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Study Of Staircase Effect On Seismic Performance Of Multistoried Frame Structure

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***Abstract**:*

In RC frame buildings, there are mainly two structural systems, Primary structural system and secondary structural system. The primary structural system to resist lateral load are beams and columns. Besides, primary structural system, some elements also contribute to lateral load resistance. These elements fall in the category of secondary systems. Secondary system can be structural secondary like staircase, structural partition etc and non-structural secondary like storage tanks, machinery etc A special case of structural secondary members which are normally designed for non seismic force are concrete staircase. There exist a large number of reinforced concrete (RC) buildings that are gravity load designed and constructed in actual seismic areas. Many of these structures were constructed in areas that are not considered seismic at the construction time or although they were located in seismic areas at that time, the earlier codes did not include seismic provisions or may have specified lower levels of seismic loads. Due to the high cost of replacement, many old structures are still in service far beyond their design life. Besides, gravity load designed structures may perform in a no-ductile manner with dangerous modes of failure. Before the 1980's the design of the structure, both in seismic and in non seismic area, did not consider the presence of the stair, although the stair offers a higher strength and stiffness influencing considerably the distribution of seismic forces. It is well known that the stair could be a vulnerable part of the structure attracting the seismic action; in the meanwhile its stiffness could preserve the structure from collapse if it was adequately designed and built. If the stair is not well designed it can lead the structure to collapse, in particular if only gravity loads are considered into the design or the reinforcement detailing is not adequate.

Keywords
staircase, structural partition, reinforced concrete, seismic loads.

1. Introduction

differently. The force generated by the seismic action of an earthquake is different than other types of loads, such as gravity and wind loads. It strikes the weakest spot in the whole three dimensional building. Ignorance in design and poor quality of construction result, many weaknesses in the structure, thus cause serious damage to life and property. The staircase is the part of secondary system of the structures and it is one of the essential parts of a building because of its functional importance. Due to the complex modeling of the staircase, it is designed separately for non-seismic and seismic forces. From a geometrical point of view, a stair is composed of inclined element (beam and slabs) and by short column. These elements contribute to increase stiffness of the building. The effect of the staircase on the RC frame structure found in literature may be summarized as imparting discontinuity in the modeling, variation in failure of allied structural elements, contributing in non-linear performance of buildings, modification of various seismic parameters such as reduction in the time period, story drift, and story displacement of the building have been considered.

2. Related Work

C Bellidoa et. al. [2] presents an assessment of the performance of pressurized staircases in six high rise buildings. All systems have been designed using a similar methodology but implemented in different ways. In all cases the control mechanism for the fan is a direct feedback loop from a single pressure sensor. The results have been evaluated showing the limitations of the control system in the event of multiple doors being opened and the limitations of the pressure release dampers (as a response mechanism) if the pressure becomes unstable.

Christoph Ho et. al. [3] create a link between human spatial cognition research and architectural design. To conducted an empirical study with human subjects in a complex multi-level building and compared thinking aloud protocols and performance measures of experienced and inexperienced participants in different way finding tasks. Three specific strategies for navigation in multilevel buildings were compared. The central point strategy relies on well-known parts of the building; the direction strategy relies on routes that first head towards the horizontal position of the goal, while the floor strategy relies on routes that first head towards the vertical position of the goal. Result show that the floor strategy was preferred by experienced participants over the other strategies and was overall tied to better way finding performance. Route knowledge showed a greater impact on way finding performance compared to survey knowledge. A cognitive-architectural analysis of the building revealed seven possible causes for navigation problems. Especially the staircase design was identified as a major way finding obstacle.

Edoardo Cosenza et. al. [4] deals with the seismic performance of existing buildings and in particular on the moment resisting frame structures that could have their critical and weak points in the stair members: columns and beams or slabs. The stair increases structural strength and stiffness of a structure but attracting seismic forces it could fail into its short columns or into the slabs due to high shear forces, into inclined beams supporting the steps a cause of high axial forces. The structural solutions and design practice of stairs in gravity load designed structures are investigated to define their real geometric definition and to understand their performance. Some numerical modal linear and non linear push-over analyses are herein presented. A typical reinforced concrete building respecting the materials and design criteria of the time is considered for the analyses. In particular two types of stairs are considered: the one with cantilever steps constrained in inclined beams, and the stair composed of simply supported slabs. The modal analysis emphasizes the different modal behavior considering the stairs. A non linear lumped plasticity models allow to perform non linear pushover analysis that allow to identify the main failure mechanisms. Some numerical simulations give some interesting results and offer some good features on the problems related to the mechanical and geometrical modeling of the structural elements of the stair, and to the principle types of failure due to flexure, or shear.

Pratik Deshmukh et. al. [5] presents the effects of staircase on the seismic performance of the RCC frame buildings of different heights and different plans have been studied. Generally, the stair model is not included in the analysis of RC frame buildings. Due to the rigidity of inclined slab and of short columns around staircase, beams and columns are often characterized by a high seismic demand. The identification of the weakest elements of the structure, the failure type considering the presence of the stairs, and their contribution in the non linear performance of RC frame buildings are some of the areas on which the present paper has presented. For analysis and design, Etab v.9 has been used. Performances of both categories of the buildings have been evaluated through Response Spectrum Method.

Ankit R. Shelotkar et. al. [6] presents the effect of staircase position on RC frame structures has been carried out by adopting various building models with and without staircase in longitudinal and transverse direction. The Linear Response Spectrum analysis of the models has been carried out as per IS: 1893 (Part 1) - 2002 and IS: 456 – 2000 with the help of Etab 2015 software. The Seismic characteristics in terms of Time period, Story Drift and Story Displacement have been compared with the seismic characteristics of models with and without a staircase. Further, the effect of change in location of the staircase on the behavior of the building has also been observed. In addition to these, short column effect, variation in moments of beams and columns that are attached to staircase slab, failure and deformation in staircase models have also been studied.

3. Stair Classification

From the early beginning of the use of reinforced concrete (RC), different types of stair have been designed. According to the literature, the existing stairs can now be classified into two main categories depending on the static behavior of the stair steps: (i) stairs with steps performing as cantilever beam, (ii) stairs with simply supported steps.

In side these two categories three principal types of stairs can be distinguished:

• Stair type A – The stair structure is composed of: 1) columns, at least four columns are located at the side of the staircase (generally at its four corners), but in some cases they can be located internally to the substructure “stair”; 2) beams that connecting the columns (storey beam and inter-storey beam); 3) beams supporting the flight steps (element bs1-bs2-bs3). In particular, storey and inter-storey landings are supported respectively by elements bs1 and bs3, while steps are cantilever beams constraint into the inclined part of the beam bs2. Three types of beam configurations can be distinguished, depending on the presence of bs1 and bs3.

• Stair type B – The substructure “stair” is composed by: 1) columns (at least four); 2) beams connecting the columns, storey beam and inter-storey beam; 3) the slab constraint at the beams at each storey and inter-storey. This slab has two horizontal parts (s1-s3) and one inclined on the horizontal (s2). On this cranked element the steps are simply supported, they are made contemporary or successively to the slab. The slab can be made of only reinforced concrete or of brick and joist.

• Stair type C – The staircase is composed by reinforced concrete walls, and the steps, having a cantilever behavior are fully constraint in these RC walls.

4. Proposed Design

General Introduction

The multi storey buildings of G+5 are modeled in six different configurations are as follows-

- Model A1 - Building with staircase at centre location.
- Model A2 - Building with staircase at mid end location.
- Model A3 - Building with staircase at corner location.
- Model B1 - Building without staircase at centre location.
- Model B2 - Building without staircase at mid end location.
- Model B3 - Building without staircase at corner location.

4.1 Part A - Structural Plan, Elevation & 3-D Figures For Different Location Of With And Without Staircase

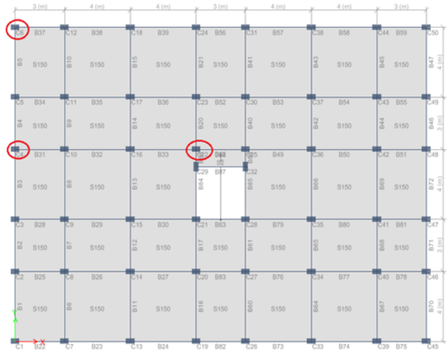

Fig. 1. Structural plan with (A1) and without (B1) staircase at centre location.

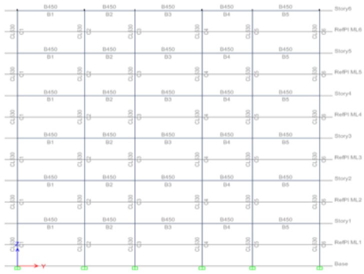

Fig 2. Elevation of shorter direction at centre location (A1).

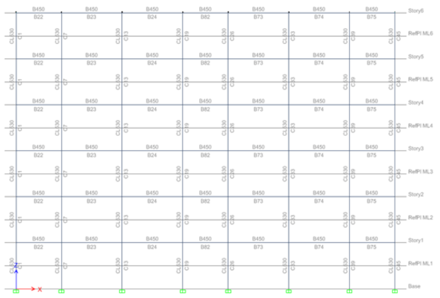

Fig. 3. Elevation of longer direction at centre location (A1).

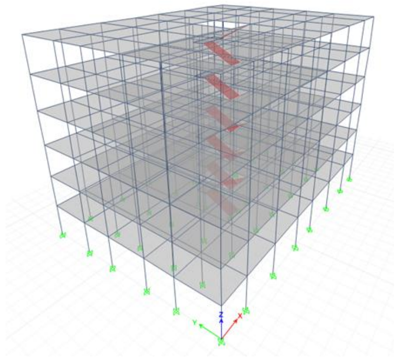

Fig. 4. 3-D model of staircase at centre location (A1).

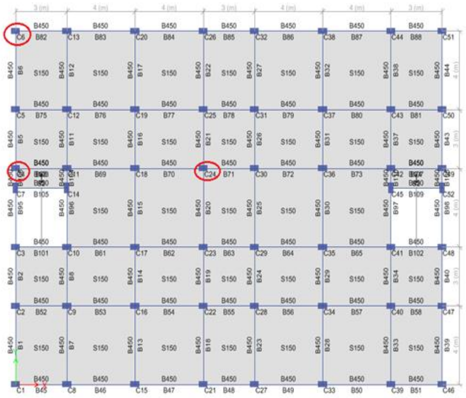

Fig. 5. Structural plan with (A2) and without (B2) staircase at mid end location.

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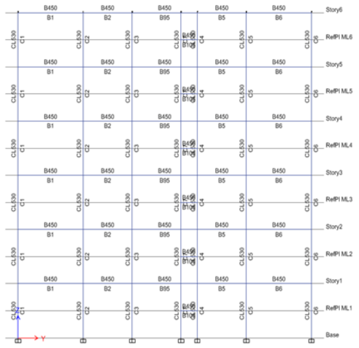

Fig. 6. Elevation of shorter direction at mid end location (A2).

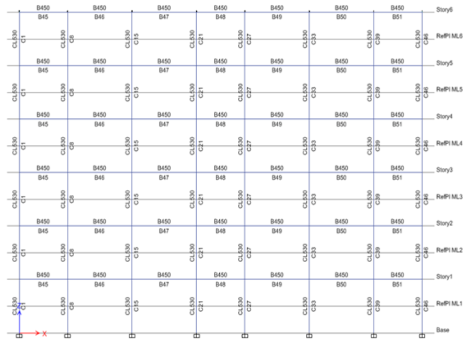

Fig. 7. Elevation of longer direction at mid end location (A2).

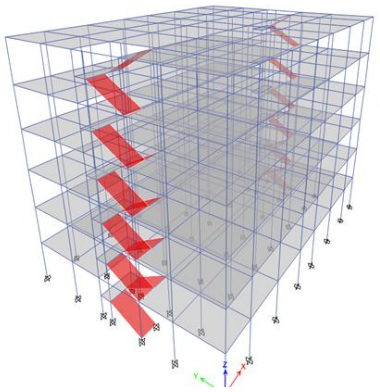

Fig. 8. 3-D model of staircase at mid end location (A2).

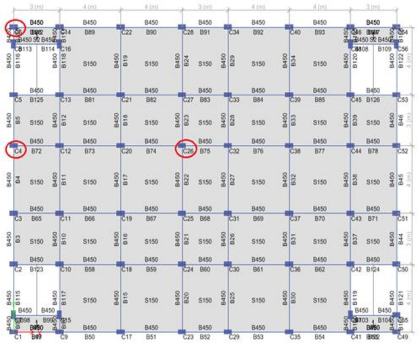

Fig. 9. Structural plan with (A3) and without (B3) staircase at corner location.

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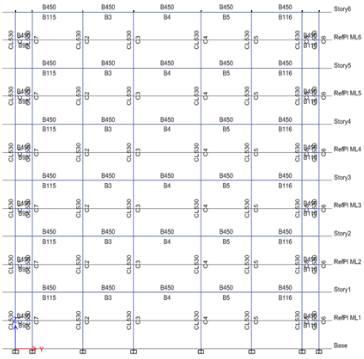

Fig. 10. Elevation of shorter direction at corner location (A3).

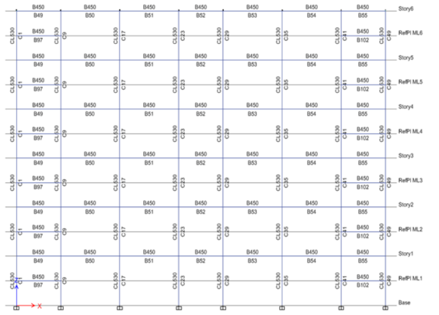

Fig. 11. Elevation of longer direction at corner location (A3).

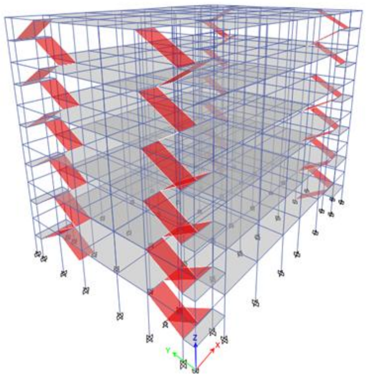

Fig.12. 3-D model of staircase at corner location (A3).

4.2 Part B - Analysis Results For Different Location Of With And Without Staircase

• Results For Storey Drift In Model A1 And B1 At Centre Location

Storey Drift						
G+5 Model						
Sr. No	Storey	Load Case EQX		Load Case EQY		Permissible Value
		A1 Model	B1 Model	A1 Model	B1 Model	
1	6	0.0010	0.0011	0.0012	0.0014	0.0120
2	5	0.0017	0.0020	0.0019	0.0028	0.0120
3	4	0.0022	0.0027	0.0023	0.0038	0.0120
4	3	0.00	0.00	0.00	0.00	0.0120

		24	32	25	43	
5	2	0.0024	0.0031	0.0024	0.0043	0.0120
6	1	0.0014	0.0018	0.0017	0.0030	0.0120
7	0	0.0000	0.0000	0.0000	0.0000	0.0000

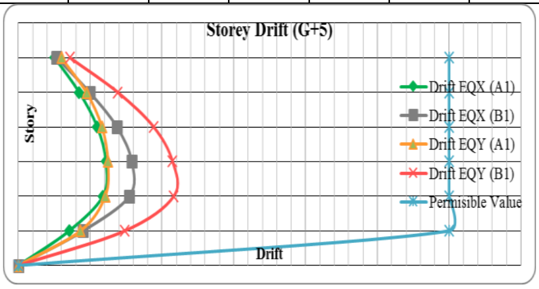

Fig. 13. Comparison of storey drift with stair and without stair model

• Results For Storey Drift In Model A2 And B2 At Mid End Location.

Storey Drift						
G+5 Model						
Sr. No	Storey	Load Case EQX		Load Case EQY		Permissible Value
		A2 Model	B2 Model	A2 Model	B2 Model	
1	6	0.0010	0.0013	0.0009	0.0011	0.0120
2	5	0.0015	0.0026	0.0014	0.0019	0.0120
3	4	0.0018	0.0037	0.0017	0.0025	0.0120
4	3	0.0020	0.0042	0.0017	0.0028	0.0120
5	2	0.0019	0.0042	0.0017	0.0028	0.0120
6	1	0.00	0.00	0.00	0.00	0.0120

		12	18	12	25	
7	0	0.0000	0.0000	0.0000	0.0000	0.0000

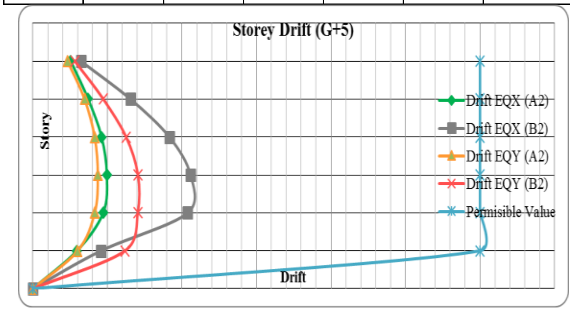

Fig. 14. Comparison of storey drift with stair and without stair model

- **Results For Storey Drift In Model A3 And B3 At Corner Location.**

Storey Drift						
G+5 Model						
Sr. No	Storey	Load Case EQX		Load Case EQY		Permissible Value
		A3 Model	B3 Model	A3 Model	B3 Model	
1	6	0.0008	0.0010	0.0007	0.0016	0.0120
2	5	0.0011	0.0018	0.0010	0.0024	0.0120
3	4	0.0013	0.0024	0.0011	0.0030	0.0120
4	3	0.0014	0.0028	0.0011	0.0033	0.0120
5	2	0.0013	0.0027	0.0010	0.0031	0.0120
6	1	0.0009	0.0016	0.0008	0.0020	0.0120
7	0	0.0000	0.0000	0.0000	0.0000	0.0000

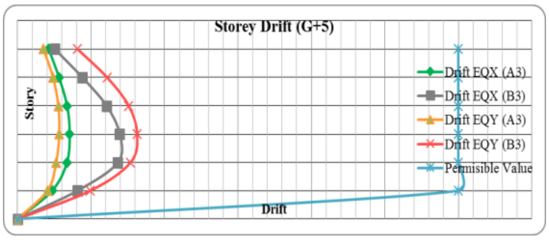

Fig. 15. Comparison of storey drifts with stair and without stair model

- **Results For Storey Displacement In Model A1 And B1 At Centre Location.**

Storey Displacement						
G+5 Model						
Sr. No	Storey	Load Case EQX		Load Case EQY		Permissible Value
		A1 Model	B1 Model	A1 Model	B1 Model	
1	6	32.90	41.20	36.10	58.70	36
2	5	29.90	38.10	32.50	54.40	36
3	4	24.80	32.20	26.90	46.10	36
4	3	18.30	24.00	19.90	34.80	36
5	2	11.20	14.60	12.40	21.90	36
6	1	4.20	5.40	5.20	8.90	36
7	0	0.00	0.00	0.00	0.00	0.00

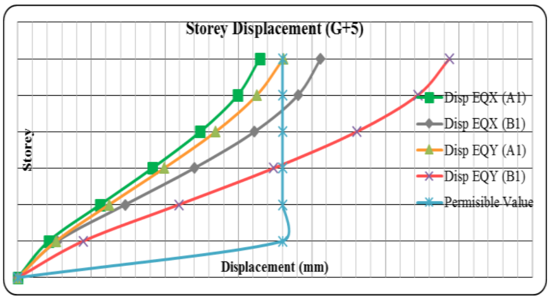

Fig. 16. Comparison of storey displacement with stair and without stair model

- **Results For Storey Displacement In Model A2 And B2 At Mid End Location.**

Storey Displacement						
G+5 Model						
Sr. No	**Storey**	**Load Case EQX**		**Load Case EQY**		**Permissible Value**
		A2 Model	**B2 Model**	**A2 Model**	**B2 Model**	
1	**6**	27.70	52.20	25.70	40.90	36
2	**5**	24.90	48.60	22.90	37.50	36
3	**4**	20.50	40.80	18.80	31.80	36
4	**3**	15.00	30.00	13.80	24.30	36
5	**2**	9.10	17.40	8.60	15.90	36
6	**1**	3.50	5.10	3.60	7.40	36
7	**0**	0.00	0.00	0.00	0.00	0.00

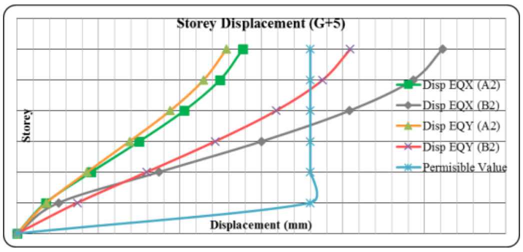

Fig. 17. Comparison of storey displacement with stair and without stair model

- **Results For Storey Displacement In Model A3 And B3 At Corner Location.**

Storey Displacement						
G+5 Model						
Sr. No	**Storey**	**Load Case EQX**		**Load Case EQY**		**Permissible Value**
		A3 Model	**B3 Model**	**A3 Model**	**B3 Model**	
1	**6**	20.60	36.80	17.10	46.10	36
2	**5**	18.30	33.90	15.00	41.30	36
3	**4**	14.90	28.60	12.10	34.00	36
4	**3**	10.90	21.30	8.80	24.90	36
5	**2**	6.60	13.00	5.40	15.20	36
6	**1**	2.60	4.80	2.30	5.90	36
7	**0**	0.00	0.00	0.00	0.00	0.00

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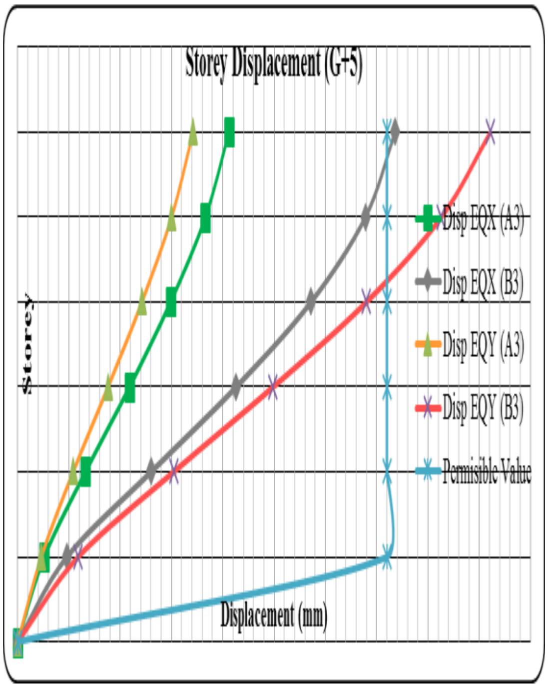
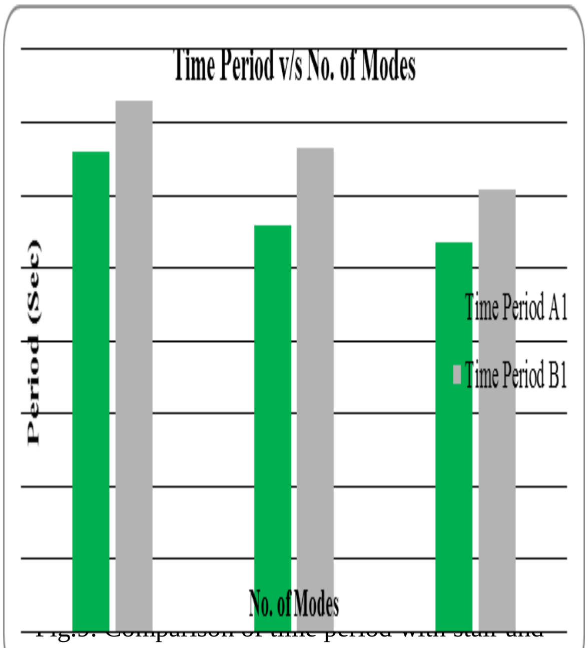


- **Results For Storey Time Period In Model A1 And B1 At Centre Location.**

Time Period			
G+5 Model			
Case	**Mode**	**A1**	**B1**
Modal	**1**	1.321	1.461
Modal	**2**	1.119	1.331
Modal	**3**	1.071	1.215



Comparison of time period with stair and without stair model.

Results For Storey Time Period In Model A2 And B2 At Mid End Location.

Time Period			
G+5 Model			
Case	**Mode**	**A2**	**B2**
Modal	**1**	0.974	1.363
Modal	**2**	0.936	1.221
Modal	**3**	0.802	1.109

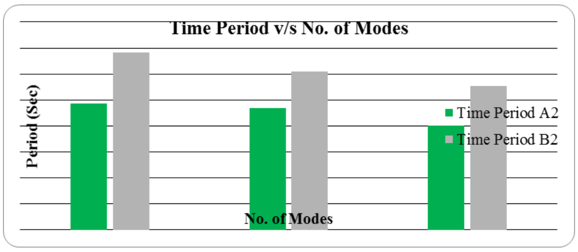


Fig. 20. Comparison of time period with stair and without stair model.

Results For Storey Time Period In Model A3 And B3 At Corner Location.

Time Period			
G+5 Model			
Case	**Mode**	**A3**	**B3**
Modal	**1**	1.255	1.255
Modal	**2**	1.147	1.147
Modal	**3**	1.018	1.018

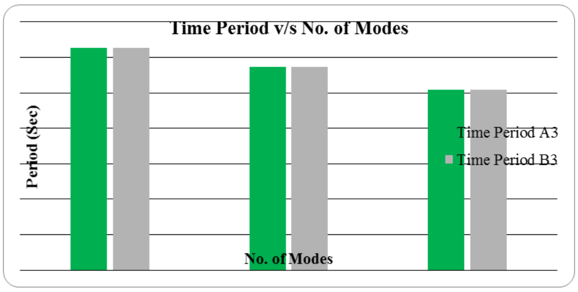


Fig. 21. Comparison of time period with stair and without stair model.

Results For Axial Load In Model A1 And B1 At Centre Location.

Axial Load (Pu)			
G+5 Model			
Column No	Model	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A1	230.12	120.76
	B1	286.45	193.35
C4	A1	231.37	61.32
	B1	285.97	100.75
C22	A1	669.52	1502.44
	B1	340.76	1345.05

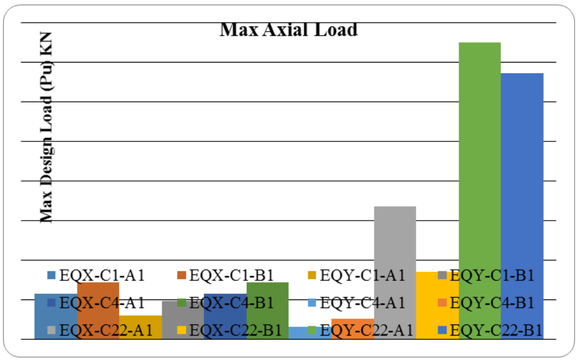


Fig. 22. Comparison of max design load with stair and without stair model in column

Results For Axial Load In Model A2 And B2 At Mid End Location.

Axial Load (Pu)			
G+5 Model			
Column No	Model	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A2	192.82	81.67
	B2	279.21	170.94
C4	A2	614.85	1030.27
	B2	531.81	1007.57
C24	A2	71.83	44.78
	B2	95.17	99.69

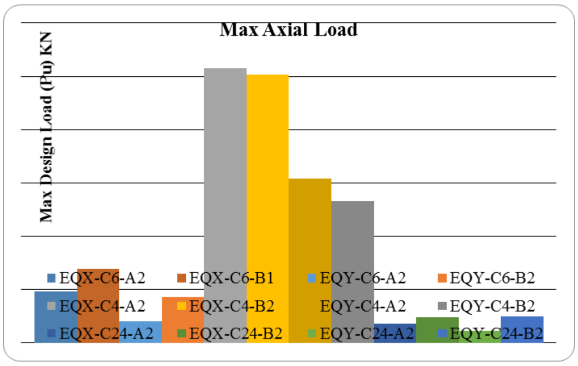


Fig. 23. Comparison of max design load with stair and without stair model in column

Results For Axial Load In Model A3 And B3 At Corner Location.

Axial Load (Pu)			
G+5 Model			
Column No	Model	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A3	459.79	736.93
	B3	411.58	1192.24
C4	A3	171.07	87.95
	B3	255.78	75.24
C26	A3	53.30	29.49
	B3	94.64	79.67

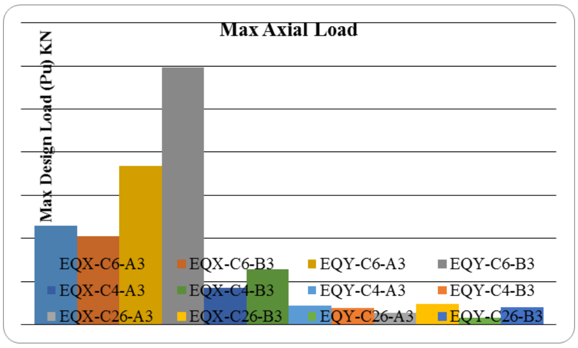


Fig. 24. Comparison of max design load with stair and without stair model in column

Results For Shear Force In Model A1 And B1 At Centre Location.

Shear Force (V)			
G+5 Model			
Column	Model	Load Case	Load Case

No		EQX	EQY
		Ground Storey	Ground Storey
C6	A1	42.96	25.00
	B1	52.41	41.68
C4	A1	42.79	33.21
	B1	52.65	56.09
C22	A1	72.54	55.41
	B1	77.60	117.98

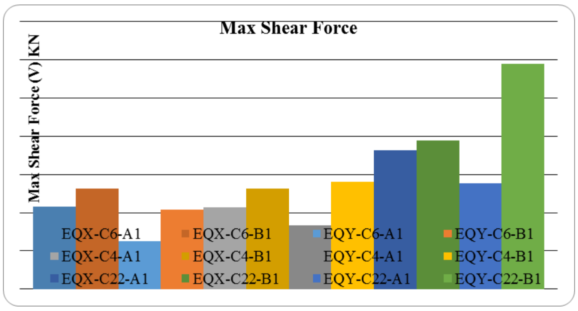


Fig. 25. Comparison of max shear force with stair and without stair model in column

Results For Shear Force In Model A2 And B2 At Mid End Location.

Shear Force (V)			
G+5 Model			
Column No	Model	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A2	35.69	17.52
	B2	48.65	36.47
C4	A2	61.32	17.41
	B2	63.69	108.49
C24	A2	44.07	23.24
	B2	65.45	44.06

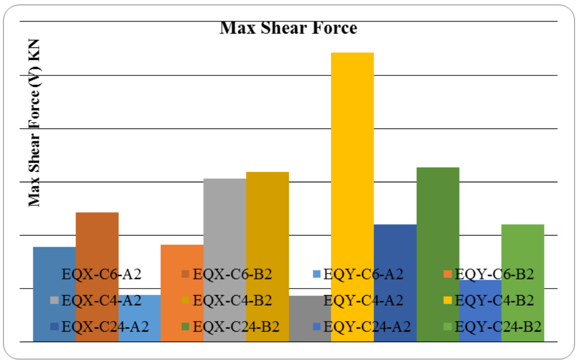


Fig.26. Comparison of max shear force with stair and without stair model in column

Results For Shear Force In Model A3 And B3 At Corner Location.

Shear Force (V)			
G+5 Model			
Column No	Model	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A3	50.06	62.53
	B3	69.33	74.26
C4	A3	28.51	14.99
	B3	47.53	36.76
C26	A3	34.47	14.47
	B3	58.79	36.90

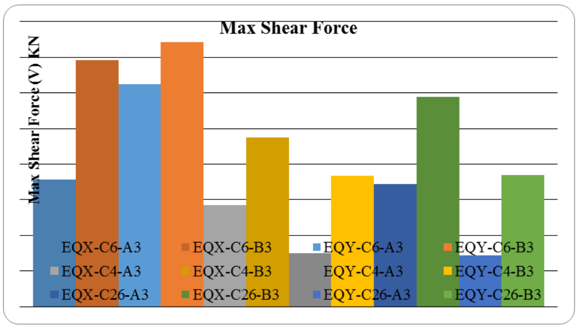


Fig. 27. Comparison of max shear force with stair and without stair model in column

Results For Max Bending Moment In Model A1 And B1 At Centre Location.

Bending Moment (M)			
G+5 Model			
Colum n No	Mode l	Load Case EQX	Load Case EQY
		Ground Storey	Ground Storey
C6	A1	108.82	51.07
	B1	135.37	86.41
C4	A1	108.15	59.20
	B1	136.03	100.67
C22	A1	123.36	39.88
	B1	144.76	123.58

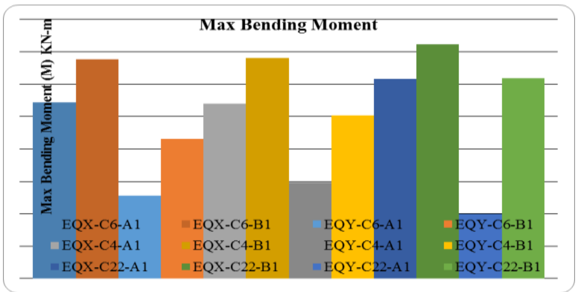


Fig. 28. Comparison of max bending moment with stair and without stair model in column

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Results For Max Bending Moment In Model A2 And B2 At Mid End Location.

Bending Moment (M)			
G+5 Model			
Column No	Model	Load Case EQX Ground Storey	Load Case EQY Ground Storey
C6	A2	89.39	35.70
	B2	127.07	73.80
C4	A2	101.55	26.31
	B2	126.42	109.81
C24	A2	97.79	41.36
	B2	144.01	81.31

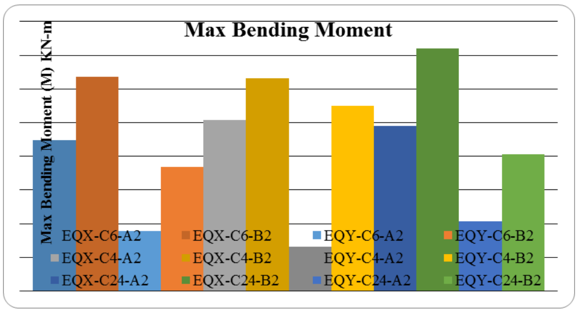

Fig. 29. Comparison of max bending moment with stair and without stair model in column

Results For Max Bending Moment In Model A3 And B3 At Corner Location.

Bending Moment (M)			
G+5 Model			
Column No	Model	Load Case EQX Ground Storey	Load Case EQY Ground Storey
C6	A3	80.11	55.29
	B3	127.65	78.68
C4	A3	69.10	26.09
	B3	122.30	66.61
C26	A3	74.87	25.77
	B3	133.20	66.75

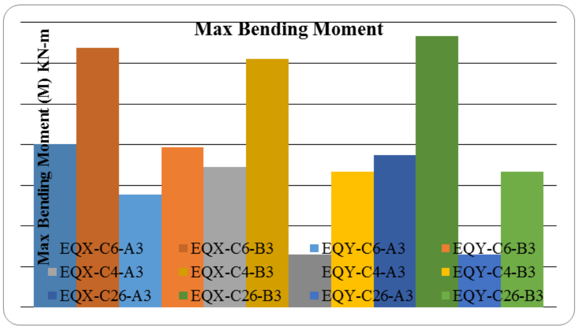

Fig. 30. Comparison of max bending moment with stair and without stair model in column

5. Conclusion

This paper found that the presence of staircase tremendously influence the design of beam & column in the periphery of staircase. It is observed that the Columns supporting landing beam have been found to be subjected to an increase in moment & beam supporting staircase flight has been found to be subjected to a decrease in area of steel at top. The presence of staircase yields in the transversal direction to an increase of strength. It is also observed that damage in main structures was due to interactions with stairways and in stairways due to high stiffness and corresponding high force demand, with insufficient strength due to inadequate design. Also, if buildings and their components are not design properly by considering diagonal effect of staircases, it may get fail under major earthquakes.

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