Study on Earthquake Resistance of Reinforced Concrete Frame Structures with and without Staircase

Anjan B.K [1], C.N. Yadunandan [2], Keerthi Gowda B.S [3]

[1] Post Graduate Student, Department of Structural Engineering, VTU PG Studies, Mysore, India

[2] Visiting Professor, Department of Civil Engineering, Sri Jayachamarajendra College of Engineering, Mysore, India

[3] Assistant Professor, Department of Structural Engineering, VTU PG Studies, Mysore, India

ABSTRACT

This paper addresses the influence of stairs about reinforced concrete frame structure with special attention to seismic performance for all earthquake zones according to IS: 1893 (Part-1): 2002. Specifically, looking at dog-legged stairs for a bare frame without and with stairs; the twelve storey building is analysed by the method Response Spectrum Analysis using ETABS. The analysis shows that by incorporating stairs, decreases the lateral displacement, storey drift, natural period, base shear and bending moment of the structure but increases shear force and axial force.

Key words: Seismic Performance, Dog-Legged Stairs, Response Spectrum.

Corresponding Author: Anjan B.K

1. INTRODUCTION

Stairways play significant roles in building performance during earth-quakes due to interactions with primary structural systems and it is the part of secondary system of structures due to its functional importance. Damaged stairways adversely affect evacuation and rescue from earthquakes may require that building occupants rescue themselves; elevators may not be functional may make immediate evacuation necessary.

The influence of staircase is often ignored in the past for the seismic design of frame structure. However in the Bhuj earthquake (2001), failure of staircase is a major cause of damage in Reinforced Concrete (RC) multi-storey complexes as stairs failed to act as an important way of escape evacuation due to the damage in the surrounding Components [1]. E Cosenza et al (2008) [2] investigated on seismic performance of stairs in the existing RC building and suggested that the stair increases strength and stiffness of the structure resulting into reduction of fundamental time period, also attracting seismic forces that could fail into short columns due to high shear force. Huanjun jiang et al (2012) [3] concluded from their study that the staircases act as the first line of defense in earthquakes and therefore they first yield and fail.

Thus from the past studies it can be noted that staircases elements act as diagonal braces and attract large lateral forces during earthquake shaking. In the present study information about understanding of stairway damage mechanism and analysis of, problems occurring in Low, Moderate, Severe and Very Sever ground shaking for RC frame building in the form of soft storey with and without considering stairs. The results have been discussed in terms of displacement at floors, storey drift, time period, base shear of the structure, and maximum internal forces in the region of stairs columns.

2. MATERIALS AND METHODS

2.1 Modeling of Structure

The plan layout of the soft storey RC moment resisting frame building with and without considering staircase, chosen for this study is shown in Fig. 1 by ETABS version 9.7.4. The overall plan layout of the building is 37m X 11m and 12 storey building has been taken for the analysis. The buildings are assumed to be fixed at ground level and the storey heights are 3.6m each and headroom of 3m above stairwell is considered. Taking concrete grade M25, Steel of grade FE 415 and the poison's ratio is 0.2 has been assumed for analyses of all the models.

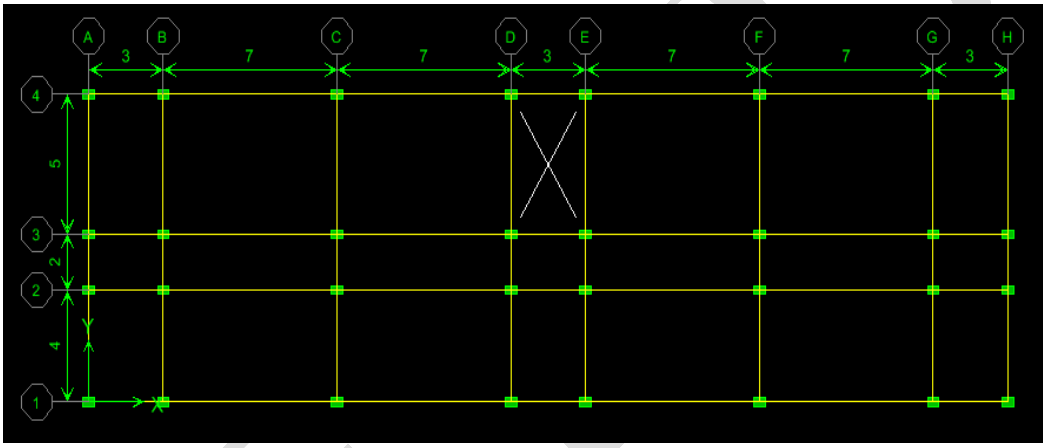

Fig. 1: Typical Structural plan Layout

2.2 Building Nomenclature

Naming of the models considered for the study of 12 storey building with and without stair model is given in Table 1. 3-D view of Model 1 and Model 2 is as shown in Fig. 2 and Fig. 3 respectively.

Table 1 - Nomenclature of the buildings

Type	Without Stair Model	With Stair Model
Model name	Model 1	Model 2

2.3 Sectional Dimensions of Main Components

Model 1: Beams and columns have been modeled as 3-D frame elements. The sectional dimension of frame column is 300mm X 450mm, frame beam is 300mm X 450mm and the slab is modeled as rigid diaphragms of thickness 125mm. The landing beam of size 300mm X 300mm is provided at a height of 1.8m from each floor and has been loaded for support reaction due to dead and live loads from stairs.

Model 2: Adding Dog-legged staircase in column grid (3-4 and D-E axis) on the basis of model 1. The staircase has been modeled by taking the depth of the solid part beneath steps of having thickness 125mm along with landing slab at a height of 1.8m above landing beam. The dead and live loads on Ramp as well as on landing slab have been applied instead of loads on landing beam.

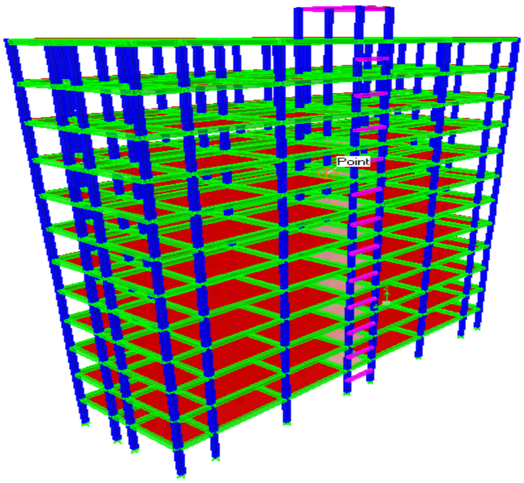

Fig. 2: 3-D view of Model 1

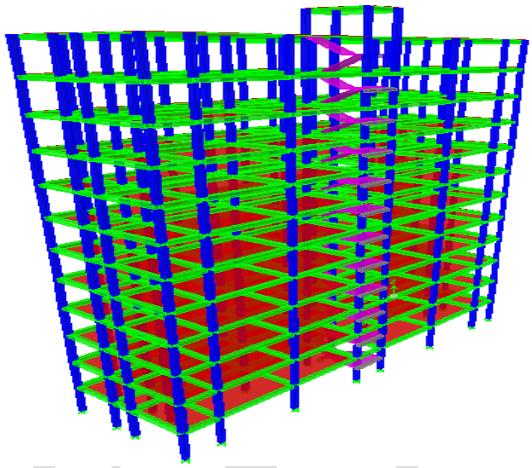

Fig. 3: 3-D view of Model 2

3. METHOD OF ANALYSIS

Response Spectrum Analysis

Linear elastic analysis is performed for all the models of the building with the help of soft computing technique as per IS 1893 (Part-1): 2002. The building is considered to be located in all seismic zones from zone 2 to 5 and intended as Public building. The building is situated in medium soil, important factor (I) 1.5, response reduction factor (R) for SMRF building is 5 and 5% damping ratio is considered as per Indian Code [4].

For lateral load calculation and its distribution along height, this paper uses Eigen vector method with maximum vibration mode number of the structure as 12; for model combinations CQC method and for direction combined the SRSS method has been used for the analysis [5]. The dead load and live load were calculated as per 875:1987. The fundamental natural period of the RC frame building is calculated as in equation (1),

$$T= 0.075h^{0.75} \quad (1)$$

Where, h= Height of building in m.

4. RESULTS AND DISCUSSION

4.1 Fundamental Natural Vibration Period

Empirical method for fundamental natural period is expressed for RC frame building as per IS 1893 (Part-1): 2002 [4] as in equation (2),

T= 0.075h0.75 = 0.075 X 46.20.75 = 1.33 Seconds. (2)

The empirical (IS: 1893-2002) and analytical (ETABS) natural periods of the building models are shown in Table 2. The maximum vibration mode is kept 12 in the analysis for the both models are as shown in Fig. 4.

Table 2 - Empirical and Analytical fundamental natural period of models

Model name	Fundamental Natural Period (Sec)	
	Empirical	Analysis (ETABS)
Model 1	1.33	4.13
Model 2	1.33	3.60

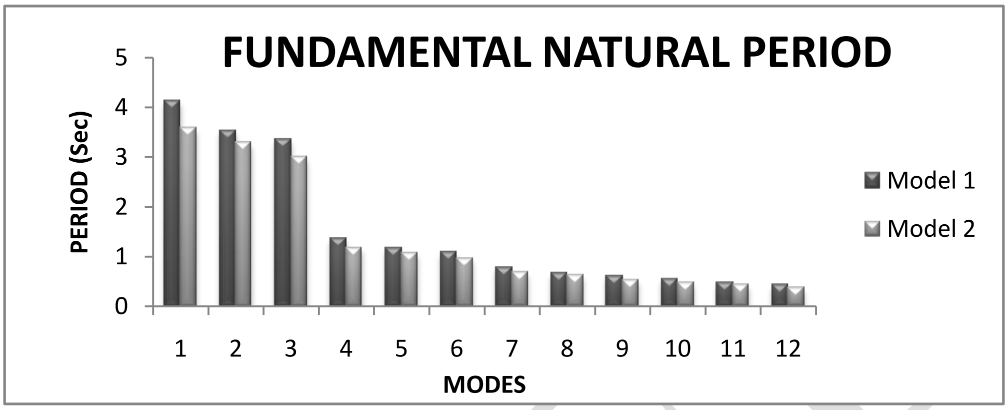

Fig. 4: Natural Vibration mode per period

It is seen from the result that the analytical natural periods do not tally with the natural periods obtained from the empirical expression of the code. The model 1 leads to sever overestimation of the natural period compared to the model 2, which leads to the consideration of lateral displacement in each storey.

4.2 Lateral Displacement

Floor deflections are caused when buildings are subjected to seismic loads. These deflections are multiplied by ductility factor, resulting in the total deflections which account for inelastic effects. Lateral displacement for all models, in all four earthquake zones along X and Y direction are as shown in Fig.5 to 8.

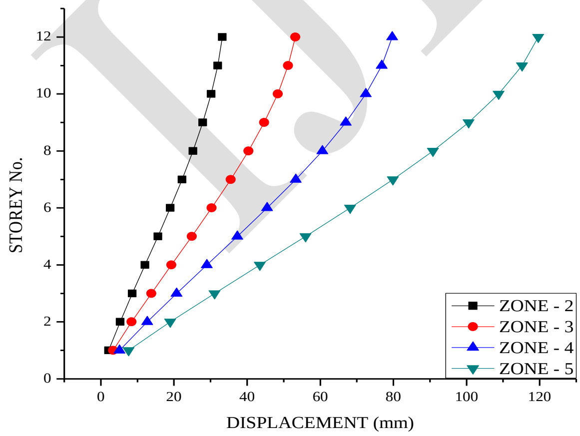

Fig. 5: Displacement of Model 1 along X direction

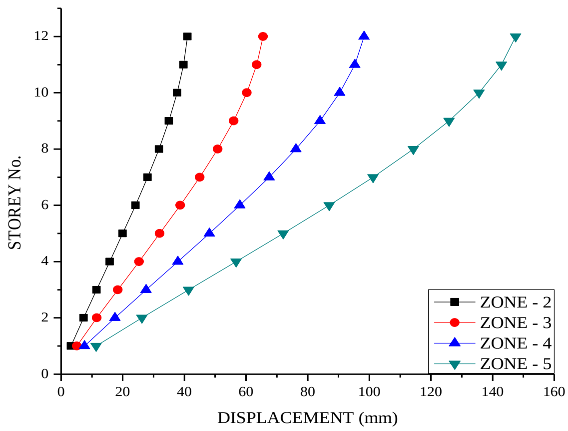

Fig. 6: Displacement of Model 1 along Y direction

 Issue 4, Vol.3 (May 2014)
ISSN 2249-6149

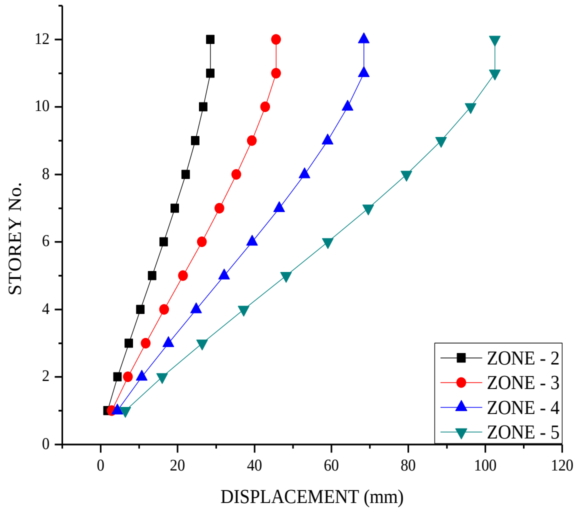

Fig. 7: Displacement of Model 2 along X direction

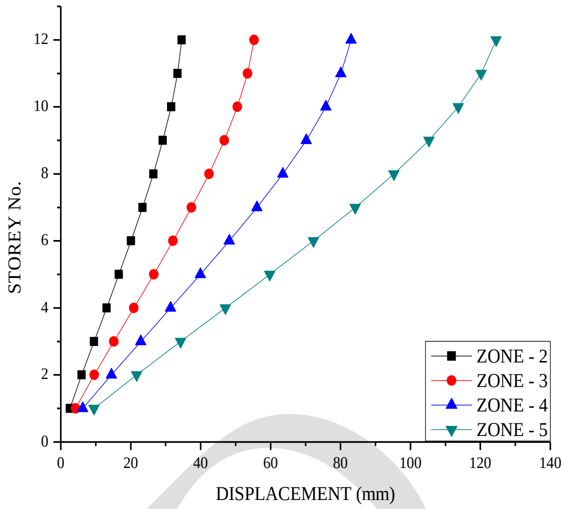

Fig. 8: Displacement of Model 2 along Y direction

From the results, it is observed that the displacement in X direction is reduced up to 10.5% in all the earthquake zones of model 2 than model 1. Where as, in Y direction the displacement is reduced up to 15.6% in all the zones of model2 than model 1. And also displacements of all models in both X and Y direction for zone 2, 3 and 4 is reduced up to 72.20%, 55.60% and 33.35% respectively as compared with zone 5.

4.3 Storey Drift Ratio

Storey drift is the displacement of one level relative to the other level above or below. Storey drift ratio according to the zones of each model is shown in fig. 9 to 12. In Software value of storey drift is given in ratio, it is calculated as in equation (3),

$$\text{Storey drift ratio} = \frac{\text{Difference between displacement of two stories}}{\text{Height of one storey}} \qquad (3)$$

The storey drift in any storey with a partial load factor of 1 should not exceed 0.004 times the storey height. Storey drift / inter storey displacement should be limited during earthquakes to limit damage to staircase elements and to provide human comfort.

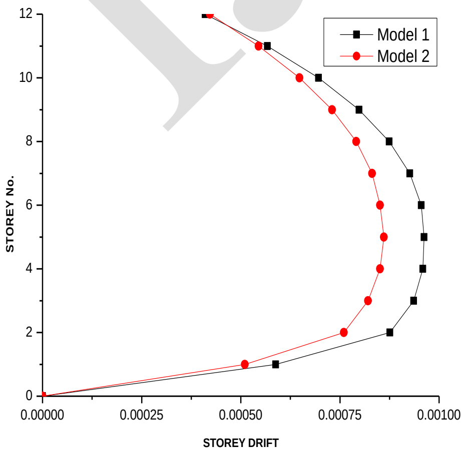

Fig. 9: Storey Drift Ratio for Zone 2

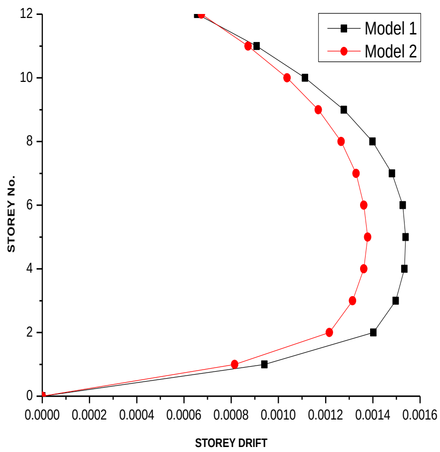

Fig. 10: Storey Drift Ratio for Zone 3

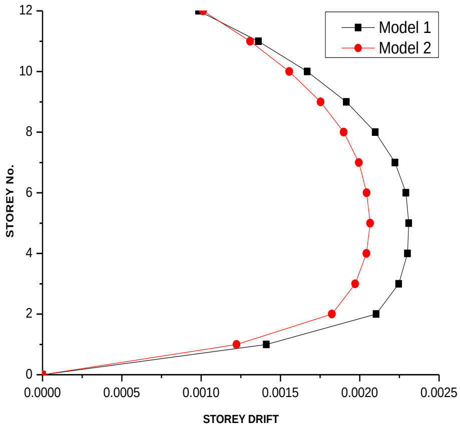

Fig. 11: Storey Drift Ratio for Zone 4

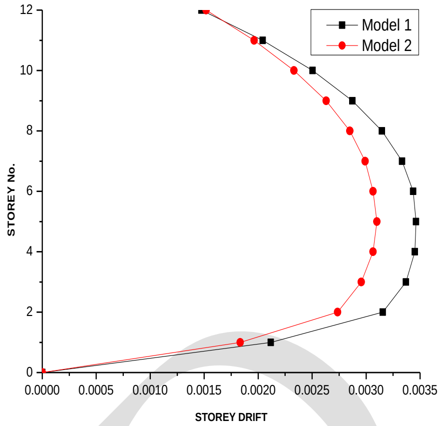

Fig.12: Storey Drift Ratio for Zone 5

From the result, all the drifts are found to be within permissible limit i.e. 0.0144m. The storey drift in X direction is reduced up to 15.4% in all zones of model 2 than model 1, similarly, in Y direction the storey drift is reduced up to 19.60% in all the zones of model 2 than model 1.

4.4 Equivalent Base Shear

A comparison of design base shear is one of the simplest ways to compare the final result. The Total base shear for the model 1 and model 2, in all four zones are as shown in Fig.13 to 14.

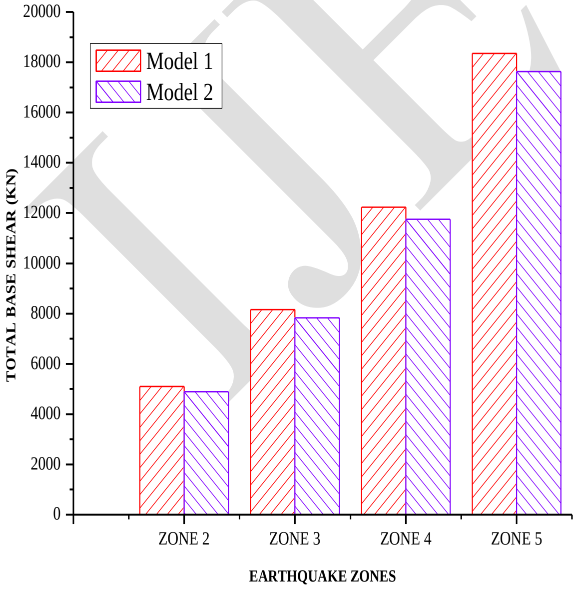

Fig. 13: Equivalent Base Shear of the Structure along X direction

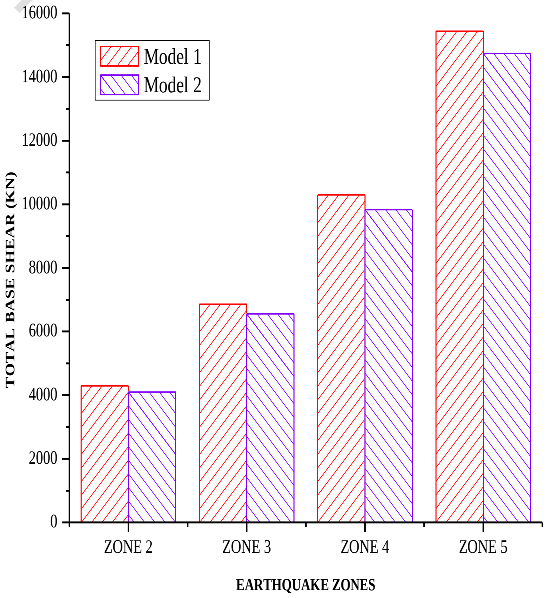

Fig. 14: Equivalent Base Shear of the Structure along Y direction

The design base shear in the X-direction, model 2 decreases by 4.14% for all zones with model1 and for the Y-direction 4.77%. Based on the results, it clearly shows that by incorporating the stairs reduces the total base shear in both directions.

Issue 4, Vol.3 (May 2014)
ISSN 2249-6149

4.5 Internal Forces of the Stair Column

Under the condition of response spectrum, the internal force of frame beam-column in the lower part of structure is bigger than that of the upper part, therefore, taking its maximum internal force of the structure for comparative analysis are shown in Table 3 and for axial force in Table 4.

Table 3: The internal forces of columns (4-D axis) in first floor and the second floor under the condition of response spectrum

Internal Forces	**Model 1**				**Model 2**			
	Storey 1		Storey 2		Storey 1		Storey 2	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Bending Moment (KN-m)								
ZONE - 2	64.45	71.16	74.85	107.7	60.15	57.96	70.07	96.81
ZONE - 3	79.16	109.96	95.95	141.41	71.96	91.42	86.25	124.51
ZONE - 4	98.76	161.68	122.83	186.39	87.7	136.03	107.81	161.44
ZONE - 5	128.17	239.26	163.1	253.79	111.31	202.95	140.16	216.85
Shear Force (KN)								
ZONE - 2	27.88	-	33.17	-	37.25	58.75	40.98	65.26
ZONE - 3	39.08	-	42.61	-	53.76	74.6	61.07	73.28
ZONE - 4	54.02	-	55.2	-	75.78	95.74	87.85	85.83
ZONE - 5	76.43	-	74.08	-	108.81	127.45	128.03	104.65

It can be seen from Table 3 and 4: 1) In model 1, the moments in the column which connected with the stair are bigger than that of the corner column and more than model 2 in all the zones. 2) In model 1, shear force of the column which connected with the stair is bigger than that of the corner column, but the shear force in model 1 smaller than that of model 2 in all the zones. 3) The maximum axial force of the column which connected with the stair in model 2 reduced up to 2% in storey1 and 1.6% in storey2 than that of model 1 in zone 2-3, but its axial forces are increased up to 1.4% in storey1 and 1.1% in storey2 for zone 4, similarly for zone 5 it increased up to 6.5% in storey1 and 8.3% in storey 2. 4) Comparing the internal forces of column in the two models, we can see that the axial force in model 2 are larger than that of model 1 in zone 4-5, but the shear force in model 2 are larger than that of model 1 in all zones and moments in model 2 are smaller than that of model 1 in all zones.

Table 4: The Axial forces of columns (4-D axis) in first floor and the second floor under the condition of response spectrum

Axial Force (KN)	**Model 1**		**Model 2**	
	Storey 1	Storey 2	Storey 1	Storey 2
ZONE - 2	4575.9	4210.45	4486.04	4145.3
ZONE - 3	4575.93	4210.45	4486.04	4145.3
ZONE - 4	4575.93	4210.45	4640.62	4256.4
ZONE - 5	4774.58	4299.47	5086.39	4655.99

CONCLUSION

The following observations and conclusions can be made on the basis of the current results:

1. The building without considering stairs leads to an underestimation of the design lateral force.
2. The displacement in X and Y direction is reduced up to 10.5% and 15.6% respectively in all the Indian earthquake zones of the model with stairs than model without stairs in RC frame building.
3. The natural period is less with stairs than without stairs in RC frame building. This leads to the conclusion that the consideration of stairs in seismic performance is essential.
4. Storey drift is more for frame without stairs than with the stairs. In X and Y directions the storey drift is reduced up to 15.4% and 19.6% respectively in all the zones of frame with stairs than frame without stairs, hence the consideration of stairs reduces the storey drift.
5. The incorporating of stairs in frames reduces the total base shear in X and Y directions due to the additional stiffness and rigidity of the stairwell bay.
6. The incorporation of the stairs in the building decreases the moments in the column, but increase the shear force in the column for all the earthquake zones. The column connected with the stair, in particular increases axial force in earthquake zone 4 and 5.

REFERENCE

[1] PankajAgarwal, S.K Thakkar, R.N Dubey, Seismic performance of reinforced concrete buildings during bhuj earthquake of January 26, 2011; *ISET Journal of Earthquake technology*, Vol. 39, pp. 195-217, 2002.

[2] EdoardoCosenza, Gerardo Mario Verderame, Alessandra Zambrano, Seismicperformance of stairs in the existing reinforced concrete building, *The 14th World Conference on Earthquake Engineering*, Beijing, China, October 12-17, 2008.

[3] Huanjun Jiang, HaiyanGao and Bin Wang, Seismic damage analyses of staircases in RC frame structures, *Advanced Materials Research*, Vols. 446-449, pp 2326-2330, 2012.

[4] IS 1893 (Part-I): 2002, Criteria for Earthquake Resistant Design of Structures, New Delhi.

[5] S.K. Duggal, (2007), Earthquake Resistant Design of Structures, *Oxford University Press*, New Delhi 2007.