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Seismic Behavior of RC Buildings with Effect of Staircase and Elevator Core Wall

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Abstract. ***Staircase and elevator are the main structural components in multi-story buildings to enable access to different floor levels. In many Multi-storey buildings staircase and elevator core wall are located at different positions as per the benefits of structure plan and user. The position of the staircase and elevator core wall plays a vital role and changing the position of the stair case and core wall leads torsional irregularity in the plan regular building. The torsion in a building occurs because of eccentricity in the mass and stiffness distributions. The staircase and core wall is an integral part of the building, and its position may change the dynamic characteristic of regular plan building. In this paper, an attempt is made to understand the seismic behaviour of RC buildings with the effect of staircase and elevator core wall with changing position. Six models of 5 storey RC buildings with different positions of staircase and elevator core wall, i.e. ideal frame, Centre, Corner, Edge-Opposite, Edge-Adjacent and Corner with cantilever or balcony are considered. The modelling and analysis is done using ETABS v17. The response spectrum analysis and Modal analysis is performed, and Results of storey displacements, storey drift, storey shear, storey stiffness, base shear and torsion irregularity are discussed. From the results, it can be observed that building model with an edge-opposite position of staircase and elevator core wall performs better than other building model and torsion for it came within the code suggested ratio of 1.2.***

Keywords: RC building, Response spectrum analysis, Staircase and Elevator core wall, Torsional effect.

I. INTRODUCTION

In multi-storey buildings staircase and elevator core wall are located at Centre, Corner, edge, etc. positions according to architectural plan and usage. A conventional staircase consists of inclined slabs known as waist slab that rest on beams at mid-landing and floor landing at different floors. Dog-legged type of staircase is commonly used in residential and commercial buildings, and it consists of two flights running in opposite directions, separated by half landing. In man-made and seismic hazards staircase serves as escape routes, the asymmetrical position of the staircase is a significant cause of damage failure of the staircase. Elevator core wall can be used as reinforced concrete (RC) shear wall to increase the stiffness of the structure. Due to non-uniform positions of staircase and elevator core wall eccentricity arises between the centre of mass and centre of rigidity in the structure which leads to plan irregularity. Torsional irregularity is a type of plan irregularity. Torsional irregularity arises in the structure due to eccentricity between the centre of mass and centre of rigidity. However, from past earthquakes, it can understand that buildings with regular geometry and uniformly distributed mass and stiffness in the plan as well as in elevation suffer much less damage compared to irregular configurations. Damage reports on past earthquakes have indicated that torsional effects cause significant damage to buildings or sometimes leads to collapse. In Chile earthquake (1985) a building in Valparaiso, with staircase and elevator at the corner and surrounded by reinforced concrete wall leads to lack of balance in rigidity was such that building rotated around its centre of rigidity, which leads to the collapse of the building. In 1985 Mexico earthquake (M 8.0) occurred a building collapsed due to stiffness irregularity, which leads to torsion and Bhuj (2001) earthquake damages were observed in staircases in a two-wing structure connected through the stair and elevator core with the open ground storey. Study on the effect of staircase and elevator core wall location on seismic resistance capacity of the structure is minimum. Past literature shows torsional irregularity in multi-storey buildings and optimum positions of staircase and core walls. Srinivasa Rao bosta et al. (2017) studied the influence of the staircase and shear wall in the lift core wall in a building. A five-storey RC building was modelled and performed nonlinear static analysis for models with a staircase only and for models with both a staircase and an elevator core at different locations [7]. The torsional irregularity in multi-storey buildings was studied by Rahila Thaskeen et al. (2016). Authors considered symmetric structure, asymmetric model, L-shape model and c-shape model of G+7 multi-storey RC buildings having the same area and with different locations of shear wall cores. Linear dynamic analysis was carried out on models in ETABS V2015 software. Highest torsional irregularity ratio was found for C-shape structure [6]. Chandana. S et al. (2017) performed linear dynamic analysis on G+20 RC building models with both symmetric and asymmetric in plan with shear walls at different locations, modelling and analysis is done by using STAAD-Pro V8i software. The results obtained shows that the symmetric plan model with a shear wall placed along the periphery performs better[1].

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In this study, the buildings models with different positions of staircase and elevator core wall, i.e. Centre, Corner, Edge-Opposite, Edge-Adjacent and Corner with cantilever or balcony are considered. In RC mid and high rise building, staircase, core wall and balcony are constructed as an integral part of the building.

The effect of the balcony is also considered for this study. Modelled and analyzed using ETABS v17. Response spectrum analysis is carried on building models. The torsional irregularity is calculated for all building models. Torsional irregularity is another criterion which measures the extent of the torsion effect on the structures. It can be expressed as the ratio of maximum displacement to the average displacement of the individual story. It can be expressed as,

$$\frac{\Delta_{max}}{\Delta_{avg}} > 1.2$$

Δ_{max} = Maximum displacement

Δ_{avg} = Average of the displacement

II. OBJECTIVE OF WORK

The main aim of the study is to understand the seismic behaviour of RC buildings with the effect of the staircase and elevator core wall at different positions in symmetrical building plan and to check torsion irregularity in buildings.

III. STRUCTURAL DETAILS

In this study, six models of five-storey RC building is modelled and analyzed using ETABS software. Details of geometry and material properties of all building models are the same and listed in table-I.

Table I Details of building model

Building members	Dimensions
Size of building	30m × 18m
No. of bays along the x-direction	5
No. of bays along the y-direction	3
The total height of the building	15m
Each story height	3m
Total no. of stories	5
Balcony length (cantilever beam at floor level)	1.70m
Grade of concrete	M25
Grade of steel	Fe 415

In this paper, six-building models of five-storey with different locations of staircase and elevator core wall are considered. Building models are designed according to IS 456:2000 [2]. The sizes of column and beam are 400 mm × 450 mm and 350 mm × 400 mm respectively. The thickness of the slab, exterior wall and interior wall is 125 mm, 230 mm and 150 mm respectively. The Response spectrum analysis is carried out by considering vertical loads and self weight of the members according to IS 875 (part 2) [5] and IS 875 (part 1) [4] respectively, live load on floors and waist slab are 2 kN/m^2 and 3 kN/m^2 respectively. Floor finish 1 kN/m^2, exterior wall load 14 kN/m, and interior wall load 9 kN/m is considered in this study. The seismic details are considered as per IS 1893-2002 [3] . Seismic details of the structure are presented in table-II.

Table II Earthquake Details

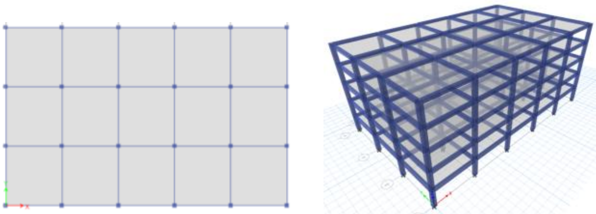
Earthquake zone	V
Zone Factor (Z)	0.36
Importance factor (I)	1
Soil type	Type II
Damping ratio	5%
Response reduction factor (R)	5

Details of building models considered in this study have shown in table-III. The plan and the 3D view are shown in Fig. 1. Model-1 is bare frame building without staircase and elevator core wall, model-2 is bare frame building with staircase and elevator core wall at centre position, model-3 is bare frame building with staircase and elevator core wall at corner position, model-4 is bare frame building with staircase and elevator core wall at Edge-opposite position, model-5 is bare frame building with staircase and elevator core wall at Edge-Adjacent position, model-6 is bare frame building with staircase and elevator core wall at corner with cantilever projections.

Table III Model details

Building models	Descriptions	Notations
Model-1	Bare frame building without staircase and elevator core wall	IF
Model-2	Staircase and elevator core wall at Centre position	CEN
Model-3	Staircase and elevator core wall at corner position	COR
Model-4	staircase and elevator core wall at edge opposite position	ED-OPP
Model-5	Staircase and elevator core wall at edge adjacent position	ED-ADJ
Model-6	Staircase and elevator core wall at corner and balcony (cantilever beam)	BAL

In this paper the elevator core consists of a continuous RC structural wall of 2m × 2m size, 150mm thickness and it can open one side to access at every floor level. M20 grade concrete is adopted as the material of the elevator core wall. The dog-legged staircase is considered in this study, the width and thickness of the waist slab are 1m and 150 mm, respectively.The balcony (cantilever beam) are considered in two directions of the plan at each roof level, and its length is taken as 1.7m.



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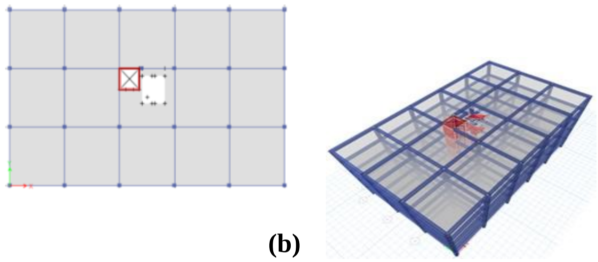

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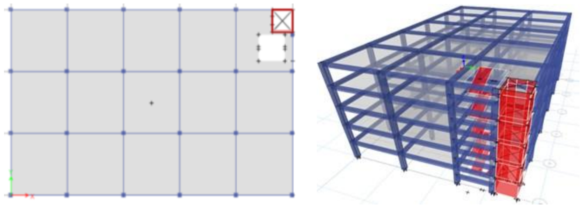

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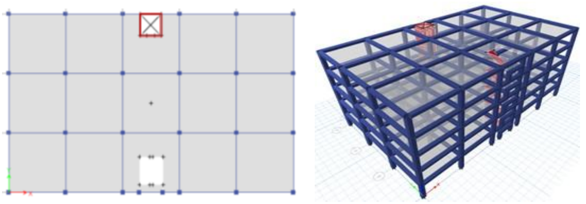

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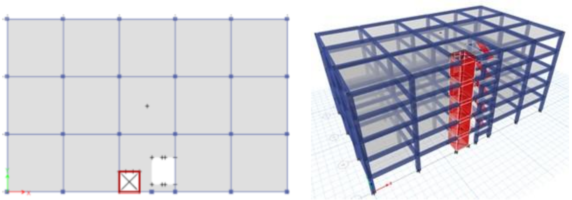

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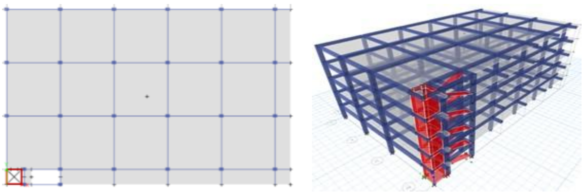


(f)

Fig.1: Plan and 3D view of (a) Model-1, (b) Model-2, (c) Model-3, (d) Model-4, (e) Model-5 and (f) Model-6.

IV. ANALYSIS

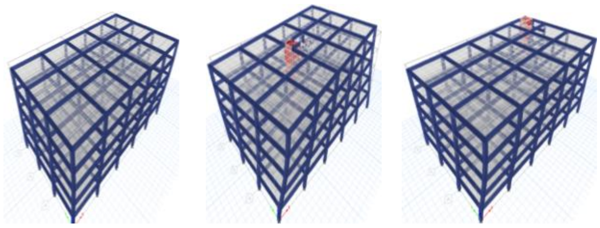
The modelling and analysis of the building are carried out using ETABS v17. The Modal analysis and response spectrum analysis method is performed in this study.

V. RESULTS AND DISCUSSIONS

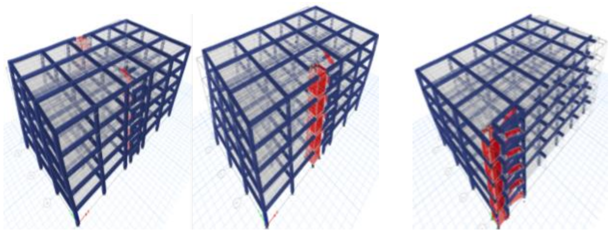
The results obtained from the analysis are discussed in this section. The parameters like time period, base shears, story shears, story displacements, story drifts, story stiffness and torsion irregularity are discussed.

A.Modal Analysis

Modal analysis is carried for building models with different positions of staircase and elevator core wall and first mode shape of considered building models are shown in Fig. 2.



(a) (b) (c)



(d) (e) (f)

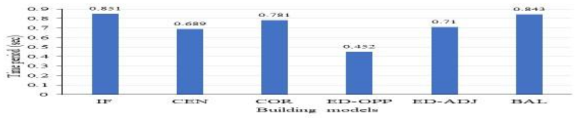
Fig. 2: First mode shapes of (a) IF, (b) CEN, (c) COR, (d) ED-OPP, (e) ED-ADJ and (f) BAL.

From Fig. 2, it is observed that the first mode as translation mode shape in building without staircase and elevator core wall, whereas, building models with staircase and elevator core wall has first mode shape as rotation mode, it is due to, eccentricity between the centre of rigidity and centre of mass. Building with staircase and elevator core wall in edge opposite position has the first mode as rotation but with least displacement in x and y-direction. Table-IV shows eccentricity between the centre of mass and centre of rigidity in all building models.

Table IV Center of mass and center of rigidity

MODEL	XCM (m)	YCM (m)	XCR (m)	YCR (m)	e_x (m)	e_y (m)
IF	15	9	15	9	0	0
CEN	15	9	14.46	10.58	-0.54	1.55
COR	15	9	25.14	13.34	**10.16**	**4.37**
ED-OPP	15	9	15.18	7.72	0.19	-1.27
ED-ADJ	15	9	15.35	2.93	0.35	-6.01
BAL	15.68	9.92	6.78	2.77	**-8.9**	**-7.1**

From table-IV, it is observed that eccentricity is zero in the ideal frame building model. Building models with staircase and elevator core wall at centre and edge-opposite has minimum eccentricity in both x and y direction, and building models corner, edge adjacent and balcony position of staircase and elevator core wall have maximum eccentricity in one or both x and y-direction. In mode-6, the centre of mass and centre of rigidity value increased as compared to other models.



From Fig. 3, it observed that time period for the ideal frame has shown the maximum time period of 0.851 sec and time period for building model with staircase and elevator core wall at edge opposite has the minimum time period of 0.452 sec, compared to other building models. The Building model with staircase and elevator core wall at centre, corner, edge-adjacent, and corner with cantilever time period has increased by 33%, 42%, 36%, and 46% respectively, when compared to the edge-opposite building model. Building models without staircase and elevator core wall has a maximum time period because it is flexible. Building model with staircase and lift core wall at edge opposite has the minimum time period because it has a staircase and elevator core wall at the symmetrical position. The time period of balcony position is very near to the ideal building model.

B. Base Shear

The base shear results are shown in Fig. 4 and base shear is minimum in the ideal frame building model. It is observed that when compared to ideal frame base shear varies by large values in the building models with staircase and elevator core wall in both x and y directions. Base shear in building model with staircase and elevator core wall at centre, corner, edge-opposite, edge-adjacent and corner with cantilever has increased by 34%, 35%, 34%, 37% and 40% in x-direction and 34%, 8%, 38%, 38% and 15% in y-direction.

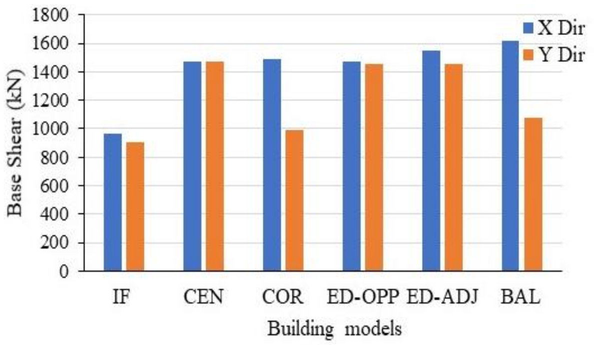
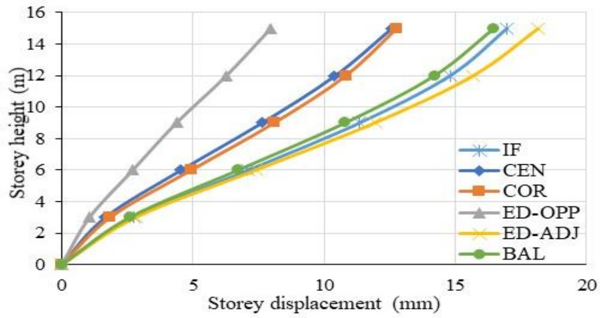


Fig. 4: Base shear for different buildings models

From Fig. 4 it is observed that building models with staircase and elevator core wall at centre and edge-opposite positions has approximately same value in x and y direction i.e. 1472 kN and 1470 kN respectively in x-direction, 1472 kN and 1458 kN respectively in y-direction as these building models has less eccentricity between centre of mass and centre of rigidity in both x and y direction compared to other building models.

C.Storey Displacement

The storey displacement results are shown in Fig. 5(a) and Fig. 5(b). From Fig. 5(a) it is observed that model-4 has minimum storey displacement of 7.972mm and model-5 has maximum storey displacement of 18.16mm when compared with other models. The storey displacement of model-2, model-3, model-4 and model-6 has decreased by 26%, 24%,53% and 2.8% respectively when compared with model-1 in x-direction. From Fig. 5(b) it is observed that model-4 has minimum storey displacement of 7.709mm and model-3 has maximum storey displacement of 2.26mm when compared with other models. The storey displacement of model-2, model-4, and model-5 has decreased by 42%, 57%, and 55% respectively when compared with model-1in y-direction.



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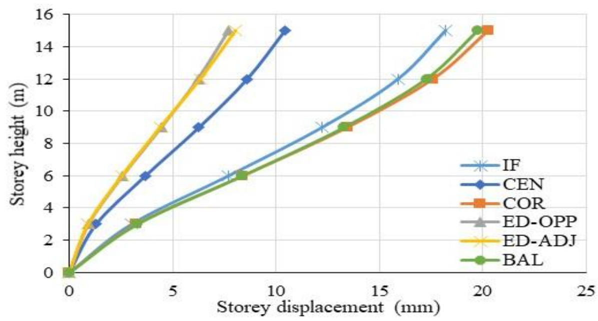


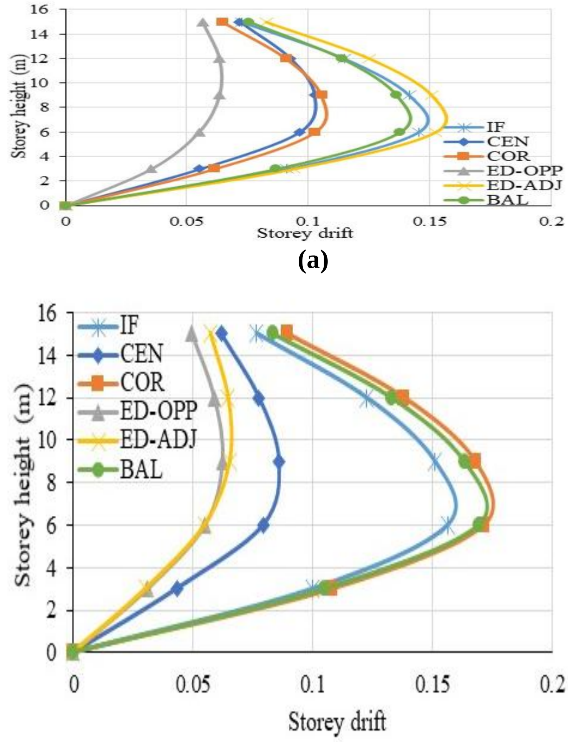
(b)

Fig. 5: Story displacements for different building models (a) x-direction (b) y-direction

From the above results, it can be observed that displacement is minimum in model-4 in both x and y directions, it is due to stiff elements like the staircase and elevator core wall are placed in symmetric position. i.e. At edges opposite to each other. The maximum storey displacement is in model-5 in x-direction and model-3 in the y-direction.

D.Storey Drift

The storey drift of different building models is shown in Fig. 6(a) and Fig. 6(b). From Fig. 6(a) it is observed that model-4 has minimum storey drift of 0.055 and model-5 has maximum storey drift of 0.1524 and storey drift of model-2, model-3, model-4 and model-6 has decreased by 39%, 33%,61% and 5% respectively when compared with model-1 in the x-direction.



(a)

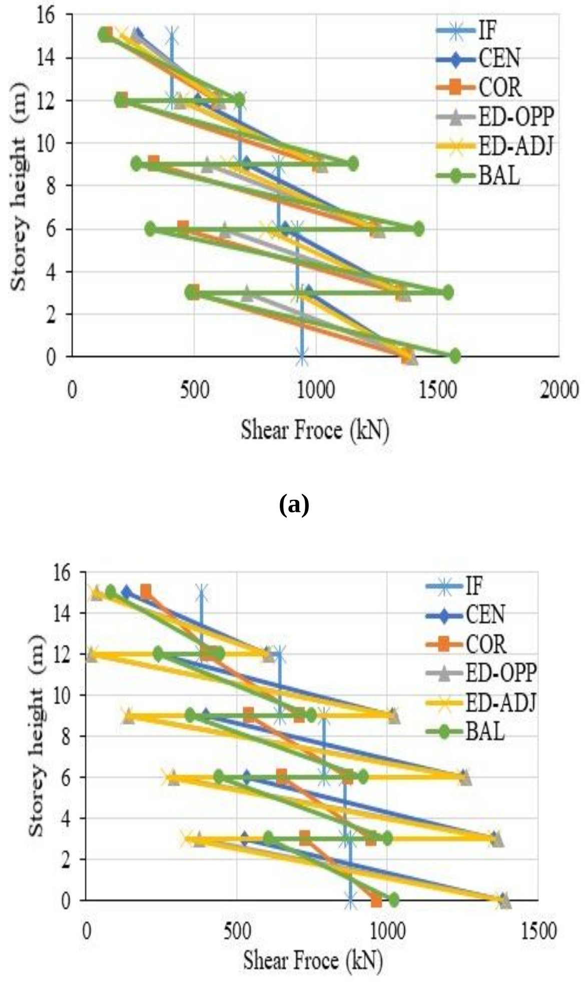
(b)

Fig. 6: Storey drifts for different building models (a) x-direction (b) y-direction

From Fig. 5(b) it is observed that model-4 has minimum storey drift of 0.0551and model-3 has maximum storey drift of 0.1717 when compared with other models. The storey drift of model-2, model-4, and model-5 has decreased by 57%, 69%, and 70% respectively when compared with model-1in y-direction. From above results, it can be observed that drift is minimum in model-4 in both x and y directions. The storey drift is maximum in model-5 and model-3 in x and y direction respectively.

E. Storey Shear

In Fig. 7(a) model-6 has maximum storey shear of 1575.54KN and model-1has minimum storey shear of 943.03KN, model-6 has 40% more storey shear when compare to model-1 in the x-direction. In Fig. 7 (b) model-4 has maximum storey shear of 1394.84KN, and model-1 has minimum storey shear of 878.94KN, model-4 has 37% more storey shear when compare to model 1 (IF) in the y-direction. It is observed that in building model without staircase and elevator core wall centre of mass and centre of rigidity coincide at one point with zero eccentricity so this building model experiences only lateral force without any resistance force, Whereas in building models with staircase and elevator core wall, stiffness or rigidity shift towards staircase and elevator core wall which leads to eccentricity between centre of mass and centre of rigidity.These building models experiences lateral force coupling with resistance force causing torsional moments in the building. From Fig. 7(a) and 7(b) we can observe that storey shear for model-1 does not have any resistance fore against lateral force both in x and y direction as its centre of mass and centre of rigidity coincides at the same point because it does not have any lateral stiff elements. In other building models with staircase and elevator core wall at centre, corner, edge-opposite, edge-adjacent and corner with cantilever positions distribution of lateral force with resistance force cause torsional moments this coupling of forces occurs due to shifting of the centre of rigidity or stiffness towards stiff elements.



(a)

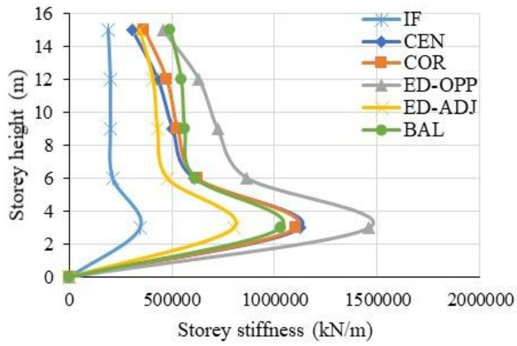
(b)

Fig. 7: Story shear for different building models (a) x-direction (b) y-direction

F. Storey Stiffness

The storey stiffness of different building models is shown in Fig. 8(a) and Fig. 8(b). From Fig. 8(a) it is observed that model-1 has minimum storey stiffness of 345043.7 kN/m and model 4 has maximum storey stiffness of 1458200 kN/m, storey stiffness of model-2, model-3, model-4, model-5, and model-6 has increased by 69%, 68%, 76%,56% and 66% respectively when compare to model-1 in x-direction. similarly, in Fig. 8(b) model-1 has minimum storey stiffness of 292343.2 kN/m, and model-4 has maximum storey stiffness of 1660492 kN/m. The Storey stiffness of model-2, model-3, model-4, model-5, and model-6 has increased by 79%, 45%, 82%, 81% and 48% respectively when compare to model-1 in y-direction. Storey stiffness in model 4 (ED-OPP) is maximum in both x and y directions when compared with other building models.

The staircase and elevator core wall increases the stiffness of the structure but, the position of staircase and elevator core wall plays an important role to strengthen the structure and to perform better during seismic events.



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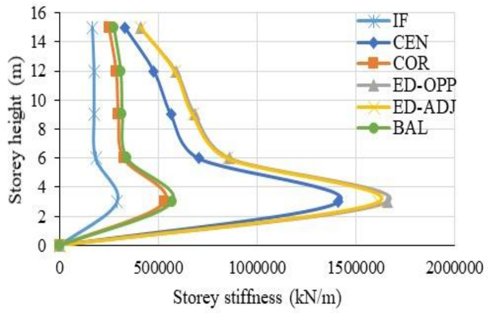

(b)

Fig. 8: Story stiffness for different building models (a) x-direction and (b) y-direction

G. Torsional Irregularity

From Fig. 9, torsional irregularity values for model-1(IF), model-2 (CEN), model-3 (COR), model-4 (ED-OPP), model-5 (ED-ADJ), and model-6 (BAL) are 1, 1.2, 1.3, 1, 1.5 and 1.5 in x direction and 1, 1.14, 1.7, 1.02, 1 and 1.6 in y direction respectively. It is observed that for model-1(IF), model-2(CEN), model-4 (ED-OPP) has values less than 1.2 in both x and y direction, thus, there is no torsion in these building models. whereas in model-3 (COR), model-5 (ED-ADJ) and model-6 (BAL) has values more than 1.2 in one direction or in both x and y direction, which leads to torsion in these building models.

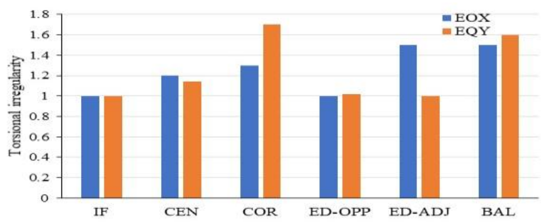

Fig. 9: Torsional irregularity for different building models in x and y directions

VI. CONCLUSIONS

1. In this study, seismic behaviour of RC buildings with the effect of the staircase and elevator core wall at different position in the symmetrical building has been carried out.
2. Time period changes with respect to the position of the staircase and core wall for the same building model and by providing the balcony in the building becomes more flexible. The time period is minimum in building with staircase and elevator core wall at edge opposite position when compared to other Building models.
3. In the presence of staircase and core wall in the building, the base shear values have been increased, and storey displacement and drift values have been decreases. It is observed that changing the position, the base shear, storey displacement, story drift, storey shear and story stiffness value are altered in both x and y direction in all model.
4. The position of the stair case and core wall, story shear values at each story increased as well decrease in except ideal building model because of centre of mass and centre of rigidity shifted, and it creates the torsion force on each storey level.
5. Building model with staircase and core wall at edge opposite and centre position has torsional values less than 1.2 which indicates there is no torsion in this building model and in other building models torsion exist.
6. It concludes the position of building with staircase and core wall at the edge opposite position and centre performs better when compared to building models with staircase and elevator core wall at the corner, edge-adjacent and corner cantilever positions.

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