

Effect of Shear Wall Shape on Seismic Response of RC Building Frames

Y.S. Ningthoucha.^{1,*}, S.S. Ningthoukhongjam²

¹Department of Civil Engineering, PG student, Manipur Institute Technology, Imphal, 795001, India

²Department of Civil Engineering, Assistant Professor, Manipur Institute Technology, Imphal, 795001, India

Paper ID - 040038

Abstract

This paper presents the effect of shape of shear wall on seismic response of a nine-storey moment resisting RC frames using non-linear static (pushover) analysis. The moment resisting RC frame is rectangular in plan and shear walls are provided along the least lateral dimension of the building plan. Different shapes of the shear wall (e.g., S, B, C, H and E) have been used in the analysis. The building frame along with shear walls has been modelled using FEM software SAP2000 and seismic responses of the building frames with different shapes of shear wall has been measured in terms of pushover curve (performance point, storey drift, top displacement and base shear). It has been observed that maximum performance level of building frame occurred when the shear walls are provided with S-shape.

Keywords: Shear wall, Performance point, Moment resisting RC frame, Pushover analysis

1. Introduction

Shear wall is one of the structural members which significantly resist lateral load due to wind or earthquake. Due to the high in-plane stiffness and strength of shear wall, it can be used to resist both large horizontal and gravity loads, thereby making the structure more stable. Shear walls are used in tall building, since in tall buildings the requirement of sectional size of beam and column is very large and reinforcement at the beam-column joints are quite heavy, so the placement of concrete aggregates get congested during construction, which in fact, is not a desirable factor for designing purpose and at the same time, it compromises the safety of building. To overcome this practical difficulty, shear wall is widely used as primary construction member for tall structure subjected to seismic loads. Shear wall can also be defined as structural vertical member that is able to resist combination of shear, moment and axial load induced by lateral load and transfer gravity loads through it to the foundation.

Research works seismic responses of building frames with or without shear wall have been investigated by many researchers. For example, A. Kadid and A. Boumrki [1] evaluated the performance of framed buildings under future expected earthquakes; a non-linear static pushover analysis has been conducted. Using finite element package SAP 2000, three RC framed buildings with 5, 8 and 12 stories respectively were analyzed. The results obtained from this study show that building with shear wall can effectively improves the stability of the structure under seismic loads. Akis et al. [2] examined asymmetric shear wall effect in building by considering two approximate

shear wall models, for open and closed sections, based on the conventional wide column analogy. In this study three dimensional analyses of open section shear walls modelled by the conventional equivalent frame model resulted into serious errors especially in the analysis subjected to torsion and the finite element modelling becomes stiffer compared to the conventional equivalent frame model. Kameshwari et al. [3] assessed the effect of various configurations of shear wall panels. It has been found that the drift as well as inter-storey drift are lesser when the shear wall panels are aligned along the shorter plan dimension, also it has been seen that the diagonal shear walls and zigzag shear walls are more effective in resisting the lateral loads during the dynamic excitation than those under consideration. Sujani et al. [4] performed pushover analysis in G+5 building situated in ZONE III to check the seismicity effect and performance level of a building by using SAP2000. It has been shown that the performance level of the building components and maximum base shear carrying capacity of the structure can be obtained from the pushover analysis. From the result it has been shown that the performance point where the intersection point of demand and capacity curves lies within the life safety levels. Therefore, it is concluded that some residual strength and stiffness left in all stories. Rahangdale and Satone [5] considered a G+5 Storey building in Zone IV is with some preliminary investigation which is analyzed by changing various position of shear wall with different shapes for determining the parameter like axial load and moments. The analysis has been performed by using Standard package STADD-Pro. It has been found that

*Corresponding author. Tel: +918257892920; E-mail address: soviet.yumnam@gmail.com

constructing shear walls decrease the damages due to effect of lateral forces due to earthquake and high winds. Chittiprolu and Kumar [6] performed dynamic linear analysis using response spectrum method in irregular high rise buildings with and without shear wall. The responses of the analysis in the form of lateral forces and story drifts of both the cases has been compared. It is observed that lateral forces are reducing when the shear walls are added at the appropriate locations of frames and it is inferred that shear walls are more resistant to lateral loads in an irregular structure. It has also been observed that torsional effect is reduced when the irregular high rise buildings is provided with shear wall. Gandhi [7] carried out linear elastic analysis on 6-storey frame-shear wall buildings, using STAAD-Pro under earthquake loads adopting equivalent static analysis. It has been seen that stiffness as well as seismic responses of structures is affected by the size and location of the openings in shear wall. It has also been observed that top lateral drift of the system can also be reduced by thickening the element in the model around the opening of shear wall. Rokanuzzaman et al. [8] analysed a G+15 residential building using software ETABS 9.6.0. Equivalent static method has been adopted in the analysis. In the analysis, three types of models (one without any shear wall, one with shear wall placed at middle of 4 periphery sides, one with shear wall placed at 4 corners in L shape) have been used. The results are presented in terms of building displacement and base shear. It is has found that Model 2 (one with shear wall placed at middle of 4 periphery sides) showed best performance as far as top displacement and base shear are concerned. Gupta and Bano [9] evaluated 3-different heights of multi-storeys building i.e. G+6, G+16 and G+25 with various geometries of shear wall namely: C-shaped, L-shaped, I-shaped, Rectangular-shaped using ETABS-2016 software. Performance of the building are obtained in terms of lateral displacement, storey stiffness and storey drift. It has been found that among the buildings with various shapes of shear wall, the maximum decrease of lateral displacement & storey drift is observed in building with I -shaped shear wall. It has been observed from the literature that limited shapes of shear wall were used while investigating seismic responses of building frames. Thus, in this paper, seismic performances of 9-storey moment resisting RC frame with different shapes of shear walls (S, B, C, H and E) has been investigated by adopting static non-linear analysis (pushover) using SAP2000. The results of the analysis are presented in terms of base shear and storey drift.

2. Methodology

Static non-linear analysis i.e. Pushover analysis has been adopted in this paper. In Pushover analysis, a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern is applied continuously until the behaviour of structure reaches an ultimate condition of non-serviceability. Lateral load may represent the range of base shear induced by earthquake loading, and its configuration may be proportional to the distribution of mass along the building height. The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation

demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter-storey drift, inelastic element deformations, deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations). The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behaviour.

Five points labelled A, B, C, D, and E as shown in Fig.1 [14], are used to define the force displacement behaviour of the hinge and three points labelled IO, LS, and CP are used to define the acceptance criteria for the hinge. The IO, the LS and the CP stand for Immediate Occupancy, Life safety and Collapse Prevention, respectively. These are informational measures that are reported in the analysis results and used for performance-based design. As shown in Fig. 1, the response is linear to an effective crack point, B, followed by cracking (with concrete cracking) to yield point C, followed by yielding (possibly with strain hardening) to ultimate point D, followed by final collapse and loss of gravity load capacity at point E.

3. Structure description

A residential building G+8 regular structure having the base dimension of plan 60.5m x 22.5 m with a typical floor of height 3.5m is considered in the analysis. Details of the building frame is shown in Table-1. The building has been designed as per IS 456-2000 [10] and IS 1893 (Part 1)-2016 [11]. Seismic design parameters are given in Table-2. Design service loads are expected to act on the structure for dead loads [12] and for imposed loads [13]. Loading details is given in Table-3. The dead load of all the reinforced concrete members will be given as self-weights of the members; all the floor loads expressed as load per square area is applied as distributed floor loads onto the supporting beams as per clause 24.5of IS 456: 2000. Material properties used in the design of the building is given in Table-4.

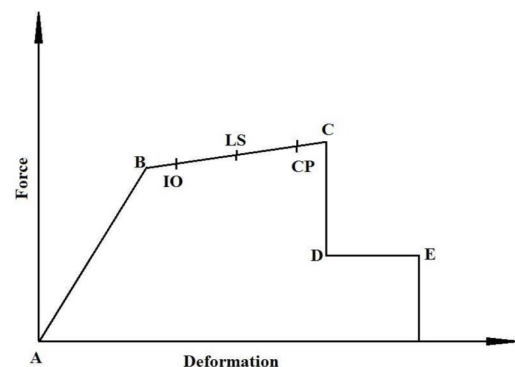


Fig.1. Force-displacement curve

Table-1. Details of the building frames.

Number of Stories	9 Storey
Height	3.5 meters
Number of Bays along X-direction	11 nos.
Number of bays along Y-direction	5 nos.
Bay Width along X-direction	60.5 meters
Bay Width along Y-direction	22.5 meters
Size of Column	750 mm X 450 mm
Size of Beam	350 mm X 500 mm
Depth of Slab	150 mm
Thickness of Shear Wall	>150 mm (IS13920:2016)
Volume of concrete (shear wall)	178.132 m ³

Table-2. Seismic Design parameter

Frame Type	Special Moment Resisting Frame(OMRF)
Location	Seismic Zone (Z) – V
Type of Soil	Medium Soil (Type-II)
Response Reduction Factor (R)	5
Importance Factor (I)	1.2
Response Spectrum	As per IS 1893 (Part- I) 2016
Terrain Category	4
Class of Structure	B

Table-3. Loading details

Live Load	3.0 kN/m ²
Floor Finish Load	1.0 kN/m ²
Waterproofing Load (only on Terrace Floor)	1.0 kN/m ²
Wall Load	13.8 kN/m
Parapet wall load	4.5 kN/m

Table-4 Material properties

Grade of Concrete	M30
Grade of Steel	Fe415
Modulus of Elasticity of concrete	27386128 kN/m ²
Co-efficient of thermal expansion	5.5 X 10 ⁻⁶
Poisson's Ratio	0.2

4. Modelling

The residential building G+8 moment resisting RC frame has been modeled using general finite element package SAP 2000[14]. The rigid diaphragm floor assumption is taken into consideration in the modeling of

the building structures. The superstructure is modelled as a space frame with a grid of columns in the vertical direction, interconnected with beam members in the orthogonal directions at each floor level. A three dimensional model of each structure has been created to undertake the nonlinear analysis. Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. SAP 2000 provides hinge properties which are used to define nonlinear force-displacement or moment-rotation behavior that can be assigned to discrete locations along the length of frame (line) objects. These nonlinear hinges are used during static nonlinear analysis and nonlinear direct integration time history analysis only. For all other types of analysis, the hinges are rigid and have no effect on the behavior of the member. Three kinds of hinge properties are available in SAP2000 they are auto hinge properties, user-defined hinge properties and program generated hinge properties. The user defined hinge properties option is used and P-M-M hinges for columns and M3 hinges for beams are used as described in FEMA-356 [15]. The nodes (the meeting points of beams with beams and beams with columns) will be treated as rigid joints due to monolithic construction. The columns will also be interconnected at the plinth beams to increase the stability of the structure. All slabs and shear wall are modeled as shell elements wherever necessary. The plane of building which were use in analyzed is shown in Fig.1 and it is same for all building modelled. The 3-dimensional building frame without shear wall is shown in Fig.3. RC frames with different shapes H, S, C, E and B shear wall are shown in Fig.4, Fig.5, Fig.6, Fig.7 and Fig.8 respectively. The volume of concrete used is same for all shear wall shapes.

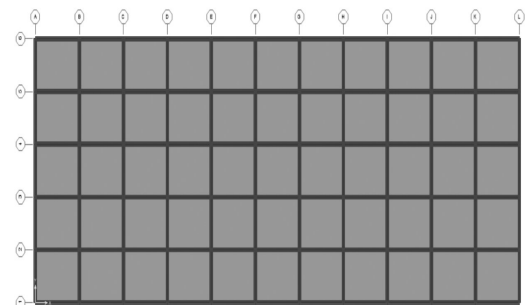


Fig.2.Plain view of building

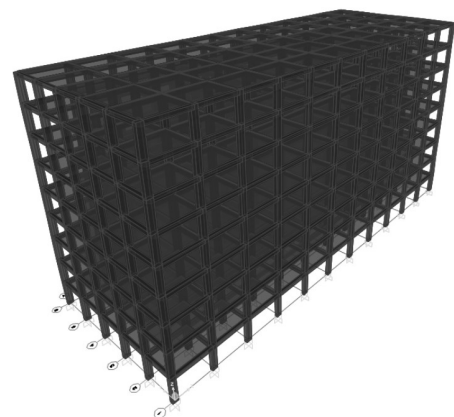


Fig.3. 3-D View

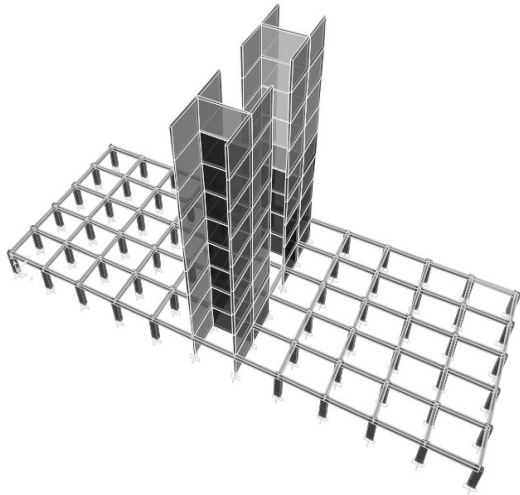


Fig.4. Building frame with H-shape shear wall

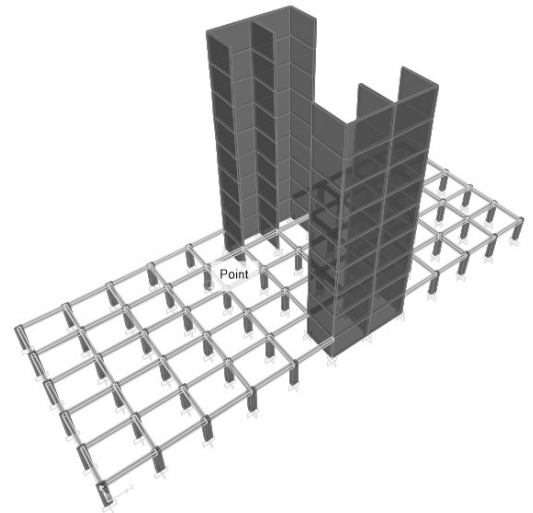


Fig.7. Building frame with E-shape shear wall

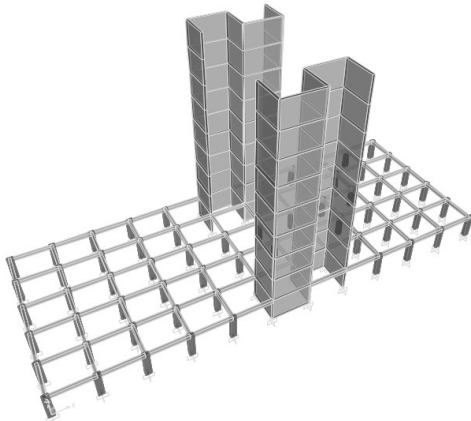


Fig.5. Building frame with S-shape shear wall

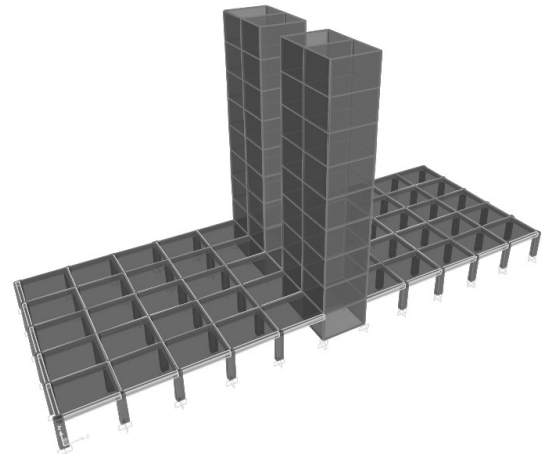


Fig.8. Building frame with B-shape shear wall

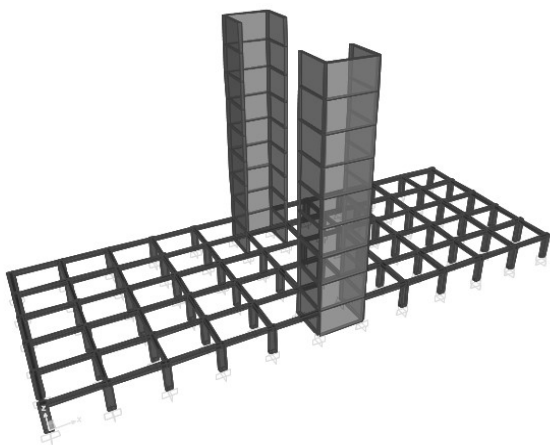


Fig.6. Building frame with C-shape shear wall

5. Results and Discussion

Pushover analysis is carried out for user defined non-linear hinge properties as per [16] guidelines.

5.1 Model without shear wall

Plastic hinge formation for the building mechanisms has been obtained at different displacements levels. The hinging patterns are plotted in Fig.9. Plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories.

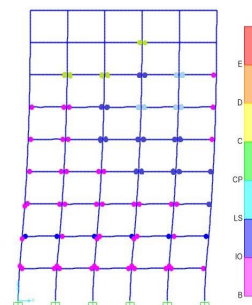


Fig.9. Hinge mechanism of frames RC frame without shear wall

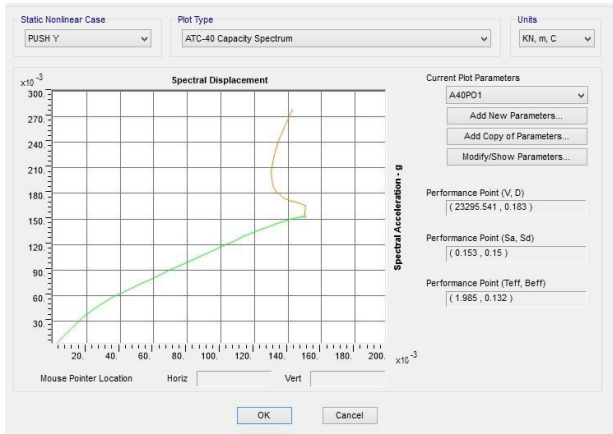


Fig.10. Seismic demand and Capacity curve of RC frame without shear wall.

4.2 Model with shear wall

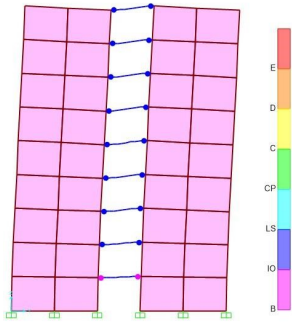


Fig.11. Hinge mechanism of RC frame with B-shape shear wall

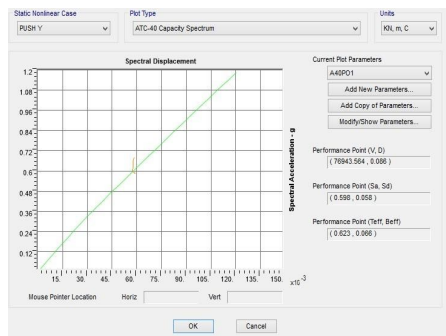


Fig.12. Seismic Demand vs Capacity curve of RC frame with B-shape shear wall

The resultant drift for various storey levels for various configurations of the shear wall panels are plotted in Fig.13 and it is clearly shown that the storey drift value decrease when shear wall is used. From Fig.13, for various configurations of shear wall panels, we can see that the bare frame is having the maximum drift of 100mm and the frame with S shape shear wall has least drift i.e 30 mm compare to other shape of shear wall. So, S shape shear wall performed well in reducing the storey drift. Table 5 compares the base shear value and top displacement value of all models in y-direction i.e. slender direction.

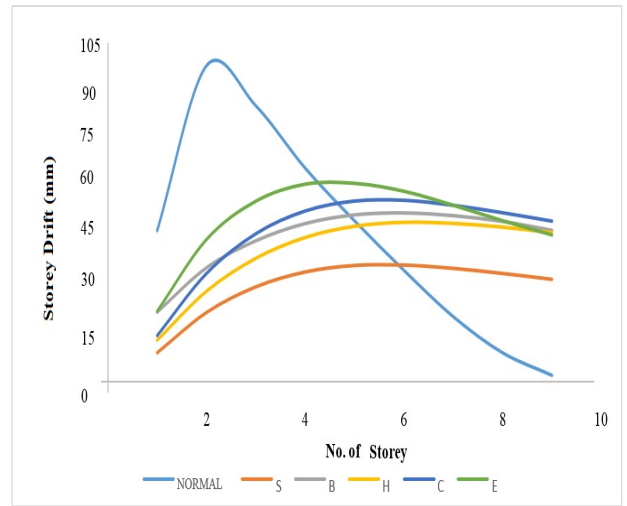


Fig.13. Storey drift

Table-5. Base shear and Displacement values of all frames

Building with	Base Shear (kN)	Displacement (mm)	Permissible displacement (mm) IS1893(Part I):2016
No shear wall	23295.541	183	126
B- shear wall	76943.564	86	126
C- shear wall	59603.635	101	126
H- shear wall	59613.467	102	126
S- shear wall	95205.696	73	126
E- shear wall	70251.825	82	126

From Table 5 it is found that the building with shear wall have higher base shear. Lesser value of base shear indicates higher seismic weight of the structure. The base shear variation for earthquake forces in all directions shows that the base shear for S shape shear wall periphery of structure is larger than the other shapes. Among the all shapes C-shape has the least base shear value with highest displacement value and S-shape shows highest base shear value with least displacement of all.

5. Conclusion

The seismic performance of G+ 8 RC building frames with and without shear wall has been investigated using SAP2000. Different shapes of shear walls S, B, C, H and E have been used in the analysis. The following observations have been made from the analysis as listed below

- Reinforced concrete frame building without shear wall will exhibit a poor performance to resist any type of lateral load.
- Building without shear wall shows the maximum top displacement value, whereas building with S

shape shear wall shows the minimum top displacement value.

- This analysis shows that the shape of the shear wall is an important factor when it comes to the seismic response of the structure.

Disclosures

Free Access to this article is sponsored by SARL ALPHA CRISTO INDUSTRIAL.

References

1. A. Kadid and A. Boumrkik. Pushover analysis of reinforced concrete framed structures. *Asian journal of civil engineering (Building and Housing)* Vol.9, No.1(2008); 5: 75-83
2. Tolga Akis, Turgut Tokdemir and Cetin Yilmaz. Modelling of asymmetric shear wall frame building structure. *Journal of Asian Architecture and Building Engineering*,2009; 8(2),531-538.
3. B. Kameshwari, G. Elangovan, P. Sivabala, G. Vaishakh. Dynamic response of high rise structure under the influence of discrete staggered shear wall. *International journal of engineering science and technology (IJEST)* 2009; ISSN:0975-5462 Vol.3 No.10.
4. Naga Sujani, K. Phanisha, N. Mohan Rupa, Sunita Sarkar, M. nageswari and P.Poluraju. *international journal of engineering research and applications(IJERA)* ISSN:2248-9622, Vol.2, issue 2, Mar-Apr2012, pp.832-837.
5. Himalee Rahangdale and S.R. Satone. Design and analysis of multistoried building with effect of shear wall. *International Journal of Engineering Research and applications (IJERA)* ISSN:2248-9622, Vol.3, Issue 3, May-Jun 2013, pp.223-232.
6. Ravikanth Chittiprolu and Ramanchrla Pradeep Kumar. Significance of shear wall in high-rise irregular buildings. *International Journal of Engineering Research and applications (IJERA)* ISSN:2348-0033, Vol.4. Issue Spl-2, Jan-June 2014.
7. Bhruguli H. Gandhi. Effect of opening on behavior of shear wall. *international journal for technical research in engineering*, ISSN:2347-4718, Vol.3, Issue 4, Dec. 2015.
8. Md. Rokanuzzaman, Farjana Khanam, Anik Das and Reza Chowdhury. effective location of shear wall on performance of building frame subjected to lateral loading. *International journal of advances in mechanical and civil engineering*, ISSN:2394-2827, Vol.4, Issue-6, Dec. 2017.
9. Richa Gupta and Alfia Bano. Performance evaluation of various geometries of shear wall in building by equivalent static judgement. *International journal of innovative technology and exploring engineering (IJITEE)* ISSN:2278-3075, Vol.8, Issue-6S4, April 2019.
10. IS 456-2000: Code of practice for plain and Reinforced concrete, Bureau of Indian Standards.
11. IS 1893(Part 1)-2016: Criteria for Earthquake Resistant Design of Structure- general provisions and buildings, Newdelhi.
12. IS:875(Part1)-1987- Code of Practice for Design Load (other than earthquake) for Buildings and Structure –Dead loads.
13. IS:875(Part2)-1987- Code of Practice for Design Load (other than earthquake) for Buildings and Structure –Imposed Load.
14. CSI, SAP2000, Ver.21.0.2, Integrated finite element analysis and designed of structure basic analysis reference manual. Berkely (CA, USA): Computer and Structure INC;2006.
15. Federal Emergency Federal Agency, FEMA-356. Pre-standard and Commentary for Seismic Rehabilitation of Buildings. Washington DC, 2000.
16. Applied Technology Council, ATC-40 (1996) Seismic Evaluation and Retrofit of Concrete Buildings, Vol.1 and 2, California.