International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Earthquakes Analysis of High Rise Buildings with Shear Walls at the Center Core and Center of Each Side of the External Perimeter with Opening

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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, Fortystorey buildings (120m) 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 with opening conditions. Symmetrical openings are provided in shear walls with proper sizes to ensure least interruption to force flow through walls. Estimation of structural response such as; storey displacements, base shear, storey drift 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: Response Spectrum method, shear walls,storey displacements, base shear, storeydrift,lateral loads.

1. Introduction

Shear walls are a type of structural system that provides lateral resistance to a building or structure. They resist in-plane loads that are applied along its height. The applied load is generally transferred to the wall by a diaphragm or collector or drag member. The efficiency of a structural system is measured in terms of their ability to resist lateral load, which increases with the height of the frame. A building can be considered as tall when the effect of lateral loads is reflected in the design. Lateral deflections of framed buildings should be limited to prevent damage to both structural and nonstructural elements. 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. “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 requires 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 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 summarized in the quote: And effectiveness in minimizing earthquake damage in structural and non- Structural elements (like glass windows and building contents).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.Door or window openings can be provided in shear walls, but their size must be small to ensure least interruption to force flow through walls. Moreover, openings should be symmetrically located. 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. 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 enclose space, whereas of cores to contain and convey services such as elevator. Wall openings are inevitably required for windows in external walls and for doors or corridors in inner walls or in lift cores. The size and location of openings may vary from architectural and functional point of view. When a building is subjected to wind or earthquake load, various types of failure must be prevented:

- Slipping off the foundation (sliding)
- Overturning and uplift (anchorage failure)
- Shear distortion (drift or racking deflection)
- Collapse (excessive racking deflection)

The first three types of failure are schematically shown in the Figure 1Clearly, the entire system must be tied together to prevent building collapse or significant deformation.

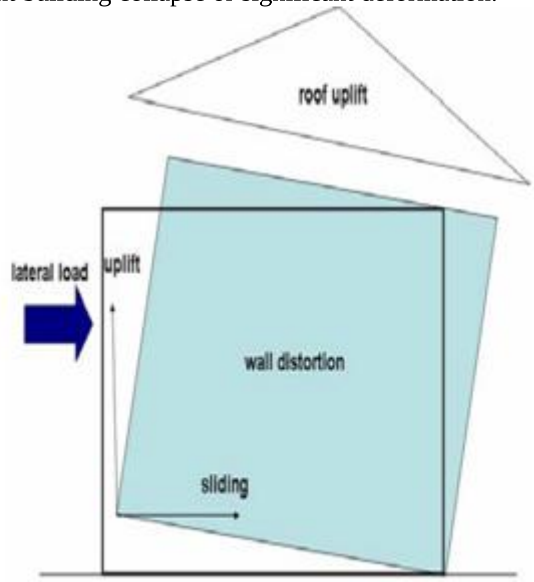


Figure 1: Schematic of the deformations of the structure due to the lateral loads

The salient objective of the present study have been identified as follows:

1) To investigate the seismic performances of the building with two different locations of shear walls in the external perimeter.
2) To evaluate the behaviour of shear wall with openings under seismic loads.
3) To evaluate the effect of openings in shear walls and comparing the results obtained with models without openings.

1.1 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 with model forty storey high and provided with a shear wall at the center core of the building and at the center of each side of the external perimeter with openings.

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

1.2 Literature Review

General

The race towards new heights and architecture has not been without challenges. When the building increases in height, the stiffness of the structure becomes more important. Tall structures have continued to climb higher and higher facing strange loading effects and very high loading values due to dominating lateral loads. The design criteria for tall buildings are strength, serviceability, stability and human comfort. Thus the effects of lateral loads like wind loads, earthquake forces are attaining increasing importance and almost every designer is faced with the problem of providing adequate strength and stability against lateral loads.

To provide a detailed review of the literature related to shear wall buildings in its entirety would be difficult to address here. A brief review on seismic performance of buildings with shear walls of previous studies is presented here. This literature review focuses on recent contributions related to shear walls and openings in them and past efforts most closely related to the needs of the present work.

Generally, the building configuration which is conceived by architects and then accepted by developer or owner may provide a narrow range of options for lateral-load resistant systems that can be utilized by structural engineers. By observing the following fundamental principles relevant to seismic responses, more suitable structural systems may be adopted (Paulay and Priestley, 1992):

1) 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.
2) Symmetry in plans should be provided, wherever possible. Lack of symmetry in plan may lead to significant torsional response, the reliable prediction of which is often difficult.
3) An integrated foundation system should tie together all vertical structural elements in both principal directions. Foundation resting on different soil condition should preferably be avoided.
4) Lateral force resisting systems with significantly different stiffness such as shear walls and frames within one building should be arranged in such a way that at every level of the building, symmetry in lateral stiffness is not grossly violated. Thus, undesirable torsional effects will be minimized.
5) Regularity in elevation should prevail in both the geometry and the variation of story stiffness.

1.3 Summary

1) 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.
2) Shear walls are more effective when located along exterior perimeter of the building. Such a layout increases resistance of the building to torsion.
3) Centre window openings are more suited than eccentric window openings and door openings.

2. 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 center of each side of the external perimeter with openings.
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.

Earthquake motion causes vibration of the structure leading to inertia forces. Thus a structure must be able to safely transmit the horizontal and the vertical inertia forces generated in the super structure through the foundation to the ground. Hence, for most of the ordinary structures, earthquake-resistant design requires ensuring that the structure has adequate lateral load carrying capacity. Seismic codes will guide a designer to safely design the structure for its intended purpose.
Quite a few methods are available for the earthquake analysis of buildings; two of them are presented here:
1) Equivalent Static Lateral Force Method (pseudo static method).
2) Dynamic analysis.
   a) Response spectrum method.
   b) Time history method.

2.1 Equivalent lateral Force (Seismic Coefficient) Method

This method of finding lateral forces is also known as the static method or the equivalent static method or the seismic coefficient method. The static method is the simplest one and it requires less computational effort and is based on formulae given in the code of practice.

In all the methods of analyzing a multi storey buildings recommended in the code, the structure is treated as discrete system having concentrated masses at floor levels which include the weight of columns and walls in any storey should be equally distributed to the floors above and below the storey. In addition, the appropriate amount of imposed load at this floor is also lumped with it. It is also assumed that the structure flexible and will deflect with respect to the position of foundation the lumped mass system reduces to the solution of a system of second order differential equations. These equations are formed by distribution, of mass and stiffness in a structure, together with its damping characteristics of the ground motion.

2.2 Dynamic Analysis

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

2.2.1 Regular buildings

Those greater than 40m in height in zones IV and V, those greater than 90m in height in zone II and III.

2.2.2 Irregular buildings

All framed buildings higher than 12m in zones IV and V, and those greater than 40m in height in zones II and III.

The analysis of model for dynamic analysis of buildings with unusual configuration should be such that it adequately models the types of irregularities present in the building configuration. Buildings with plan irregularities, as defined in Table 4 of IS code: 1893-2002 cannot be modeled for dynamic analysis.

Dynamic analysis may be performed either by the TIME HISTORY METHOD or by the RESPONSE SPECTRUM METHOD

2.3 Response Spectrum Method

The word spectrum in engineering conveys the idea that the response of buildings having a broad range of periods is summarized in a single graph. This method shall be performed using the design spectrum specified in code or by a site-specific design spectrum for a structure prepared at a project site. The values of damping for building may be taken as 2 and 5 percent of the critical, for the purposes of dynamic of steel and reinforce concrete buildings, respectively. For most buildings, inelastic response can be expected to occur during a major earthquake, implying that an inelastic analysis is more proper for design. However, in spite of the availability of nonlinear inelastic programs, they are not used in typical design practice because:
1) Their proper use requires knowledge of their inner workings and theories. design criteria, and
2) Result produced are difficult to interpret and apply to traditional design criteria , and
3) The necessary computations are expensive.

Therefore, analysis in practice typically use linear elastic procedures based on the response spectrum method. The response spectrum analysis is the preferred method because it is easier to use.

3. Modeling of Building

3.1 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.

3.2 Details of the Building

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. Centre window openings of size 2m X 1.2m were provided in model.

In this paper a high rise multi-storey building is studied for the following cases.

Building with Shear Walls provided at the centre core and at the center of each side of the external perimeter with openings.
The buildings are modeled using software ETABS. Dynamic analysis is carried out for the case.

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.

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/m2
Floor finish	1.0 KN/m2
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/m3
Type of soil	Medium
Response spectra	As per IS 1893(Part-1):2002
Damping of structure	5 percent

3.3 Layout of the Buildings

Building with Shear Walls provided at the centre core and at the center of each side of the external perimeter with openings.

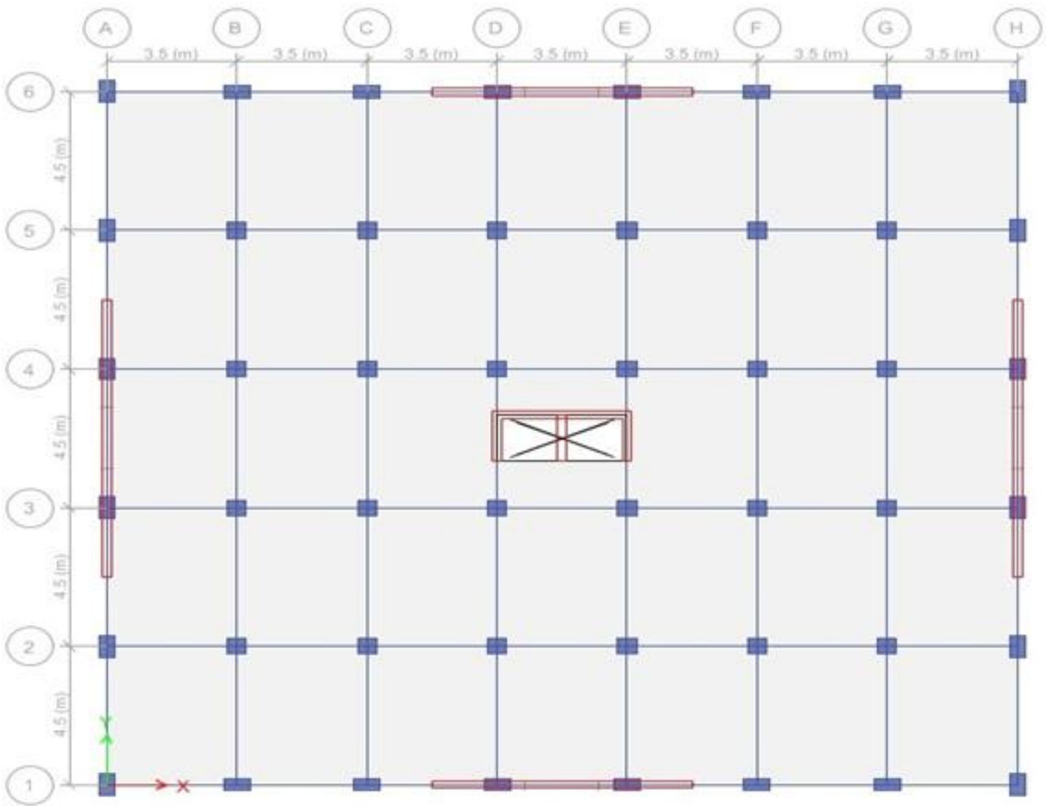


Figure 2: Plan of the building with shear wall openings

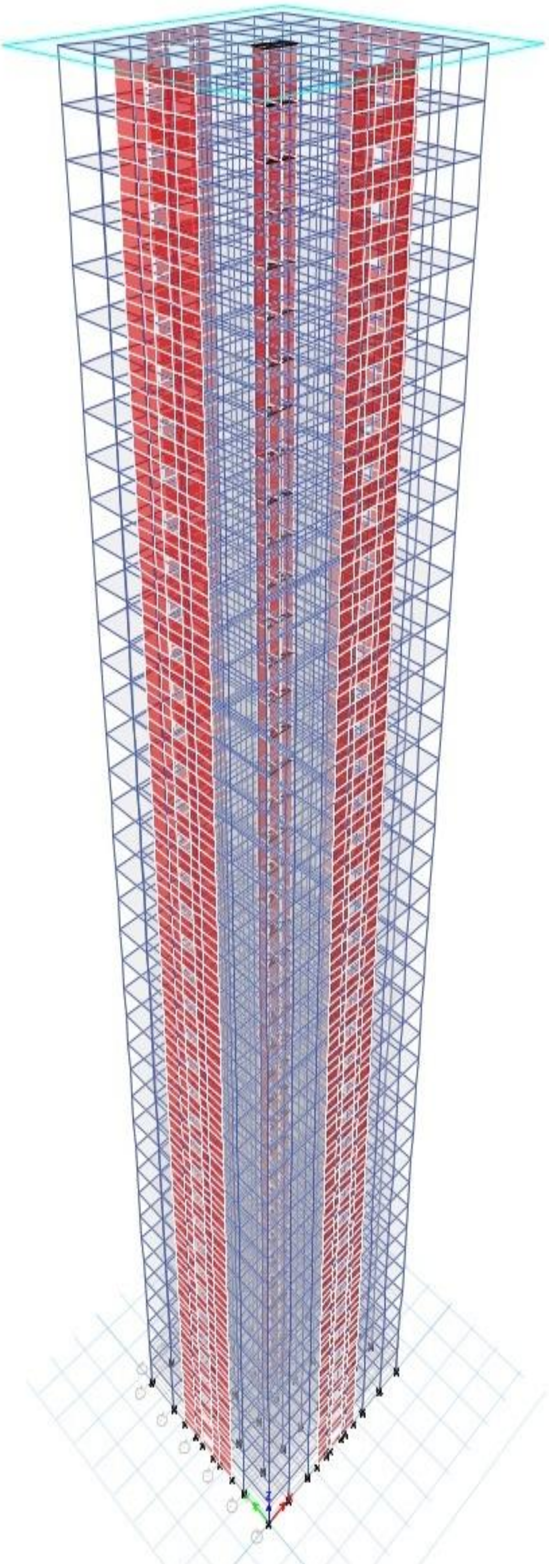


Figure 3:3D view showing openings in shear walls

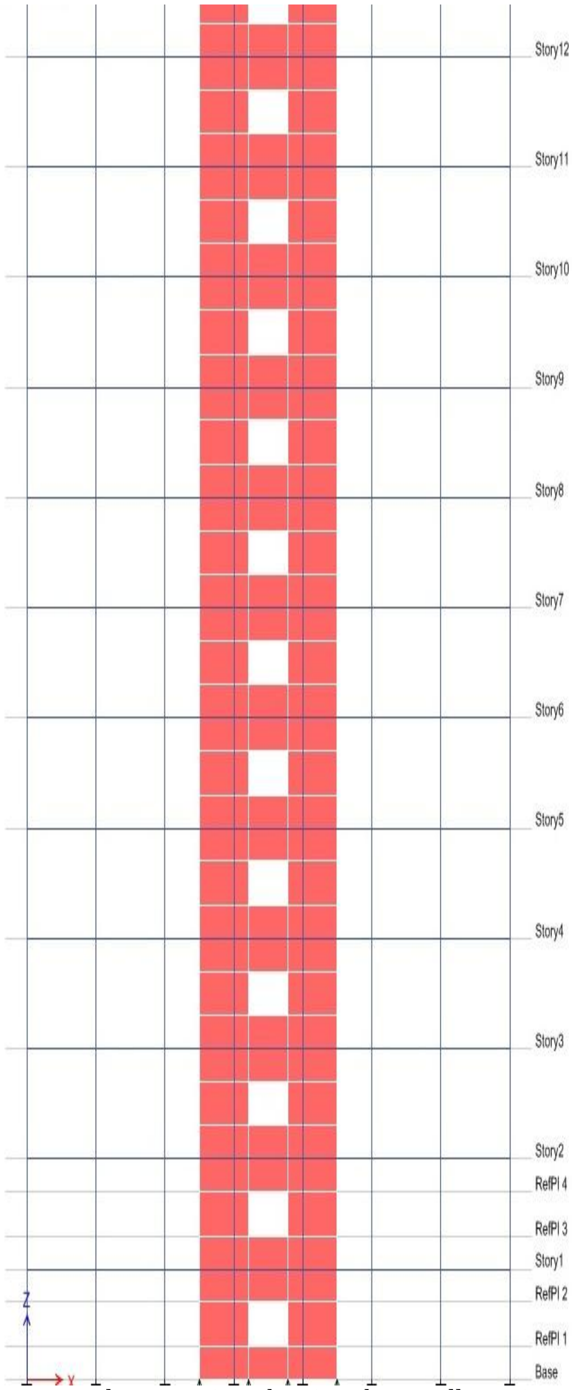


Figure 4: Elevation view showing shear wall openings of size 2 m X 1.2 m

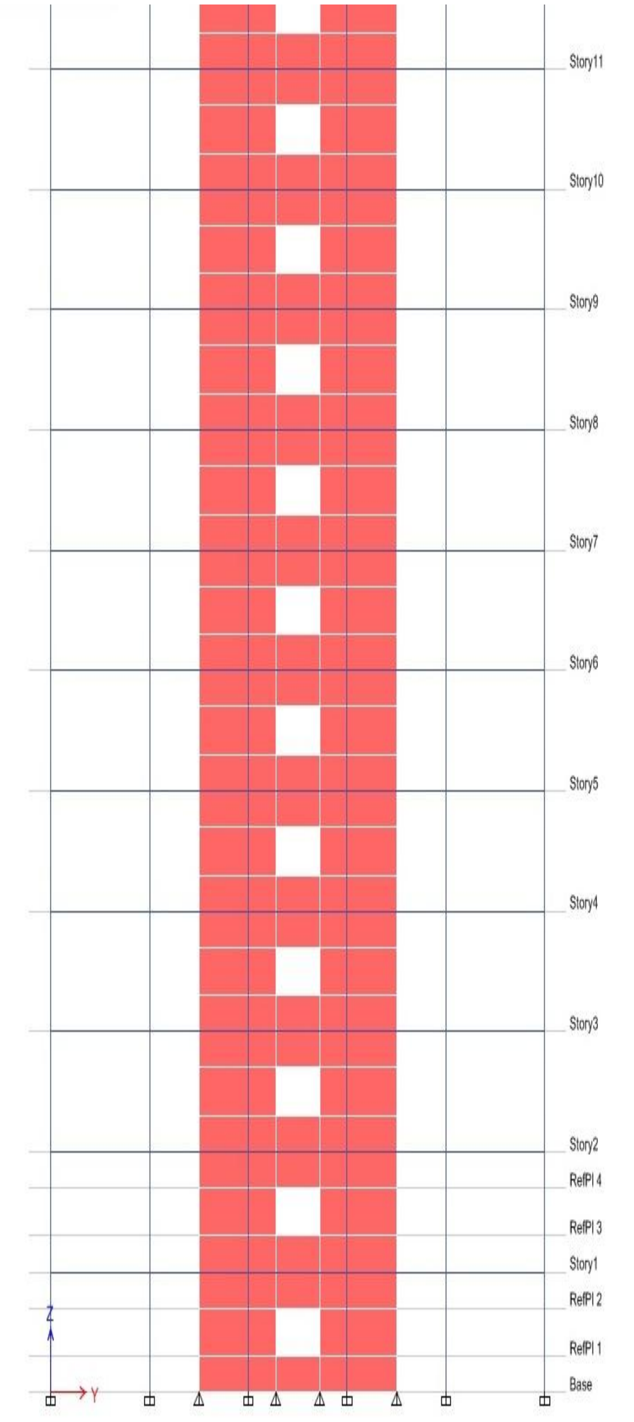


Figure 5: Side view showing shear wall openings of size 2 m X 1.2 m

3.4 Building Design Requirements

Introduction

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.

3.5 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.

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

Hence, ok.

As per IS 13920; Clause 6.1.3
b≥ 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 ¼ of the clear span.
Here, D=450 mm and clear span length is 3000 mm.
¼ (clear span) = 3000/4 =750 mm > 450 mm
Hence, ok.

3.7 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 model

Building Model	p_t values
Model	1.38

Therefore, the model pass the reinforcement check.

3.8 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 each model were noted down as follows;

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

Building Model	$Axial\ Stresses\ (Mpa)$
Model	4.01

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

3.9 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.
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 largerof the two reinforcements shall be adopted. This is similar to what is done for design of continuousbeam reinforcements at the support. The end moments and end shears are available fromcomputer 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

3.10 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 model

Building Model	p_t values
Model	2.16

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.

4. Results and Discussions

Building With Shear Walls Provided At The Centre Core And At The Center Of Each Side Of The External Perimeter With Openings.

Table 5: Storey Maximum Displacement in X and Y directions

Storey	Elevation m	Location	X-Dir mm	Y-Dir mm
Storey40	120	Top	102.8	104.9
Storey39	117	Top	101	102.8
Storey38	114	Top	99.1	100.5
Storey37	111	Top	97.2	98.2
Storey36	108	Top	95.2	95.9
Storey35	105	Top	93.1	93.5
Storey34	102	Top	90.9	91
Storey33	99	Top	88.7	88.5
Storey32	96	Top	86.4	85.9
Storey31	93	Top	84	83.3
Storey30	90	Top	81.6	80.6
Storey29	87	Top	79.1	77.9
Storey28	84	Top	76.5	75.1
Storey27	81	Top	73.8	72.2
Storey26	78	Top	71.1	69.3
Storey25	75	Top	68.3	66.4
Storey24	72	Top	65.4	63.4
Storey23	69	Top	62.5	60.3
Storey22	66	Top	59.5	57.3
Storey21	63	Top	56.5	54.2
Storey20	60	Top	53.5	51.1
Storey19	57	Top	50.4	47.9
Storey18	54	Top	47.3	44.8
Storey17	51	Top	44.2	41.7
Storey16	48	Top	41	38.5
Storey15	45	Top	37.9	35.4
Storey14	42	Top	34.7	32.3
Storey13	39	Top	31.6	29.2
Storey12	36	Top	28.4	26.2
Storey11	33	Top	25.3	23.2
Storey10	30	Top	22.3	20.3
Storey9	27	Top	19.3	17.5
Storey8	24	Top	16.4	14.7
Storey7	21	Top	13.5	12.1
Storey6	18	Top	10.8	9.6
Storey5	15	Top	8.3	7.3
Storey4	12	Top	5.9	5.2
Storey3	9	Top	3.8	3.3
Storey2	6	Top	2	1.8
Storey1	3	Top	0.7	0.6
Base	0	Top	0	0

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

Storey	Shear X kN	Drift X mm	Stiffness X kN/m	Shear Y kN	Drift Y mm	Stiffness Y kN/m
Storey40	362.9988	2	179877.4	369.295	2.4	154779.7
Storey39	694.0613	2.1	329541.1	711.0624	2.5	289548.5
Storey38	965.0807	2.2	440456.3	997.2023	2.5	394809.8
Storey37	1177.573	2.3	516533.6	1227.648	2.6	472440.9
Storey36	1337.751	2.4	565269.9	1405.195	2.7	526383.5
Storey35	1456.285	2.4	594480.3	1535.926	2.7	561135.9
Storey34	1546.618	2.5	611686.8	1628.993	2.8	581669.6
Storey33	1622.226	2.6	623187.3	1695.81	2.9	593033.9
Storey32	1693.646	2.7	633339.4	1748.598	2.9	599955.5
Storey31	1766.55	2.7	644268.6	1798.416	3	606331.5
Storey30	1841.8	2.8	656237.4	1853.192	3	614752.8
Storey29	1917.321	2.9	668515.3	1916.515	3.1	626278.3
Storey28	1990.556	2.9	680296.6	1987.754	3.1	640615.5
Storey27	2060.251	3	691275	2063.417	3.1	656645.4
Storey26	2126.94	3	701743.2	2139.072	3.2	673058.9
Storey25	2192.256	3.1	712328.3	2211.059	3.2	688868.2
Storey24	2257.691	3.1	723592	2277.508	3.2	703675.9
Storey23	2323.583	3.2	735737.4	2338.558	3.3	717698.7
Storey22	2388.903	3.2	748568.4	2395.877	3.3	731601.5
Storey21	2451.877	3.2	761694.9	2451.745	3.3	746223.4
Storey20	2511.049	3.2	774845.2	2508.018	3.3	762367.8
Storey19	2566.13	3.3	788107.5	2565.362	3.3	780547.9
Storey18	2618.199	3.3	801981.4	2623.017	3.3	800386.6
Storey17	2669.125	3.3	817550.1	2679.194	3.3	821903.9
Storey16	2720.551	3.3	834931.2	2731.929	3.2	844885
Storey15	2773.017	3.2	854925.1	2780.106	3.2	869418.7
Storey14	2825.766	3.2	877758.6	2824.288	3.2	896173.3
Storey13	2877.432	3.2	903609	2867.07	3.1	926577.7
Storey12	2927.276	3.1	933009.1	2912.757	3	962864.4
Storey11	2976.331	3.1	967282.4	2966.362	2.9	1007969
Storey10	3027.733	3	1008852	3032.105	2.8	1065345
Storey9	3085.856	2.9	1061350	3111.892	2.7	1138851
Storey8	3154.386	2.8	1129622	3204.31	2.6	1232970
Storey7	3234.124	2.7	1220026	3304.555	2.4	1353728
Storey6	3321.613	2.5	1341816	3405.309	2.3	1510927
Storey5	3409.4	2.3	1511309	3498.227	2	1723304
Storey4	3487.922	2	1763883	3575.615	1.8	2032562
Storey3	3548.308	1.6	2193707	3631.925	1.4	2551830
Storey2	3585.211	1.1	3236737	3664.973	1	3848089
Storey1	3599.06	0.7	5251061	3676.988	0.6	6268001

Table 7: Modes and periods

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY
Modal	1	4.894	0	0.7051	0	0	0.7051
Modal	2	4.875	0.7217	0	0	0.7217	0.7051
Modal	3	3.117	2.30E-05	0	0	0.7217	0.7051
Modal	4	1.421	0.1347	0	0	0.8564	0.7051
Modal	5	1.36	0	0.1455	0	0.8564	0.8506
Modal	6	0.918	6.44E-06	0	0	0.8564	0.8506
Modal	7	0.714	0.0484	0	0	0.9048	0.8506
Modal	8	0.657	0	0.0524	0	0.9048	0.903
Modal	9	0.462	8.84E-07	0	0	0.9048	0.903
Modal	10	0.452	0.0265	0	0	0.9314	0.903
Modal	11	0.407	0	0.0282	0	0.9314	0.9312
Modal	12	0.318	0.0163	0	0	0.9477	0.9312

Here the minimum modal mass for accelerations Ux and Uy is 94.77 % and 93.12 % respectively.

4.1 Mode Shapes

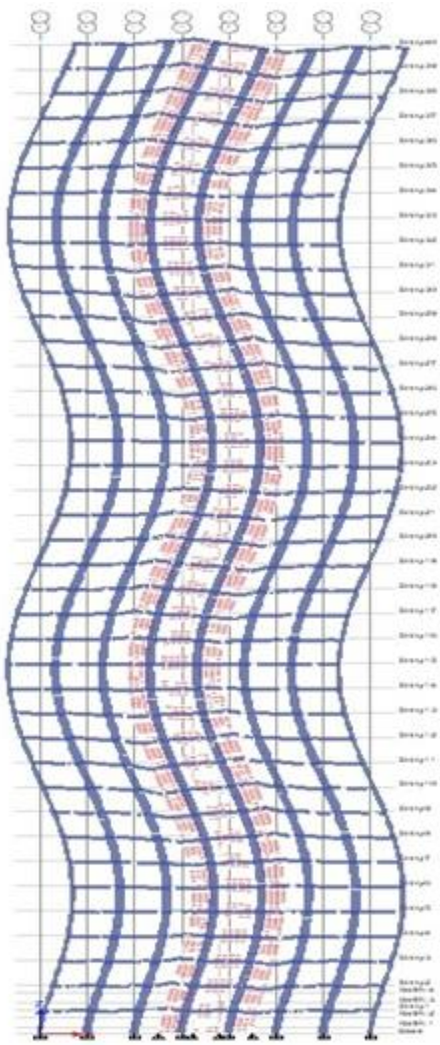


Figure 6: Mode shape for model

4.2 Stress Distribution

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

Paper ID: ART20163168 DOI: 10.21275/ART20163168

Stress distribution in Model

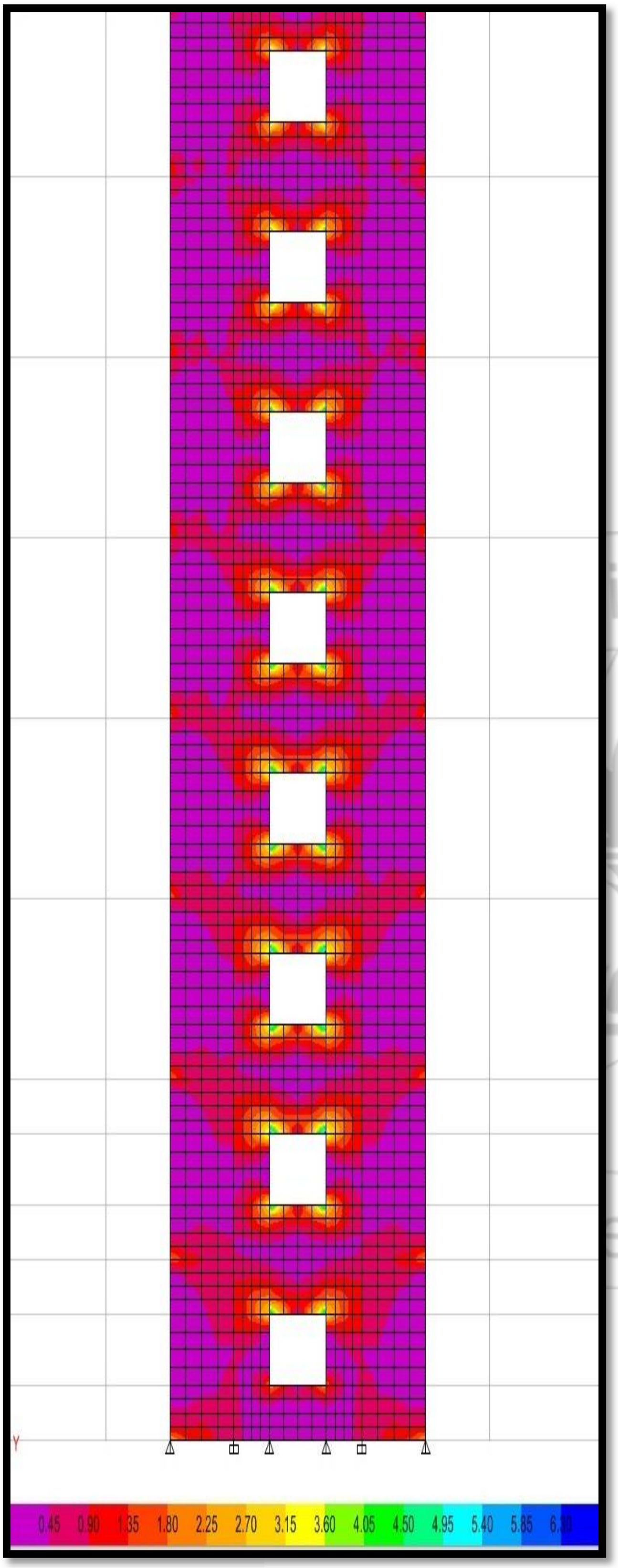


Figure 7: (a) Stress distribution in Model

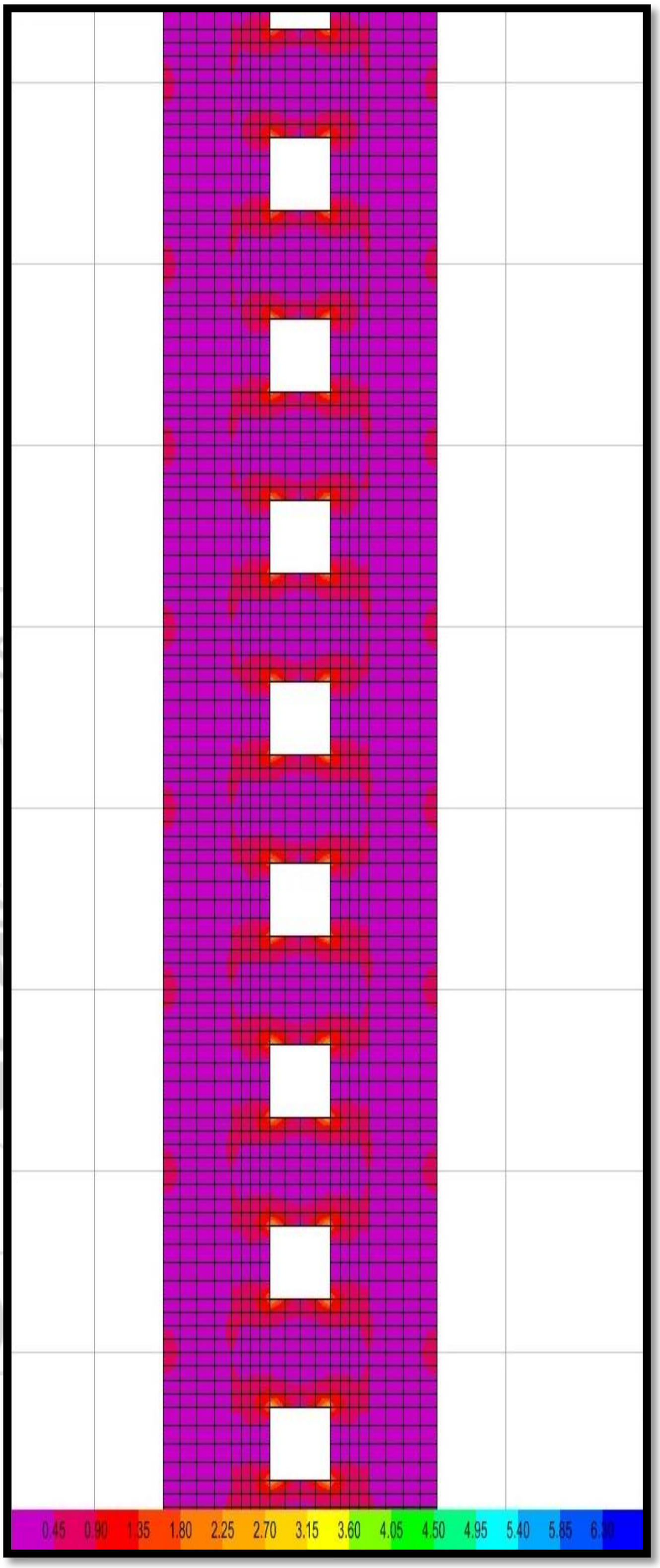


Figure 7: (b) Stress distribution in Model

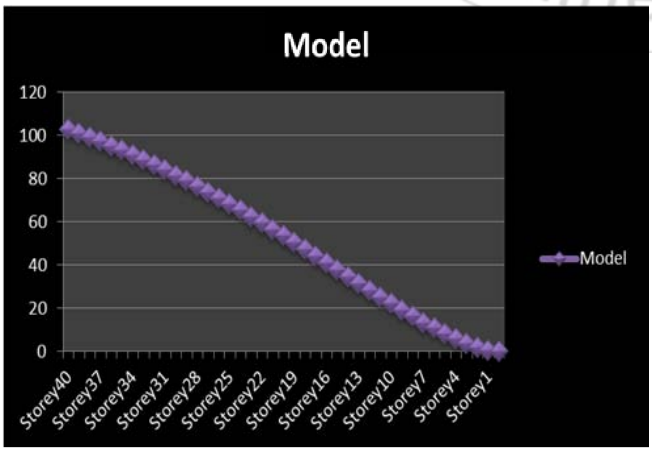
The variation of stress distribution in this case is 0.45 MPa to 6.30 MPa. The concentration of stress is more at the corners of the openings only. Arresting the high induced stresses at the corners would ensure a low level stress distribution across the shear wall at all storie.

Table 8: Maximum Storey Displacements in X Direction

Storey level	Elevation(m)	Model
Storey40	120	102.8
Storey39	117	101
Storey38	114	99.1
Storey37	111	97.2
Storey36	108	95.2
Storey35	105	93.1
Storey34	102	90.9
Storey33	99	88.7
Storey32	96	86.4
Storey31	93	84
Storey30	90	81.6
Storey29	87	79.1
Storey28	84	76.5
Storey27	81	73.8
Storey26	78	71.1
Storey25	75	68.3
Storey24	72	65.4
Storey23	69	62.5
Storey22	66	59.5
Storey21	63	56.5
Storey20	60	53.5
Storey19	57	50.4
Storey18	54	47.3
Storey17	51	44.2
Storey16	48	41
Storey15	45	37.9
Storey14	42	34.7
Storey13	39	31.6
Storey12	36	28.4
Storey11	33	25.3
Storey10	30	22.3
Storey9	27	19.3
Storey8	24	16.4
Storey7	21	13.5
Storey6	18	10.8
Storey5	15	8.3
Storey4	12	5.9
Storey3	9	3.8
Storey2	6	2
Storey1	3	0.7
Base	0	0

All values are in mm

A plot for Displacement at 40 storey levels for the models has been shown here



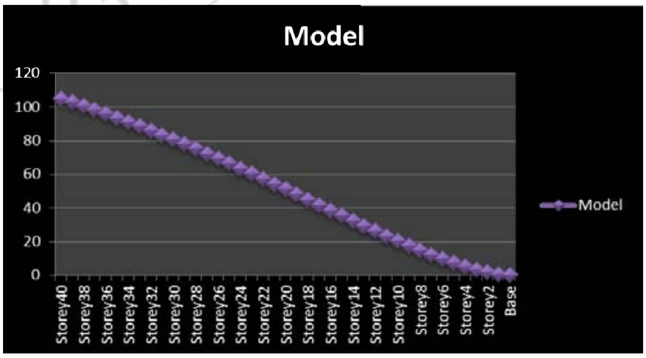
Graph 1: Displacements at various storeys(X-dir)

Table 9: Maximum Storey Displacements in Y Direction

Storey Level	Elevation (m)	Model
Storey40	120	104.9
Storey39	117	102.8
Storey38	114	100.5
Storey37	111	98.2
Storey36	108	95.9
Storey35	105	93.5
Storey34	102	91
Storey33	99	88.5
Storey32	96	85.9
Storey31	93	83.3
Storey30	90	80.6
Storey29	87	77.9
Storey28	84	75.1
Storey27	81	72.2
Storey26	78	69.3
Storey25	75	66.4
Storey24	72	63.4
Storey23	69	60.3
Storey22	66	57.3
Storey21	63	54.2
Storey20	60	51.1
Storey19	57	47.9
Storey18	54	44.8
Storey17	51	41.7
Storey16	48	38.5
Storey15	45	35.4
Storey14	42	32.3
Storey13	39	29.2
Storey12	36	26.2
Storey11	33	23.2
Storey10	30	20.3
Storey9	27	17.5
Storey8	24	14.7
Storey7	21	12.1
Storey6	18	9.6
Storey5	15	7.3
Storey4	12	5.2
Storey3	9	3.3
Storey2	6	1.8
Storey1	3	0.6
Base	0	0

All values are in mm

A plot for Displacement at 40 storey levels for the models has been shown here



Graph 2: Displacements at various storeys (Y-dir)

The maximum storeydisplacements is less than 5 % i.e, well within the engineering limits. So, it can be safely assumed that displacement wise, the openings provided in shear walls are effective to the extent of shear walls without openings.

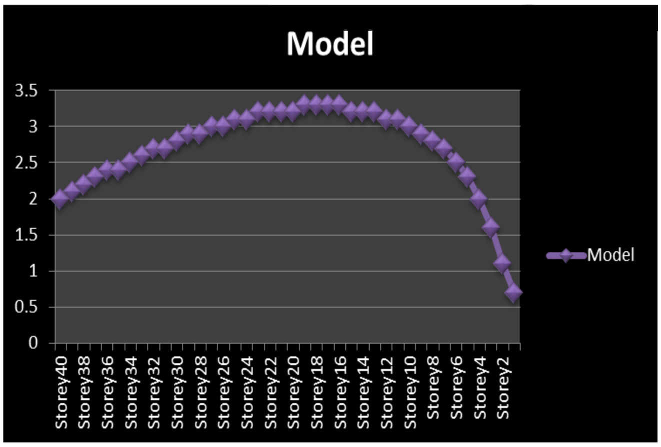
4.3 Storey Drifts

Table 10: Storey drifts in X direction

Storey	Model
Storey40	2
Storey39	2.1
Storey38	2.2
Storey37	2.3
Storey36	2.4
Storey35	2.4
Storey34	2.5
Storey33	2.6
Storey32	2.7
Storey31	2.7
Storey30	2.8
Storey29	2.9
Storey28	2.9
Storey27	3
Storey26	3
Storey25	3.1
Storey24	3.1
Storey23	3.2
Storey22	3.2
Storey21	3.2
Storey20	3.2
Storey19	3.3
Storey18	3.3
Storey17	3.3
Storey16	3.3
Storey15	3.2
Storey14	3.2
Storey13	3.2
Storey12	3.1
Storey11	3.1
Storey10	3
Storey9	2.9
Storey8	2.8
Storey7	2.7
Storey6	2.5
Storey5	2.3
Storey4	2
Storey3	1.6
Storey2	1.1
Storey1	0.7

All values are in mm

A plot for Drifts at different storey levels for different models has been shown here



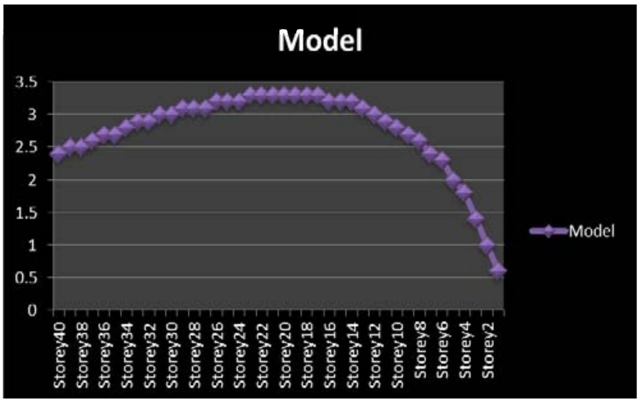
Graph 3: Drifts at various storeys (X-dir)

Table 11: Storey drifts inY direction

Storey	Model
Storey40	2.4
Storey39	2.5
Storey38	2.5
Storey37	2.6
Storey36	2.7
Storey35	2.7
Storey34	2.8
Storey33	2.9
Storey32	2.9
Storey31	3
Storey30	3
Storey29	3.1
Storey28	3.1
Storey27	3.1
Storey26	3.2
Storey25	3.2
Storey24	3.2
Storey23	3.3
Storey22	3.3
Storey21	3.3
Storey20	3.3
Storey19	3.3
Storey18	3.3
Storey17	3.3
Storey16	3.2
Storey15	3.2
Storey14	3.2
Storey13	3.1
Storey12	3
Storey11	2.9
Storey10	2.8
Storey9	2.7
Storey8	2.6
Storey7	2.4
Storey6	2.3
Storey5	2
Storey4	1.8
Storey3	1.4
Storey2	1
Storey1	0.6

All values are in mm

A plot for Drifts at 40storey levels for the model has been shown here



Graph 4: Drifts at various storeys(Y-dir)

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.

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The height of the each storey is 3 m. So, the drift limitation as per IS 1893 (part 1) : 2002 is 0.004 X 3 m = 12 mm.

The maximum drift in the models is 6 mm which is well within the limits.

4.4 Base Shears

Table 12: Base shears in X direction

Model	*Base Shears in X (kN)*
Model	3599.06

Table 13: Base Shears in Y direction

Model	Base Shears in Y(kN)
Model	3676.988

4.5 Modal Results

Table 14: Modes and natural periods

Case	Mode	Model Period (sec)
Modal	1	4.894
Modal	2	4.875
Modal	3	3.117
Modal	4	1.421
Modal	5	1.36
Modal	6	0.918
Modal	7	0.714
Modal	8	0.657
Modal	9	0.462
Modal	10	0.452
Modal	11	0.407
Modal	12	0.318

Table 15: Modal Masses

Model	*Dynamic %*	
	Acceleration Ux	*Acceleration Uy*
1	94.77	93.12

According to IS-1893:2002 the number of modes to be used in the analysis should be such thatthe total sum of modal masses of all modes considered is at least 90 percent of the total seismicmass. Here the minimum modal mass is 93.12 percent.

5. Conclusion and Recommendations

5.1 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 Building Withshear walls provided at the centre core and center of each side of the external perimeter with openings.

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

1) The location of shear walls in the the outermost perimeter considerably reduce the effects of displacements and drifts.
2) Building with shear walls provided at the centre core and center of each side of the external perimeter with openings showed better performance in terms of maximum storey displacements and storey drifts. Also, the base shear was found to be highest for this case. It was also found that this model exhibited high stiffness.
3) The concentration of stresses in shear walls increases when openings are provided. It was foud that the maximum stress induced increased threefold due to openings.

4) The presence of openings in shear walls gave a result with a deviation of approximately 5% with that of shear walls without openings. As mentioned earlier only centre window openings are studied in this thesis. The displacements, drifts and also the base shear values were within the 5% range. So provision shear wall with openings helps to achieve economy.

5.2 Recommendations

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.
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 the model. Further studies should be carried out for damping ratious of 10%, 15% and so on.

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