Effect of Seismicity on Irregular Shape Structure

Dr. S. A. Halkude[1], Mr. C. G. Konapure[2], Ms. C. A. Madgundi[3]
(Civil Engg. Dept. Walchand Institute of Technology Solapur, Solapur University, India

***Abstract*— Shear wall systems are one of the most commonly used lateral load resisting in high rise building. Shear walls are high in plane stiffness and strength which can be simultaneously used to resist large horizontal loads and support gravity loads. Incorporation of shear wall has become inevitable in multi-storey building to resist lateral forces. It is very necessary to determine effective, efficient and ideal location of shear wall. In present study investigations are done by varying percentage length of shear wall with possible combinations of location of shear wall for determining seismic behavior through parameters like top displacement, base shear, beam moment & column moments, storey drift, and torsion. The seismic analysis has been performed by Equivalent Lateral Force Method (ELF) and analysis of the building is carried out using ETABS application software,**

Keywords—Shear wall, Top displacements, Base shear, Beam & Column moment, Story drift, Torsion.

1. INTRODUCTION

Shear wall systems are one of the most commonly used lateral load resisting in high rise building. Shear walls are high in plane stiffness and strength which can be used to simultaneously resist large horizontal loads and support gravity loads. When building is designed without shear wall, beam and column sizes required are quite large, therefore it becomes costly as there is lot of congestion at joint so it is difficult to place and vibrate concrete at these places so displacement is quite large which induces forces in member. Shear wall may become imperative from the point of view of economy and control of lateral deflection.

In this study providing shear wall at different positions of the building to reduce the control on seismic effect and to control lateral stiffness in wall when seismic comes in picture.

1.1 Equivalent Lateral Force Method (ELF)

The total design lateral force or design base shear along any principal direction is given in terms of design horizontal seismic coefficient and seismic weight of the structure. Design horizontal seismic coefficient depends on the zone factor of the site, importance of the structure, response reduction factor of the lateral load resisting elements and the fundamental period of the structure. The procedure employed for the equivalent static analysis is as mentioned below:

For the purpose of determining seismic force in accordance with IS: 1893 (Part 1). The design seismic base shear (V_B) along with any principal direction is calculated by using following expression

$$V_B = A_h W$$

Where,

V_B=design seismic base shear

A_h= design horizontal seismic coefficient for structure

W= seismic weight of building

Ashish S. Agrawal, S. D. Charkha [2] in their study of 25 storey building in zone V have presented some preliminary investigations by analyzing various changing position of shear wall with different shapes for determining seismic parameters like storey drift, axial load and displacement. This analysis is done by using standard package ETAB. *Ashraf et al* [3] studied to determine the optimum configuration of a multi-storey building by changing shear wall location, which is very effective against seismic induced torsion. Four different cases of shear wall position for a 25-storey building have been analyzed as a space frame system using a standard package ETABS subjected to lateral and gravity loading in accordance with UBC provisions. *Castillo et al.* (2001) [6] studied the tensional response of ductile structures indicating the need for improvements in current seismic design provisions. This is because most standards deal with the torsion problems were based on the concept of elastic response. These provisions may be satisfactory at the serviceability limit state but are generally irrelevant for ductile structures. This paper evaluates the rotation of asymmetric structures and its effect on the displacement ductility demand using a displacement approach based on a realistic element modeling

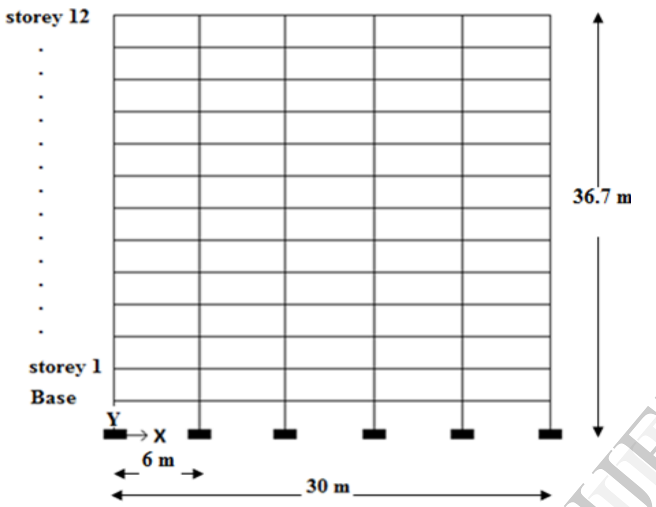
Patil and Dyavanal [13] presented gravity load analysis, seismic analysis namely equivalent static and response spectrum method are carried as per IS1893:2002(part-1) for different analytical models with various positions of shear walls and their seismic performance is assessed. The analysis is carried out using finite element analysis software ETAB. *Reza karami mohammadi and Hesham el nagger* [14] have carried out modifications on equivalent lateral force method. In this paper, a statistical process is outlined to estimate the seismic demands of roof and storey for MDOF structures. The analysis involves MDOF shear and frame buildings with various dynamic characteristics. Nonlinear and corresponding linear time history analyses were performed for severe earthquake ground motions. The data were used to derive empirical formulae for the maximum storey and roof displacements.

ISSN: 2278-0181
Vol. 3 Issue 6, June - 2014

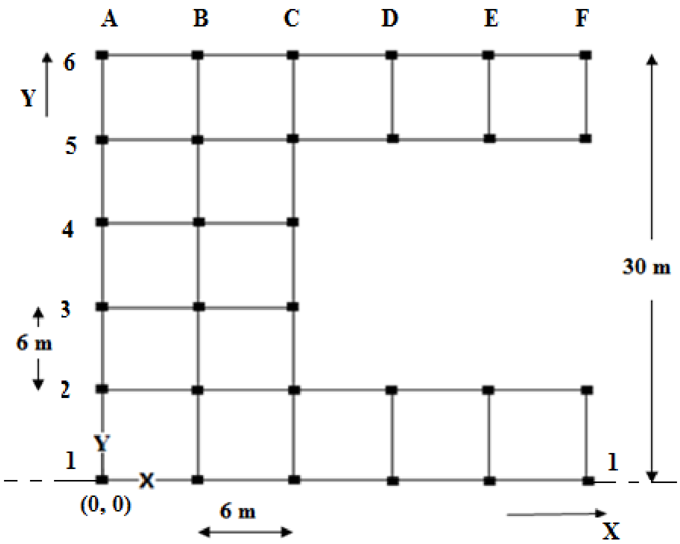
2. PROBLEM FORMULATION

The present study aims at keen understanding of the importance of codal provisions, which are particularly provided for the analysis of torsionally unbalanced structures. The influence of structural configuration (i.e. buildings having C-shape in plan) on the seismic response of the structure up to (G+11) storey building, having height 36.7 m and its reduction in parameters by providing shear wall at different positions in the building. Seismic analysis has been performed by Equivalent Lateral Force Method (ELF) with the help of IS 1893-2002 (Part I) and analysis of the building is carried out using ETABS application software package.

Structural data: Building consists of 5 bays of 6M in X-direction and Y- direction.



(a) Sectional Elevation 1-1



(b) Plan

Fig. 1 C Shape Irregular Building

A layout plan, Sectional elevation 1-1 of structure is as shown in above in the Fig.1 (a) and (b).

Fig 2 which show various building models considered for studying the effect of configuration of structure are given. The various models are formulated by varying percentage length of shear wall from 15 % to 31 %. Also, for given percentage of length of shear wall various different models are configured for study by varying location and orientation of shear wall. The objective of above is to arrive at efficient model of building plan with percentage shear wall and their orientation and location.

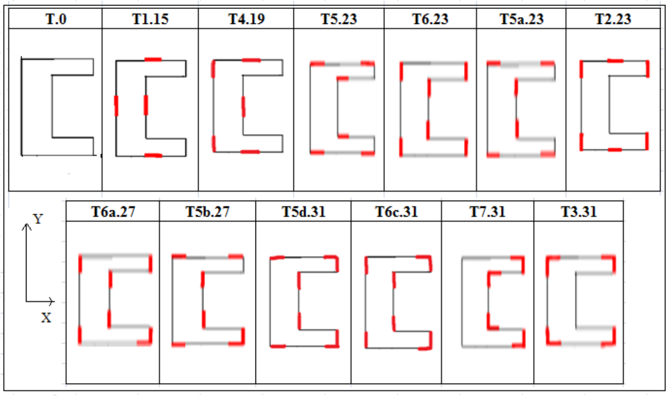
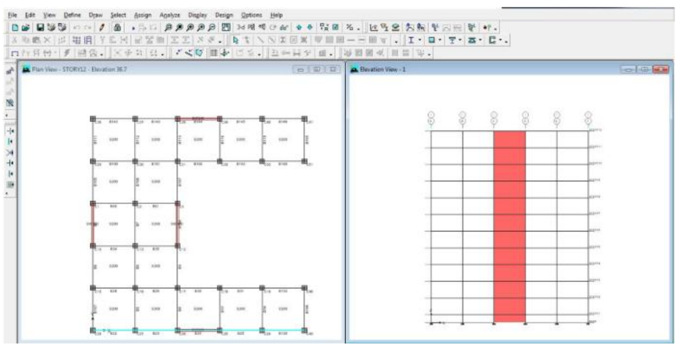


Fig. 2 Configuration of the Building

i) Model T.0 without shear wall building and
ii) Model T1.15 with shear wall building:
As shown in following Fig 3 (a) Plan and Fig 3(b) Elevation snapshots are taken from ETAB software and structure which has C shape with shear wall in Plan with columns and its Elevation respectively.



(a) Plan (b) Elevation

Fig. 3(a) Plan and (b) Elevation

2.1 Tables

TABLE I to II indicate the various input parameters used in the analysis. TABLE I shows the Structural Data of Building,

TABLE I Structural Data of Building

Geometry of building	
Height of storey	3.2 m
Number of storey's	G+11
Shear wall thickness	300 mm from base up to 11^{th} storey
Thickness of slab	200 mm
Size of beam in longitudinal and transverse direction	230x 600 mm
Material properties	
Grade of concrete and steel	M25 and Fe 415
Density of brick masonry	19 kN/m3
Young's modulus of concrete, Ec	25x 106 kN/m2
Density of reinforced concrete	25 kN/m3
Poisson's Ratio of reinforced concrete	0.20
Loading	
Soil type	Medium
Seismic Zone (Z)	IV

TABLE II indicates various models formulated for study

TABLE II Models Formulated For Study

Sr. No	Models	Building Type	% of shear wall in building	location of shear wall
1	T.0	T	0	Without shear wall
2	T1.15	T1	15	50% (2-Nos vertical dir) at middle of inner & outer edge + 50% (2-Nos horizontal dir) at middle of top & bottom, in both dir
3	T4.19	T4	19	60% (3-Nos vertical dir) at inner & outer edge +40% (2-Nos horizontal dir) at middle of top and bottom
4	T5.23	T5	23	All in horizontal dir
5	T6.23	T6	23	All in vertical dir
6	T5a23	T5a	23	66% (4-Nos horizontal dir) top & bottom + 34% (2-Nos vertical dir) inner edge
7	T2.23	T2	23	66% (4-Nos vertical dir)at outer edge + 34% (2-Nos horizontal dir) middle of top & bottom
8	T6a.27	T6a	27	29% 1-no at corner (horizontal + vertical) dir + 71 % (5-vertical dir)
9	T5b.27	T5b	27	29% 1-no at corner (horizontal dir + vertical dir) on bottom + 29% (2-Nos vertical dir) at inner edge + 42 % (3-Nos horizontal dir) at top & bottom
10	T5d.31	T5d	31	50% 2-Nos at corner (2-Nos horizontal dir + 2-Nos vertical dir) + 25% 2-Nos vertical dir + 25% 2-Nos horizontal dir
11	T6c.31	T6c	31	50% 2-Nos at corner (2-Nos horizontal dir + 2-Nos vertical dir) + 50% 4-Nos vertical dir
12	T7.31	T7	31	50% 2-Nos at re-entrant corner (2-Nos vertical dir + 2-Nos horizontal dir)+ 50% 2-Nos in outer corner(2-Nos horizontal dir + 2-Nos vertical dir)
13	T3.31	T3	31	100% 4-Nos at outer corner (4-Nos horizontal dir + 4-Nos vertical dir)

TABLE III shows combined results parameter wise for different models.

TABLE III Combined Parameter Results for the Entire Building Model Configuration

Building Model Type	T.0	T1.15	T4.19	T5.23	T6.23	T5a.23	T2.23
Top Displacement (m)	0.12987	0.0588	0.05633	0.12564	0.10944	0.04469	0.04219
Base Shear (kN)	6317.21	6458.25	6493.51	6528.77	6528.77	6528.77	6528.77
Beam Moment (kNm)	489.081	342.292	333.053	537.401	494.036	342.184	333.982
Column Moment (kNm)	989.157	289.872	289.540	181.951	984.593	194.643	290.321
Storey Drift (m)	0.00482	0.00203	0.00195	0.00467	0.00408	0.00155	0.00146
Torsion (kNm)	7.91348	12.6634	16.6874	2.62154	2.13724	1.11418	2.28051

Building Model Type	T6a.27	T5b.27	T5d.31	T5c.31	T7.31	T3.31
Top Displacement (m)	0.08118	0.04201	0.04058	0.03835	0.029039	0.022249
Base Shear (kN)	6564.03	6564.03	6599.29	6599.29	6599.294	6599.294
Beam Moment (kNm)	384.124	323.794	314.931	331.541	299.5002	306.4575
Column Moment (kNm)	536.31	197.2822	185.4129	272.2424	197.0589	180.2591
Storey Drift (m)	0.00275	0.00146	0.00141	0.00133	0.001029	0.000780
Torsion (kNm)	19.8609	9.43938	12.1827	4.95608	7.192915	1.025416

3. RESULTS AND DISCUSSION

There are in all 13 models studied which are placed on X axis for study, whereas, Y axis represents various seismic parameters. The percentage difference between sequential 2 models is 4% of length of shear wall. First model T.0 represents building without shear wall. For a given percentage of shear walls different models are constituted for various locations and orientation of shear wall and placed on X axis in increasing order of percentage shear wall.. The objectives of having different location and orientation of shear wall for given percentage of parameters is to arrive at best performing models.

3.1) Top Displacement (m):

Fig 4 shows variation of top displacement for different percentage of shear wall. It is observed that the top displacement having 85% and above shear wall in one direction only is producing maximum top displacement. However, as the shear wall distribution in either direction is getting balanced, the top displacement decreases. The above phenomenon is observed for all percentage of shear walls. The model with 31% of shear walls which has outer corner and closed box type produces least top displacement.

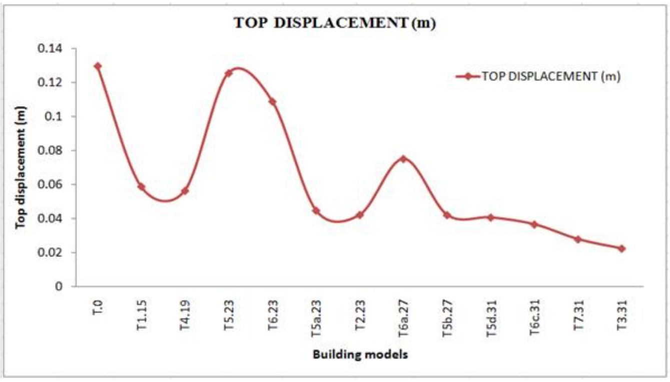


Fig. 4 Indicates Variation of Top Displacement For Various Percentage of Shear Wall.

3.2) Base Shear (kN):

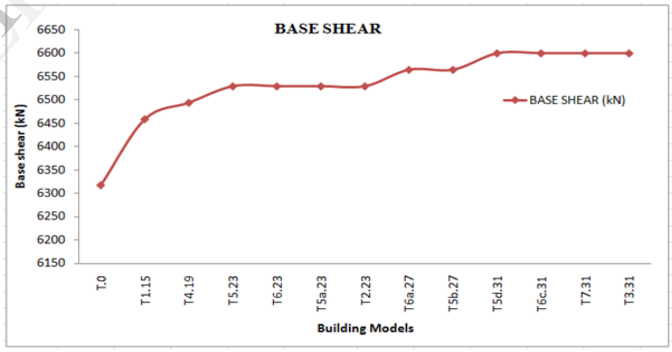


Fig. 5 Indicates Variation of Base Shear For Various Percentage of Shear Wall.

Fig 5 shows variation of base shear for different percentage of shear wall. The base shear increases with increasing percentage of shear wall. The percentage length of shear wall increased which gives `higher base shear'. For addition of every 4% of shear wall there is @ 0.54% increase in base shear.

3.3) Beam Moment (kNm) :

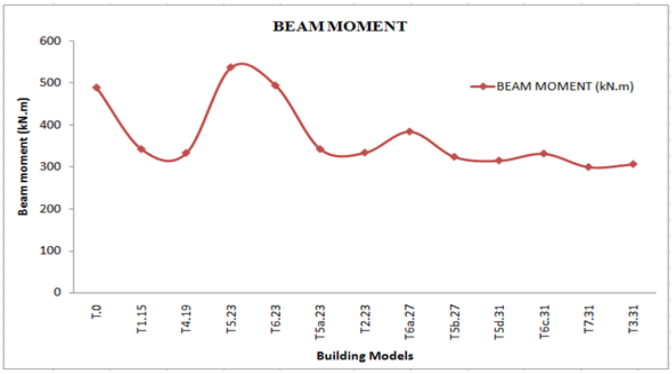


Fig. 6 Indicates Variation of Beam Moments For Various Percentage of Shear Wall.

Fig 6 shows variation of beam moment for different percentage of shear wall. It is observed that only the beam moment having 85% and above shear wall in one direction is producing maximum beam moment about asymmetry axis(Y axis). From models T5.23, T6.23 and T6a.27 it is also observed with increasing percentage of shear wall beam moment decrease. However, as the shear wall distribution is either direction is getting balanced, the beam moment decreases. The model with 31% of shear wall which has outer corner, re-entrant and closed box type produces least beam moment.

3.4) Column Moment (kNm):

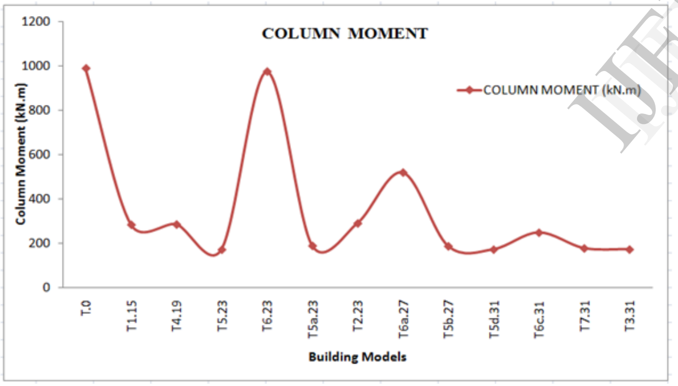


Fig. 7 Indicates Variation of Column Moments For Various Percentage of Shear Wall.

Fig 7 shows variation of column moment for different percentage of shear wall. It is observed that for model having 85% and above shear wall in one vertical direction only is producing maximum column moment. However, as the shear wall distribution is either direction is getting balanced, column moment decreases. For 23% length of shear walls located in plan, it is observed that there is reduction of column moment and for Model T6.23 when placing of shear walls is only in Y direction i.e. asymmetry axis, it results in maximum column moment in column C1 and C14 on storey1. The model with 31% of shear wall which has outer corner and closed box type produces least column moment.

3.5) Storey Drift (m):

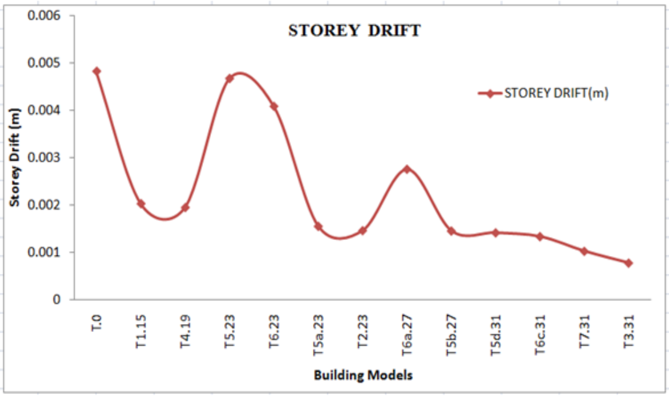


Fig. 8 Indicates Variation of Storey Drift For Various Percentage of Shear Wall.

Fig 8 shows variation of storey drift for different percentage of shear wall. It is observed that for model having 85% and above shear wall in any one direction is producing maximum storey drift. Using 31% length of shear wall in Model T3.31 and its position equally distributed in X and Y direction (closed box type) which has resulted in minimum storey drifts and gives good performance.

3.6) Torsion (kNm):

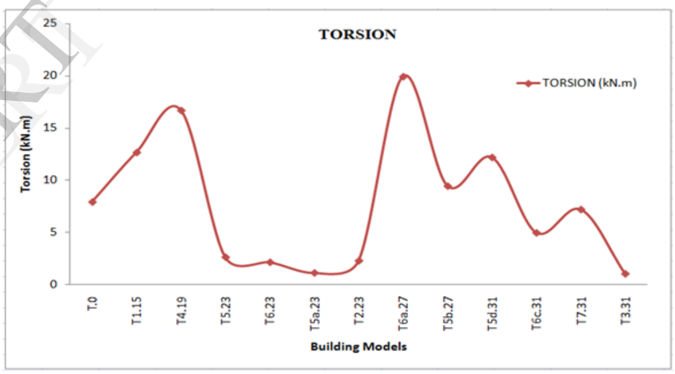


Fig. 9 Indicates Variation of Torsion For Various Percentage of Shear Wall.

Fig 9 shows variation of torsion for different percentage of shear wall. It is observed that the use of 15-19% length of shear wall in building models has resulted in increased torsion effect of shear wall in different orientations in plan. For models having 60% and above shear walls in asymmetry axis i.e. vertical direction and one at corner produces maximum torsion for Model T6a.27. The provision of shear wall with appropriate orientation plays an important role in twisting of building Model T5a.23 by giving lower torsion value is a good example of reducing twisting of building. The model with 31% of shear wall which has outer corner and closed box type produces variation in torsion.

A. Effect of Location of Shear Wall:

The effect of placement of shear wall (location & orientation) is studied model wise. After studying total 13 building frame models for various load combination it is observed that performance of the frame models with given percentage of shear wall is influenced due to its location & orientations in the plan.

The top displacement decreases with increasing percentage of shear wall. Top displacement is controlled in opposite direction of shear wall. Here, placing of shear wall at outer corner and closed box type produces least top displacement. The base shear increases with increasing percentage of shear wall. For the given percentage of shear wall, base shear does not vary with orientation and location of shear wall. The beam moment reduces with increasing percentage of shear wall. When placing of shear walls are only in Y direction i.e. asymmetry axis, there is maximum column moment. Here, column moment is attracted towards the shear walls. Storey drift decreases with increasing percentage of shear wall.

B. Best Models:

The best performing models are T1.15, T4.19, T2.23, T5b.27 and T3.31. The performance yardstick is in the order of performance of 1) top displacement 2) storey drift 3) base shear 4) beam moment 5) column moment and 6) torsion for various position of shear wall as shown. The most important parameter for assessing performance is top displacement followed by other parameters like beam moment, column moment, storey drift and torsion in the order of preference.

1) Top Displacement:-

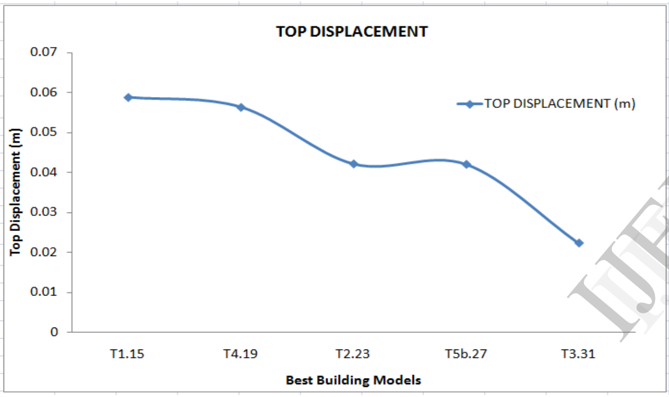


Fig. 10. Variation of Top Displacement Vs Various Best Building Models

Fig 10 shows the rate of decrease of the top displacement, increases with increasing percentage of shear wall. For 31% of shear wall the top displacement is minimum. The average reduction in top displacement is 0.0025 % percentage for every percentage increase of shear wall. It is clear that the value of displacement of Model T3.31 is 83% less as compared to Model T.0 without shear wall and maximum top displacement is found for Model T1.15 and minimum top displacement for Model T3.31.

2) Storey Drift:-

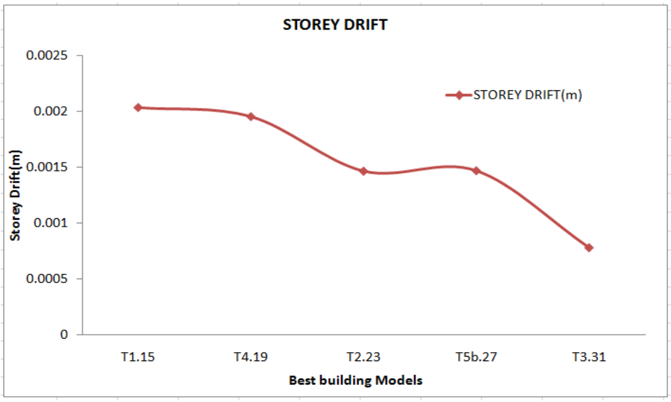


Fig 11. Variation of Storey Drift Vs Various Best Performing Models

Fig 10 and 11 which shows nature of graph observed same for both top displacements and storey drift. The drift is highest for Models T1.15 and lowest for Models T3.31.

3) Base Shear:-

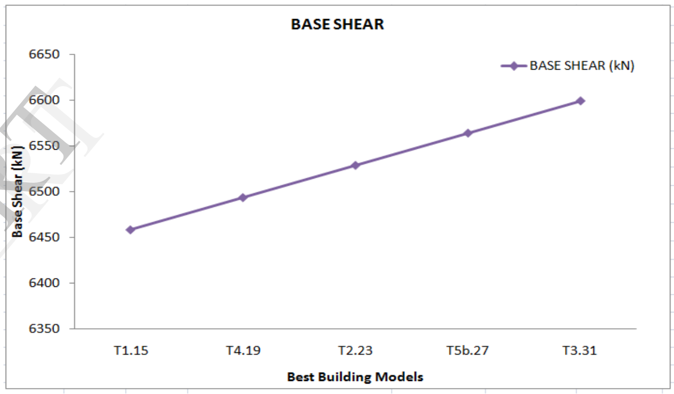


Fig 12. Variation of Base Shear Vs Various Best Performing Models

Fig 12 it is observed that base shear increases linearly with increasing percentage length of shear wall. By observing the above Fig 12, it concludes that base shear increases 0.54% with increasing every 4% length of shear wall due to increasing seismic weight of building.

4) Beam Moment:-

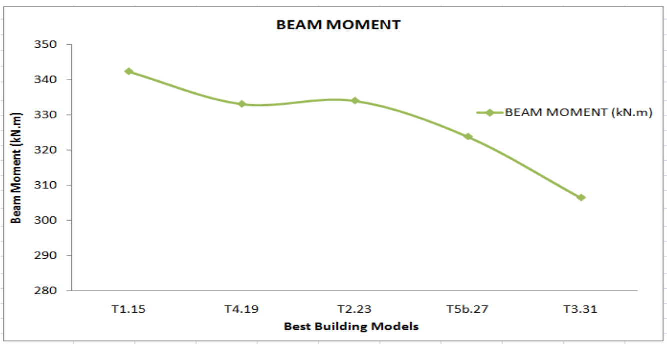


Fig 13. Variation of Beam Moment Vs Various Best Performing Models

In Fig 13 it is observed that beam moments initially decreases then slightly increases and afterwards decreases with further increases in percentage length of shear wall. It is clear that induced maximum moment in Model T1.15 due to placement of shear wall in both directions and the value of displacement of Model T3.31 is 5.35% less as compared to Model T5b.27 when shear walls are placed in closed box type.

5) Column Moment:-

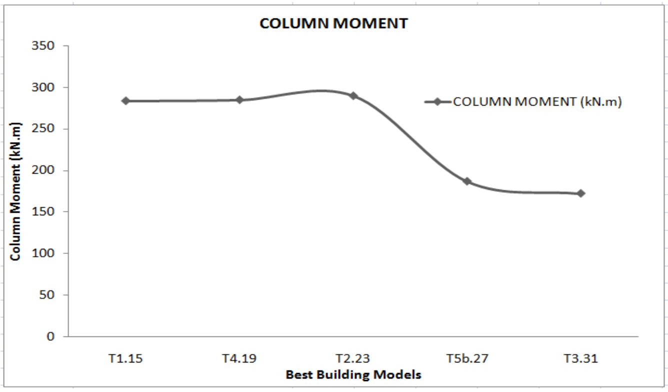


Fig . 14 Variation of Column Moment Vs Various Best Performing Models

Fig 14 shows column moment initially is nearly constant up to 19% increase of shear wall and there afterwards there is a slightly increase for Model T2.23 further it becomes deep decreased up to Model T3.31. The column moment is highest for Models T2.23 and lowest for Models T3.31. The value of column moment of Model T2.23 is 32% more as compared to Model T5b.27. The value of displacement of Model T3.31 is 37.91 % less as compared to Model T2.23.

6) Torsion:

Fig 15 shows the overall profile is sinusoidal indicating two Models T2.23 and Model T3.31which have less value of torsion due to major shear walls in plan on asymmetry Y axis and shear walls at outer corners (closed box type) respectively. The value of torsion of Model T4.19 is 24% more as compared to Model T1.15.

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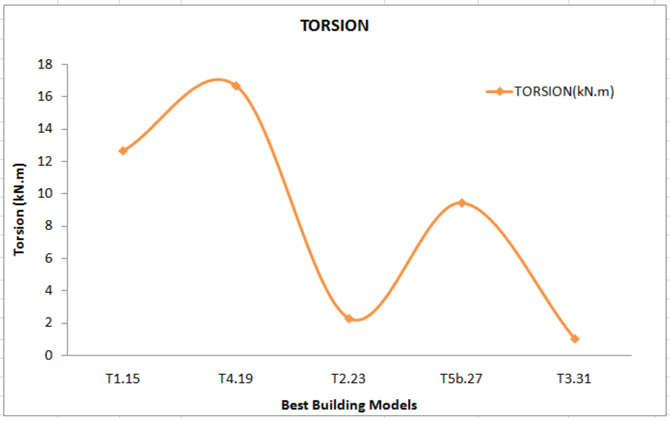

Fig. 15 Variation of Torsion Vs Various Best Building Models

C. Identification of severely affected Beams and Columns in the best models:

Shear walls are placed in the either direction, at outer corner & closed box type and performance increases with increasing percentage of shear wall up to 31%. This makes the model best.

On the basis of the above study, detail study for knowing the critical beams from flexural l action to what extent they are affected is done. The study presented below aims at identifying the critical beams and columns for a given efficient models. The models presented below are Models T1.15, T4.19, T2.23, T5b27 and T3.31 which are found efficient. Out of all the Models T2.23 and T3.31 are most efficient so details of the this models as follows-

1) *Model T2.23:*

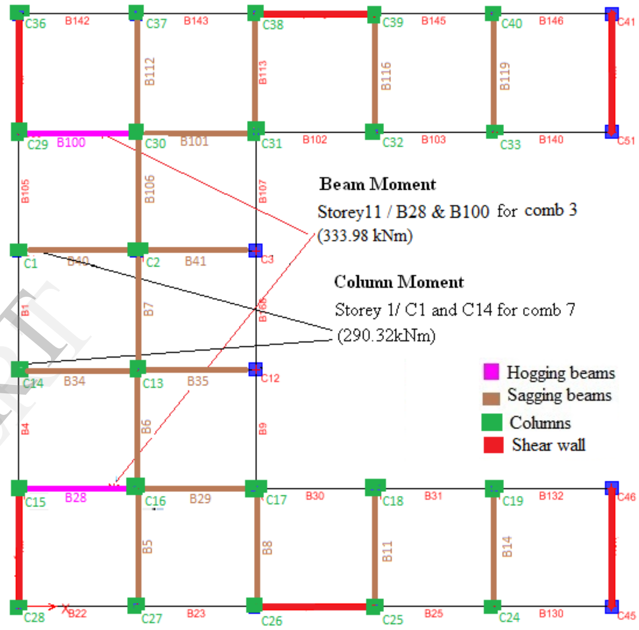

Fig. 16 A Typical Floor Level of the Model T2.23

Fig 16 shows a typical floor level of the Model T2.23 which has 23% shear wall, out of which 66% of shear wall along the asymmetry axis i.e. Y axis and remaining 34% parallel to symmetry axis i. e. X axis.

For the 11th storey for load combination [1.2 (DL + IL - EQX)] the maximum hogging beam moment, beams B28 & B100. The hogging beam moment goes on reducing from higher to lower storey levels. It is observed that hogging beam moment in the range of 90-100% is found in two beams which are symmetry about X axis and perpendicular to shear wall.

For the 11th storey for load combination [1.5 (DL + IL)] the maximum sagging beam moment, beams B28 & B100. The sagging beam moment goes on increasing lower to higher stories. The sagging moment is predominantly observed in most of the beam in both directions which have in the range of 90-100% highest moment in the entire frame.

There are total 30 columns in the plan. The highest column moment is at 1st storey level in column number C1 & C14 for a load combination [1.5 (DL - EQX)]. The column moment decreases as we move towards the upper storey levels. The variation in moment is observed in the range of 49.31%. The columns in the range of 90-100% are found nearly in all columns except the columns at the open end in Y direction.

2) *Model T3.31:*

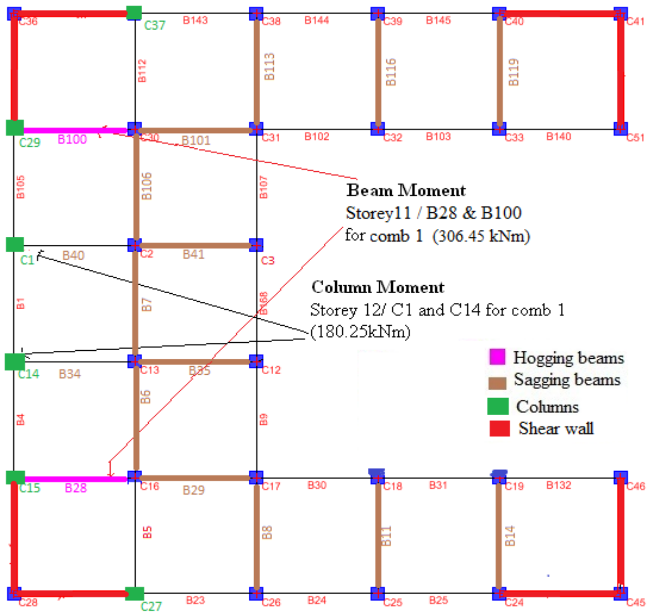

Fig. 17 A Typical Floor Level of the Model T3.31

Fig 17 shows a typical floor level of the Model T3.31 which has 31% shear wall. This model is provided with four outer corner shear wall (closed box type) therefore 50% shear walls are in X and Y direction respectively. There are only two beams of highest moment in the range of 90-100% and they are perpendicular to shear wall.

For the 11th storey for load combination [1.5 (DL + IL)] the maximum hogging beam moment, beams B28 & B100. The hogging beam moment goes on reducing from higher to lower storey levels. It is observed that hogging beam moment in the range of 90-100% is found two beams which are symmetry about X axis and perpendicular to shear wall.

For the 11th storey for load combination [1.5 (DL + IL)] the maximum sagging beam moment, beams B28 & B100. The sagging beam moment goes on increasing from lower to higher stories. The sagging moment in top 90-100% is observed in most of beams in either direction. The beams are in X direction in central position are carrying sagging moment and beams in Y directions which are discontinuous carrying higher sagging moment.

The highest moment in column is at 12th storey level in column numbers C1 & C14 for load combination [1.5 (DL + IL)]. The column moment decreases as we move towards the upper storey levels. The variation in moment is observed in the range of 29.23%. The variation moment in column is in the range of 10% of the highest value indicating the 20% columns are affected in the stiffer portion.

4. CONCLUSION

The present work is focused on the study of seismic response of irregular shaped (in plan) structures and reduction of displacements, bending in beam moments, column moments, storey drift and torsion by providing shear walls. For irregular shaped buildings which are vulnerable to twisting, the use of shear walls at proper location minimizes twisting effect and with increasing length of shear wall, the stiffness of the structure also increases.

1) Providing shear walls on interior bays is not much effective. Provision of shear walls as closed box type is very much effective in resisting the seismic effects.
2) Buildings having asymmetric location of shear walls develop torsion imbalance. However, present study shows that if shear walls are placed such that, the centre of mass almost coincides with centre of rigidity, then the torsion balance is minimum.
3) For a given percentage of shear walls, base shear does not alter to great extent. However, the base shears increases, proportionally with increasing percentage of shear wall.
4) Use of shear walls is effective in minimizing earthquake damage in structural and non structural elements. Effectiveness of shear wall increases when they are located along exterior perimeter of building. Buildings with shear wall on exterior perimeter are found to be more resistance to the twisting effect.
5) Use of shear wall in range of 23 to 31% of perimeter of structure is found very much effective in controlling displacement and minimizing bending moments. It is observed that increasing percentage of shear wall beyond 31% in structural framing does not improve the seismic perform of structure to a great extent.
6) Providing shear walls on interior bays is not much effective. Provision of shear walls as closed box type is very much effective in resisting the seismic effects.
7) High rise buildings which are vulnerable to thrust, need shear walls to reduce displacements, bending in beam moments and torsion.
8) Shear walls are placed ($\frac{2}{3}$)rd in X direction and ($\frac{1}{3}$)rd in Y direction, which is very effective orientation of shear walls to reduce seismic effect.
9) Column moments are more in the columns near the outer edges as compared to columns near the re-entrant corner.
10) Provision of shear wall near re-entrant corner and at the end of projections which are parallel to the direction of lateral load is very effective in resisting seismic effect (Model T6.23).
11) The shear wall placed at edges helps to reduce the torsion.

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AUTHORS BIOGRAPHY

First Author

Dr. S. A. Halkude,
M.Tech. (IIT, Bombay in Civil Engineering), Ph.D. (IIT Bombay) is working as a Principal at Walchand Institute of Technology Solapur. At present shouldering the responsibility as Dean, faculty of Engineering & Technology, Solapur University, Solapur (Maharashtra, India). He has 11 Journal and 14 Conference Research publications to his credit & is recipient of IGS-Dr. B.B. Rai- S. N. Gupta Bi-ennial Prize for the best paper on "Earth and Earth Retaining Structures". Fellow member of The Institution of Engineers (India), Life Member of Indian Society for Technical Education, New Delhi and Life Member of Indian Society for Rock Mechanics and Tunnelling Technology, New Delhi.
He is recipient of Eminent Educationist Award by National & International Compendium, New Delhi (India).

Second Author

Mr. C.G. Konapure,
B.E. (Civil Engineering), M.E. (Civil - Structures), Assistant Professor, Civil Engg. Dept., WIT Solapur.

Third Author

Ms. C.A. Madgundi,
B.E. (Civil Engineering), M.E (Civil - Structures),