Seismic Analysis of High Rise Building with L Shape Shear Walls at the Centre Core and Corners with Opening

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Abstract:*In present work, Forty storey buildings (120m) have been modeled using software ETABS by dynamic 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. This study is done on RC framed multistory building with RC shear walls with fixed support conditions. 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. 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 ,lateral loads, shear wall, structural response*

I. INTRODUCTION

1.1 Background

Reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Wallsin 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 summarized 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).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. 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. 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 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.

1.2 Objectives

A literature review is carried out to define the objectives of the paper.

1.3 Literature Review

Sumegh S.P. et al., (2014) studied the influence of shear wall openings in the behaviour of the structure. It was observed that eccentric window opening gives more displacement while center window opening gave the least.

Prajapati R.J. et al., (2013) carried out study on deflection in high rise buildings for different position of shear walls. It was observed that deflection for building with shear walls provided at the corners in both the directions was drastically less when compared with other models.

Chandurkar P.P. et al., (2013) conducted a study on seismic analysis of RCC building with and without shear walls. They have selected a ten storied building located in zone II, zone III, zone IV and zone V. Parameters like Lateral displacement, story drift and total cost required for ground floor were calculated in both the cases.
Bhat S.M. et al., (2013) carried out study on Eathquakebehaviour of buildings with and without shear walls. Parameters like Lateral displacement, story drift etc were found and compared with the bare frame model.

Sardar S.J. et al., (2013) studied lateral displacement and inter-story drift on a square symmetric structure with walls at the centre and at the edges, and found that the presence of shear wall can affect the seismic behaviour of frame structure to large extent, and the shear wall increases the strength and stiffness of the structure.

Sagar K.et al., (2012) carried out linear dynamic analysis on two sixteen storey high buildings.It was concluded that shear walls are one of the most effective building elements in resisting lateral forces during earthquake. Providing shear walls in proper position minimizes effect and damages due to earthquake and winds.
Kumbhare P.S. et al., (2012) carried out a study on shear wall frame interaction systems and member forces. It was found that shear wall frame interaction systems are very effective in resisting lateral forces induced by earthquake. Placing shear wall away from center of gravity resulted in increase in the most of the members forces. It follows that shear walls should be coinciding with the centroid of the building.
Rahman A. et al., (2012) studied on drift analysis due to earthquake load on tall structures. In this study regular shaped structures have been considered. Estimation of drift was carried out for rigid frame structure, coupled shear wall structure and wall frame structure.

Anshuman et al., (2011) conducted a research on solution of shear wall location in multi storey building. An earthquake load was calculated and applied to a fifteen storied building located in zone IV. It was observed that the top deflection was reduced and reached within the permissible deflection after providing the shear wall.

Kameshwari B. et al., (2011) analyzed the effect of various configurations of shear walls on high-rise structure. The drift and inter-storey drift of the structure in the following configurations of shear wall panels was studied and was compared with that of bare frame. Diagonal shear wall configuration was found to be effective for structures in the earthquake prone areas.

Based on the literature review, the salient objective of the present study have been identified asfollows:

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.

1.4 Shear Wall Structure

The usefulness of shear walls in framing of buildings has long been recognized. Walls situated in advantageous positions in a building can form an efficient lateral-force-resisting system, simultaneously fulfilling other functional requirements. When a permanent and similar subdivision of floor areas in all stories is required as in the case of hotels or apartment buildings, numerous shear walls can be utilized not only for lateral force resistance but also to carry gravity loads. In such case, the floor by floor repetitive planning allows the walls to be vertically continuous which may serve simultaneously as excellent acoustic and fire insulators between theapartments. Shear walls may be planar but are often of L-, T-, I-, or U- shaped section to better suit the planning and to increase their flexural stiffness.

The positions of shear walls within a building are usually dictated by functional requirements. These may or may not suit structural planning. The purpose of a building and consequent allocation of floor space may dictate required arrangements of walls that can often be readily utilized for lateral force resistance. Building sites, architectural interests or client's desire may lead the positions of walls that are undesirable from a structural point of view. However, structural designers are often in the position to advice as to the most desirable locations for shear walls in order to optimize seismic resistance. The major structural considerations for individual shear walls will be aspects of symmetry in stiffness, torsional stability and available overturning capacity of the foundations (Paulay and Priestley, 1992).

1.5 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.

II. METHODOLOGY

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.

1- Dynamic analysis.
   I. Response spectrum method.
   II. Time history method.

2.1 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:

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

2.1.2 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 .However in either method, the design base shear V_B shall be compared with a base shear V_B calculated using a fundamental period *Ta*. When V_B is less than V_B all the response quantities shall be multiplied by V_B /*Vb*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.

2.2 Time History Method

The usage of this method shall be on an appropriate ground motion and shall be performed using accepted principles of dynamics. In this method, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake at the base of the structure.

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.

2.4 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.

2.5 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

2.6 Response Analysis of MDOF System

Multi degree of freedom (MDOF) systems are usually analyzed using Modal Analysis. This system when subjected to ground motion undergoes deformations in number of possible ways. These deformed shapes are known as modes of vibration or mode shapes. Each shape is vibrating with a particular natural frequency. Total unique modes for each MDOF system are equal to the possible degree of freedom of system.

2.7 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, 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.
b) Earthquake generated vertical forces, if significant, as in large spans where differential settlement is not allowed, must be considered.

c) 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.

d) 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 then 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.

e) 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.

f) In steel structures, members and their connections should be so proportioned that high ductility is obtained.

g) 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.

h) 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 clause2.3.3 IS 1893 (part 1) : 2002.

i) 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.

III. NUMERICAL ANALYSES

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

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 (l shape) with openings.

Table I: 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

Layout of the Buildings

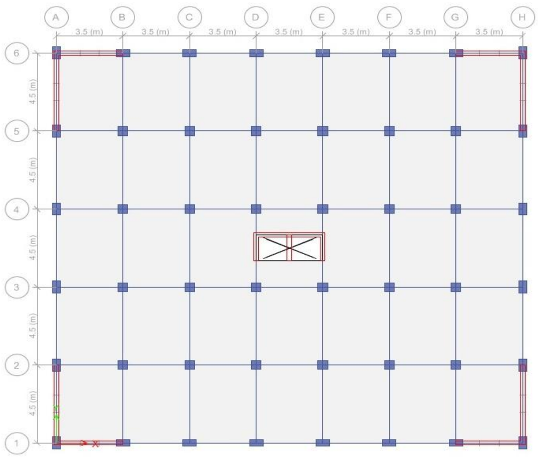


Fig. 1.Plan of the building with openings in shear walls

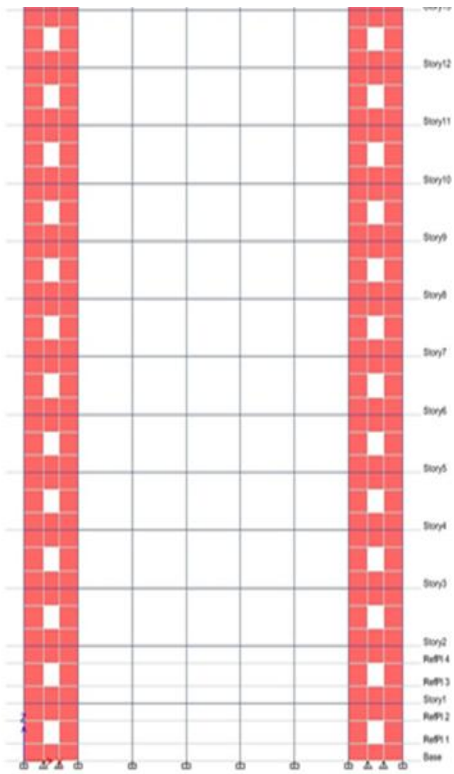


Fig. 3.Elevation view showing centre window openings of size 1 m X 1.2 m

3.3 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.

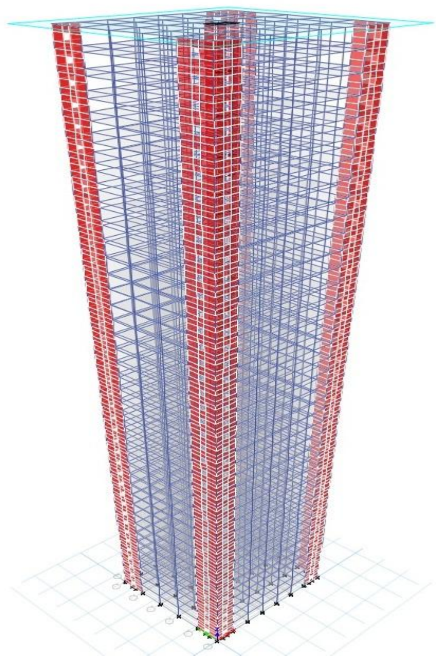


Fig. 2. 3D view with openings in corner(L shaped) shear walls

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.

3.4 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.

3.5 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.

3.6 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 II:p_t values of most critical member of building model.

Building Model	p_t values
Model	1.29

Therefore, the model pass the reinforcement check.

3.7 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 III: Axial stress values of most critical member of building model.

Building Model	$Axial\ Stresses\ (Mpa)$
Model	6.78

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

3.8 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 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

3.9 Reinforcement Check

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

Table IV:p_t values of most critical member of building model.

Building Model	p_t values
Model	3.44

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.

Table V:Storey Maximum Displacement in X and Y directions

Storey	Elevation	Location	X-Dir	Y-Dir
	m		mm	mm
Storey40	120	Top	118.4	128.6
Storey39	117	Top	116.5	126.1
Storey38	114	Top	114.5	123.5
Storey37	111	Top	112.5	120.9
Storey36	108	Top	110.4	118.2
Storey35	105	Top	108.2	115.4
Storey34	102	Top	105.9	112.6
Storey33	99	Top	103.5	109.7
Storey32	96	Top	101	106.7
Storey31	93	Top	98.4	103.6
Storey30	90	Top	95.7	100.4
Storey29	87	Top	92.9	97.2
Storey28	84	Top	90	93.8
Storey27	81	Top	87	90.4
Storey26	78	Top	83.9	86.8
Storey25	75	Top	80.7	83.2
Storey24	72	Top	77.4	79.5
Storey23	69	Top	74	75.8
Storey22	66	Top	70.6	71.9
Storey21	63	Top	67	68
Storey20	60	Top	63.4	64.1
Storey19	57	Top	59.8	60.2
Storey18	54	Top	56.1	56.2
Storey17	51	Top	52.3	52.1
Storey16	48	Top	48.5	48.1
Storey15	45	Top	44.7	44.1
Storey14	42	Top	40.9	40.1
Storey13	39	Top	37.1	36.2
Storey12	36	Top	33.3	32.3
Storey11	33	Top	29.5	28.4
Storey10	30	Top	25.8	24.7
Storey9	27	Top	22.2	21.1
Storey8	24	Top	18.7	17.6
Storey7	21	Top	15.3	14.3
Storey6	18	Top	12.1	11.2
Storey5	15	Top	9.1	8.3
Storey4	12	Top	6.4	5.8
Storey3	9	Top	4	3.6
Storey2	6	Top	2.1	1.8
Storey1	3	Top	0.7	0.6
Base	0	Top	0	0

IV. RESULTS AND DISCUSSIONS

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

	Shear X	Drift X	Stiffness X	Shear Y	Drift Y	Stiffness Y
Storey	kN	mm	kN/m	kN	mm	kN/m
Storey40	363.304	2.1	169484.1	362.3883	2.7	132007.4
Storey39	685.675	2.2	307220.9	690.0274	2.8	244630.1
Storey38	941.56	2.3	405959.8	957.4502	2.9	330803.7
Storey37	1135.45	2.4	470193.9	1166.85	3	392146.8
Storey36	1276.86	2.5	508241.2	1323.493	3.1	432601
Storey35	1379.76	2.6	528692.8	1436.008	3.1	456772.5
Storey34	1460.29	2.7	539576	1515.971	3.2	469689.7
Storey33	1533.34	2.8	547202.7	1576.726	3.3	476302.9
Storey32	1609	2.9	555369.3	1631.395	3.4	480948.4
Storey31	1690.85	3	565259	1690.423	3.5	486769.5
Storey30	1777.01	3.1	576199.7	1759.559	3.6	495326.9
Storey29	1863.06	3.2	586850.5	1839.26	3.6	506634.3
Storey28	1945.07	3.3	596194.5	1925.829	3.7	519637.5
Storey27	2021.43	3.3	603991	2013.635	3.8	532900.4
Storey26	2092.92	3.4	610703.2	2097.369	3.8	545206
Storey25	2161.63	3.5	617112.1	2173.62	3.9	555911.8
Storey24	2229.5	3.6	623877.7	2241.529	4	565043.8
Storey23	2297.12	3.6	631270.1	2302.577	4	573187.5
Storey22	2363.67	3.7	639171.9	2359.712	4.1	581245.3
Storey21	2427.59	3.8	647305.1	2416.102	4.1	590139.9
Storey20	2487.74	3.8	655523.7	2473.918	4.1	600548.7
Storey19	2544.18	3.8	664007.4	2533.553	4.1	612748.2
Storey18	2598.15	3.9	673260.5	2593.549	4.1	626697.8
Storey17	2651.39	3.9	683933	2651.259	4.1	641937
Storey16	2705.04	3.9	696569.5	2703.965	4.1	658191
Storey15	2758.81	3.9	711549.1	2750.077	4.1	675487
Storey14	2811.13	3.9	728740	2790.032	4	694388.9
Storey13	2860.08	3.8	748333.4	2826.608	3.9	716156.6
Storey12	2904.85	3.8	770869.7	2864.501	3.9	742773.5
Storey11	2946.88	3.7	797729.3	2909.179	3.7	776868.1
Storey10	2990.11	3.6	831399.8	2965.248	3.6	821588.3
Storey9	3039.75	3.5	875574.6	3034.846	3.4	880575.2
Storey8	3100.13	3.3	935209.3	3116.647	3.3	958280.7
Storey7	3172.3	3.1	1016938	3205.894	3	1060995
Storey6	3252.7	2.9	1130687	3295.427	2.7	1199267
Storey5	3333.69	2.6	1294281	3377.314	2.4	1393444
Storey4	3405.78	2.2	1546512	3444.584	2	1688330
Storey3	3460.6	1.7	1989529	3492.665	1.6	2202537
Storey2	3493.63	1.1	3061189	3520.352	1	3434392
Storey1	3505.96	0.7	5151180	3530.307	0.6	5914690

Table VII: Modes and periods

Case	Mode	Period sec	UX	UY	Sum UX	Sum UY
Modal	1	5.45	0	0.707	0	0.707
Modal	2	5.259	0.7247	0	0.7247	0.707
Modal	3	3.742	0.0001	0	0.7248	0.707
Modal	4	1.541	0.1243	0	0.8491	0.707
Modal	5	1.519	0	0.1343	0.8491	0.8414
Modal	6	1.021	1.24E-05	0	0.8491	0.8414
Modal	7	0.768	0.049	0	0.8981	0.8414
Modal	8	0.72	0	0.0539	0.8981	0.8953
Modal	9	0.471	0.0281	0	0.9262	0.8953
Modal	10	0.468	1.60E-06	0	0.9262	0.8953
Modal	11	0.429	0	0.0303	0.9262	0.9255
Modal	12	0.322	0.0179	0	0.9441	0.9255

Here the minimum modal mass for accelerations Ux and Uy is 94.41 % and 92.55% respectively.

4.2 Stress Distribution

distribution for shear walls located in the external periphery of the plan of building is studied.

4.2.1 Stress distribution in Model

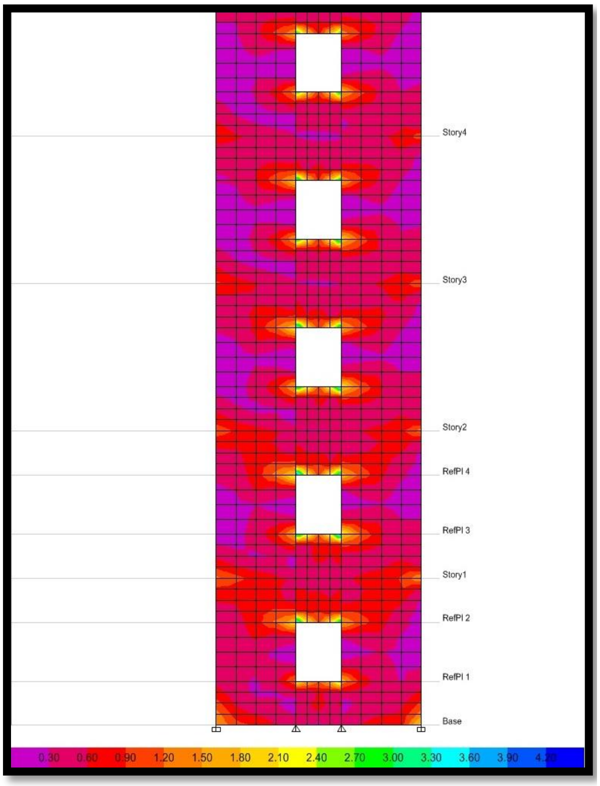


Fig. 5.:(a) Stress distribution in Model

4.1 Mode Shape

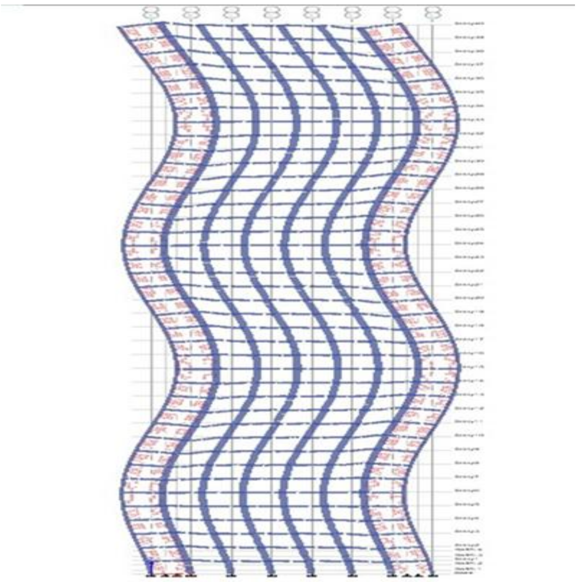


Fig. 4.Mode shape for model

The stress distribution in shear walls is represented diagrammatically for the models. The stress

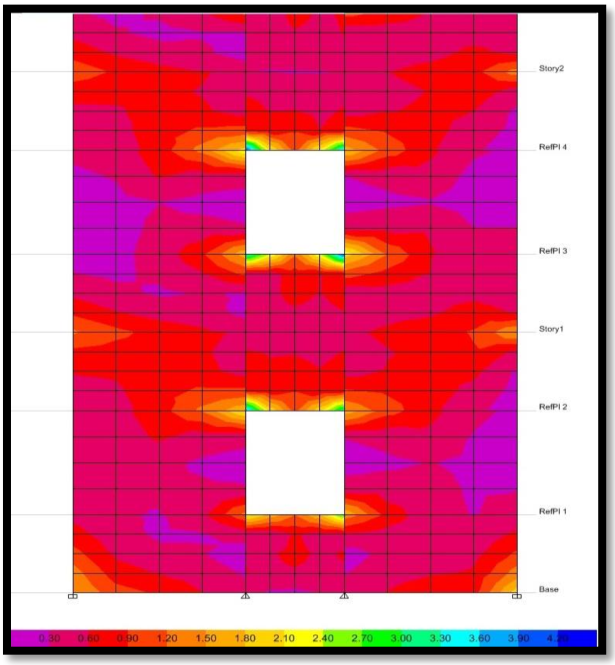


Fig.5.:(b) Stress distribution in Model

The variation of stress in model is in between 0.3 MPa and 4.2 MPa. The stress induced due to an opening has become threefold. The maximum concentration of stress is seen at the corners of the opening and from there on a decreasing contour is observed. Therefore arresting the stresses at the corners can significantly reduce the concentration of stresses on a whole.

Table VIII: Maximum Storey Displacements in X Direction

Storey level	Elevation(m)	Model
Storey40	120	118.4
Storey39	117	116.5
Storey38	114	114.5
Storey37	111	112.5
Storey36	108	110.4
Storey35	105	108.2
Storey34	102	105.9
Storey33	99	103.5
Storey32	96	101
Storey31	93	98.4
Storey30	90	95.7
Storey29	87	92.9
Storey28	84	90
Storey27	81	87
Storey26	78	83.9
Storey25	75	80.7
Storey24	72	77.4
Storey23	69	74
Storey22	66	70.6
Storey21	63	67
Storey20	60	63.4
Storey19	57	59.8
Storey18	54	56.1
Storey17	51	52.3
Storey16	48	48.5
Storey15	45	44.7
Storey14	42	40.9
Storey13	39	37.1
Storey12	36	33.3
Storey11	33	29.5
Storey10	30	25.8
Storey9	27	22.2
Storey8	24	18.7
Storey7	21	15.3
Storey6	18	12.1
Storey5	15	9.1
Storey4	12	6.4
Storey3	9	4
Storey2	6	2.1
Storey1	3	0.7
Base	0	0

All values are in mm

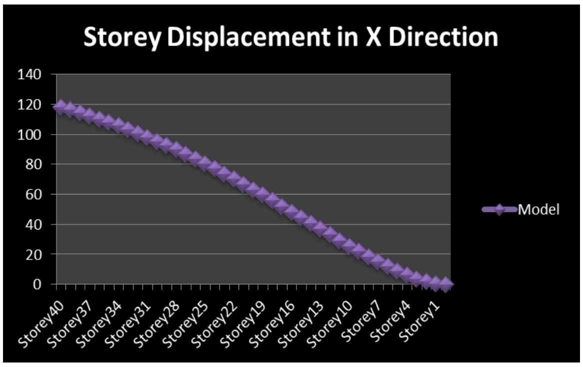
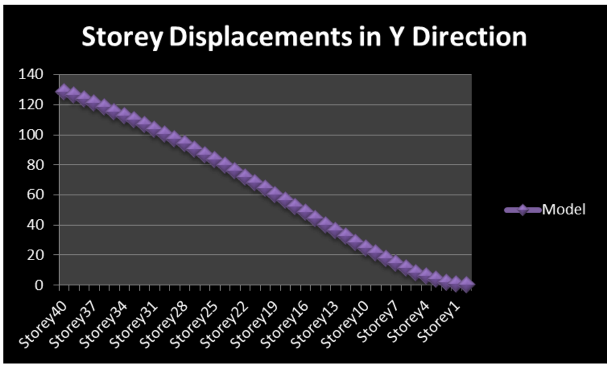


Table IX:Maximum Storey Displacements in Y Direction

Storey Level	Elevation (m)	Model
Storey40	120	128.6
Storey39	117	126.1
Storey38	114	123.5
Storey37	111	120.9
Storey36	108	118.2
Storey35	105	115.4
Storey34	102	112.6
Storey33	99	109.7
Storey32	96	106.7
Storey31	93	103.6
Storey30	90	100.4
Storey29	87	97.2
Storey28	84	93.8
Storey27	81	90.4
Storey26	78	86.8
Storey25	75	83.2
Storey24	72	79.5
Storey23	69	75.8
Storey22	66	71.9
Storey21	63	68
Storey20	60	64.1
Storey19	57	60.2
Storey18	54	56.2
Storey17	51	52.1
Storey16	48	48.1
Storey15	45	44.1
Storey14	42	40.1
Storey13	39	36.2
Storey12	36	32.3
Storey11	33	28.4
Storey10	30	24.7
Storey9	27	21.1
Storey8	24	17.6
Storey7	21	14.3
Storey6	18	11.2
Storey5	15	8.3
Storey4	12	5.8
Storey3	9	3.6
Storey2	6	1.8
Storey1	3	0.6
Base	0	0

All values are in mm



For both X and Y directions, the behaviour of the graph is similar for the model as shown. The order of maximum storey displacement in both the directions for model is same.maximumstorey displacements 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 X:Storey drifts in X direction

Storey	Model
Storey40	2.1
Storey39	2.2
Storey38	2.3
Storey37	2.4
Storey36	2.5
Storey35	2.6
Storey34	2.7
Storey33	2.8
Storey32	2.9
Storey31	3
Storey30	3.1
Storey29	3.2
Storey28	3.3
Storey27	3.3
Storey26	3.4
Storey25	3.5
Storey24	3.6
Storey23	3.6
Storey22	3.7
Storey21	3.8
Storey20	3.8
Storey19	3.8
Storey18	3.9
Storey17	3.9
Storey16	3.9
Storey15	3.9
Storey14	3.9
Storey13	3.8
Storey12	3.8
Storey11	3.7
Storey10	3.6
Storey9	3.5
Storey8	3.3
Storey7	3.1
Storey6	2.9
Storey5	2.6
Storey4	2.2
Storey3	1.7
Storey2	1.1
Storey1	0.7

All values are in mm

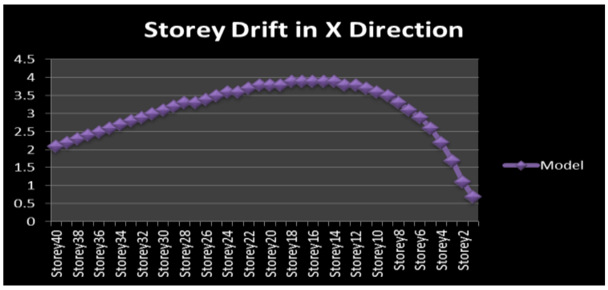
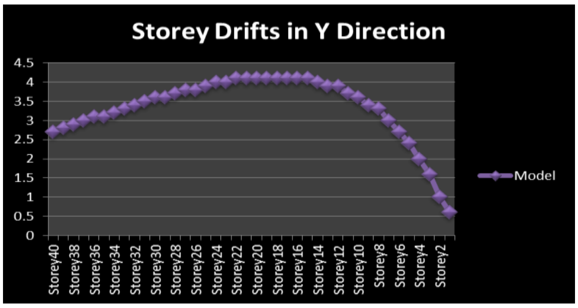


Table XI:Storey drifts inY direction

Storey	Model
Storey40	2.7
Storey39	2.8
Storey38	2.9
Storey37	3
Storey36	3.1
Storey35	3.1
Storey34	3.2
Storey33	3.3
Storey32	3.4
Storey31	3.5
Storey30	3.6
Storey29	3.6
Storey28	3.7
Storey27	3.8
Storey26	3.8
Storey25	3.9
Storey24	4
Storey23	4
Storey22	4.1
Storey21	4.1
Storey20	4.1
Storey19	4.1
Storey18	4.1
Storey17	4.1
Storey16	4.1
Storey15	4.1
Storey14	4
Storey13	3.9
Storey12	3.9
Storey11	3.7
Storey10	3.6
Storey9	3.4
Storey8	3.3
Storey7	3
Storey6	2.7
Storey5	2.4
Storey4	2
Storey3	1.6
Storey2	1
Storey1	0.6

All values are in mm



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 X 3 m = 12 mm.

The model show a similar behaviour for storey drifts as shown in graph.the building Model are very closely related.

4.4 Base Shears

Table XII: Base shears in X& Y direction

Model	Base Shears in X (kN)	Mode l	Base Shears in Y(kN)
Model	3505.956	Mode l	3530.30 7

4.5 Modal Result

Table XIII: Modes and natural periods

Case	**Mode**	Natural Periods(sec)
Modal	1	5.45
Modal	2	5.259
Modal	3	3.742
Modal	4	1.541
Modal	5	1.519
Modal	6	1.021
Modal	7	0.768
Modal	8	0.72
Modal	9	0.471
Modal	10	0.468
Modal	11	0.429
Modal	12	0.322

Table XIV: Modal Masses

Model	Dynamic %	
	Acceleration Ux	Acceleration Uy
Model	94.41	92.55

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 seismic mass. Here the minimum modal mass is 92.25 percent.
Since natural period is inversely related to stiffness, the stiffness pattern can be represented in the order.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In this paper, reinforced concrete shear wall buildings were analyzed with the procedures laid out in IS codes.

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

1. 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.

2. 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 paper. The displacements, drifts and also the base shear values were within the 5% range. So provision shear wall with openings helps to achieve economy.

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. Shear walls are more effective when located along exterior perimeter of the building. Such a layout increases resistance of the building to torsion.

5. Based on the analysis and discussion ,shear wall are very much suitable for resisting earthquake induced lateral forces in multistoried structural systems when compared to multistoried structural systems whit out shear walls. They can be made to behave in a ductile manner by adopting proper detailing techniques.

6. The vertical reinforcement that is uniformly distributed in the shear wall shall not be less than the horizontal reinforcement .
7. Shear walls must provide the necessary lateral strength to resist horizontal earthquake forces.

8. Shear walls also provide lateral stiffness to prevent the roof or floor above from excessive side-sway.

5.2 Recommendations

Different assumptions and limitations have been adopted for simplicity in modeling the proposed structures. In reality, it might effect on results. Thus, all factors which may influence on the behavior 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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