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Earthquake Resistance Performance of a Multistorey RCC Frame Considering Two Different Positions of the Staircase

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Abstract: The stairs have significant influence on the seismic lateral stiffness, vibration mode and internal force of frame beam column of the reinforced concrete frame structure. In this paper, 3 analysis models have been made by E-TABS. In these models, relevant analysis has been made about the influence of stairs in 10-storey building while it has no staircase, it is near the middle of the building and while it is near the corner of the building. Results from linear analysis show that in concrete structure, it is essential to consider the modelling of staircase as it causes additional stiffness and change in coordinate of center of rigidity. These effects can be evaluated in period, stiffness, base shear, lateral load and displacement of the structure.
Keywords: Seismic performance, Center of mass, Storey Drift, Base Shear, Stiffness.

I. INTRODUCTION

Staircase is an architectural element which has high potential to change structural behaviour especially moment frames against lateral forces, while it is usually neglected in structural design and it is not included in the model of structure. In fact, what is included in modelling structure of conventional buildings, are beams and columns around the staircase as a void and applied dead and live loads. Due to importance of the staircase in crisis and disasters as a way of escape and rescue routes and maintaining its function after the earthquake, it is necessary to pay special attention to the effects of the staircase in structural analysis and design, in a way that not only does no damage to structures, but also in the event of damage to the structures, this part of building remains intact and in service.

Earthquake is an impulsive event and acts quite differently. The force generated by seismic action of earthquake is different than other types of loads, such as, gravity, Dead load, Live load and wind load. It strikes the weakest spot in the whole structural frame building. Ignorance in structural design and poor quality & maintenance of construction result many weaknesses & faults in the structure member and Structural Building also, thus cause vulnerable damage to life and Structural property of building. In RC frame structural buildings, the primary structural system to resist Lateral & Gravity load are beams and columns. Besides, primary frame structural system, some structural member also contributes 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.

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 change in the time period, storey stiffness, and storey displacement of the building have been considered.

The seismic analysis of structures by computer should meet the requirements of establishment of computation model, the necessary simplified calculation and processing should be consistent with the actual working condition of structure and should be considered the influence of staircase construction in calculation. This paper compares and analysis the frames structures at different positions of the staircase as per the provisions made in Indian seismic design code IS:1893-2016 and using linear static analysis methodology.

II. LITERATURE REVIEW

The main aim of this research is to study the effects of staircase on structure in design phase. In the following paragraph, the previous research is briefly reviewed.

1) Hoseini and Jafarnejad's research on two reinforced concrete structure has shown that staircase causes the increase of the stiffness of the structure, base shear and internal force of structural elements around the staircase and reduction of the natural period of structure. Moreover, changing center of rigidity may lead to significant torsional effect. [1]
2) Cao et al. reported that the staircase increases the lateral stiffness, storey shear and overturning moment and decreases the period, based on the studies along the length of the staircase on two reinforced concrete structures. [2]
3) Pratik Deshmukh 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. [3]
4) Results of Bastami et al. studies on a reinforced concrete structure with three different types of construction details of staircase have shown that bracing behaviour of staircase in longitudinal direction and its inclined shear wall behaviour in transverse direction causes the reduction of the natural period of structure and lateral displacement and increase in the stiffness of the structure. By increasing the structure height, effect of staircase on stiffness reduces. Eliminating the staircase from the model of structure is safe for columns and beams away the staircase, but it is unreliable for the ones near the staircase. The behaviour model with suspended stair is similar to the models without stair, but stair with this construction detail will be unstable during earthquakes.[4]
5) Singh and Choudhary's studies on two types of geometrical plan configuration with RC structure and on 4 different heights have shown reduction in period of structure, increase in internal forces of landing beams and columns and reduction in inter storey drift ratio along two directions of models with staircase.[5]
6) Feng et al. analysed 18 RC structure models. They concluded that in the direction parallel to ladder running the stiffness of structure increases and the storey displacement ratio reduces, but in the direction perpendicular to the ladder running effects of staircase on structure can be neglected. Irrational layout of staircase may lead to torsional effect on structure. Staircase increases the internal forces in the members of structure, especially the columns at the location adjacent to the landing platform, where short column formed, while in the frames away the staircase the internal forces are reduced. To avoid the detrimental effects of staircase on structure, they proposed two details for isolating the staircase including full-isolated staircase and semi-isolated staircase.[6]
7) Tegos et al. studied five different types of staircases in a model. They concluded that staircase increases the stiffness of the structure, decreases structure's natural period vibration and relative displacements in longitudinal direction and the influence of the vertical component of the earthquake in staircases with a free landing and helical one, is significant.[7]

III.METHOGOLOGY

The algorithm for determining IS:1893-2016 seismic loads is based on Sections 6.4.2, 7.6.1 and 7.6.2 of IS:1893-2016 code. A period is calculated as described in IS:1893-2016.[8]

The value of seismic base shear is computed using the following expression.

(IS:1893 Section.7.6.1)

$$V_b = A_h W$$

and A_h is given be the following equation:

(IS:1893 Section.6.4.2)

$$A_h = \frac{Z\, I\, S_a}{2\, R\, g}$$

where,

- A_h = The design horizontal spectrum value
- Z = Seismic zone factor

Seismic Zone Factor	II	III	IV	V
Z	0.10	0.16	0.24	0.36

- I = Importance factor
  - (a) 1.5 for critical and lifeline structure
  - (b) 1.2 for business continuity structures
  - (c) 1.0 for the rest
- $\frac{S_a}{g}$ = Design acceleration coefficient for different soil types, normalized with peak ground acceleration, corresponding to natural period T of structure.
- For Equivalent static method, for T<0.4 sec $S_a/g = 2.5$ (constant) but in Response Spectrum method, S_a/g values varies up to 0.10 sec.
- R = Response Reduction factor given in IS:1893-2016 (parts 1 to 5) for the corresponding structures.
- Vertical Distribution of Base Shear to Different Floor Levels

The design base shear V_b shall be distributed along the height of the building as per the following expression:

$$Q_i = (W_i h_i^2 / \Sigma W_i h_i^2) * V_b$$

Where, Q_i = design lateral force at floor i;
W_i = seismic weight of floor i;
h_i = height of floor measured from base;
n = number of storeys in building.

IV. NUMERICAL STUDY

A. Load Parameters

The seismic parameters considered in dynamic analysis of all the models are assumed as per IS:1893-2016. The buildings are assumed to be in Zone IV. The importance factor, I taken as 1. Also, the response reduction factor R taken as 5 for SMRF system of the buildings. The soil strata beneath the foundation is assumed as medium soil. The gravity and imposed loads are taken as per IS 875 (Part 1 and 2): 1987, self-weight of the structure is calculated automatically and imposed load is assumed to be 2 kN/m^2 for a typical residential building.

B. Geometrical Properties

TABLE I. GEOMETRIC PROPERTIES OF MODEL

Height of Building	30 m	Each Storey Height	3 m
Column Size	400 X 400 mm	Time Period in X & Y Direction	1.363 sec
Beam Size	300 X 400 mm	Live load on Slab	2 KN/m^2
Slab Thickness	150 mm	Live load on Stair case	3 KN/m^2
Staircase Slab Thickness	200 mm	Floor Finish on slab	1.25 KN/m^2
Storey Length in X & Y Dir.	28.8 m	Floor finish on Stair case	2.25 KN/m^2
Self-Weight	Auto Calculate by Software	Seismic Zone	IV
Soil type	Medium	Response reduction factor	5
Importance factor	1	Grade of concrete & steel	M 30, Fe500

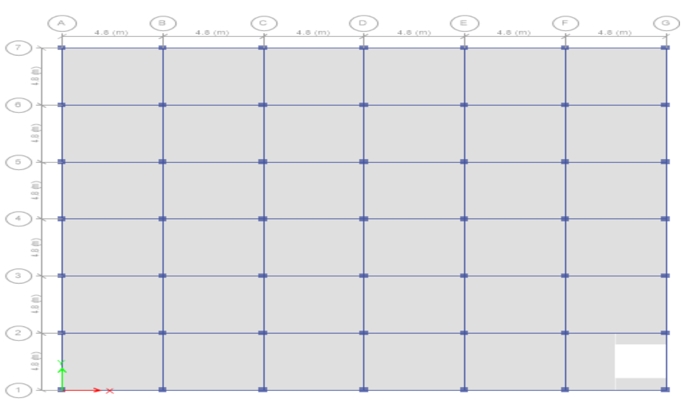

Fig. 1 Plan view (staircase is in corner)

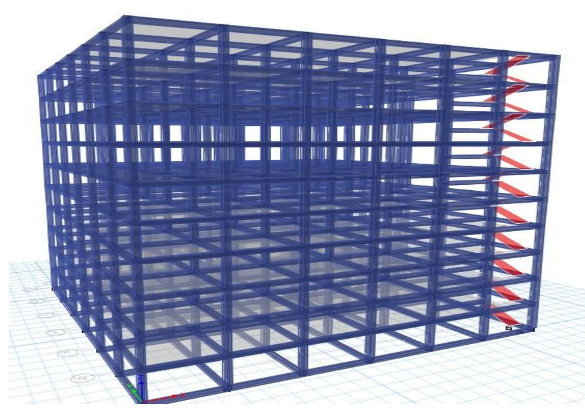

Fig. 2 3-D view (staircase is in corner)

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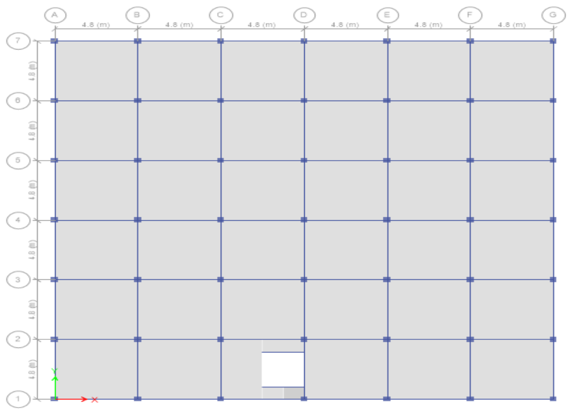

Fig. 3 Plan view (staircase is in center)

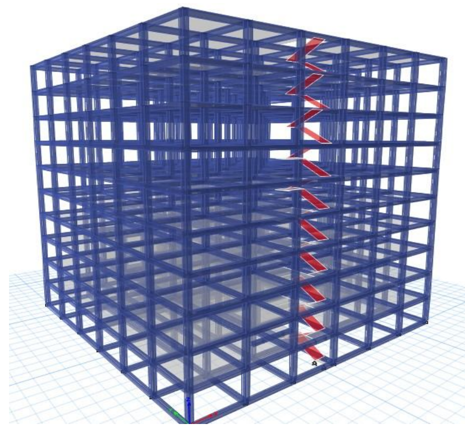

Fig.4 3-D view (staircase is in center)

TABLE II

CALCULATED BASE SHEAR BY E-TABS WHEN NO STAIRCASE IS PROVIDED

Load Pattern	Type	Direction	Period Method	Top Story	Bottom Story	Z Type	Z	Soil Type	I	R	Period Used sec	Coeff Used	Weight Used kN	Base Shear kN
EQx	Seismic	X	Program Calculated	Story10	Base	Per Code	0.24	II	1	5	1.363	0.023954	48465.6843	1160.9643
EQy	Seismic	Y	Program Calculated	Story10	Base	Per Code	0.24	II	1	5	1.363	0.023954	48465.6843	1160.9693

TABLE III

CALCULATED BASE SHEAR BY E-TABS WHEN STAIRCASE IS IN CORNER

Load Pattern	Type	Direction	Period Method	Top Story	Bottom Story	Z Type	Z	Soil Type	I	R	Period Used sec	Coeff Used	Weight Used kN	Base Shear kN
EQx	Seismic	X	Program C...	Story10	Base	Per Code	0.24	II	1	5	1.011	0.032287	48781.2888	1575.0193
EQy	Seismic	Y	Program C...	Story10	Base	Per Code	0.24	II	1	5	1.314	0.024841	48781.2888	1211.772

TABLE IV

CALCULATED BASE SHEAR BY E-TABS WHEN STAIRCASE IS IN CENTER

Load Pattern	Type	Direction	Period Method	Top Story	Bottom Story	Z Type	Z	Soil Type	I	R	Period Used sec	Coeff Used	Weight Used kN	Base Shear kN
EQx	Seismic	X	Program Calculated	Story10	Base	Per Code	0.24	II	1	5	1.296	0.025179	48657.1255	1225.1262
EQy	Seismic	Y	Program Calculated	Story10	Base	Per Code	0.24	II	1	5	0.898	0.036343	48657.1255	1768.3553

V. RESULTS

Fig. 4 Maximum Storey Displacement (staircase is in center)

Fig. 5 Maximum storey Displacement (staircase is in corner)

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TABLE V
MAXIMUM STOREY DISPLACEMENT

Storey	Max storey Displacement due to EQx & EQy (without staircase)	Max storey Displacement due to EQx		Max. storey Displacement due to EQy	
		X-Dir (stair in centre)	X-Dir (stair in corner)	Y-Dir (stair in centre)	Y-Dir (stair in corner)
	mm	mm	mm	mm	mm
Storey10	20.104	20.332	22.361	15.073	19.272
Storey9	19.348	19.571	21.519	14.445	18.537
Storey8	18.067	18.276	20.099	13.44	17.304
Storey7	16.342	16.530	18.187	12.122	15.648
Storey6	14.276	14.438	15.894	10.565	13.665
Storey5	11.962	12.092	13.323	8.837	11.444
Storey4	9.477	9.573	10.565	7.001	9.06
Storey3	6.889	6.949	7.693	5.109	6.577
Storey2	4.26	4.281	4.775	3.199	4.053
Storey1	1.712	1.703	1.933	1.321	1.609
Base	0.000	0.000	0.000	0.000	0.000

TABLE VI
LATERAL LOAD TO STOREYS

Storey	Lateral load to storeys due to EQx & EQy (without staircase)	Lateral load to storeys due to EQx		Lateral load to storeys due to EQy	
		X-Dir (stair in centre)	X-Dir (stair in corner)	Y-Dir (stair in centre)	Y-Dir (stair in corner)
	kN	kN	kN	kN	kN
Storey10	287.879	303.296	437.780	389.518	299.683
Storey9	248.139	261.991	378.160	336.932	259.225
Storey8	196.061	207.005	298.793	266.218	204.820
Storey7	150.109	158.489	228.763	203.823	156.815
Storey6	110.284	116.441	168.071	149.747	115.211
Storey5	76.586	80.862	116.716	103.991	80.008
Storey4	49.015	51.751	74.698	66.554	51.205
Storey3	27.571	29.110	42.018	37.437	28.803
Storey2	12.253	12.938	18.675	16.639	12.801
Storey1	3.063	3.243	4.681	4.160	3.201
Base	0.000	0.000	0.000	0.000	0.000

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STOREY STIFFNESS

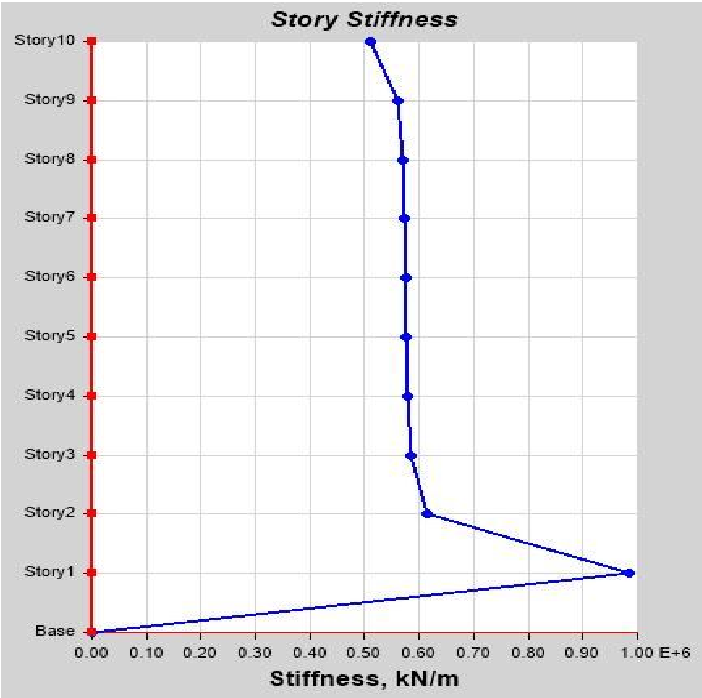

Fig. 6 Storey Stiffness in X- Dir. (staircase is in center) (EQx)

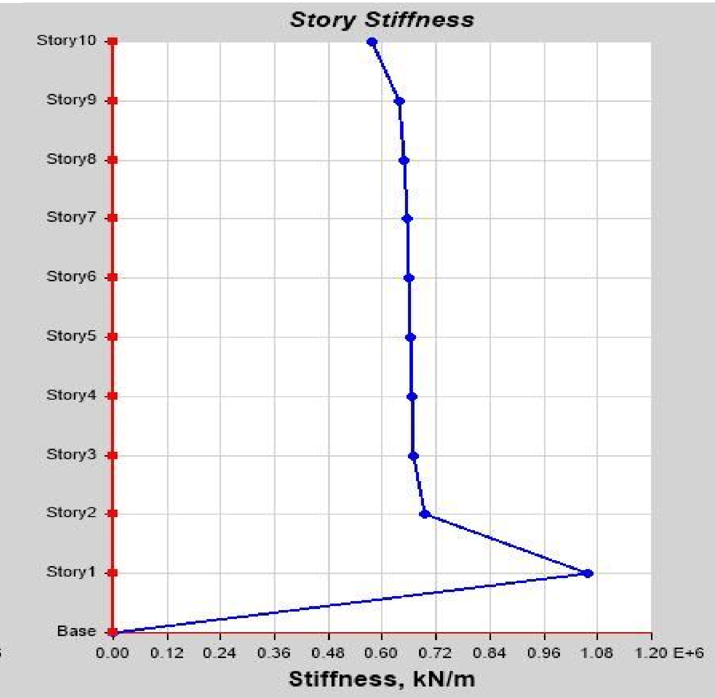

Fig. 7 Storey Stiffness in X-Dir. (staircase is in center) (EQy)

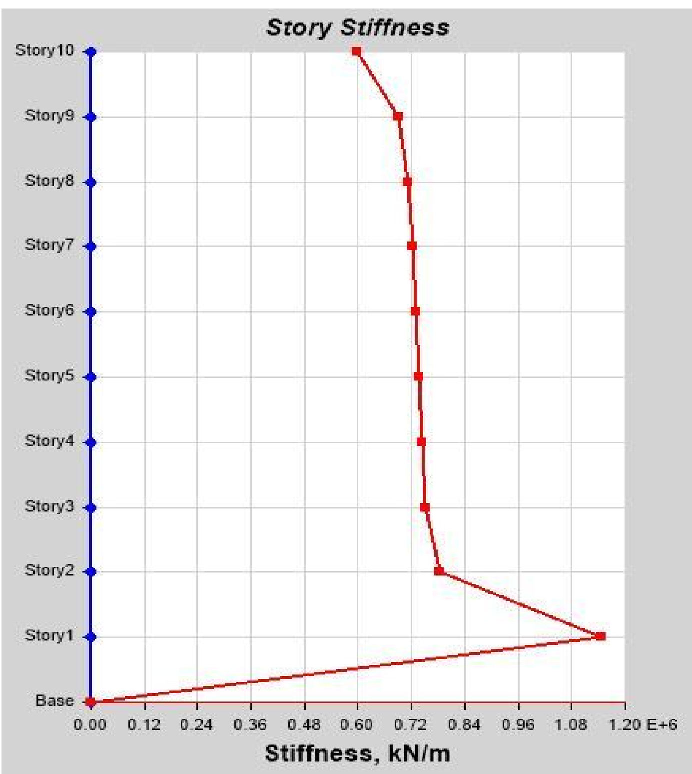

Fig.8 Storey Stiffness in Y-Dir. (stair is in corner) (EQx)

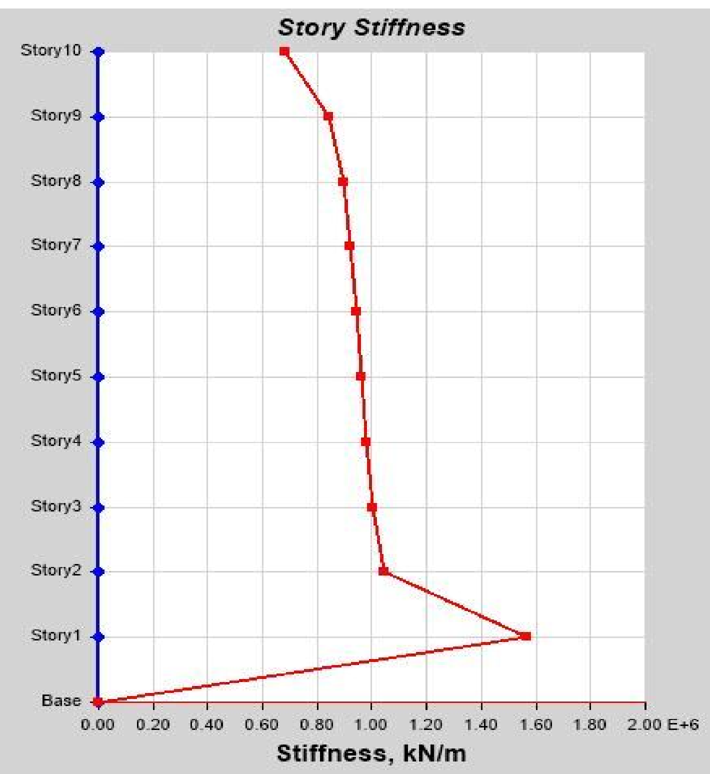

Fig. 9 Storey Stiffness in Y-Dir. (staircase is in corner) (EQy)

TABLE VII
Storey stiffness in X & Y-Dir. due to EQ loading

Storey	Elevation	Storey Stiffness due to EQx & EQy (without staircase)	Storey Stiffness due to EQx		Storey Stiffness due to EQy	
			X-Dir (stair in centre)	X-Dir (stair in corner)	Y-Dir (stair in centre)	Y-Dir (stair in corner)
	m	kN/m	kN/m	kN/m	kN/m	kN/m
Storey10	30	381073.341	510905.361	575533.123	683750.272	596946.312
Storey9	27	418800.618	562044.281	638290.133	840890.183	690729.757
Storey8	24	424933.176	569655.750	649632.110	894979.164	712895.931
Storey7	21	427542.449	572698.193	654560.997	922157.53	722672.812
Storey6	18	429271.456	574682.729	657891.803	941543.55	729395.408
Storey5	15	430801.041	576452.043	660868.486	959482.575	735531.139
Storey4	12	432565.611	578621.538	664140.600	979076.588	742451.845
Storey3	9	436234.687	583485.622	669113.931	1000994.765	752672.284
Storey2	6	454836.002	614053.313	693394.350	1046053.836	784400.695
Storey1	3	679024.647	983913.691	1056802.311	1564030.605	1146752.427
Base	0	0.000	0.000	0.000	0.000	0.000

VI. CONCLUSION

This paper found that the presence of staircase tremendously influences the design of beam & column in the periphery of staircase. Stairs have a significant contribution to the bidirectional lateral stiffness of the structure. Some of the major conclusion can be drawn from above analysis are listed below:

1) When staircase is in corner position the base shear in X-dir. is 1575 KN and 1225 KN when stair is in centre position, so it can be concluded that the base shear is more (approximately 28.5% in this model) in corner staircase position.
2) Maximum storey displacement due to earthquake in X-direction (EQx) when staircase is in centre is 20.332 mm & 22.361 mm when stair is in corner so it can be concluded that displacement is more in corner position of stair (approx. 10% more).
3) When stair is in corner position the lateral load on 10th storey in X-dir. is 437 KN & 303 KN when stair is in centre position due to EQx, so it can be concluded that the lateral load is more (approximately 44% in this model) in corner stair position.
4) When staircase is provided it contributes significantly in stiffness of structure.

The stair models yield less displacement at the center position rather than the corner ones in the study. Similarly, while considering the case of lateral load, greater values are evolved for corner positions of stair which implies that the structure could be stiffer by assigning the staircases at centre positions rather than corner

VII. ACKNOWLEDGMENT

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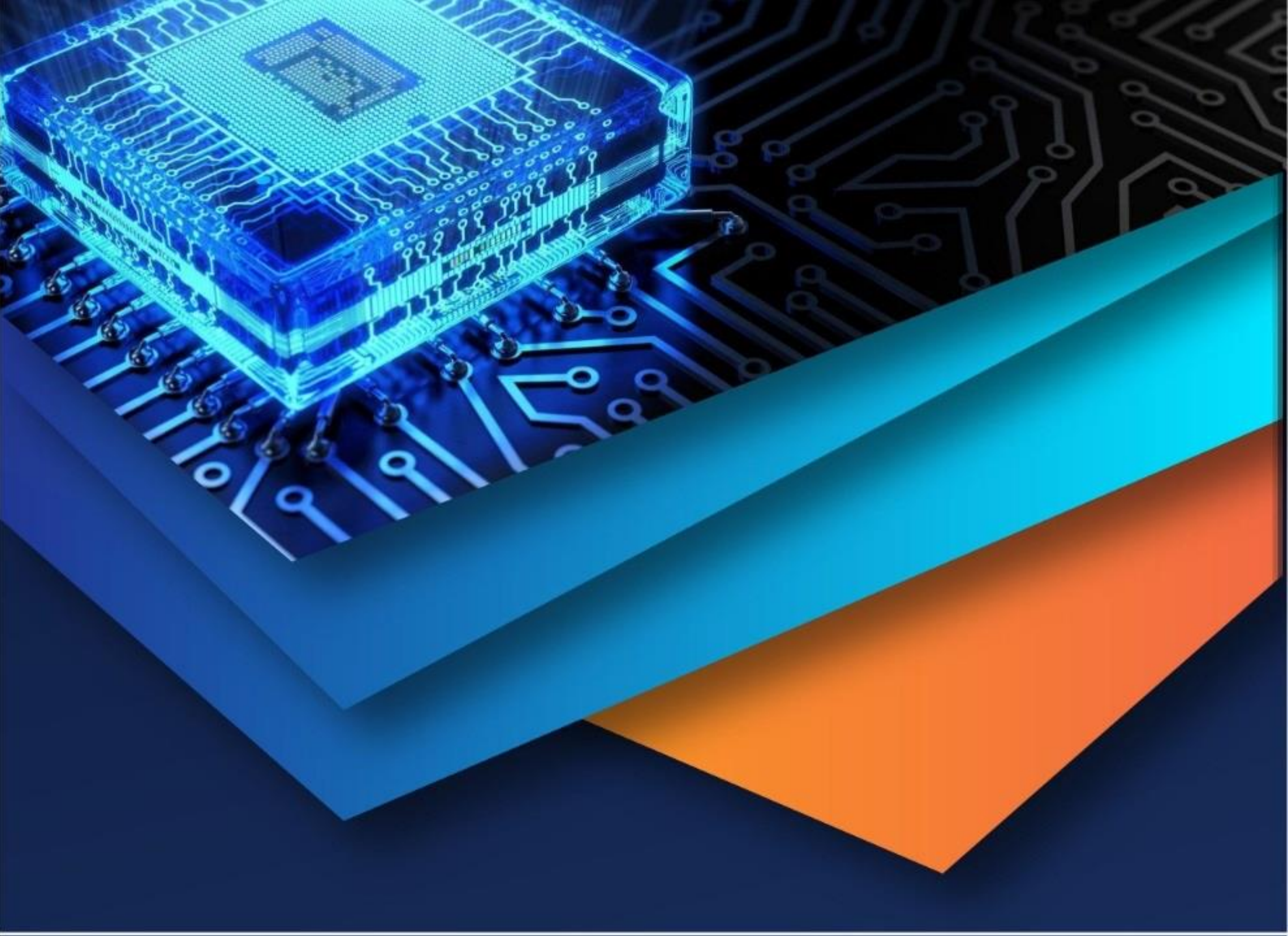

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