



INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

SHEAR WALL ANALYSIS & DESIGN OPTIMIZATION IN HIGH RISE BUILDINGS

Gangisetty Sri Harsha *, Dr. H. Sudarsana Rao

* M.Tech Scholar, Civil Engineering Department, JNTUA Ananthapuramu, AP, India
Prof & Vice Chancellor, JNTUA Ananthapuramu, AP, India

ABSTRACT

A Residential Building with 19 floors is analyzed with and without shear walls for wind and earthquake loads. The Building consists of four flats for each floor and comes under zone 2. Shear walls were taken at lift and stair and corners of the building as L shape. Vertical loads, Moments, Lateral forces, Torsional moments were compared for both cases at each floor during analysis part. Optimization techniques are used to solve structural engineering problems where the most complex high rise structures using design optimization, involving both size and topological optimization is solved by considering stability, safety, response to different type of loadings. Wall-frame structure optimization is the part of project.. For this system of wall and cores they were checked for displacement, Internal Stresses and Intensities when subjected to various loadings.

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

INTRODUCTION

A) Seismology:

An earthquake is a phenomenon of shaking on the surface of the earth, due to the movement along geological faults present in the earth's lithosphere. Where, movement of plates is caused by convective currents in the mantle. As the plates tend to move high strain energies are built up along the fault plane because of friction between the plates and when the friction is overcome, the sudden release of energy from the fault plane will generate seismic waves to travel in all directions. The seismic waves that reach the earth's surface cause an earthquake.

In brief, the study of seismology or earthquake engineering is important because

- It helps us in understanding the earthquakes, their nature and effect on our life.
- It helps us in designing and building earthquake resistant structures to minimize the loss of lives and property.

B) Why High Rise Buildings?

The rapid growth of the urban population and the consequent pressure on limited space have considerably influenced city residential development. The high cost of land, the desire to avoid a continuous urban sprawl, and the need to preserve

important agricultural production have all contributed to drive residential buildings upward. In some cities, for example, Hong Kong and Rio de Janeiro, local topographical restrictions make tall buildings the only feasible solutions for housing needs

C) Structural System in High Rise Building

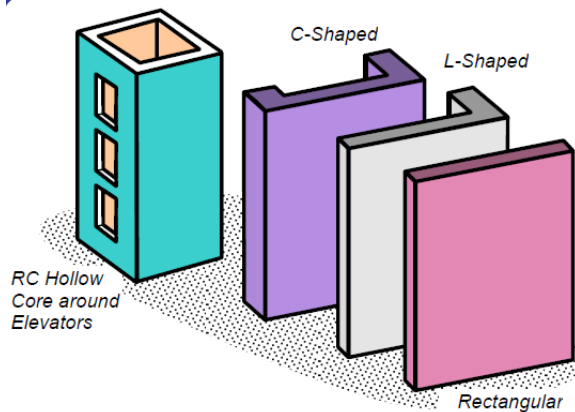
The two primary types of vertical load resisting elements of tall buildings are columns and walls, the later acting either independently as a shear walls or in assemblies as shear wall cores. The building function will lead naturally to the provision of all to divide and enclose space, and cores to contain and convey services such as elevators. Column will be provided, in otherwise unsupported regions, to transmit gravity loads and, in some types of structures horizontal loads.

D) SHEAR WALL – FRAME BUILDINGS

A Shear Wall is a structural system composed of braced panels (also known as shear panels) to counter the effects of lateral load acting on a structure. Wind and seismic loads are the most common loads that shear walls are designed to carry. Under several building codes all exterior wall lines in wood or steel frame construction must be braced.

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



Various Types of Shear Walls

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

Scope of Work:

In current scenario use of optimization in civil engineering field 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

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 seismically deficient structures, particularly when it is not possible to vacate the building during retrofitting

OPTIMIZATION

What is optimization?

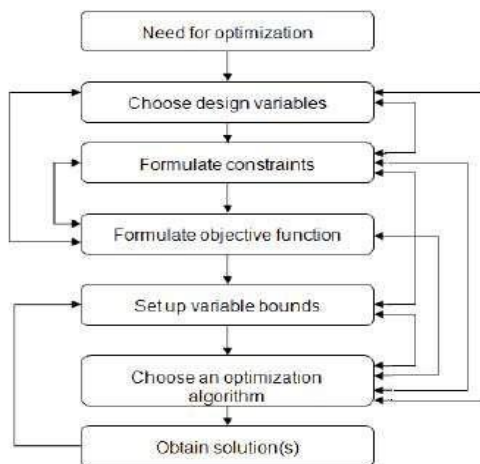
The simple and most general definition of optimization is ‘making the things best’ Structural optimization is the subject of making an assemblage of materials sustain loads in the best way.

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.

Optimum Problem Formulation

A naive of optimal design is achieved by comparing a few alternative design solutions created by using a priori problem knowledge. In this method feasibility of each design solution is investigated then objective of each solution is compared and best solution is adopted. According to objective and varying design parameters problem formulation techniques used are different for different problems. The goal is to create mathematical model of the optimal design problem.



Types of optimization problems

- i. Sizing optimization
- ii. Shape optimization

iii. Topology optimization
Here we will consider ‘x’ is our design variable

i. Sizing optimization: This is when ‘x’ is some type of thickness i.e. cross

sectional area of truss member, beam or column.

ii. Shape optimization: In this case ‘x’ represent form or contour of some boundary of the structural domain.

iii. Topology optimization: This is the most general form of structural optimization.

Optimization of the Building

The main objective of this project is to introduce optimization technique in structural engineering. Mainly structural engineering deals with stability and safety of the structure which means building is designed in such a way that it can resist all the type of forces to which it is subjected. When building is subjected to the lateral forces like earthquake forces, wind load etc. stiffness of building is the key factor to resist such forces. Now our aim is to optimize structure in such a way that it should have sufficient stiffness and strength to resist forces which may cause failure of structure.

Components of building which resist lateral forces and increase stiffness of structure:

- a. Shear walls
- b. Lift cores

In this project, Single variable Optimization Technique is used for optimizing the G + 19 Residential Building which deals with the sizing of optimization technique globally.

Dynamic Analysis using Response Spectrum Method

The dynamic analysis using the response spectrum method is carried out in this project for the G + 19 Building to assess the seismic behavior when subjected to earthquake loadings. A plot or steady – state response (displacement, velocity or acceleration) of a series of oscillators of varying natural frequency, that are forced into motion by the same base vibration or shock. The resulting plot can then be used to pick off the responses of any linear system, given its natural frequency of oscillation. One such use is in assessing the peak response of buildings to earthquake

Wind loading as per IS 875 : Part 3

Exposure Parameters

Basic Wind Speed $V_b = 44$ m/sec

Height of Building above G.L = 60.96 m

Width of Building = 23.343 m

Length of Building = 30.537 m

Top Story = Story19

Bottom Story = Base

Exposure From = Diaphragms

Structure Class = Class B

Terrain Category = Category 2

Wind Direction = 0;90 degrees

Windward Coefficient $C_{p,wind} = 0.8$

Leeward Coefficient $C_{p,lee} = 0.5$

Factors and Coefficients

Risk Coefficient, k_1 [IS 5.3.1] $k_1 = 1$

Terrain Factor [IS 5.3.2] $k_2 = 1.115$

Topography Factor, k_3 [IS 5.3.3] $k_3 = 1$

Lateral Loading

Design wind speed [IS 5.3] $V_z = V_b \times K_1 \times K_2 \times K_3$

$$V_z = 49.06 \text{ m/sec}$$

Design Wind Pressure, [IS 5.4] $P_z = 0.6 \cdot V_z^2$

$$P_z = 1444.13 \text{ N/m}^2$$

$$= 1.5 \text{ kN/m}^2$$

CALCULATION OF HOIRZONTAL SEISMIC COEFFICIENT IN X DIRECTION

Base dimension in x- direction (D) = 23.343 m

Height of Building (H) = 60.96 m

$$T_a = 0.09 H / \sqrt{D} \left(\frac{S_a}{g}\right) = 1.13556$$

$$(S_a/g) = 2.5$$

$$A_h = \text{Horizontal Seismic Co-eff} = \frac{Z I \left(\frac{S_a}{g}\right)}{2R}$$

Where Z = Zone Factor = 0.1

I = Importance Factor = 1

R = Response Reduction Factor = 3

$$A_h = \frac{0.1 * 1 * 3}{2.5 * 2} = 0.04167$$

CALCULATION OF HOIRZONTAL SEISMIC COEFFICIENT IN Y DIRECTION

Base dimension in x- direction (D) = 30.537 m

Height of Building (H) = 60.96 m

$$T_a = 0.09 H / \sqrt{D} \left(\frac{S_a}{g}\right) = 0.99283$$

$$(S_a/g) = 2.5$$

$$A_h = \text{Horizontal Seismic Co-eff} = \frac{Z I \left(\frac{S_a}{g}\right)}{2R}$$

Where Z = Zone Factor = 0.1

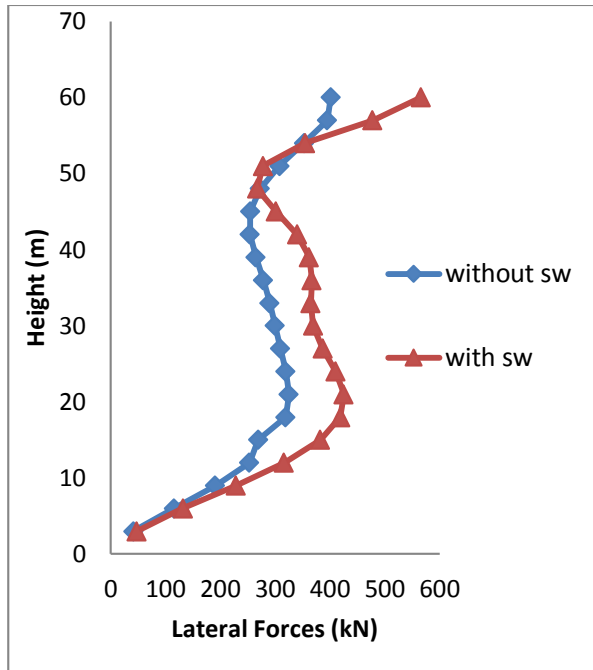
I = Importance Factor = 1

R = Response Reduction Factor = 3

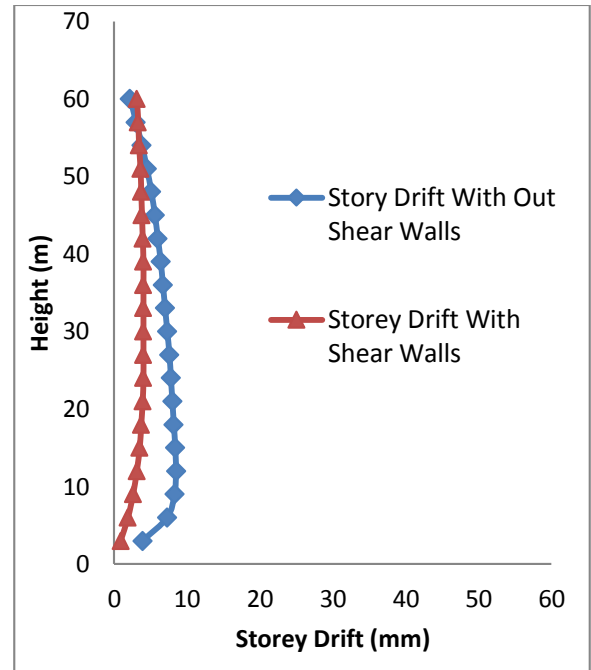
$$A_h = \frac{0.1 * 1 * 3}{2.5 * 2} = 0.04167$$

Initial Design Loads:

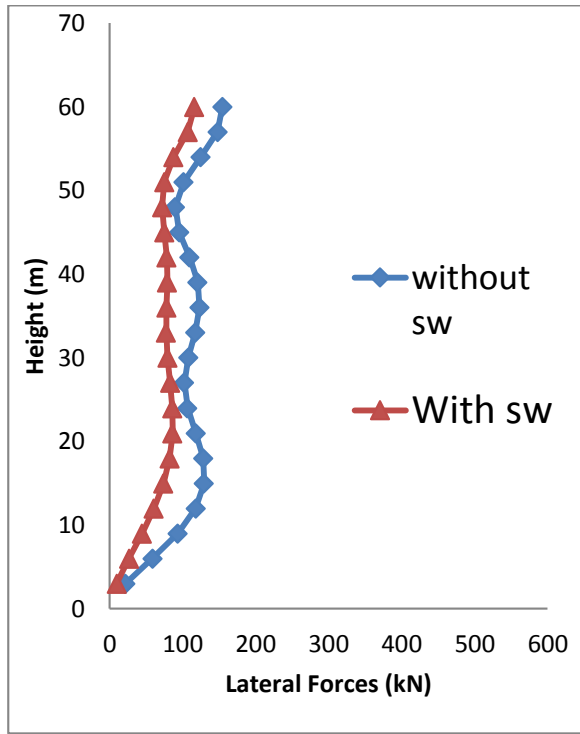
S.no	Name	Type	Self Weight Multiplier
1	DL	Dead	6
2	LL	Live	2
3	LL for stairs	Live	3
4	Walls	Live	9
5	wind	Wind	0
6	sidl	Dead	0
7	eqx	Seismic	0
8	eqy	Seismic	0



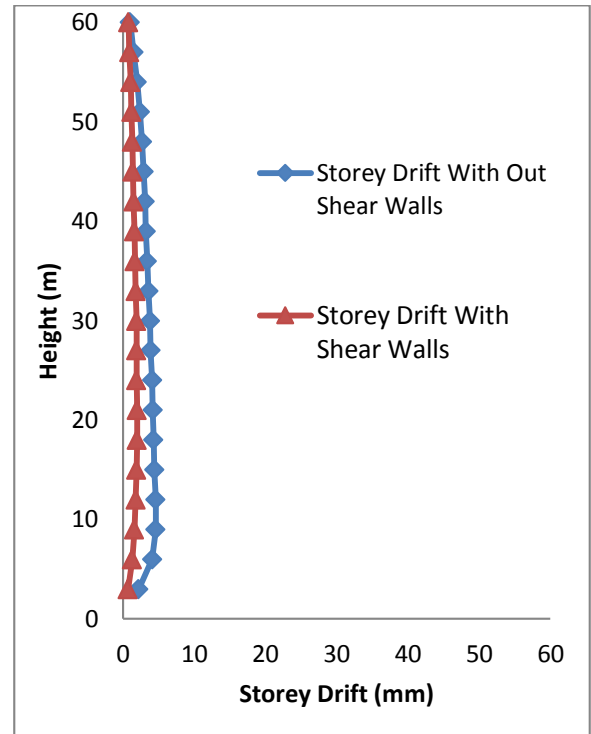
Comparison of Lateral Forces of a Building with and without Shear Walls in X Direction



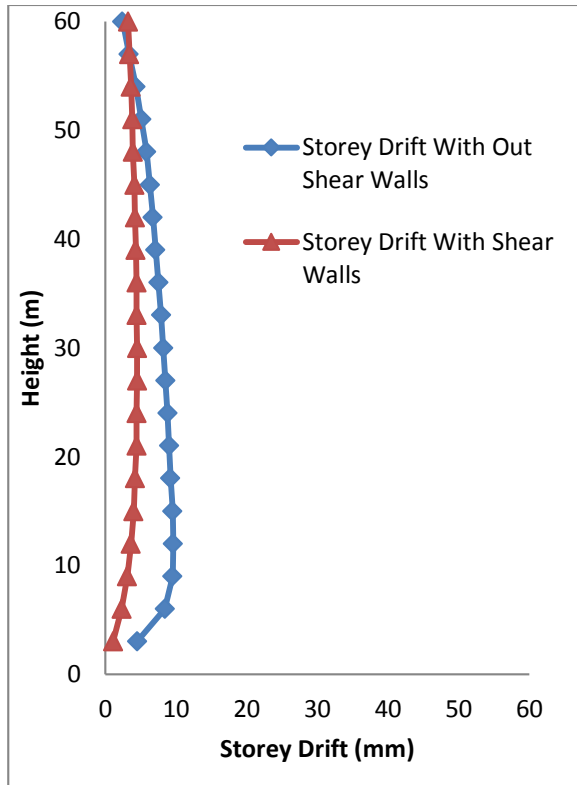
Comparison of Drifts of Building With and Without Shear Walls in X Direction



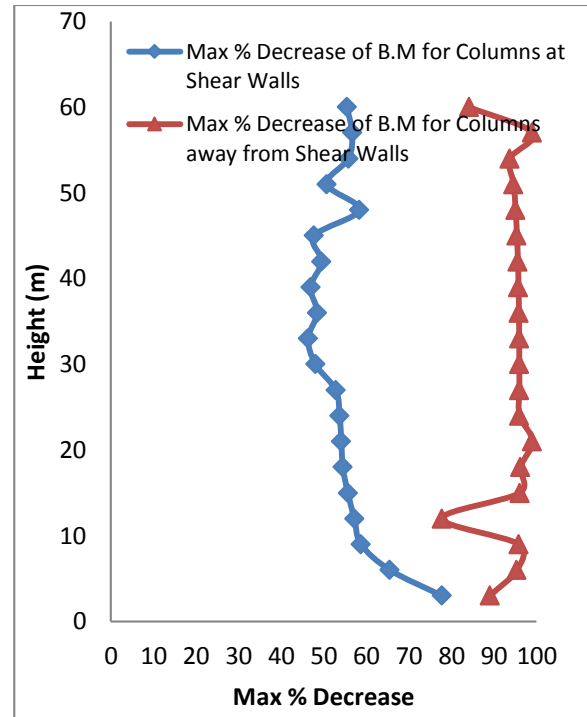
Comparison of Lateral Forces of a Building with and without Shear Walls in Y Direction



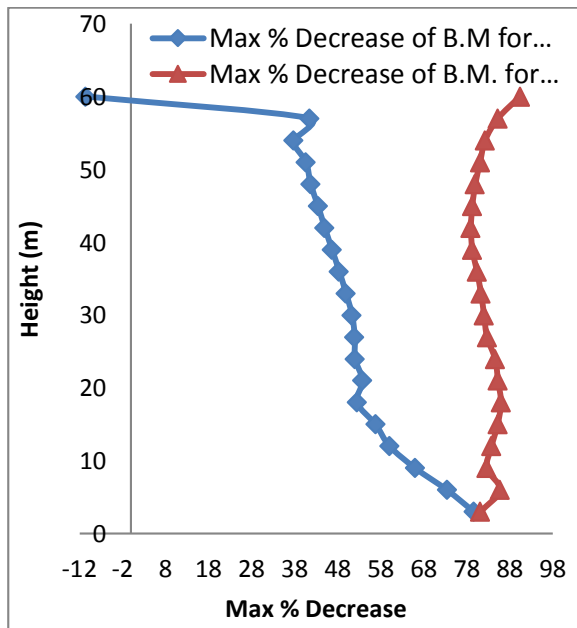
Comparison of Drifts of Building With and Without Shear Walls in Y Direction



Comparison of Drifts of Building With and Without Shear Walls in Z Direction



Comparison of Max % Decrease of Bending Moments by Using Shear Walls for columns at Shear Walls and for Columns away from Shear Walls in Y – Direction



Comparison of Max % Decrease of Bending Moments by Using Shear Walls for columns at Shear Walls and for Columns away from Shear Walls in X – Direction

Optimization for G+ 19 Residential Building –

In first run thickness of wall is kept constant throughout and columns which are modeled as line elements are also of constant size throughout the height of building. Bounds for design variables are decided on the basis of limit state of collapse and serviceability.

Shear walls are constructed around all the lift cores and corners of the structure for optimization of especially D.L & L.L elements.

Bounds for wall thickness are as follows :
Minimum thickness = 150 mm
Maximum thickness = 210 mm

In view of this four shear walls of varying thicknesses are considered and after running various iterations best optimized wall had been selected in various positions depending on all factors.

1. Shear wall – SW-150 (150 mm thick)
2. Shear wall – SW- 175 (175 mm thick)
3. Shear wall – SW-203 (203 mm thick)
4. Shear wall – SW-150 (250 mm thick)

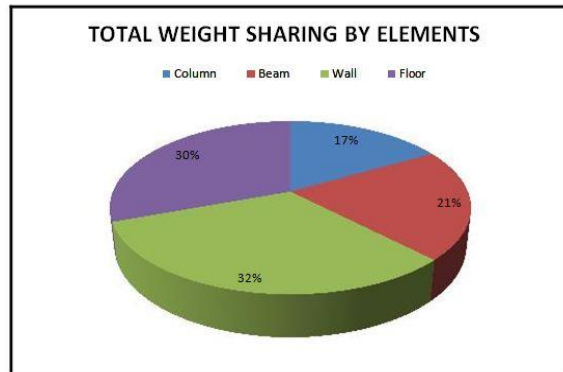
FIRST RUN OF OPTIMIZATION

Material List by Element Type

Element Type	Material	Total Weight (KN)
Column	M80	310152
Beam	M60	1182162
Wall	M80	1815315
Floor	M60	1736233

Element	Weight KN	% IN TOTAL WT
Column	955190.74	16.79
Beam	1182162.27	20.78
Wall	1815315.39	31.91
Floor	1736233.24	30.52
	5688901.64	100.00

Total Weight of structure (KN)	5688901.64
Total Weight of structure (TON)	568890.16



Intensity

S.No	Load Case/Combo	KN/M2
1	DEAD	22.94
2	LIVE	1.72
3	SIDL	2.43
4	WALLS	0.77
5	COMBO'S	27.85

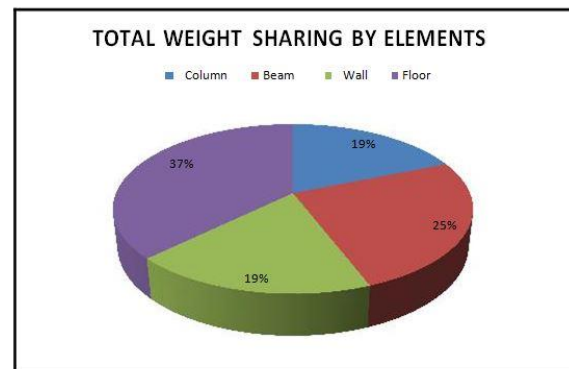
SECOND RUN OF OPTIMIZATION

Material List by Element Type

Element Type	Material	Total Weight(KN)
Column	M80	283252.8
Beam	M60	1181270
Wall	M80	866479.9
Floor	M60	1736233

Element	Weight KN	% IN TOTAL WT
Column	876384.01	18.81
Beam	1181269.73	25.35
Wall	866479.94	18.59
Floor	1736233.24	37.26
	4660366.92	100.00

Total Weight of structure (KN)	4660366.92
Total Weight of structure (TON)	466036.69



Intensity

S.No	Load Case/Combo	KN/M2
1	DEAD	18.83
2	LIVE	1.72
3	SIDL	2.43
4	WALLS	0.77
5	COMBO'S	23.76

Comparison of results :

Constraints	Allowable value	Case	Before Optimization	After Optimization
Internal Stresses	80 MPa		79.81 Mpa	72.22 Mpa
Displacement	1244 mm	EQX	49 mm	44.74 mm
	1244 mm	EQY	276.5 mm	275.1 mm
	622 mm	WX	19.2 mm	14.84 mm
	622 mm	WY	315.3 mm	266.66 mm
	0.012	WX	0.00008	0.00006
	0.012	WY	0.001336	0.001088
Intensity	15 TO 25	DLLL	23.76	27.83

DISCUSSION OF RESULTS

1. 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.
2. 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.
3. Bending Moments of the columns gets reduced from ground floor to 18th floor and again increased for terrace floor i.e for 19th floor in both directions for the case of buildings without shear walls.
4. Bending Moments for columns which are away from shear walls gets reduced from 0 to 79.66% in X – Direction for the case of building with shear walls.
5. Bending Moments for columns which are away from shear walls gets reduced from 0 to 77.77% in Y – Direction for the case of building with shear walls.
6. Bending Moments for columns with shear walls gets reduced from 0 to 90.37% in X – Direction for the case of building with shear walls.
7. Bending Moments for columns with shear walls gets reduced from 0 to 99.01% in Y – Direction for the case of building with shear walls.
8. Natural Frequencies were increased from 21.15% for 1st mode to 79.85% for 9th mode and again decreased to 31.53% for 15th mode when shear walls were used. Corresponding time periods also increased and again decreased upto 15th mode.
9. Lateral Forces were increased from 0 to 41% in the direction in which shear walls were constructed and reduced from 18% to 55% in the other direction i.e., Y direction comparable to the building without shear walls
10. For Buildings without shear walls Lateral Forces were increased from ground floor to 6th floor and decreased upto 13th floor and again increased upto 19th floor in X direction. In Y direction, these forces were increased from ground floor to 4th floor and decreased upto 8th floor and again increased upto 11th floor, then decreased upto 15th floor and again increased upto 19th floor.
11. For Buildings with shear walls Lateral Forces were increased from ground floor to 6th floor and decreased upto 15th floor and again increased upto 19th floor in X direction. In Y direction, these forces were increased from ground floor to 6th floor and decreased upto 10th floor and again increased upto 12th floor, then decreased upto 15th floor and again increased upto 19th floor.
12. The Storey Drifts were reduced from 0 to 77% in X direction and 0 to 68% in Y direction and 0 to 75.5% in Z direction from ground floor to 19th floor.
13. Maximum Torsional Moments of each floor along the axis of the vertical members were reduced from 0 to 60% by using shear walls for the building.
14. In Optimization of internal stresses, they are reduced from 79.81 mpa to 72.2 mpa when the shear walls are provided for the lift cores and corners of the building.
15. Displacements during Earthquake load in X direction is reduced from 49 mm to 44.74 mm and in Y direction is reduced from 276.5 mm to 275.1 mm.

- Displacements during Wind load in X direction is reduced from 19.2 mm to 14.84 mm and in Y direction is reduced from 315.3 mm to 266.6 mm.

After optimization of the structure by reducing each material element wise the dead weight of the building is reduced by **102853.47 tons** which was a good accomplishment.

CONCLUSIONS

- Bending Moments of columns in both directions were reduced at each floor level by using shear walls for a building.
- Lateral Forces were increased in the direction in which shear walls were constructed at each floor level and reduced in the other direction comparable to the building without shear walls.
- Axial Forces in columns were reduced from ground floor to 19th floor by providing shear walls
- Variation in floor wise column moments is less in the direction in which shear walls were provided comparable to floor wise moments in the building without shear walls.
- Storey drifts were reduced by providing shear walls for the building.
- Reduction in bending moments for columns with shear walls is more comparable to columns away from shear walls.
- Torsional Moments were reduced by using shear walls for a building.

Based on the all the above results and discussions finally can conclude the importance of shear walls in High Rise Buildings which play a major role in resisting the seismic forces and also in the optimization of design which include various parameters such as displacement, drifts, intensity and internal stresses for which the structure gains more life time and more stability compared to ordinary structures without shear walls

REFERENCES

JOURNALS/ CONFERENCE PAPERS

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

- Learning Earthquake Design and construction a conference paper in IIT Kharagpur

BOOKS / CODES

- DIAPHRAGMS & SHEAR WALLS - Design / Construction Guide 7th Edition by APA Engineered Association.
- Mariopaz – Structural Dynamics: Theory and Computations 2nd Edition CBS Publishers and Distributors.
- Seismic Behavior, Design and detailing of RC Shear walls Part – II by M.S. Medhekar and Sudhir K. Jain.
- IS: 875 (part-1) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Dead Loads.
- IS: 875 (part-2) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Imposed Loads.
- IS: 875 (part-1) – 1987 Code of Practice for design loads (other than Earthquake) for buildings and structures - Wind Loads.
- IS 1893 (part 1) – 2002: Criteria for Earthquake resistant Design of Structures.

REPORTS

- Earthquake facts, “<http://earthquake.usgs.gov/learn/facts.php>” United States Geological Survey (USGS).
- ‘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.
- Kusunoki koich, Mukai Tomohi ‘Lateral Force and Varied Axial Force for wall frames in reinforced concrete buildings’ with multistory shear walls.
- Mo and Jost A report of seismic response of multistory reinforced concrete framed shear walls using a nonlinear model.
- E.M. Wdowicka, J.A. Wdowicka of Poznan 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.
- Lew et al. (2008) discussed the challenges in the selection of earthquake accelerograms for use in the seismic design of tall buildings
- ETABS Training Manual – Shear Wall Designs and space frame modelling.