SHEAR WALL ANALYSIS & DESIGN OPTIMIZATION IN HIGH RISE BUILDINGS

Mohammed Saadat Hasan Imtiyaz[1], Mohd Arbaz Khan[2], Adil Ahmed Bhameshan[3]
Mohd Khaleel Uddin[4]

[1, 2, 3] UG Students, Department of Civil Engineering [4] Asst Professor of Civil Engineering
ISL Engineering College, Hyderabad, Telangana

Abstract - *Wind and seismic loads are assessed on a 19-story residential building with and without shear walls. The building has four flats on each storey and is located in zone 2. Shear walls in the shape of a L were erected at the elevator and stairwell, as well as at the building's corners. During the analytical phase, vertical loads, moments, lateral forces, and torsion moments were compared for both situations at each floor. Optimization techniques are used to address structural engineering issues. The most difficult high-rise buildings are handled utilising design optimization approaches that include both size and topological optimization. Stability, safety, and response to various types of loads are all considered. Optimization of the wall-frame construction is a component of the project. The displacement, internal stresses, and intensities of this wall and core system were determined when exposed to varied loadings.*

Key Words: Shear Walls, Optimization, Lateral Forces, Bending Moments, Torsional Moments, Storey Drifts, Maximum Displacements, Internal Stresses, Intensities

1. INTRODUCTION

Structurally a multistory building may consist of a frame with rigid connections, a frame with braces, parallel sets of shear wall, box units or a combination of these sets of elements. design of multistory buildings for earthquake motions requires the consideration of several factors such as probable intensity of earthquake, stiffness of the structure and its ductility and without impairing its functional utility.

"The response of any structure during an earthquake is a dynamic phenomenon and the principles of dynamics must be used to explain the behavior of the buildings during ground motions. Two broad approaches of earthquakes analysis of multistoried structure in present day are:

I. Equivalent static approach

II. Dynamic method of analysis.

1.1 PLANNING AND DESIGN OF BUILDING FROM SEISMIC VIEW POINT

Certain factors should be taken into consideration in planning and design of multistory buildings in seismic zones; these factors are established from damage study of buildings during the earthquakes.

1.1.1 Planning

1. The torsion effect in building should be minimized in unsymmetrical plans such as T, L or U shapes and unsymmetrical elevations should be avoided.

2. Two adjacent buildings or adjacent blocks of the same buildings should be separated enough to avoid damage due to pounding action. Impact absorbing pads may be interposed between the blocks to avoid pounding damage.

3. Earthquake resisting elements in the form of bracing shear walls or suitable column arrangements should be provided in both the directions of the building.

4. Shear walls should be well distributed over the plans. If the functional requirements dictate adoption of geometrical, asymmetry in the plan of the building, it will be appropriate to adjust the moments of inertia of shear walls so that the center of inertia of shear walls and the center of mass of the building in each storey coincides with the center of stiffness

1.1.2 Design principles

1. In elastic studies indicate the desirability of various storeys for adequate behavior. The inverted parabolic distribution of seismic force is appropriate to take off its effect. This will also suffice against whipping effect in top storey of building.

2. Ductility demands in lower storey may be smaller compared to higher stories unless special care is taken against large displacements. A more or less uniform distribution of ductility is desirable for seismic view point. "Strong column weak girder" will be good basis of design for withstanding severe shock of earthquake.

3. Design for torsion needs special consideration. Even for symmetrical buildings an eccentricity of at least 5% of the dimension of the building in plan should considered to compute torsion shear.

4. Continuity in structural members is desirable since it provides multiple path of load resistance. Therefore rigid or semi rigid connections in steel and monolithic connections in concrete are desirable even when braces or shear walls are used.

5. For building safety against severe shocks, it is specified that the members of the reinforced or prestressed concrete shall be under reinforced and so designed that premature failure due to shear or bond may not occur .Similarly for steel structures the members and their connections are to be detailed such that failure due to elastic or inelastic buckling may not occur.

6. Certain structures are functionally more important than the other structures and some other structures are important because their failure can be hazardous to community such as nuclear power buildings. For such structures code specifies important factor and large seismic coefficient for their design during probable maximum ground motion.

7. Equipment's: The equipment's in the building must be properly anchored in order that they are not disturbed, displaced or overturned during an earthquake motion.

8. The staircases if monolithically constructed with the frame providing continuity at all levels result in bracings or strut action they are liable to crack at elbow between landing flight. It is desirable to provide sliding joint at the end of the flight so as to permit relative moments and avoid strut action.

1.2 PURPOSE OF CONSTRUCTING SHEAR WALLS

Shear walls are not only designed to resist gravity/ vertical loads (due to its self-weight and other living/ moving loads), but they are also designed for lateral loads of earthquakes/wind. The walls are structurally integrated with roofs/floors (diaphragms) and other lateral walls running across at right angles.

Shear wall structural systems are more stable. Because, their supporting area (total cross-sectional area of all shear walls) with reference to total plans area of building, is comparatively more, unlike in the case of RCC framed structures.

Walls have to resist the uplift forces caused by the pull of the wind. Walls have to resist the shear forces that try to push the walls over. Walls have to resist the lateral force of the wind that tries to push the walls in and pull them away from the building.

Shear walls are quick in construction, as the method adopted to construct is concreting the members using formwork.

Shear walls doesn't need any extra plastering or finishing as the wall itself gives such a high level of precision, that it doesn't require plastering.

1.3 COMPARISONS OF SHEAR WALL WITH CONSTRUCTION OF CONVENTIONAL LOAD BEARING WALLS

Load bearing masonry is very brittle material. Due to different kinds of stresses such as shear, tension, torsion, etc., caused by the earthquakes, the conventional unreinforced brick masonry collapses instantly during the unpredictable and sudden earthquakes.

The RCC framed structures are slender, when compared to shear wall concept of box like three-dimensional structures. Though it is possible to design the earthquake resistant RCC frame, it requires extraordinary skills at design, detailing and construction levels, which cannot be anticipated in all types of construction projects.

On the other hand even moderately designed shear wall structures not only more stable, but also comparatively quite ductile. In safety terms it means that, during very severe earthquakes they will not suddenly collapse causing death of people. They give enough indicative warnings such as widening structural cracks, yielding rods, etc., offering most precious moments for people to run out off structures, before they totally collapse.

For structural purposes we consider the exterior walls as the shear-resisting walls. Forces from the ceiling and roof diaphragms make their way to the outside along assumed paths, enter the walls, and exit at the foundation.

1.4 FORCES ON SHEAR WALL

Shear walls resist two types of forces: shear forces and uplift forces. Shear forces are generated in stationary buildings by accelerations resulting from ground movement and by external forces like wind and waves. This action creates shear forces throughout the height of the wall between the top and bottom shear wall connections.

Uplift forces exist on shear walls because the horizontal forces are applied to the top of the wall. These uplift forces try to lift up one end of the wall and push the other end down. In some cases, the uplift force is large enough to tip the wall over. Uplift forces are greater on tall short walls and less on low long walls. Bearing walls have less uplift than non-bearing walls because gravity loads on shear walls help them resist uplift. Shear walls need hold down devices at each end when the gravity loads cannot resist all of the uplift. The hold down device then provides the necessary uplift resistance.

Shear walls should be located on each level of the structure including the crawl space. To form an effective box structure, equal length shear walls should be placed symmetrically on all four exterior walls of the building. Shear walls should be added to the building interior when the exterior walls cannot provide sufficient strength and stiffness.

Shear walls are most efficient when they are aligned vertically and are supported on foundation walls or footings. When exterior shear walls do not provide sufficient strength, other parts of the building will need additional strengthening. Consider the common case of an interior wall supported by a sub floor over a crawl space and there is no continuous footing beneath the wall. For this wall to be used as shear wall, the sub floor and its connections will have to be strengthened near the wall. For Retrofit work, existing floor construction is not easily changed. That's the reason why most retrofit work uses walls with continuous footings underneath them as shear walls.

Depending on the size of the building some interior walls must be braced as well.

The main function of shear wall for the type of structure being considered here is to increase the rigidity for lateral load resistance. Shear walls also resist vertical load, and the difference between a column and a shear wall may not always be obvious. The distinguishing features are the much higher moment of inertia of the shear wall than a column and the width of the shear wall, which is not negligible in comparison with the span of adjacent beams

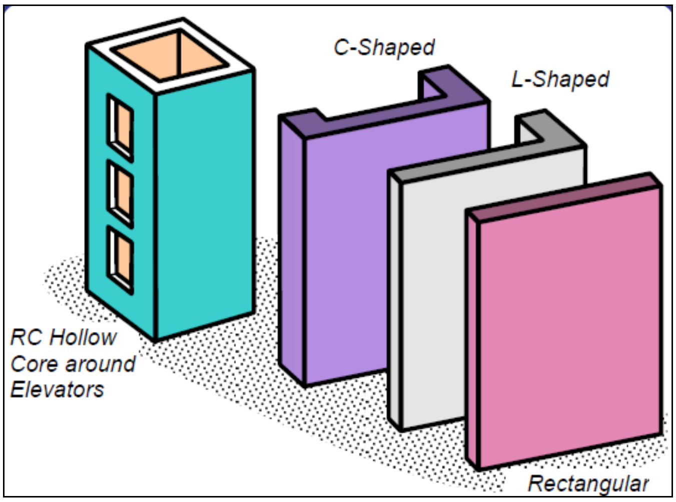


Fig -1: Various Types of Shear Walls

1.5 NEED FOR PRESENT STUDY

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.

Since shear walls carry large horizontal earthquake forces, the overturning effects on them are large; so design of their foundations requires special attention. Shear walls should be provided along preferably both length and width. However, if they are provided along only one direction, a proper grid of beams and columns in the vertical plane (called a moment-resistant frame) must be provided along the other direction to resist strong earthquake effects

1.6 SCOPE OF WORK

In current scenario use of optimization in civil engineering filed is very less compared to other industries. Here we are moving towards use of optimization techniques to solve structural engineering problems in which we are going to solve most complex high rise structures using design optimization, which involves both size and topological optimization of structure, also during optimization stability, safety, response to different type of loading conditions are taken into consideration. Wall-frame structure optimization is the part of project.

Core shares maximum part of horizontal load, and also some part of gravity load, it means core is important part of high rise building. Here we are going to optimize such core to find its efficiency for its minimum possible size. For this system of wall and cores should be checked for drift when subjected to horizontal loading. It means drift is taken as a constraint for optimization of core structure

2. LITERATURE REVIEW

Early 1940s

In the early 1940s when the first shear walls were introduced, their use in high rise buildings to resist lateral loads has been extensive, in particular to supplement frames that if unaided often could not be efficiency designed to satisfy lateral load requirements. The walls in a building which resist lateral loads originating from wind or earthquakes are named as shear walls at first. A large portion of the lateral load on a building is often assigned to such structural elements made of RCC

Mo and Jost (1993) predicted the seismic response of multistory reinforced concrete framed shear walls using a nonlinear model. From results it was concluded that the effect of concrete strength on the framed shear walls is significant because increasing the concrete strength from 25MPa to 35.0 MPa can cause the maximum deflection to decrease by 30% for El Centro record.

Arthur Tena-Colunga and Miguel Angel Perez-Osornia(2005) had studied on shear deformations and said that Shear Deformations are of paramount importance in the planar two dimensional analysis of shear wall systems, both for strains and stresses, so they should be included in the analysis of such systems.

Lew et al. (2008) discussed the challenges in the selection of earthquake accelerograms for use in the seismic design of tall buildings. They suggest that in order to cover the response effects of different modes, tall buildings need to be analysed using many more ground motion accelerograms than the sets of three or seven accelerograms that are normally used in the current design practice for tall buildings

S.V. Venkatesh, H. Sharada Bai (2013) discussed the difference in structural behavior of 10 storey basic moment resisting RC frames when provided with two different types of shear walls as lateral load resisting structural systems (LLRS) and concluded that external shear walls serve as an alternative to internal shear walls in retrofitting

3. OPTIMIZATION

What is Optimization?

The simple and most general definition of optimization is 'making the things best' Structural optimization is the subject of making an assemblage of materials sustain loads in the best way.

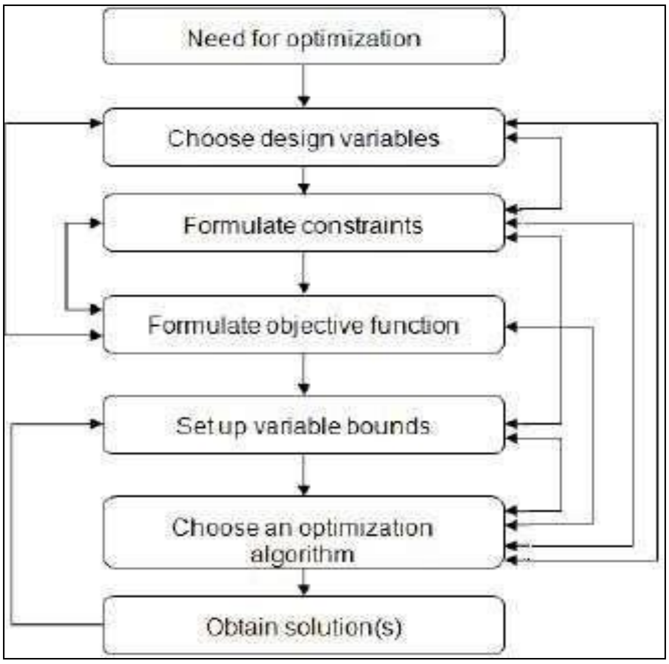


Fig -2: Structural flowchart of Optimization

What is 'Best' means? Or what is 'Need' of the optimization?

It makes the structure as light as possible but it should be insensitive to Buckling or instability as possible. Here constraints come into action, without constraints such as minimization and maximization will not be possible. In general structural optimization problems constraints are stresses, displacements or geometry. Objective function and constraints are most important parameters in optimization

3.1 ANALYSIS METHOD

As per the Indian Standard code for Earthquake IS:1893-2002, seismic analysis can be performed by three methods.
1. Static Method
A. Equivalent Static Coefficient Method
2. Dynamic Methods
A. Time history Method
B. Response Spectrum Method

3.2 SOFTWARE IMPLEMENTATION

Etabs software is exclusively made for modeling, analysis and design of buildings. Various facilities in the Etabs are listed below.

(1)Etabs has feature known as similar story. By which similar stories can be edited and modeled simultaneously. Due to which building is modeled very speedily.

(2)Etabs can perform various seismic coefficient , Response Spectrum, Static Non-linear, Time History, Construction sequence and many more analysis with good graphics.

(3) Etabs provide object based modeling. It takes slab as area object, column, beam, brace as line object and support, mass, loads as point objects. .

(4)Etabs automates templates for typical structures like steel deck, waffle slab, Flat slab, Ribbed Slab etc.

(5)Etabs can do optimization of steel section.

(6)Etabs has a facility to design composite beam. Also composite deck can be modeled in Etabs.

Stepwise Procedure for modeling of Building in ETABS

Step 1: Define Storey data like storey height, no. of storey etc.

Step 2: Select Code preference from option and then define material properties from define Menu

Step 3: Define Frame Section from Define menu like column, beam,

Step 4: Define Slab Section

Step 5: Draw building Elements from draw menu

Step 6: Give Support Conditions

Step 7 : Define Load cases and Load combinations

Step 8 : Assign Load

Step 9 : Define Mass Source

Step 10 : Give structure auto line constraint

Step 11 : Give renumbering to the whole structure.

Step 12 : Select analysis option and Run Analysis.

3.3 OPTIMUM PROBLEM FORMULATION

In present work in order to compare the response of reinforced concrete shear wall for use in Earthquake prone area multi storey building having plan dimension 18m x18m is modeled and analyzed in ETABS 19.10 Non Linear Version software. Equivalent static analysis and dynamic Response spectrum analysis is performed on the structure. In present work total 2 models are prepared. Two models of G+9 storey buildings, which includes shear wall in different position at core of building and at edge of building. And for both the models Equivalent static analysis and dynamic Response spectrum analysis is performed.

3.3.1 Geometrical Data

Type of Building : Commercial building
Location of Building : Hyderabad
Typical Storey Height : 3 m
Bottom Storey Height : 3.5 m

3.3.2 Earthquake Data

Frame : Special moment Resisting Frame
Location : Hyderabad (Zone II)
Importance Factor : 1.5
Response Reduction Factor : 5
Type of Soil : Medium (Type 2)

3.3.3 Material Data

Table -1: Sample Table format

Material	Weight (kN/m^3)	Modulus of Elasticity -(E)- (kN/m^2)	Shear-Modulus (G)	Poissons Ratio	Coeffi-Of-Thermal Expansin
Concrete (fck=M25)	25	$25x10^6$	10416666.7	0.2	$9.9x10^{-6}$
Steel-(Fe-415)	78.5	$2x10^8$	76884615	0.3	$11.7x10^{-6}$

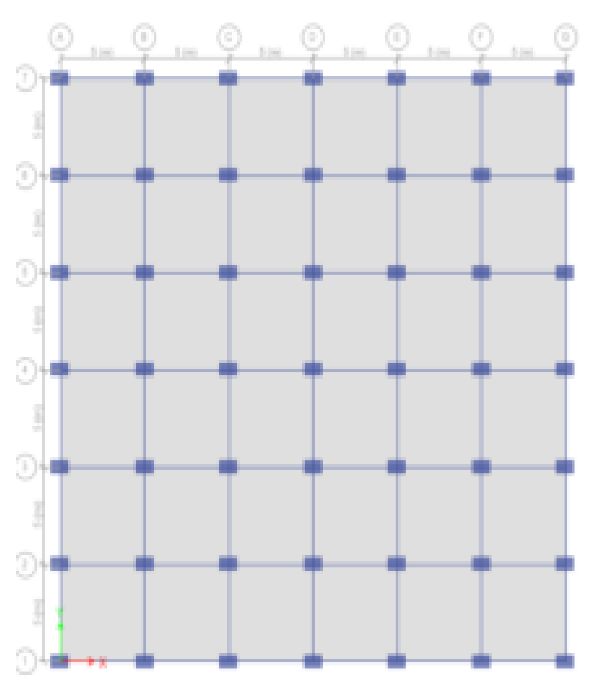


Fig -3: Plan View of Building

3.3.4 Loading Data

Live load : On floor 4 kN/m2 , On roof 1 kN/m2
Floor Finish : 1.5 kN/m2
Earthquake load in X and Y direction
RCC

- 1.5 (DL + LL)
- 1.2 (DL + LL ± EQx)
- 1.2 (DL + LL ± EQy)
- 1.5 (DL ± EQx)
- 1.5 (DL± EQy)
- 0.9 DL ± 1.5 EQx
- 0.9 DL ± 1.5 EQy

3.3.5 Element Sizes

- Slab Depth : 125 mm
- Element : 10 Storey
- Column : 600 mm X 600 mm
- Main Beam : 350 mm X 600 mm
- Shear Wall : 200 mm thick (RCC)

3.3.6 Models of Building

3.3.6.1 Multi storey building with No-RCC shear wall

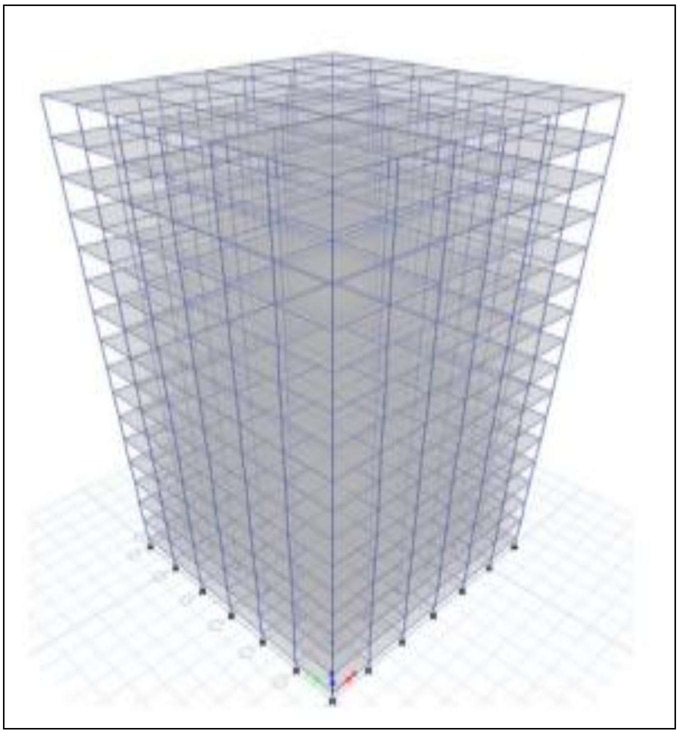


Fig -4: Multi storey building with No-RCC shear wall

3.3.6.2 Multi storey building with RCC shear wall at Edges

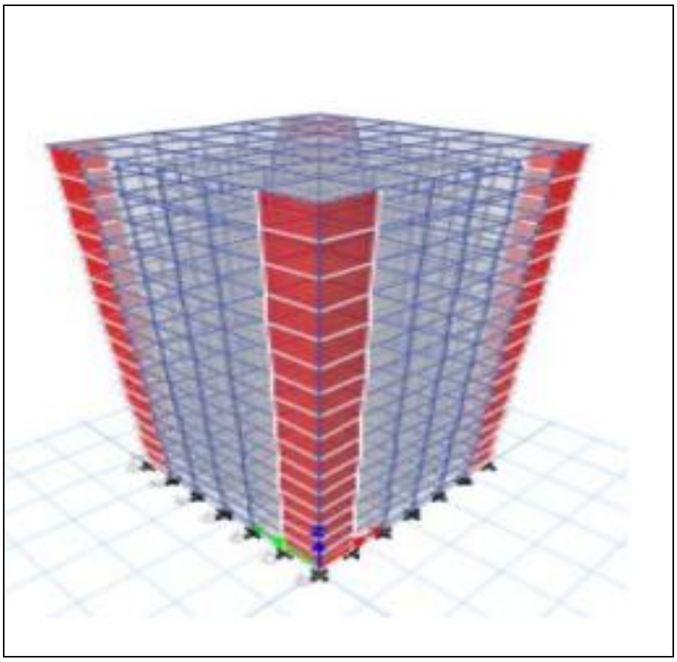


Fig -5: Multi storey building with RCC shear wall at Edges

3.3.6.3 Multi storey building with RCC shear wall on Periphery at Centers

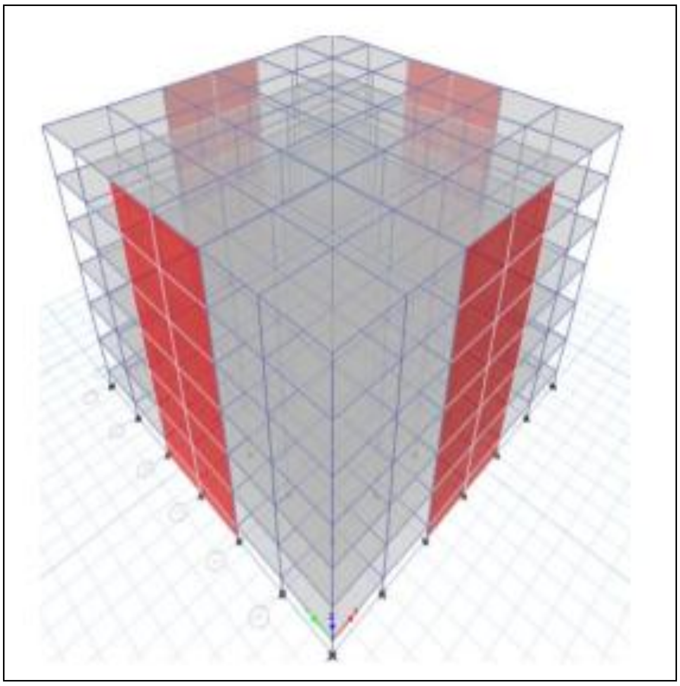


Fig -6: Multi storey building with RCC shear wall on Periphery at Centers

3.3.6.4 Multi storey building with RCC shear wall at the center of the geometry

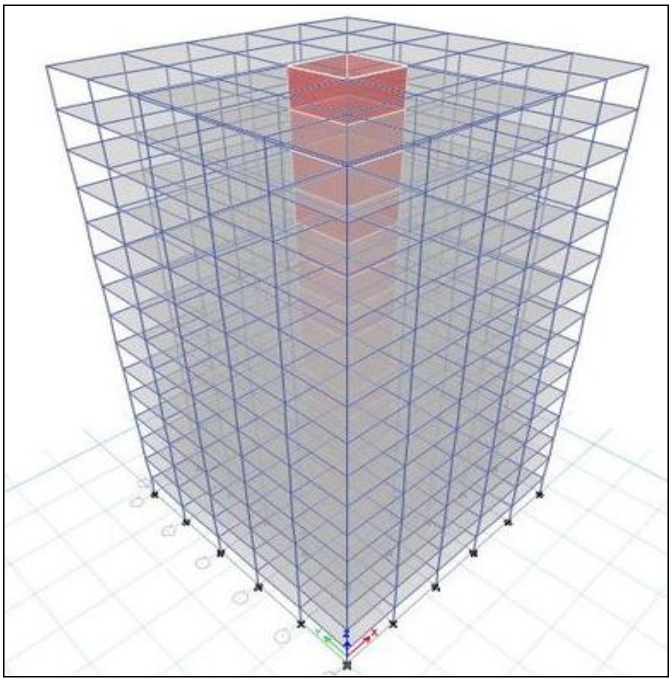


Fig -7: Multi storey building with RCC shear wall at the center of the geometry

The behavior of all the framing systems is taken as a basic study on the modeled structure. The lateral drift/deflection ratio is checked against the clause 7.11.1 of IS-1893:2002 i.e. under transient seismic loads.

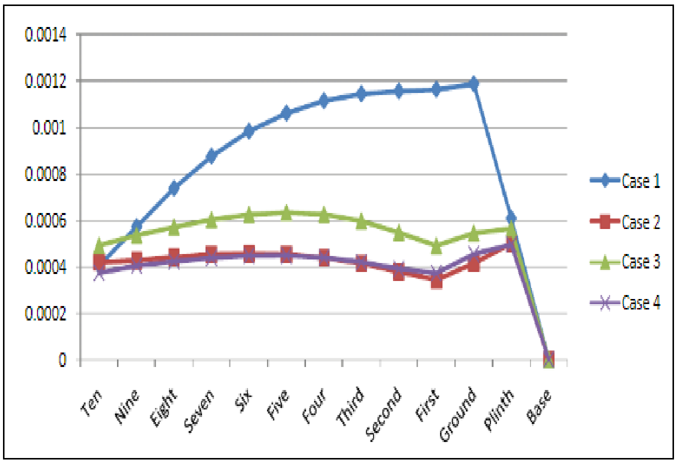
The following parameters were considered to present a comparison between the different frames:

- Maximum Storey Drift
- Maximum Storey Displacement
- Storey Shears
- Storey Overturning Moment

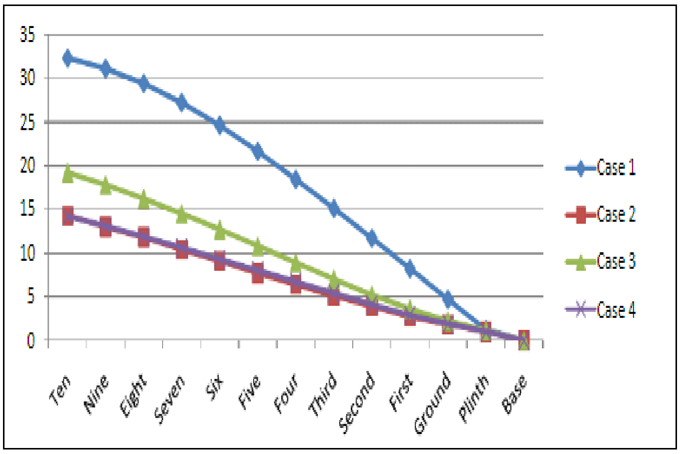
For asserting the simplest yet reliable method for analysis, the combined action of DL, LL & EQ forces are considered i.e. 1.2 DL + 1.2 LL + 1.2 EQX with different framing system has been modeled using ETABS software with the above mentioned load conditions and combinations.

4. DISCUSSION OF RESULTS

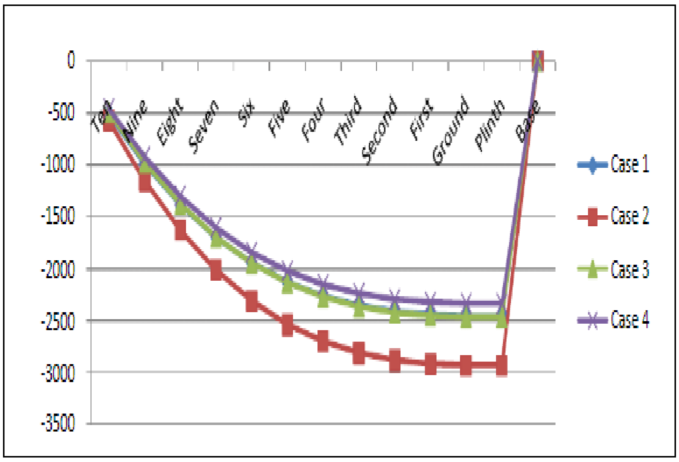
Storey Drift



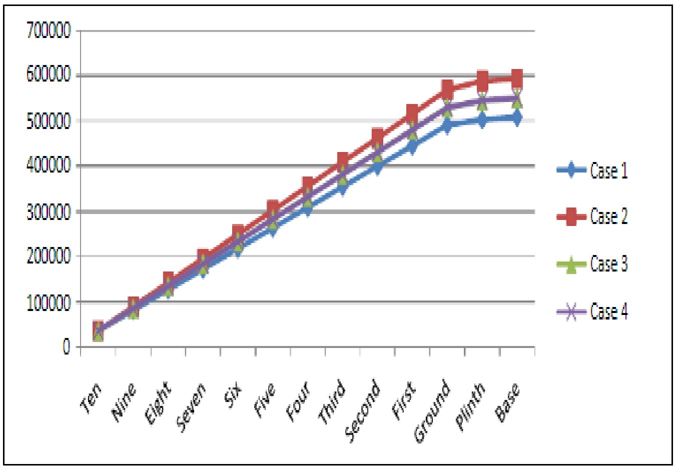
Storey Displacement (in mm)



Storey Shear (in kN)



Storey Overturning Moment (in kNm)



Graphs: Storey Drift, Displacement, Shear and Overturning Shown in Diff graphs

5. SUMMARY & CONCLUSIONS

It is clear to all that the seismic hazard has to be carefully evaluated before the construction of important and high-rise structures. Based on the above analytical study carried out on 4 models, it is evident that buildings with shear walls behave more effectively than conventional frames when subjected to seismic loads. Bending Moments of columns at Ground floor level were high in the case of building without shear walls in both directions i.e., in x and y directions. Bending Moments of columns in both directions were reduced at each floor level by using shear walls for a building from 0 to 99 % depending on the floor height.

The following deductions are made from the obtained results: 1. The frame with Shear Walls clearly provides more safety to the designers and although it proves to be a little costly, they are extremely effective in terms of structural stability. 2. Due to the falling of the zone, the earthquake hazard will also increase. In such cases, use of shear walls become mandatory for achieving safety in design. 3. In all the systems, the Storey Drift is within the permissible limits as per IS:1893 (Part 1). However CASE 4, closely followed by CASE 2, showed better results when compared to other models. This lead us to believe that when Shear Walls are placed at the center of the geometry in the form of a box or at the corners, the structures behave in a more stable manner. This practice of providing Box-type Shear Walls is becoming more popular now-a-days as high rise structures generally have a lift system and these box-type shear walls serve the dual purpose of Shear walls and also as a vertical duct or passage for the movement of the lifts. 4. The Storey Displacement also follows a similar pattern as storey drifts. Best results are obtained for CASE 4, followed closely by CASE 2, proving again that the optimum position of shear walls is either at the center of the building or at the corners. 5. The main difference in the behaviors of CASE 4 and CASE 2 can be noted when comparing Storey Shear. CASE 2 displayed very higher values of storey shear as compared to the other models. Here again CASE 4 proved to be the best. 6. Overturning Moments are minimum in conventional buildings. However the lower performance of CASE 1 in terms of Storey Drifts, Storey Displacements and Lateral Loadings make it unfit for use in higher seismically active zones. 7. To further increase the effectiveness of the structure, earthquake resisting techniques such as Seismic Dampers & Base Isolation can be used. It is hence safe to conclude that among all other possibilities, CASE 4 (Building with Box-type Shear Wall at the center of the geometry) is the ideal framing technique for high rise buildings

REFERENCES

[1] Design of concrete shear wall buildings for Earthquake induced - 4th structural specialty conference of the canadian society for civil engineering, Montreal - Canada.

[2] ISSN - Significance of Shear Wall in Highrise Irregular Buildings by Ravikanth Chittiprolu, Ramancharla Pradeep Kumar, Earthquake Engineering Research Centre, International Institute of Information Technology Hyd – AP India.

[3] Learning Earthquake Design and construction a conference paper in IIT Kharagpur

[4] DIAPHRAGMS & SHEAR WALLS - Design / Construction Guide 7th Edition by APA Engineered Association.

[5] Mariopaz – Structural Dynamics: Theory and Computations 2nd Edition CBS Publishers and Distributors.

[6] Seismic Behavior, Design and detailing of RC Shear walls Part – II by M.S. Medhekar and Sudhir K. Jain.

[7] IS: 875 (part-1) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Dead Loads.

[8] IS: 875 (part-2) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Imposed Loads.

[9] IS: 875 (part-1) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Wind Loads.

[10] IS 1893 (part 1) – 2002: Criteria for Earthquake resistant Design of Structures.

[11] Earthquake facts, "http://earthquake.usgs.gov/learn /facts.php" United States Geological Surgvey (USGS).

[12] 'Optimization & Design of High Rise Buildings with Different Structural Framing Systems Subjected To Seismic Loads' by Mr. Anant A. Kapse , Prof. R.V.R.K. Prasad.

[13] Kusunoki koich, Mukai Tomohi 'Lateral Force and Varied Axial Force for wall frames in reinforced concrete buildings' with multistory shear walls.

[14] Mo and Jost A report of seismic response of multistory reinforced concrete framed shear walls using a nonlinear model.

[15] E.M. Wdowicka, J.A. Wdowicka of Pozman University of Technology, Poland, A study on the tallest building designed in western part of Poland having an RC slab and column system with shear walls and cores.

[16] Lew et al. (2008) discussed the challenges in the selection of earthquake accelerograms for use in the seismic design of tall buildings

[17] ETAS Training Manual – Shear Wall Designs and space frame modelling.

BIOGRAPHIES

Mohammed Saadat Hasan Imtiyaz
(UG Student, Department of
Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Mohd Arbaz Khan
(UG Student, Department of
Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Adil Ahmed Bhameshan
(UG Student, Department of
Civil Engineering,
ISL Engineering College,
Hyderabad, Telangana)

Mohd Khaleel Uddin (Asst Professor, Department of Civil Engineering, ISL Engineering College, Hyderabad, Telangana)