildings.” *International Journal of Engineering Trends and Technology*. vol. 4, pp 4629-4633, Oct. 2013.

[6] *Bangladesh National Building Code 2006*, The Housing and Building Research Institute, Mirpur, Dhaka, Bangladesh, 2006.