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Effectiveness of Configuration of Shear Wall on Performance of a Torsionally Irregular Structure During an Earthquake

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Abstract:- When the mass of on one side of a building is more than the mass on the other side, the heavier side of the building tends to move more as compared to the lighter side under the influence of seismic forces. The horizontal displacement of the floors that occurs in such cases, in addition to rotation is termed as torsion. Excessive torsional behavior severely affects the building during an earthquake. Torsion should be minimized by ensuring symmetry in plan. However, it may not be always possible to have a structure with uniformly distributed mass and uniformly placed lateral load resisting systems. Mostly, structures are designed without considering effects of dynamic forces. But the negligence of dynamic forces sometimes proves to be the cause of disaster, particularly in case of earthquake. In this study, a torsionally irregular structure subjected to the 2001 Bhuj earthquake, is tested with different configurations of shear walls, namely, rectangular, C, T, and I, to derive an arrangement which ensure maximum safety to a torsionally irregular structure during the occurrence of the earthquake. The models are analyzed in ETABS 18 software using the time history data of Bhuj earthquake and are compared based on horizontal displacement, story drift, base shear, eccentricity, and torsional irregularity. It has been concluded that the model with I-shaped shear wall arrangement is the most ideal for the structure.

***Keywords:-** Torsion; Shear Wall; Eccentricity; Time History; Bhuj Earthquake; Irregularity.*

I. INTRODUCTION

A structure is termed as regular, when it is symmetrical in plan and elevation about the axis and has uniform distribution of horizontal force-resisting system. The building which lacks symmetry in terms of geometry of the structure, mass distribution and placement of load-resisting elements, is known as an irregular structure. The asymmetric arrangement of mass and stiffness of elements leads to generation of large torsional forces in the building.

Sometimes, due to certain utility requirements, one side of the floors of a building may be subjected to heavier masses than the other side. During an earthquake, the heavier side of the structure tends to twist. This may cause significant damage or collapse to the structure.

Torsion can be avoided by planning the structure symmetrically, i.e., by uniform distribution of mass on all the floors. But it may not be possible to load the structure uniformly because of the functionality restrictions of the structure. In such cases, the arrangements should be made to account for the additional shear forces which arise. Hence, shear walls can be provided to reduce the eccentricity and resist the additional shear forces.

II. LITERATURE REVIEW

M. Durga Prasanna, Dr. B. Panduranga Rao – A Comparative study on Behavior of High-Rise Building with Shear Wall Under Seismic Analysis: The authors have carried out seismic analysis of 12-storied building using seismic coefficient method and response spectrum method. The results obtained from manual calculations are compared with those obtained from analysis in ETABS. Lateral load distribution, shear forces, bending moments and drifts at various levels of the building are worked out.

Mr. Basavalingappa, Mr. Anil Kumar B.– Analysis of High-Rise Building and its Behavior due to Shear Wall at Different Locations and in Different Seismic Zones: The response of a thirteen-storied symmetric building in seismic zones II, III, IV and V, with and without shear walls has been compared by analysis using ETABS software. Parameters like story drift, base shear, story displacement, etc. have been compared for each seismic zone.

MD Agroz Patel, Prof. Shaikh Abdulla – A Study on Positioning of Different Shapes of Shear Walls in L Shaped Building Subjected to Seismic Forces: In this research papers, the authors have carried out an investigation to study the optimum location and different shapes of shear walls in L-shaped twenty-one storied structure. The study is carried out based on parameters like time period, base shear, story drift and story displacement. The structure has been modelled and analyzed using ETABS software to determine the above parameters. Response spectrum analysis and time history method are used.

Pratibha Reddy T. – Evaluation of Multi-Story Building by Changing the Location of Shear Walls: A regular building without and with shear wall has been analyzed. Shear walls have been placed at three different locations and the response

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of the building with each position has been compared with the other.

III. OBJECTIVES

1. To identify the center of mass, the center of stiffness and the eccentricity in the structure.
2. To provide the most effective configuration of shear wall in order to reduce eccentricity for preventing the undesired effects of torsion on the performance and safety of the structure.
3. To identify the effectiveness of each configuration of shear wall on the performance of the structure during Bhuj earthquake.

IV. METHODOLOGY

A. General

A G+10 structure is modelled in ETABS 18. It is a 42 m*30 m reinforced concrete framed structure with 5 horizontal and 7 vertical bays of 6 m length. Two of the horizontal bays are loaded heavily to introduce torsion in the structure. Different arrangements of shear walls are studied. Rectangular, C, T and I-shaped shear walls are provided in the structure to explore the effectiveness of each of the arrangement on seismic performance of the structure.

The structure is analyzed by time history method using time history data of Bhuj earthquake.

B. Time History Method

Time History analysis technique is the most sophisticated method of dynamic analysis for buildings. In this method, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake at the base of the structure. The method consists of a step-by-step direct integration over a time interval. The equations of motion are solved with the displacements, velocities and accelerations of the previous step serving as initial functions.

In this study, the time history data of Bhuj earthquake is used which occurred on January 26, 2001. The magnitude of the earthquake was 6.9 on Richter scale. The epicenter of the earthquake was located near Bhachau with focal depth of 25 km radius of fault area as 23 kms.

V. DETAILS OF THE STRUCTURE

TABLE 1: DETAILS OF THE STRUCTURE

General Details				
Structure	RCC framed structure			
Storey Heights	3 m			
Material Properties				
Concrete Grade:	Steel Grade: HYSD 415			
Structural Members				
Beams	300 mm*500 mm			
Columns	300 mm*600 mm 400 mm*600 mm 500 mm*500 mm 500 mm*600 mm			
Slab	150 mm			
Shear Wall	200 mm			
Loading (kN/m²)				
Slabs	***Roof***		***Storey 1-10***	
	D.L.	L.L.	D.L.	L.L.
Rows 1, 2, 3	1.5	1.5	2	3
Rows 4, 5	3	1.5	4	3

VI. SHEAR WALL ARRANGEMENTS

Fig. 1. Model 0 – No Shear Wall

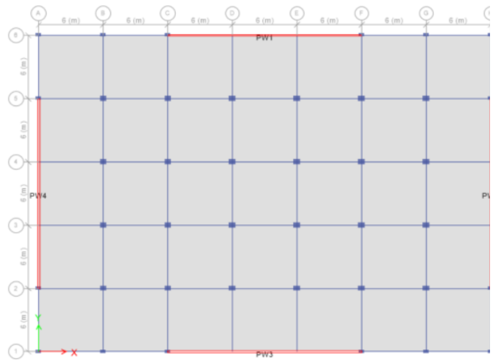

Fig. 2. Model 1 – Rectangular shear walls placed symmetrically on all 4 sides

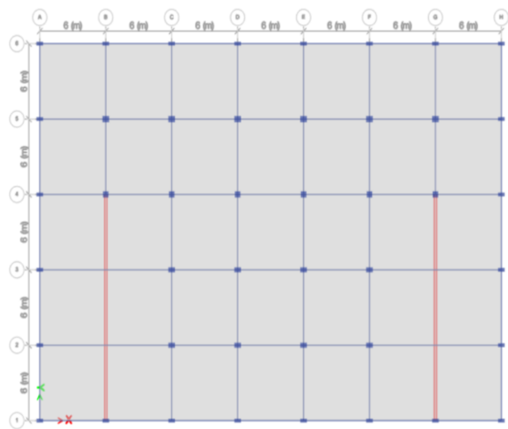

Fig. 3. Model 2 – Rectangular shear walls placed eccentrically

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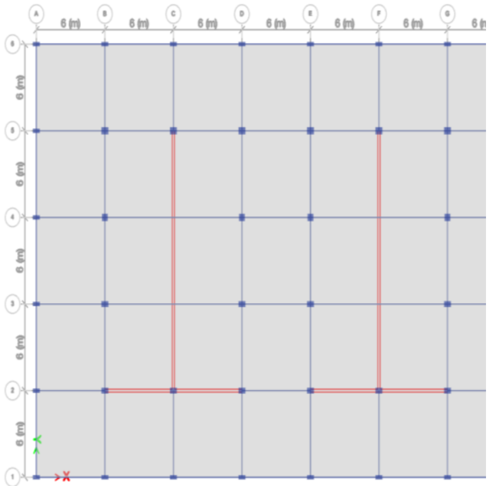

Fig. 4. Model 3 – T-shaped shear walls

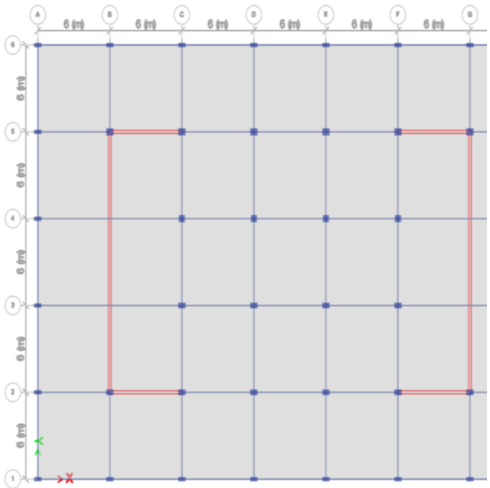

Fig. 5. Model 4 – C-shaped shear walls

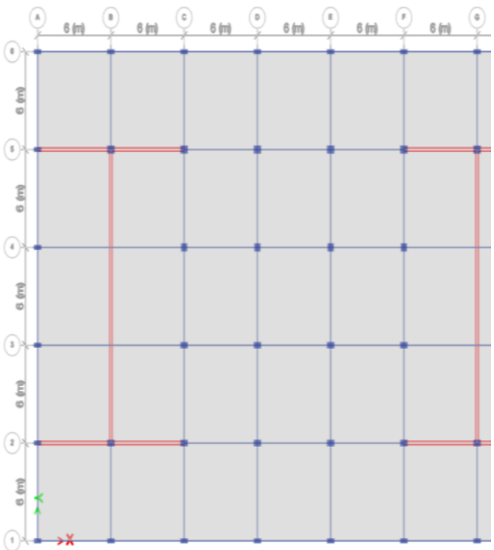

Fig. 6. Model 5 – I-shaped shear walls

VII. RESULTS AND DISCUSSIONS

A. *Horizontal Displacement*

TABLE 2: HORIZONTAL DISPLACEMENT IN X-DIRECTION (MM)

Storey	***Model 0***	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Roof	12.80	5.31	11.38	19.92	22.27	12.34
10	12.55	4.74	11.15	18.12	19.79	10.99
9	12.10	4.13	10.75	16.14	17.19	9.60
8	11.43	3.50	10.13	14.05	14.54	8.19
7	10.52	2.87	9.30	11.89	11.91	6.78
6	9.36	2.26	8.26	9.71	9.36	5.41
5	7.98	1.71	7.03	7.58	6.98	4.10
4	6.41	1.22	5.63	5.57	4.83	2.91
3	4.80	0.78	4.10	3.74	3.00	1.86
2	3.35	0.46	2.47	2.14	1.54	0.99
1	1.34	0.19	0.92	0.84	0.51	0.36

- In X-direction, model 1, 2 and 5 undergo a decrease in horizontal displacement of 74.54%, 14.95% and 40.99%, respectively. However, model 3 and 4 undergo an increase of 5.40% and 2.14%.
- In Y-direction, there is a decrease of horizontal displacement by 72.75%, 65.79%, 57.79%, 84.60% and 90.50%, respectively in model 1, 2, 3, 4 and 5.

TABLE 3: HORIZONTAL DISPLACEMENT IN Y-DIRECTION (MM)

Storey	***Model 0***	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Roof	20.15	7.16	8.58	11.04	3.38	1.97
10	18.23	6.44	7.77	9.96	3.14	1.85
9	15.57	5.69	6.91	8.68	2.86	1.71
8	13.27	4.9	6.03	7.29	2.56	1.54
7	12.41	4.11	5.12	5.85	2.23	1.36
6	11.86	3.33	4.2	4.85	1.89	1.16
5	10.73	2.57	3.3	3.89	1.53	0.95
4	8.9	1.86	2.44	2.95	1.18	0.74
3	6.77	1.23	1.65	2.06	0.84	0.54
2	4.47	0.7	0.95	1.25	0.52	0.34
1	1.87	0.29	0.39	0.53	0.23	0.16

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B. Story Drift

TABLE 4: STORY DRIFT IN X-DIRECTION

Story	***Model 0***	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Roof	0.0004	0.0002	0.0003	0.0006	0.0008	0.0005
10	0.0005	0.0002	0.0004	0.0007	0.0009	0.0005
9	0.0004	0.0002	0.0004	0.0007	0.0009	0.0005
8	0.0005	0.0002	0.0004	0.0007	0.0009	0.0005
7	0.0004	0.0002	0.0004	0.0007	0.0009	0.0005
6	0.0005	0.0002	0.0004	0.0007	0.0008	0.0004
5	0.0005	0.0002	0.0005	0.0007	0.0007	0.0004
4	0.0006	0.0002	0.0005	0.0006	0.0006	0.0004
3	0.0006	0.0001	0.0005	0.0005	0.0005	0.0003
2	0.0007	0.0001	0.0005	0.0004	0.0003	0.0002
1	0.0005	0.0001	0.0003	0.0003	0.0002	0.0001

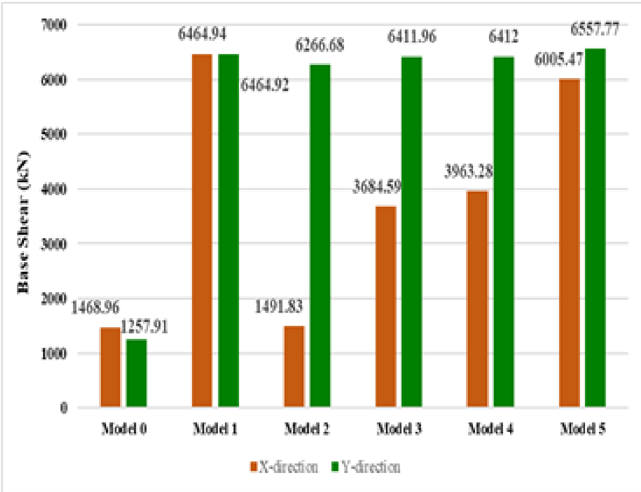
TABLE 5: STORY DRIFT IN Y-DIRECTION

Story	***Model 0***	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Roof	0.0006	0.0002	0.0003	0.0004	0.0001	0.0000
10	0.0009	0.0003	0.0003	0.0004	0.0001	0.0001
9	0.0008	0.0003	0.0003	0.0005	0.0001	0.0001
8	0.0006	0.0003	0.0003	0.0005	0.0001	0.0001
7	0.0007	0.0003	0.0003	0.0005	0.0001	0.0001
6	0.0007	0.0003	0.0003	0.0004	0.0001	0.0001
5	0.0007	0.0002	0.0003	0.0004	0.0001	0.0001
4	0.0007	0.0002	0.0003	0.0003	0.0001	0.0001
3	0.0008	0.0002	0.0002	0.0003	0.0001	0.0001
2	0.0009	0.0001	0.0002	0.0002	0.0001	0.0001
1	0.0006	0.0001	0.0001	0.0002	0.0001	0.0001

- In X-direction, model 1, 2 and 5 undergo a decrease in story drift by 65.42%, 15.30% and 20.47%, respectively. However, model 3 and 4 undergo an increase of 26.41% and 44.02%.
- In Y-direction, there is a decrease of story drift by 69.68%, 63.62%, 49.50%, 85.55% and 91.52%, respectively in model 1, 2, 3, 4 and 5.

C. Base Shear

- In X-direction, there is an increase in base shear by 340.10%, 1.56%, 150.83%, 169.80% and 308.82%, respectively in model 1, 2, 3, 4 and 5.
- In Y-direction, the base shear increases in model 1, 2, 3, 4 and 5 by 413.94%, 398.18%, 409.73%, 409.73% and 421.32%, respectively.



Graph 1. Base Shear in X and Y-direction

D. Eccentricity

TABLE 6: ECCENTRICITIES AT EACH STORY

Storey	***Model 0***	***Model 1***	***Model 2***	***Model 3***	***Model 4***	***Model 5***
Roof	698	698	946	8342	239	381
10	798	797	1036	8533	367	499
9	798	798	1040	8648	400	525
8	797	800	1044	8776	436	552
7	795	801	1046	8909	476	582
6	790	803	1045	9040	519	613
5	783	804	1039	9162	567	647
4	770	805	1025	9264	617	682
3	750	806	999	9328	668	716
2	716	805	954	9327	715	747
1	652	798	882	9030	749	770

- The average eccentricity is 792.27 mm, 1005.09 mm, 8941.73 mm, 523 mm, and 610.36 mm in model 1, 2, 3, 4 and 5, respectively.

E. Check for Torsional Irregularity

TABLE 7: ΔMAX/ΔMIN IN X–DIRECTION

Time (sec)	*Model 0*	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
4	**3.09**	1.08	1.01	**1.90**	1.01	1.03
8	**6.91**	1.08	1.06	**2.00**	1.01	1.03
12	1.27	1.04	1.01	**3.10**	1.01	1.06
16	1.09	**2.06**	1.01	**3.59**	1.01	1.07
20	1.12	1.06	1.01	1.26	1.01	1.03
24	**1.89**	1.03	1.01	**5.41**	0.99	1.02
28	1.20	1.04	1.01	**1.97**	1.01	1.11
32	1.26	1.01	1.01	**10.51**	1.01	1.01
36	1.31	1.36	1.00	**2.57**	1.00	1.01
40	**6.95**	1.01	1.11	**2.34**	1.01	1.02

TABLE 8: $\Delta_{MAX}/\Delta_{MIN}$ IN Y–DIRECTION

Time (sec)	*Model 0*	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
4	**1.59**	1.23	1.03	1.04	**1.50**	1.25
8	1.18	1.09	1.00	**2.13**	1.04	1.26
12	**1.58**	1.00	1.06	**4.60**	1.02	1.15
16	**2.68**	1.09	1.19	**2.16**	1.05	1.32
20	**3.21**	1.28	1.28	**5.68**	1.01	1.41
24	**1.74**	1.00	1.01	**2.55**	1.01	1.38
28	1.18	1.11	1.04	**2.95**	1.08	1.24
32	1.17	1.01	1.08	**3.47**	1.12	0.91
36	1.17	1.06	1.00	**1.62**	1.01	1.02
40	1.24	1.04	1.02	**2.29**	1.20	1.18

- The value Δmax/Δmin is less than 1.50 in model 2 and model 5 in both the directions at all the time intervals.

F. Conclusion

Model 5, with shear walls of I shape, is the most ideal arrangement for the torsionally irregular building under the influence of Bhuj Earthquake, since

- in X-direction, it undergoes the second highest and in Y-direction, the highest reduction in horizontal displacement and storey drift.
- it exhibits the second highest value of base shear in X-direction and the highest in Y-direction.
- it has the second lowest value of eccentricity.
- it is within safe limits of torsion, i.e. the ratio of maximum to minimum displacement of the top most storey is less than 1.5 at all the time intervals.

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