

Earthquake Analysis of Multi-Storey Building with Effect of Shear Walls (Shear Walls at the Centre Core and Corners)

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ABSTRACT: The usefulness of shear walls in the structural planning of multistory buildings has long been recognized. When walls are situated in advantageous positions in a building, they can be very efficient in resisting lateral loads originating from wind or earthquakes. Incorporation of shear wall has become inevitable in multi-storey building to resist lateral forces. In present work, Forty storey buildings (120m) with I shape shear walls at the centre core and corners have been modeled using software package ETABS for earthquake zone V in India. This paper aims to study the behaviour of reinforced concrete building by conducting dynamic analysis for most suited positions and location of shear wall. Estimation of structural response such as; storey displacements, base shear, storey drift and Stress Distribution is carried out. Dynamic responses under zone V earthquake as per IS 1893 (part 1) : 2002 have been carried out. In dynamic analysis; Response Spectrum method is used.

KEYWORDS: Lateral Loads, Shear Wall, Structural Response, Response Spectrum Method

I. INTRODUCTION

Background

Reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Walls in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150mm, or as high as 400mm in high rise buildings. Shear walls are usually provided along both length and width of buildings. Shear walls are like vertically-oriented wide beams that carry earthquake loads downwards to the foundation.

Properly designed and detailed buildings with shear walls have shown very good performance in past earthquakes. The overwhelming success of buildings with shear walls in resisting strong earthquakes is summarised in the quote:

“We cannot afford to build concrete buildings meant to resist severe earthquakes without shear walls.” Mark Fintel, a noted consulting engineer in USA.

Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and effectiveness in minimizing earthquake damage in structural and nonstructural elements (like glass windows and building contents).

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Most RC buildings with shear walls also have columns; these columns primarily carry gravity loads(i.e., those due to self-weight and contents of building). Shear walls provide large strength and stiffness to buildings in the direction of their orientation, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents. Shear walls should be provided along preferably both length and width. Special design checks are required to ensure that the net cross sectional area of a wall at an opening is sufficient to carry the horizontal earthquake force. Shear walls in buildings must be symmetrically located in plan to reduce ill-effects of twist in buildings. They could be placed symmetrically along one or both directions in plan. Buildings are designed primarily to serve the needs of an intended occupancy. One of the dominant design requirements is therefore the provision of an appropriate internal layout of buildings. Once the functional layout is established, one must develop a structural system that will satisfy the established design criteria as efficiently and economically as possible, while fitting into the architectural layout. The vital structural criteria are an adequate reserve of strength against failure, adequate lateral stiffness and an efficient performance during the service life of the buildings. In modern tall buildings, shear walls are commonly used as a vertical structural element for resisting the lateral loads that may be induced by the effect of wind and earthquakes. Shear walls of varying cross sections i.e. rectangular shapes to more irregular cores such as channel, T, L, barbell shape, box etc. can be used. Provision of walls helps to divide an enclosed space, whereas of cores to contain and convey services such as elevator.

II. LITERATURE REVIEW

A literature review is carried out to define the objectives of the paper. The literature review is discussed briefly summarized as follows:

1. Kumbhare P.S. et al., (2012) in his study found that placing shear wall away from center of gravity resulted in increase in the most of the members forces and suggested that shear walls should be coinciding with the centroid of the building for better performance.
2. Prajapati R.J. et al., (2013) found that deflection for building with shear walls provided at the corners in both the directions was drastically less when compared with other models.
3. Shear Walls must be coinciding with the centroid of the building for better performance. It follows that a centre core Shear wall should be provided.
4. To perform well in an earthquake, a building should possess simple and regular configurations. Buildings with articulated plans such as T and L shapes should be avoided. (Paulay and Priestley, 1992)

Scope Of The Present Study

In the present study, a typical multi storey building is analyzed using software ETABS by dynamic (Response Spectrum) analysis. All the analyses has been carried out as per the Indian Standard code books. Based on the literature of previous studies most effective positioning of shear walls has been chosen. Analysis is done on forty storey high and provided with a shear wall at the center core and corners of the building.

This study is done on RC framed multistory building with RC shear walls with fixed support conditions.

III. METHODOLOGY

- a) A thorough literature review to understand the seismic evaluation of building structures and to find out most effective and efficient position of shear walls in the structure.
- b) Modelling a forty storey high building. Building with Shear Walls provided at the centre core and at the four corners (L shape).
- c) Carrying out the design check for the building as per prevailing Indian Standard for dead load, live load, and earthquake load.
- d) Analyzing the building using linear static dynamic analysis i.e, Response Spectrum Analysis.
- e) Analyzing the results and arriving at conclusions.

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Essentials Of Structural Systems For Seismic Resistance

The primary purpose of all structural members used in buildings is to support gravity loads. However, buildings may also be subjected to lateral forces due to wind and earthquakes. The effects of lateral forces in buildings will be more significant as the building height increases. All structural systems will not behave equally under seismic excitation. Aspects of structural configuration, symmetry, mass distribution and vertical regularity must be considered. In addition to that, the importance of strength, stiffness and ductility in relation to acceptable response must be evaluated in structural system (Paulay and Priestley, 1992).

The first task of the structural designer is to select the appropriate structural system for the satisfactory seismic performance of the building within the constraints dictated by architectural requirements. It is better where possible to discuss architect and structural engineer for alternative structural configuration at the earliest stage of concept development. Thus, undesirable geometry is not locked into the system before structural design is started.

Irregularities in buildings contribute to complexity of structural behavior. When not recognized, they may result in unexpected damage and even collapse of the structures. There are many possible sources of structural irregularities. Drastic changes in geometry, interruptions in load path, discontinuities in both strength and stiffness, disruption in critical region by openings and unusual proportion of members are few of the possibilities. The recognition of many of these irregularities and of conceptions for remedial measures for the mitigation of their undesired effects relies on sound understanding of structural behavior.

Response Spectrum Method

In order to perform the seismic analysis and design of a structure to be built at a particular location, the actual time history record is required. However, it is not possible to have such records at each and every location. Further, the seismic analysis of structures cannot be carried out simply based on the peak value of the ground acceleration as the response of the structure depend upon the frequency content of ground motion and its own dynamic properties. To overcome the above difficulties, earthquake response spectrum is the most popular tool in the seismic analysis of structures. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions.

This chapter deals with response spectrum method and its application to various types of the structures. The codal provisions as per IS 1893 (Part 1) : 2002 code for response spectrum analysis of multi-story building is also summarized.

Response Spectra

Response spectra are curves plotted between maximum response of SDOF system subjected to specified earthquake ground motion and its time period (or frequency). Response spectrum can be interpreted as the locus of maximum response of a SDOF system for given damping ratio. Response spectra thus helps in obtaining the peak structural responses under linear range, which can be used for obtaining lateral forces developed in structure due to earthquake thus facilitates in earthquake-resistant design of structures.

Usually response of a SDOF system is determined by time domain or frequency domain analysis, and for a given time period of system, maximum response is picked. This process is continued for all range of possible time periods of SDOF system. Final plot with system time period on x-axis and response quantity on y-axis is the required response spectra pertaining to specified damping ratio and input ground motion. Same process is carried out with different damping ratios to obtain overall response spectra.

Design Of Earthquake Resistant Structure Based On Codal Provisions

General principles and design philosophy for design of earthquake-resistant structure are as follows:

- a) The characteristics of seismic ground vibrations at any location depends upon the magnitude of earth quake,

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- its depth of focus, distance from epicenter, characteristic of the path through which the waves travel, and the soil strata on which the structure stands. Ground motions are predominant in horizontal direction.
- Earthquake generated vertical forces, if significant, as in large spans where differential settlement is not allowed, must be considered.
 - The response of a structure to the ground motions is a function of the nature of foundation soil, materials size and mode of construction of structures, and the duration and characteristic of ground motion.
 - The design approach is to ensure that structures possess at least a minimum strength to withstand minor earthquake (DBE), which occur frequently, without damage; resist moderate earthquake without significant damage though some nonstructural damage may occur, and aims that structures withstand major earthquake (MCE) without collapse. Actual forces that appeared on structures are much greater than the design forces specified here, but ductility, arising due to inelastic material behavior and detailing, and over strength, arising from the additional reserve strength in structures over and above the design strength are relied upon to account for this difference in actual and design lateral forces.
 - Reinforced and pre-stressed members shall be suitably designed to ensure that premature failure due to shear or bond does not occur, as per IS:456 and IS:1343.
 - In steel structures, members and their connections should be so proportioned that high ductility is obtained.
 - The soil structure interaction refers to the effect of the supporting foundation medium on the motion of structure. The structure interaction may not be considered in the seismic analysis for structures supporting on the rocks.
 - The design lateral forces shall be considered in two orthogonal horizontal directions of the structures. For structures, which have lateral force resisting elements in two orthogonal directions only, design lateral force must be considered in one direction at a time. Structures having lateral resisting elements in two directions other than orthogonal shall be analyzed according to clause 2.3.2 IS 1893 (part 1) : 2002. Where both horizontal and vertical forces are taken into account, load combinations must be according to clause 2.3.3 IS 1893 (part 1) : 2002.
 - When a change in occupancy results in a structure being re-classified to a higher importance factor (I), the structure shall be confirm to the seismic requirements of the new structure with high importance factor.

Response Spectrum Method (Dynamic Analysis)

General Codal Provisions

Dynamic analysis should be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to various lateral load resisting elements, for the following buildings: —

- Regular buildings- Those are greater than 40 m in height in zone IV, V and those are greater than 90 m height in zones II, III, and
- Irregular buildings- All framed buildings higher than 12 m in zone IV and V, and those are greater than 40 m in height in zone II and III.

Dynamic analysis may be performed either by time history method or by the response spectrum method. However in either method, the design base shear V_B shall be compared with a base shear V_B calculated using a fundamental period T_a . When V_B is less than V_B all the response quantities shall be multiplied by V_B / V_b

The values of damping for a building may be taken as 2 and 5 percent of the critical, for the purpose of dynamic analysis of steel and reinforced concrete buildings, respectively.

Modes To Be Considered

The number of modes to be considered in the analysis should be such that the sum of the total modal masses of all modes considered is at least 90% of the total seismic mass and the missing mass correction beyond 33%. If modes with natural frequency beyond 33 Hz are to be considered, modal combination shall be carried out only for modes up to 33 Hz.

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Computation Of Dynamic Quantities

Buildings with regular, or nominally irregular plan configuration may be modeled as a system of masses lumped at the floor levels with each mass having one degree of freedom, that of lateral displacement in the direction of consideration.

IV. MODELING OF BUILDING

Model Design

One of the objectives of this model generation is to ensure that the models represent the characteristics of residential buildings. High-rise buildings are different in shape, height and functions. This makes each building characteristics different from each other. There are some standards for each kind of high-rise buildings, such as residential, office and commercials. However, for model generation, main factors such as column layout, grid spacing, floor shape, floor height, mass and stiffness irregularity, and column orientation were considered.

Mostly in Residential buildings, floor plan will be same for all floors. So the buildings were considered with same floor plan in all floors. Shear walls of same section were used for same height of buildings throughout the height.

In this paper a high rise multi-storey building is studied for building with shear walls provided at the centre core and at the four corners (I shape).

The buildings are modeled using software ETABS. Dynamic analysis is carried out for this case.

Structural Modeling Of Building

To study the effects of openings sizes and locations in shear walls on seismic responses of buildings, three dimensional (3D) geometric models of the buildings were developed in ETABS. Beams and columns were modeled as frame elements. Shear walls were modeled as plate elements. Floor slabs were modeled as rigid horizontal plane.

Due to time limitations, it was impossible to account accurately for all aspects of behavior of all the components and materials even if their sizes and properties were known. Thus, for simplicity, following assumptions were made for the structural modeling:

1. The materials of the structure were assumed as homogeneous, isotropic and linearly elastic.
2. The effects of secondary structural components and non structural components such as staircase, masonry infill walls were assumed to be negligible.
3. Floors slabs were assumed rigid in plane.
4. Foundation for analysis was considered as rigid.

Structural Analysis

Initial dimensions of the structural elements for the buildings were assumed on the basis of gravity loads and imposed loads. Since, the buildings were assumed as apartment buildings, imposed load of 2 kN/m² and load due to floor finish were taken as 1.0 kN/m² as per Indian Standard, IS 875 (part2) : 1987. Lateral loads due to earthquake (EL) were calculated considering full dead load (DL) plus 25% of imposed load (IL), using seismic coefficient method given in IS 1893 (Part 1) : 2002.

Since the buildings were assumed as apartment buildings with dual system (shear wall and special moment resisting frame) situated in seismic zone V, importance factor (I) = 1, zone factor (Z) = 0.36 and response reduction factor (R) = 5 as given in IS code (Appendix A) were used for lateral load calculations. Assuming medium type of soil on which the foundations rest and the damping ratio of 5% for concrete structure, average response acceleration coefficient (Sa/g) was obtained from Appendix, depending on the approximate fundamental natural time period of the structure estimated by:

$$T_a = \frac{0.09}{\sqrt{d}} \quad \text{Eq. (4.1)}$$

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In which,

H = height of building in meter

d = base dimension of the building at plinth level, in meter, along the considered direction of lateral force

$$Q_i = V_B \times \frac{W_i h_i^2}{\sum_{i=1}^n W_i h_i^2} \quad \text{Eq. (4.2)}$$

Where,

Q_i = design lateral force at floor i

W_i = seismic weight of floor i

h_i = height of floor i measured from base, and

n = number of stories in the building, is the number of levels at which masses are located. Assuming the floor is capable of providing rigid diaphragm action (floor to be infinitely rigid in the horizontal plane), total shear in any horizontal plane is distributed to the various vertical elements according to their relative stiffness.

After several analyses in ETABS using equivalent static lateral force analysis for various load combinations given in IS 1893 (Part 1): 2002 (Appendix A), final dimensions of the structural elements for further analyses of the buildings were obtained. The maximum percentage of reinforcements for structural elements was limited to 4% of concrete gross area as per IS 456 : 2000. Concrete grade of M30 i.e. characteristic compressive strength (f_{ck}) of 30 N/mm² was assumed for all structural elements. Material properties were assumed same for all structural elements used in both all the buildings. The material properties assumed for final structural analysis are as follows:

Modulus of elasticity (E) = 2.5 × 10⁷ kN/m²

Poisson's ratio (ν) = 0.17

Unit weight of concrete (γ) = 25 kN/m³

Section properties of structural members and other properties used for the final structural analyses of buildings are tabulated in Table 3.1

Details Of The Building

A symmetrical building of plan 24.5m X 22.5m located with location in zone V, India is considered. Seven bays of length 3.5m along X - direction and five bays of length 4.5m along Y - direction are provided. Shear Wall is provided at the center core and corners of building model.

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Table 1.Details of the building

Building Parameters	Details
Type of frame	Special RC moment resisting frame fixed at the base
Building plan	24.5m X 22.5m
Number of storeys	Forty
Floor height	3.0 m
Depth of Slab	150 mm
Size of beam	(230 × 450) mm
Size of column (exterior)	(400 × 700) mm
Size of column (interior)	(500 × 500) mm
Spacing between frames	3.5 m along x - direction 4.5m along y - direction
Live load on floor	2 KN/m ²
Floor finish	1.0 KN/m ²
Wall load	10 KN/m
Grade of Concrete	M 30 concrete
Grade of Steel	Fe415
Thickness of shear wall	230mm
Seismic zone	V
Density of concrete	25 KN/m ³
Type of soil	Medium
Response spectra	As per IS 1893(Part-1):2002
Damping of structure	5 percent

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Layout Of The Buildings

Building With Shear Walls Provided At The Centre Core And At The Four Corners (L Shape).

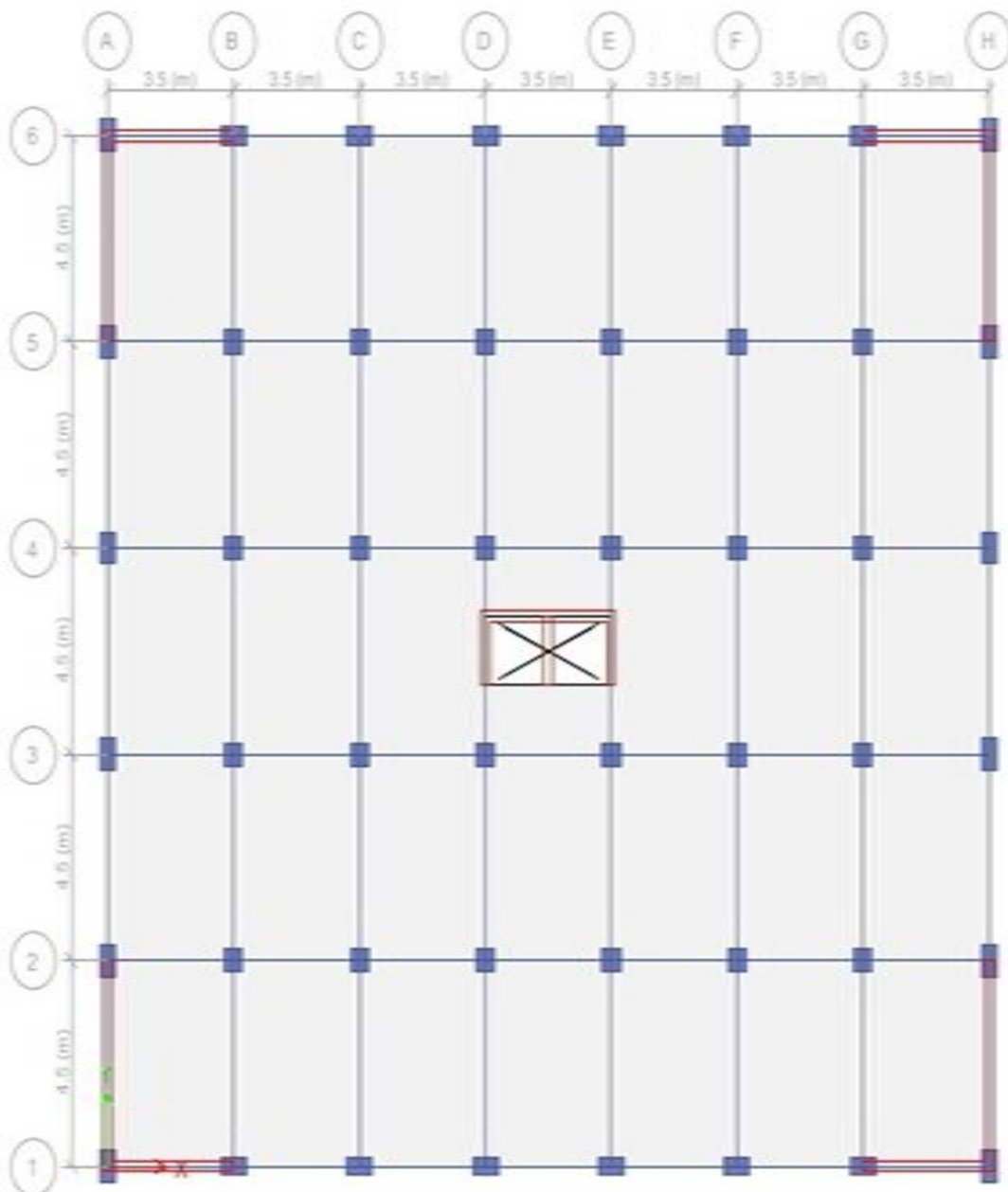


Figure 1. Plan of the building

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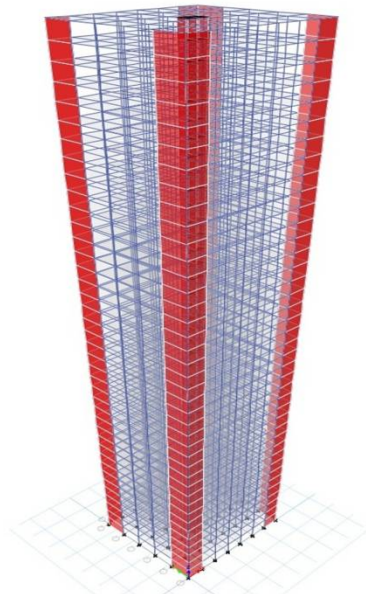


Figure 2.3D view showing shear wall location

Building Design Requirements

The proposed reinforced concrete shear wall buildings are located in zone V, India. Code requirements from IS 456 : 2000, IS 13920 : 1993 and IS 1893 (part 1) : 2002 were used for structural design.

In the ETABS design model, modeling was done in order to verify sufficient strength and stiffness. Rigid diaphragms, along with lumped masses, were assigned at each level.

Load Combinations

As per IS 1893 (Part 1): 2002 Clause no. 6.3.1.2, the following load cases have to be considered for analysis:

1.5 (DL + IL)

1.2 (DL + IL ± EL)

1.5 (DL ± EL)

0.9 DL ± 1.5 EL

Earthquake load must be considered for +X, -X, +Y and -Y directions.

Design Of Beams

General Requirements

The flexural members shall fulfil the following general requirements. (IS 13920; Clause 6.1.2)

$$\frac{b}{D} \geq 0.3$$

In the present study beam of size (230 X 450) mm has been used.

Here, $\frac{b}{D} = \frac{230}{450} = 0.51 > 0.3$.

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Hence, ok.

As per IS 13920; Clause 6.1.3

$b \geq 200$ mm

Here $b = 300$ mm ≥ 200 mm

Hence, ok.

As per IS 13920; Clause 6.1.4

The depth D of the member shall preferably be not more than $\frac{1}{4}$ of the clear span.

Here, $D=450$ mm and clear span length is 3000 mm.

$\frac{1}{4}$ (clear span) = $3000/4 = 750$ mm > 450 mm

Hence, ok.

Check For Reinforcement

As per IS 13920; Clause 6.2.1 (b)

The tension steel ratio on any face, at any section, shall not be less than $p_{min} = 0.24 \sqrt{f_{ck}/f_y}$

Therefore, $p_{min} = 0.361$ %

As per IS 13920; Clause 6.2.2

The maximum steel ratio on any face at any section, shall not exceed $p_{max} = 0.025$ or 2.5 %.

Design was carried out by the software and p_t values for critical members were noted down as follows;

Table 2. p_t values of most critical member of building model.

Building Model	p_t values
Model	1.28

Therefore, the model pass the reinforcement check.

Design Of Columns

Check For Axial Stress

As per IS 13920; Clause 6.1.1

The factored axial stress on the member under earthquake loading shall not exceed $0.1f_{ck}$ (=3 Mpa)

The factored axial stress values for the most critical member of model were noted down as follows;

Table 3. Axial stress values of most critical member of building model.

Building Model	Axial Stresses (Mpa)
Model	6.49

the model do not satisfy the above clause. However, IS 13920 specifies another clause for this case.

Design Requirements Which Have Axial Stress In Excess Of $0.1f_{ck}$

In the present study, the minimum dimension of the member provided is 500 mm. Also the shortest dimension provided is 500 mm. As per IS 13920; Clause 7.1.2, the minimum dimension of the member shall not be less than 200 mm.

Hence the above clause is in fulfillment of the building models.

Two types of columns were provided in the present study.

Column 1 has a cross section of 400 X 700 mm while Column 2 has 500 X 500 mm

Column 1; $400/700 = 0.57 > 0.4$.

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Column 2; $500/500 = 1 > 0.4$

As per IS 13920; Clause 7.1.3, the ratio of the shortest cross sectional dimension to the perpendicular dimension shall preferably not be less than 0.4.

Hence, both the columns satisfy the clause.

The column section shall be designed just above and just below the beam column joint, and larger of the two reinforcements shall be adopted. This is similar to what is done for design of continuous beam reinforcements at the support. The end moments and end shears are available from computer analysis. The design moment should include:

- (a) The additional moment if any, due to long column effect as per clause 39.7 of IS 456:2000.
- (b) The moments due to minimum eccentricity as per clause 25.4 of IS 456:2000.

The longitudinal reinforcements are designed as per IS 456 : 2000

Reinforcement Check

Design was carried out by the software and p_t values for critical members were noted down as follows;

Table 4. p_t values of most critical member of building model.

Building Model	p_t values
Model	3.18

As per IS 456 : 2000; Clause 26.5.3.1(a) the cross sectional area of longitudinal reinforcement, shall not be less than 0.8 % nor more than 6 % of the gross cross sectional area of the column. It should be noted that percentage of steel should not exceed 4 % since it may involve practical difficulties. Therefore, the model pass the reinforcement check.

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V. RESULTS AND DISCUSSIONS

Building With Shear Walls Provided at the Centre Core and at the Four Corners (L Shape).

Table 5.Storey Maximum Displacement in X and Y directions

Storey	Elevation m	Location	X-Dir mm	Y-Dir mm
Storey40	120	Top	115.7	125
Storey39	117	Top	113.8	122.5
Storey38	114	Top	111.8	119.9
Storey37	111	Top	109.8	117.3
Storey36	108	Top	107.8	114.7
Storey35	105	Top	105.6	112
Storey34	102	Top	103.4	109.2
Storey33	99	Top	101	106.4
Storey32	96	Top	98.6	103.4
Storey31	93	Top	96	100.4
Storey30	90	Top	93.4	97.3
Storey29	87	Top	90.6	94.1
Storey28	84	Top	87.8	90.8
Storey27	81	Top	84.8	87.4
Storey26	78	Top	81.8	84
Storey25	75	Top	78.7	80.4
Storey24	72	Top	75.4	76.8
Storey23	69	Top	72.1	73.2
Storey22	66	Top	68.7	69.4
Storey21	63	Top	65.3	65.6
Storey20	60	Top	61.7	61.8
Storey19	57	Top	58.1	58
Storey18	54	Top	54.5	54.1
Storey17	51	Top	50.8	50.1
Storey16	48	Top	47.1	46.2
Storey15	45	Top	43.3	42.3
Storey14	42	Top	39.6	38.4
Storey13	39	Top	35.9	34.6
Storey12	36	Top	32.1	30.8
Storey11	33	Top	28.4	27.1
Storey10	30	Top	24.8	23.5
Storey9	27	Top	21.3	20
Storey8	24	Top	17.8	16.6
Storey7	21	Top	14.5	13.4
Storey6	18	Top	11.4	10.5
Storey5	15	Top	8.5	7.7
Storey4	12	Top	5.9	5.3
Storey3	9	Top	3.7	3.3
Storey2	6	Top	1.9	1.6
Storey1	3	Top	0.6	0.5
Base	0	Top	0	0

Table 6.Storey Stiffness, Shears and Drifts in X and Y directions.

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Storey	Shear X kN	Drift X mm	Stiffness X kN/m	Shear Y kN	Drift Y mm	Stiffness Y kN/m
Storey40	374.942	2.1	178292	376.309	2.7	139018
Storey39	706.43	2.2	323877	715.805	2.8	258110
Storey38	967.348	2.3	428658	990.736	2.8	349534
Storey37	1163.38	2.3	496278	1204.09	2.9	414267
Storey36	1305.11	2.4	535829	1361.9	3	456571
Storey35	1407.39	2.5	556594	1473.51	3.1	481361
Storey34	1487.01	2.6	567233	1551.22	3.1	494076
Storey33	1559.1	2.7	574445	1609.03	3.2	500061
Storey32	1633.73	2.8	582167	1660.64	3.3	503987
Storey31	1714.35	2.9	591569	1716.94	3.4	509233
Storey30	1799	3	601924	1783.96	3.4	517475
Storey29	1883.41	3.1	611883	1862.24	3.5	528732
Storey28	1963.98	3.2	620493	1948.06	3.6	541881
Storey27	2039.45	3.2	627624	2035.73	3.7	555401
Storey26	2110.87	3.3	633837	2119.86	3.7	568005
Storey25	2180.41	3.4	639949	2197	3.8	579018
Storey24	2249.74	3.5	646574	2266.21	3.9	588458
Storey23	2319.07	3.5	653879	2328.85	3.9	596910
Storey22	2387.12	3.6	661629	2387.6	3.9	605260
Storey21	2451.99	3.7	669466	2445.3	4	614389
Storey20	2512.43	3.7	677223	2503.76	4	624912
Storey19	2568.51	3.7	685113	2563.07	4	637043
Storey18	2621.64	3.8	693695	2621.66	4	650628
Storey17	2673.73	3.8	703671	2677.01	4	665335
Storey16	2726.04	3.8	715612	2726.81	4	680923
Storey15	2778.41	3.8	729807	2770.06	4	697530
Storey14	2829.42	3.8	746317	2807.92	3.9	715892
Storey13	2877.42	3.8	765276	2843.87	3.9	737461
Storey12	2921.96	3.7	787300	2883.12	3.8	764387
Storey11	2964.91	3.6	813871	2931.27	3.7	799391
Storey10	3010.46	3.6	847556	2992.62	3.5	845584
Storey9	3063.8	3.4	892021	3068.56	3.4	906412
Storey8	3128.74	3.3	952001	3156.78	3.2	985959
Storey7	3205.51	3.1	1033599	3251.6	3	1089940
Storey6	3289.62	2.9	1145714	3345.16	2.7	1227947
Storey5	3372.76	2.6	1304050	3429.27	2.4	1418405
Storey4	3445.23	2.2	1541826	3497.09	2.1	1700877
Storey3	3499.04	1.8	1943682	3544.54	1.6	2174665
Storey2	3530.49	1.3	2789237	3571.18	1.1	3164069
Storey1	3541.71	0.6	6078604	3580.47	0.5	6986167

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Table 7. Modes and periods

Case	Mode	Period	UX	UY	Sum UX	Sum UY
		sec				
Modal	1	5.369	0	0.704	0	0.704
Modal	2	5.196	0.7224	0	0.7224	0.704
Modal	3	3.701	0.0001	0	0.7225	0.704
Modal	4	1.514	0.1232	0	0.8457	0.704
Modal	5	1.483	0	0.1337	0.8457	0.8377
Modal	6	0.991	1.20E-05	0	0.8457	0.8377
Modal	7	0.747	0.0492	0	0.8949	0.8377
Modal	8	0.692	0	0.0542	0.8949	0.8919
Modal	9	0.452	0.0284	0	0.9233	0.8919
Modal	10	0.444	0	0	0.9233	0.8919
Modal	11	0.405	0	0.0306	0.9233	0.9225
Modal	12	0.304	0.0182	0	0.9415	0.9225

Here the minimum modal mass for accelerations U_x and U_y is 94.15 % and 92.25 % respectively.

Mode Shape

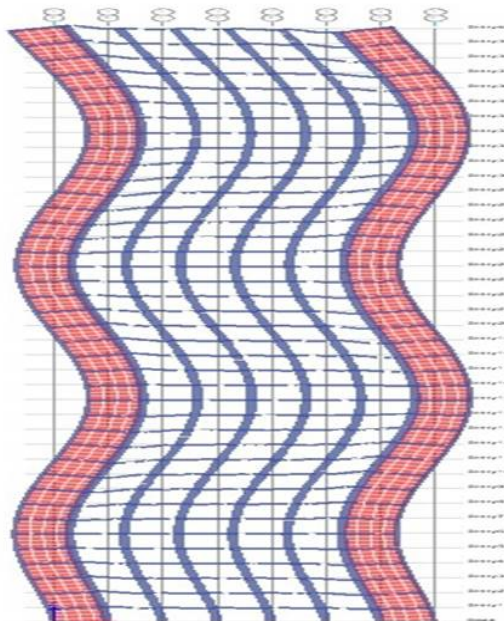


Figure3. Mode shape for model

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Stress Distribution

The stress distribution in shear walls is represented diagrammatically for the model. The stress distribution for shear walls located in the external periphery of the plan of building is studied.

Stress Distribution in Model

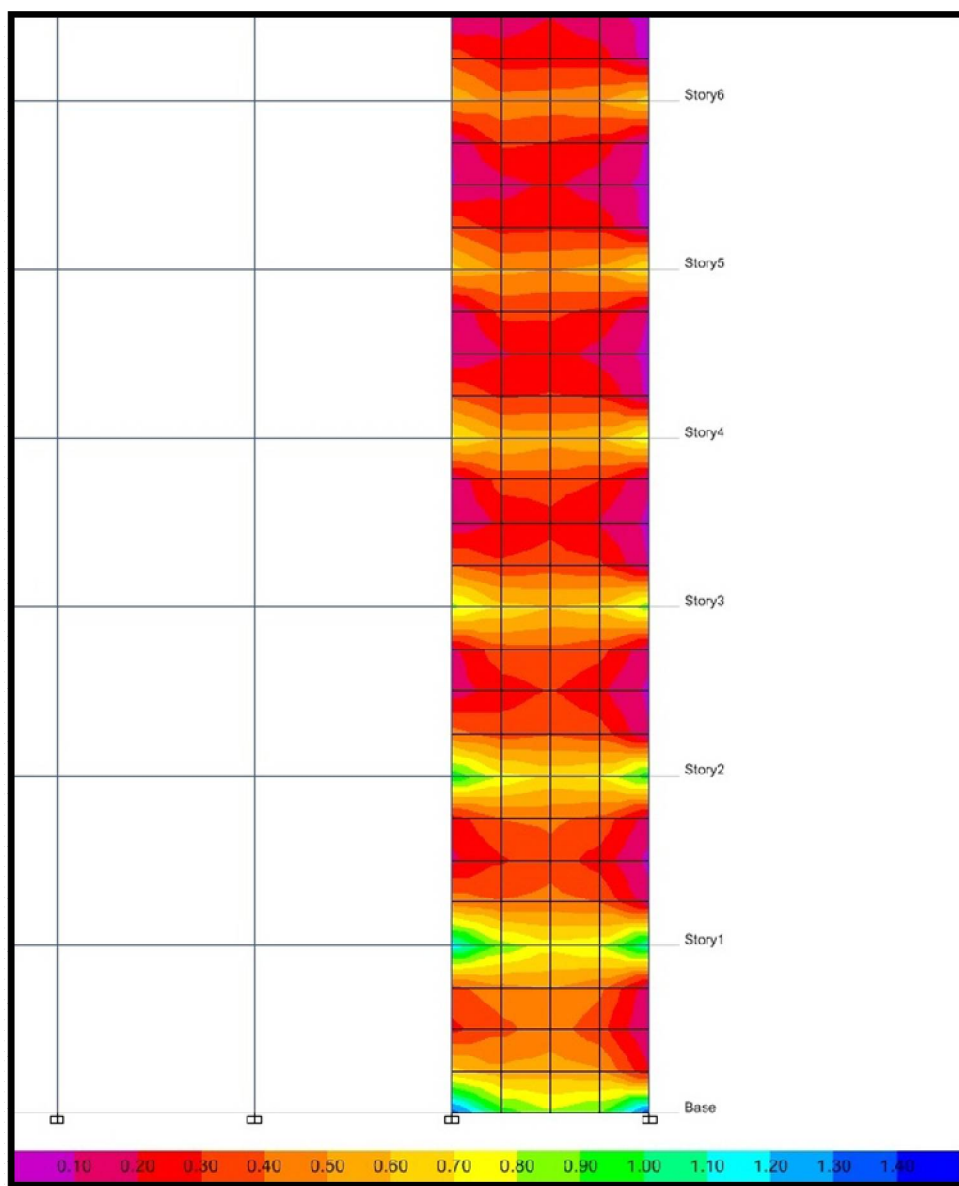


Figure 4.. Stress distribution

A similar stress pattern is seen across all stories. The concentration in stress is minimum at the centre of the shear wall and maximum at edges between stories. Bottom stories tend to exhibit stresses relatively higher compared to the upper stories. Fig 4.shows the stress distribution across the bottom six stories. The scale underneath the figure indicates the range of stress developed which is in between 0.10 MPa to 1.4 MPa.

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Storey Maximum Displacements

Table 8. Maximum Storey Displacements in X Direction

Storey level	Elevation(m)	Model
Storey40	120	115.7
Storey39	117	113.8
Storey38	114	111.8
Storey37	111	109.8
Storey36	108	107.8
Storey35	105	105.6
Storey34	102	103.4
Storey33	99	101
Storey32	96	98.6
Storey31	93	96
Storey30	90	93.4
Storey29	87	90.6
Storey28	84	87.8
Storey27	81	84.8
Storey26	78	81.8
Storey25	75	78.7
Storey24	72	75.4
Storey23	69	72.1
Storey22	66	68.7
Storey21	63	65.3
Storey20	60	61.7
Storey19	57	58.1
Storey18	54	54.5
Storey17	51	50.8
Storey16	48	47.1
Storey15	45	43.3
Storey14	42	39.6
Storey13	39	35.9
Storey12	36	32.1
Storey11	33	28.4
Storey10	30	24.8
Storey9	27	21.3
Storey8	24	17.8
Storey7	21	14.5
Storey6	18	11.4
Storey5	15	8.5
Storey4	12	5.9
Storey3	9	3.7
Storey2	6	1.9
Storey1	3	0.6
Base	0	0

All values are in mm

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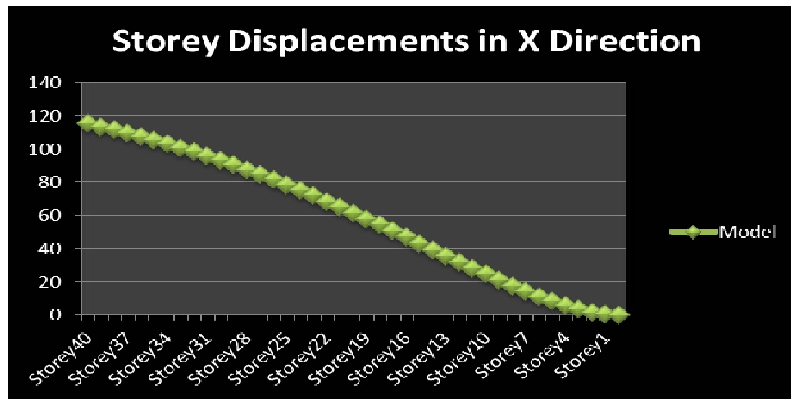


Table 9. Maximum Storey Displacements in Y Direction

Storey Level	Elevation (m)	Model
Storey40	120	125
Storey39	117	122.5
Storey38	114	119.9
Storey37	111	117.3
Storey36	108	114.7
Storey35	105	112
Storey34	102	109.2
Storey33	99	106.4
Storey32	96	103.4
Storey31	93	100.4
Storey30	90	97.3
Storey29	87	94.1
Storey28	84	90.8
Storey27	81	87.4
Storey26	78	84
Storey25	75	80.4
Storey24	72	76.8
Storey23	69	73.2
Storey22	66	69.4
Storey21	63	65.6
Storey20	60	61.8
Storey19	57	58
Storey18	54	54.1
Storey17	51	50.1
Storey16	48	46.2
Storey15	45	42.3
Storey14	42	38.4
Storey13	39	34.6
Storey12	36	30.8
Storey11	33	27.1
Storey10	30	23.5
Storey9	27	20
Storey8	24	16.6
Storey7	21	13.4
Storey6	18	10.5
Storey5	15	7.7
Storey4	12	5.3
Storey3	9	3.3
Storey2	6	1.6
Storey1	3	0.5
Base	0	0

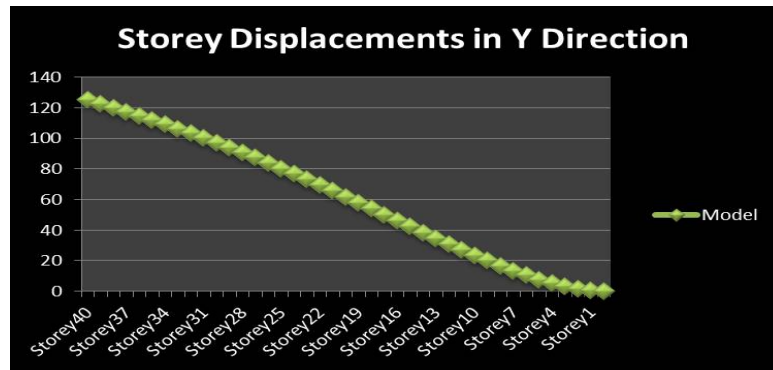
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For both X and Y directions, the behaviour of the graph is similar for model as shown. The order of maximum storey displacement in both the directions for the models is same. The maximum storey displacements is less than 5 % i.e, well within the engineering limits.

Storey Drifts

Table 10. Storey drifts in X direction

Storey	Model
Storey40	2.1
Storey39	2.2
Storey38	2.3
Storey37	2.3
Storey36	2.4
Storey35	2.5
Storey34	2.6
Storey33	2.7
Storey32	2.8
Storey31	2.9
Storey30	3
Storey29	3.1
Storey28	3.2
Storey27	3.2
Storey26	3.3
Storey25	3.4
Storey24	3.5
Storey23	3.5
Storey22	3.6
Storey21	3.7
Storey20	3.7
Storey19	3.7
Storey18	3.8
Storey17	3.8
Storey16	3.8
Storey15	3.8
Storey14	3.8
Storey13	3.8
Storey12	3.7
Storey11	3.6
Storey10	3.6
Storey9	3.4
Storey8	3.3
Storey7	3.1
Storey6	2.9
Storey5	2.6
Storey4	2.2
Storey3	1.8
Storey2	1.3
Storey1	0.6

All values are in mm

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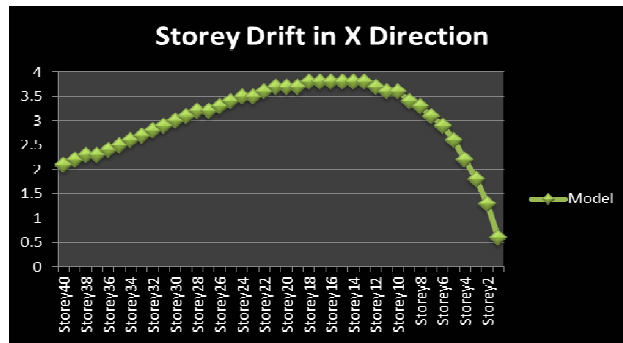


Table 11. Storey drifts in Y direction

Storey	Model
Storey40	2.7
Storey39	2.8
Storey38	2.8
Storey37	2.9
Storey36	3
Storey35	3.1
Storey34	3.1
Storey33	3.2
Storey32	3.3
Storey31	3.4
Storey30	3.4
Storey29	3.5
Storey28	3.6
Storey27	3.7
Storey26	3.7
Storey25	3.8
Storey24	3.9
Storey23	3.9
Storey22	3.9
Storey21	4
Storey20	4
Storey19	4
Storey18	4
Storey17	4
Storey16	4
Storey15	4
Storey14	3.9
Storey13	3.9
Storey12	3.8
Storey11	3.7
Storey10	3.5
Storey9	3.4
Storey8	3.2
Storey7	3
Storey6	2.7
Storey5	2.4
Storey4	2.1
Storey3	1.6
Storey2	1.1
Storey1	0.5

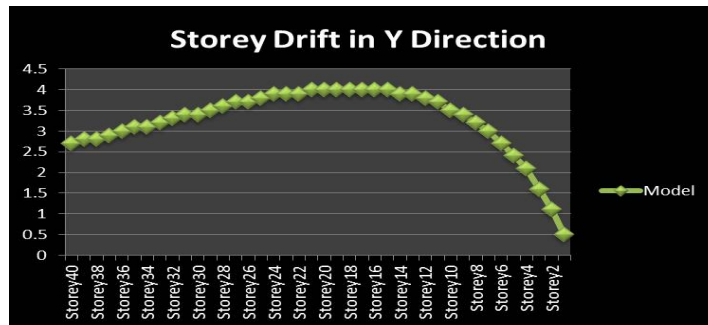
All values are in mm

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As per Indian standard, Criteria for earthquake resistant design of structures, IS 1893 (Part 1) : 2002, the story drift in any story due to service load shall not exceed 0.004 times the story height. The height of the each storey is 3 m. So, the drift limitation as per IS 1893 (part 1) : 2002 is $0.004 \times 3 \text{ m} = 12 \text{ mm}$. The model show a similar behaviour for storey drifts as shown in graph.

Base Shears

Table 12. Base shears in X direction

Model	Base Shears in X (kN)
Model	3541.714

Table 13. Base Shears in Y direction

Model	Base Shears in Y (kN)
Model	3580.471

Modal Results

Table 14. Modes and natural periods

Case	Mode	Model
		Period (sec)
Modal	1	5.369
Modal	2	5.196
Modal	3	3.701
Modal	4	1.514
Modal	5	1.483
Modal	6	0.991
Modal	7	0.747
Modal	8	0.692
Modal	9	0.452
Modal	10	0.444
Modal	11	0.405
Modal	12	0.304

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Table 15. Modal Masses

Model	Dynamic %	
	Acceleration Ux	Acceleration Uy
Model	94.15	92.25

According to IS-1893:2002 the number of modes to be used in the analysis should be such that the total sum of modal masses of all modes considered is at least 90 percent of the total seismic mass. Here the minimum modal mass is 92.25 percent.

VI. CONCLUSION AND FURTHER STUDY

Conclusions

In this paper, reinforced concrete shear wall buildings were analyzed with the procedures laid out in IS codes. The intent of the paper was to investigate the seismic behaviour of buildings.

From the above results and discussions, following conclusions can be drawn:

1. Based on the analysis and discussion, shear walls are very much suitable for resisting earthquake induced lateral forces in multistoried structural systems when compared to multistoried structural systems without shear walls. They can be made to behave in a ductile manner by adopting proper detailing techniques.
2. The location of shear walls in the center core and corners considerably reduce the effects of displacements and drifts.
3. Shear walls must be coinciding with the centroid of the building for better performance. It follows that a center core shear wall should be provided.
4. The vertical reinforcement that is uniformly distributed in the shear wall shall not be less than the horizontal reinforcement. This provision is particularly for squat walls (i.e. Height-to-width ratio is about 1.0). However, for walls with height-to-width ratio less than 1.0, a major part of the shear force is resisted by the vertical reinforcement. Hence, adequate vertical reinforcement should be provided for such walls.
5. Shear walls must provide the necessary lateral strength to resist horizontal earthquake forces.

Further Study

Different assumptions and limitations have been adopted for simplicity in modeling the proposed structures. In reality, it might affect on results. Thus, all factors which may influence on the behaviour of the structures should be considered in the modeling. For the further study, to obtain the real responses of the structures, the following recommendations are made:

1. Since the study was performed for only one type of shear wall, the further investigations should be made for different types of shear walls.
2. Further investigations should be done for shear walls with different aspect ratio (h/L), in frame-shear wall structures.
3. A flexible foundation will affect the overall stability of the structure by reducing the effective lateral stiffness. So the soil structure interaction should be considered in further study.

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4. Shear wall structure have been shown to perform well in earthquakes, for which ductility becomes an important consideration. Thus, further study should be made considering geometric and material non-linear behavior of the members concerned.
5. The study was performed for a damping ratio of 5% for model. Further studies should be carried out for damping ratios of 10%, 15% and so on.

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