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Effect of Shear Wall Location on the Linear and Nonlinear Behavior of Eccentrically Loaded Buildings

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Abstract

Objectives: To discuss the effect of shear wall and its location on the linear and nonlinear behavior of irregular buildings with different eccentricities. **Analysis:** The behavior of eccentrically loaded buildings with and without shear wall is compared using linear static, linear dynamic and nonlinear static analysis with the help of a finite element based software. The parameters considered are Base shear, Storey drift, Torsion and Reinforcement in columns and hinge formation in the structure. **Findings:** The study concludes that provision of a box type shear wall at the core gives the best behavior but it is not desired from architectural point of view. Hence shear wall on the outer edges is more advisable to improve the behavior of asymmetric buildings. The location of shear wall do not have significant effect on the nonlinear behavior except that the position of hinges vary. **Novelty:** The study of effect of shear wall location in eccentrically loaded structures, especially its nonlinear behaviour gives a more precise idea on provision of shear wall.

Keywords: Behavior, Eccentricity, Location, Loaded, Shear wall

1. Introduction

High rise buildings structures offer some major advantages but also pose serious challenges to designers in the case of seismic and wind loading. The height of the building plays a very important role in its seismic performance[10]. When these high rise buildings have eccentric distribution of mass and stiffness, then their design becomes even more challenging. Due to asymmetry, there will be eccentricity between the Center of Mass (CM) and Center of Rigidity (CR) thereby inducing torsion. This torsional behavior of asymmetrically loaded building is one of the most frequent causes of structural damage and failure during strong ground motions. When such building is designed without shear wall, beam and column sizes are quite heavy and there is lot of reinforcement congestion at the joints which makes it difficult to place and vibrate concrete at these places. Hence buildings with shear wall are more economical[1]. The use of shear wall in high rise structure is more effective than use in low rise building[2]. The size, configuration and position of shear wall affects the behavior of the building. Shear walls away from center of gravity increases most of the member forces[3]. The existence of shear wall reduces remarkably shear deformation at the lower frame[4]. The studies on shear wall have been concentrated on symmetric buildings while asymmetric structures and its nonlinear behavior have not been researched on yet. The objective is to have a detailed study of the behaviour of eccentrically loaded buildings with and without shear wall using linear static, linear dynamic and nonlinear static analysis.

2. Methodology

A geometrically symmetrical building structure has been considered for this study with asymmetric loading. Its behaviour has been studied with various positions of shear wall.

2.1 Description of Building Structure

To study the behaviour of RCC frame structures with

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asymmetric distribution of mass in plan, a 24m x 24m grid, G+14 storey RCC bare frame has been used. The shear wall is modelled using shell elements. A total of 40 models, have been analysed each of which as described below.

- No of bays along X axis :6
- No of bays along Y axis :6
- Spacing in both directions :4m
- No of stories :G+14
- Storey height :3.5m
- Size of column :0.4x0.4m
- Size of beams :0.3x0.4m
- Slab :0.12m thick
- Shear wall :0.2m thick

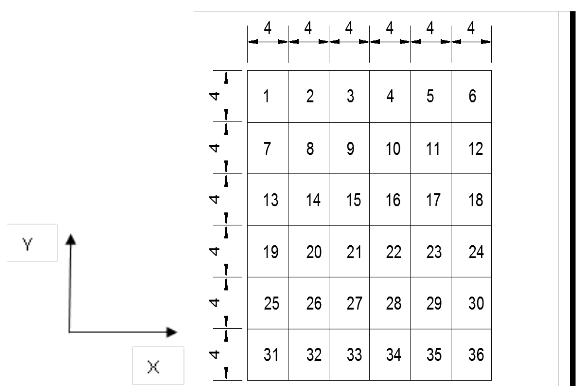

Figure 1. Plan view of the bare frame.

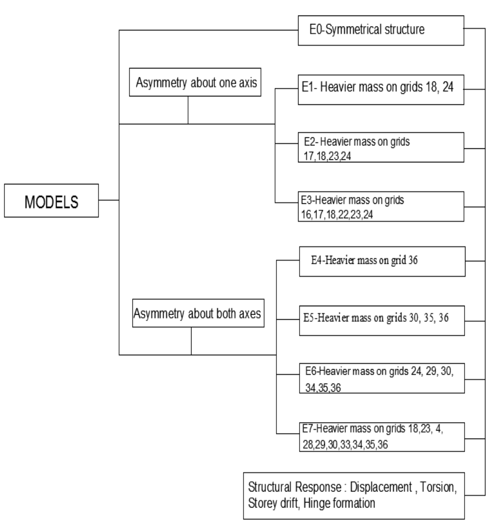

Figure 2. Description of various load arrangements for the study.

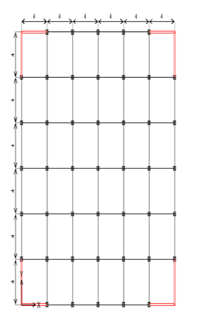

Figure 3. Plan view of model SW1.

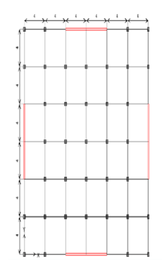

Figure 4. Plan view of model SW2.

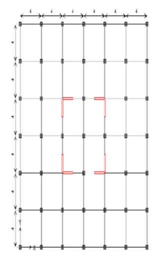

Figure 5. Plan view of model SW3.

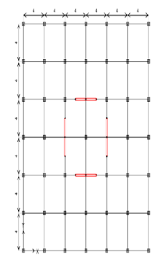

Figure 6. Plan view of model SW4.

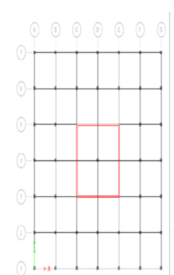

Figure 7. Plan view of model SW5.

Two sets of models, one with shear wall and one without shear wall has been analysed, the load arrangement of which is as shown in Figure 2. Various positions of shear wall as shown in Figures 3 to7 have been considered. For pushover analysis, coupled PMM interaction plastic hinges are assigned to columns and moment M3 hinges are assigned to beams.

2.2 Design data

Following design parameters have been considered for the study:

Live load : 3kN/m^2 on typical floor
Floor finish : 1kN/m^2 on typical floor

Earthquake load for Type II : As per IS 1893:2002(Part 1)[5]
Seismic zone : II
Wind load : As per IS 875(Part 3)[6], Class C, Terrain category 3

3. Results and Discussions

Linear and nonlinear static pushover analysis is performed to investigate the behaviour of the building frame. Various load combinations as per IS 1893:2002[5] are also used for this purpose. Pushover analysis procedure is followed as per the prescriptions in ATC-40[7]. The hinge properties are applied by default method as per codal provisions in FEMA 356[8].

3.1 Eccentricity

For asymmetric structures the centre of mass and rigidity does not coincide. The eccentricity is defined as the difference between the Centre of Mass (CM) and the Centre of Rigidity (CR). Since the shear walls have been provided symmetrically for the study, the eccentricity does not change. For buildings with high eccentricity, shear wall can be provided such that the eccentricity between CM and CR reduces.

3.2 Torsion

Although in a building moments are unavoidable, torsional moment is that which all structural engineers try to eliminate as they cause undesirable responses in the structure. Provision of shear wall reduces the torsion in the building and the average torsion is observed in earthquake load combination and is shown in Figure 8. Torsion is zero for wind loading. For earthquake loading, rate of increase of torsion is directly proportional to that of eccentricity. For box type shear wall at the core, torsion induced in column is the minimum. When shear wall is provided in the outer edges, the torsion has reduced by a large amount.

3.3 Top Storey Displacement

The magnitude of displacement due to wind load is higher than that of seismic loads and increases with the eccentricity due to mass asymmetry. As the eccentricity increases the variation in displacement for positive and negative direction loading increases. Structures with shear wall have lesser top storey displacement than those without shear wall and displacement is minimum when shear wall is provided at the core as an enclosed box as shown in Figure 9. Also the presence of shear wall reduces the difference in positive and negative direction loading behaviour of mass asymmetric buildings.

3.4 Base shear and Storey Drift

Storey drift is defined as the relative displacement of adjacent stories and is given by the following formula.

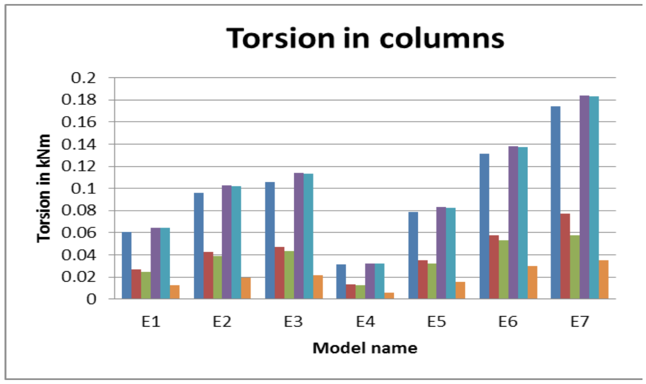

Figure 8. Average Torsion in the columns for seismic load in Y direction.

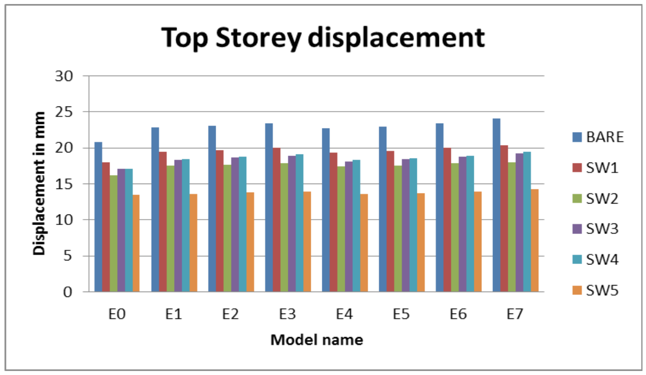

Figure 9. Top storey displacements in the models for seismic loading in Y direction.

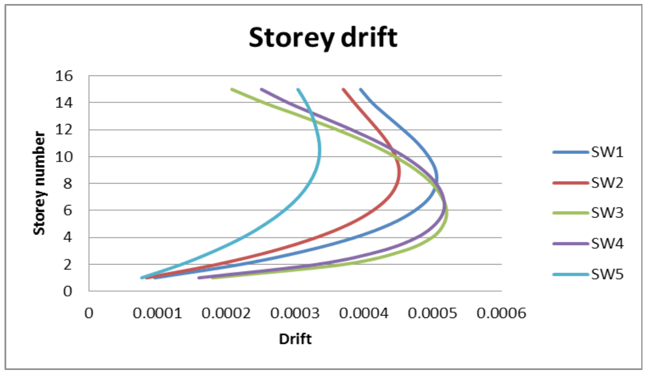

Figure 10. Storey drift due to seismic load in Y direction for model E6.

$\Delta = (\delta_i - \delta_{i-1})/h$

Δ - Storey drift

δ_i - Displacement of the i th storey

h - Storey height

The base shear increases due to provision of shear wall. As shown in Table 1, the buildings with shear wall at the core has maximum base shear. When shear wall is provided at the corners the base shear is found to be lesser by 20% than when provided at the centre of outer edges. When shear wall of lesser length is provided near the core, base shear reduces due to the different sizes.

Table 1. Percentage increase in base shear for shear walled buildings

Model	SW1	SW2	SW3	SW4	SW5
E0	50.12	70.07	35.6	39.13	150.4
E1	50.18	70.43	38.82	41.9	129.93
E2	49.98	70.22	39.36	42.37	129.61
E3	49.83	70.02	39.7	42.65	129.34
E4	50.27	70.53	38.47	41.59	130.1
E5	50.13	70.38	38.39	41.5	129.58
E6	49.92	70.14	38.28	41.39	129.34
E7	49.67	65.95	38.14	41.25	128.91

When shear wall was provided the storey drift reduced by 14.7% for model SW1, 23.8% for model SW2, 12.2% for model SW3, 12.8% for model SW4 and 43.4% for model SW5[Figure 10]. Hence providing shear wall at the core edges reduced storey drift by a greater amount. When shear wall is provided at the outer edges, the increase in drift with increase in eccentricity reduces more when compared to shear wall at the core.

3.5 Time Period

The time period of the structure increases with increase in mass as shown in Table 2. Time period decreases when shear wall is provided and is minimum for shear walls on the outer edges of the structure.

3.6 Percentage Area of Reinforcement

Concrete frame design is done as per IS 456:2000[9] and the maximum percentage area of reinforcement for column is calculated and is shown in Table 3. For asymmetrically loaded structures, rebar percentage is higher than that of symmetrical case. The maximum reinforcement percentage that can be given to columns as per IS 456:2000[9] is 4%. Provision of shear wall reduces the percentage reinforcement in columns especially in those columns near the shear wall. The effect of location of shear wall is more as eccentricity increases. Providing shear wall at the core of the structure reduces the reinforcement demand more.

Table 2. Fundamental time periods of all models

Model	Time period					
	BARE	SW1	SW2	SW3	SW4	SW5
E0	2.049	1.496	1.321	1.665	1.646	1.619
E1	2.264	1.619	1.427	1.8	1.774	1.074
E2	2.297	1.639	1.445	1.817	1.791	1.087
E3	2.326	1.658	1.462	1.825	1.798	1.1
E4	2.248	1.609	1.419	1.796	1.771	1.068
E5	2.287	1.63	1.437	1.835	1.809	1.081
E6	2.346	1.66	1.464	1.882	1.854	1.101
E7	2.416	1.7	1.471	1.933	1.903	1.127

Table 3. Percentage reinforcement in columns

Model	SW1	SW2	SW3	SW4	SW5
E0	3.72	3.68	2.32	2.41	2.19
E1	3.92	3.75	2.95	2.94	2.63
E2	4.73	4.01	3.71	3.7	3.29
E3	5.48	5.34	3.78	3.77	3.33
E4	3.77	3.72	2.72	2.81	2.64
E5	3.79	3.74	3.58	3.69	3.48
E6	4.27	4.16	4.13	4.24	4.04
E7	5.21	4.2	4.27	4.39	4.18

3.7 Nonlinear Behavior

Pushover analysis is done for all the models. They are pushed above the target displacement and the sequence of formation of hinges is studied. For asymmetrically loaded structures without shear wall, hinges

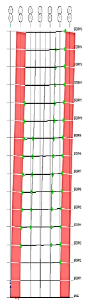

Figure 11. Hinge formation in the structure.

are formed in the beams in asymmetry area at small displacements whereas when shear wall is provided the effects of asymmetry reduces. Hinges are formed first in the beams connected to the wall and then in the columns near the wall. The beams in the second to fourth stories show plastic behaviour initially for bare structures whereas for structures with shear wall hinges are formed more in the middle stories as shown in Figure 11. All hinges are within the Immediate Occupancy level (IO). Structures with asymmetry about one direction have almost same nonlinear behaviour as symmetrical structures.

4. Conclusions

The linear behaviour of all the models is studied and the following conclusions are drawn:

1. The provision of shear wall improves the lateral stability of the building especially for asymmetrical structures.
2. When shear wall is provided at the core as a box, the displacement, drift and torsion reduces by a larger value. Since provision of a box type shear wall at the core is practically not preferred, providing shear wall on the outer edges is the next best option.
3. Base shear increases when shear wall is provided and it is maximum when shear wall is provided at the core.
4. Reduction in the time period of the structure is due to the presence of shear wall. The position of shear wall has only a small effect on the time period of the structure and this might be due to the difference in length of shear wall.
5. Buildings with shear wall have lesser reinforcement demand in the columns as the shear wall is designed for both lateral load and gravity load. Provision of shear wall at the core reduces the reinforcement in columns more than when provided at the outer edge.
6. Buildings with shear wall show more plastic behaviour in the middle stories. As the position of shear wall varies, the only difference is that the beams and columns near the shear wall come into plastic stage first.

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